Volume 3

ON THE WATER FRONT

Selections from the 2011 World Water Week in Stockholm

Edited by Jan Lundqvist

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PREFACE

Since 1991, the World Water Week in Stockholm has been an important annual event and meeting place for people from various professions, cultures and parts of the world with a common concern and ambition. One important ambition of the World Water Week is to combine and merge new thinking, concepts and experiences with practice, in policy and in the field. Each year, the World Water Week features a theme. In 2011, the theme was "Responding to Global Changes: Water in an Urbanised World". The ambience in over 100 sessions during the week and also in the informal exchanges in corridors and other meeting places is characterised by dialogue and an urge to scrutinise, learn, reassess concepts and standpoints and capture the best and most appropriate knowledge on water and development issues for policy and its implementation.

On the Water Front vol. 3 offers a collection of innovative and important insights on water and urban development issues that were presented at the 2011 World Water Week in Stockholm. Five chapters are authored by prominent and experienced colleagues from science and public policy and builds upon research presented at the 2011 World Water Week in Stockholm, August 21-26, 2011. Chapters with a scientific orientation are complemented by a case study that demonstrates the factors for success to advance green infrastructure in the city of Milwaukee in the United States and poignant reflections from UN-HABITAT on the planning and design of basic infrastructure that provide the foundation for clean, healthy development of urban centers around the world.

The texts aim to illuminate the need for scientific findings in policy and in practice and vice versa; the need to formulate scientific enquiries and carry out scientific studies, which are relevant for policy and human endeavors. The Scientific Programme Committee (SPC) plays a central role in the identification of the authors together with staff at SIWI. The texts submitted have been peer reviewed by the members of the SPC and other colleagues who are familiar with the topics discussed in the articles in line with the procedures applied in Scientific Journals.

The full programme for the World Water Week and documents from the deliberations in 2011 as well as from other years can be accessed and downloaded at www.worldwaterweek.org.

Jan Lundqvist,
Editor, On the Water Front

Torkil Jonch-Clausen
Chair, Scientific Programming Committee

Jens Berggren,
Director, World Water Week in Stockholm

Torgny Holmgren,
Executive Director, Stockholm International Water Institute

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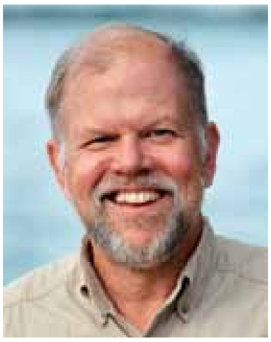

DR. STEPHEN R. CARPENTER
Stockholm Water Prize Laureate 2011
Center for Limnology, University of Wisconsin, Madison, USA

COMPLEX CONNECTIONS OF AGRICULTURE AND WATER QUALITY: LINKAGES OF FOOD AND WATER SECURITY

Agriculture and fresh waters are the most extensively transformed ecosystems on Earth. Agriculture affects fresh water through climate change, direct water use, nutrient mobilisation, toxin discharges, physical modifications (e.g. dams and levees) and loss of habitat and biodiversity. The global phosphorus cycle creates unique linkages of food and water security. Excess phosphorus causes severe water quality problems in some parts of the world, but shortage of phosphorus limits agricultural yields in other regions. Phosphorus reserves are finite, localised in only a few countries and will eventually be exhausted. Conservation and recycling of phosphorus could simultaneously mitigate water quality and phosphorus deficiencies in agriculture. Currently, however, most water quality management is focused on blocking flows of phosphorus to surface waters instead of recycling phosphorus to regions of deficiency. Thus we have an opportunity to create policies, practices and technologies that efficiently recycle phosphorus and thereby improve both food and water security.

Key words: Agriculture, eutrophication, food security, phosphorus, water security

Introduction

Agricultural and fresh water ecosystems have been massively transformed by human activity. Pastures and croplands occupy about 38 per cent of the planet's ice-free terrestrial surface (Ramankutty *et al.*, 2008). Globally, conversion for human food production has affected 70 per cent of the grassland, 50 per cent of the savannah, 45 per cent of the temperate deciduous forest and 27 per cent of the tropical forest (Foley *et al.*, 2011). Agricultural activities cause extensive changes to soils, vegetation, nutrients and water cycles and productivity of the affected land (Millennium Ecosystem Assessment, 2005).

Fresh water ecosystems – lakes, reservoirs and rivers – have also been altered extensively by human activity, and especially agriculture (Carpenter *et al.*, 2011). The morphology and hydrology of fresh waters have been altered to facilitate water withdrawal, mainly for irrigation. Inputs of nutrients and toxic substances have increased. Many fresh water processes have been greatly altered, including carbon cycling and storage. Biotic changes in fresh waters include loss of native species, expansion of invasive species and emergence of diseases. The most important direct drivers of change in fresh waters are climate change, hydrologic flow modification, land-use change, chemical inputs, aquatic invasive species and harvest (Carpenter *et al.*, 2011). All of these drivers have links to agriculture or aquaculture.

The massive changes in agricultural lands and fresh waters are linked (Fig. 1). Rain-fed agriculture is the world's largest user of fresh water (Foley *et al.*, 2011). Irrigation accounts for about 70 per cent of global fresh water withdrawals (Carpenter *et al.*, 2011). By altering the balance between evapotranspiration, runoff and infiltration, agriculture has changed the allocation of water flows among the atmosphere, surface waters and ground water. Climate change, with its implications for the distribution of precipitation across the Earth's surface, is driven in part by agriculture. About one-third of global greenhouse gas emissions are contributed by agriculture, principally from tropical deforestation, methane emissions from livestock and rice cultivation, and nitrous oxide emissions from fertilised soils (Foley *et al.*, 2011). Precipitation and air temperature play key roles in the water cycle. Thus, the indirect effect, mediated through climate, of agriculture on fresh waters may eventually become as important as the direct hydrologic impacts of agriculture.

In addition to its effects on the water cycle, agriculture has fundamentally changed the Earth's nitrogen and phosphorus cycles through fertiliser use, manure application and the planting of nitrogen-fixing crops (Galloway *et al.*, 2008; Bennett *et al.*, 2001). Total emissions of reactive nitrogen to the atmosphere and oceans have increased more than nine-fold since 1860 (Galloway *et al.,* 2008). Similarly, the flow of phosphorus in surface waters has increased about three-fold since the industrial revolution (Bennett *et al.*, 2001). Almost all increased phosphorus flow, and much of the increased nitrogen flow, is a result of agricultural fertiliser use.

Climate change and nutrient release have interacting effects on water quality. The effects of nutrient pollution, and most regulatory frameworks for excess nutrients, are based on concentration, which is a ratio of the nutrient mass to the water volume. Thus the consequences and management of pollution are closely related to the hydrologic cycle and the flows of water available to dilute pollutants.

Agriculture has a number of other effects on fresh waters. Herbicides and pesticides in farm runoff can be toxic to fresh water organisms. Habitat and biodiversity are adversely affected by physical modifications of channels and shorelines (Carpenter *et al.*, 2011).

This article focuses on the role of agriculture in nutrient pollution and eutrophication. Eutrophication and its consequences are summarised. Changes in the global phosphorus cycle, the key driver of most fresh water eutrophication, are then discussed. Non-point pollution is the vector of phosphorus pollution that is most difficult to manage, and these difficulties are described. Mitigation options, ranging from managing the global phosphorus cycle to managing the internal dynamics of individual fresh waters, are summarised. The paper closes with some open challenges of governance for of the phosphorus cycle and fresh water eutrophication.

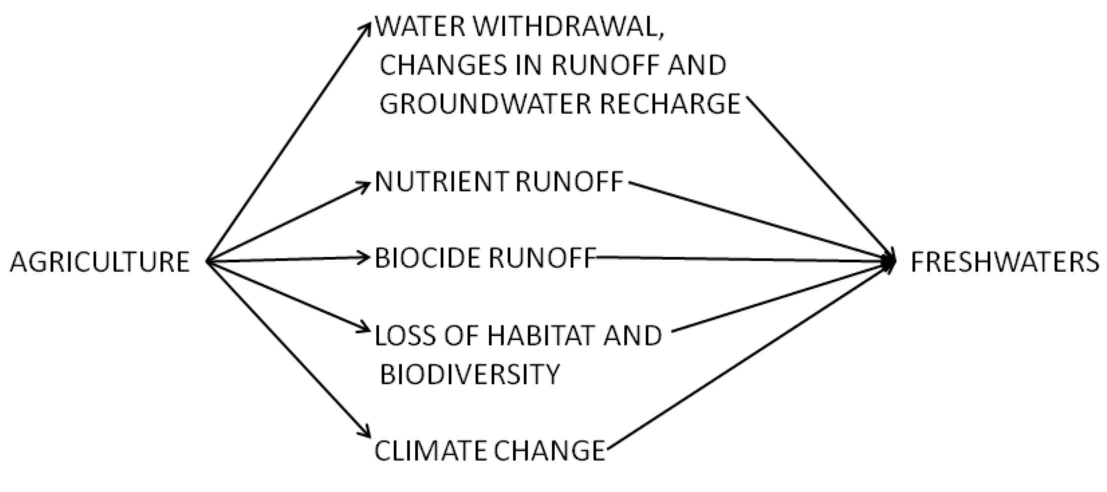

Figure 1. Linkages of agriculture to fresh water ecosystems

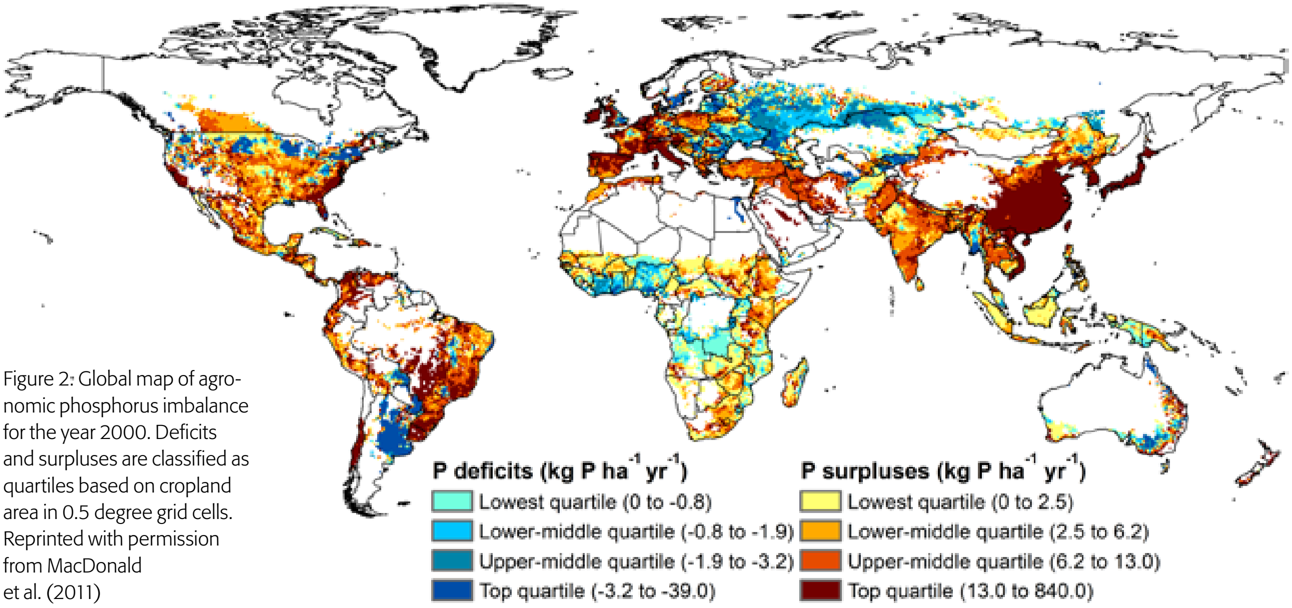

Figure 2: Global map of agronomic phosphorus imbalance for the year 2000. Deficits and surpluses are classified as quartiles based on cropland area in 0.5 degree grid cells. Reprinted with permission from MacDonald et al. (2011)

Eutrophication

Eutrophication is the over-enrichment of ecosystems with nutrients. Phosphorus enrichment is the most common driver of fresh water eutrophication, but other nutrients sometimes play a role (Smith, 2003).

Eutrophication of lakes, reservoirs and rivers leads to the excessive growth of aquatic plants, including phytoplankton, attached algae and rooted vegetation. The excess plant growth is often composed of species that are not eaten by aquatic animals. These increases in plant growth can lead to oxygen depletion and reduced yields of desirable fishes, as well as threats to other aquatic species. Murky, turbid water leads to taste and odour problems in drinking water supplies, and increases costs of water treatment. Decreases in the perceived quality of the water body may affect property values or other social and economic amenities (Dodds *et al.*, 2008; Pretty *et al.*, 2002; Wilson and Carpenter, 1999).

Human health is affected by eutrophication. Enrichment with phosphorus causes shifts in phytoplankton species that favour bloom-forming species, including toxic cyanobacteria (sometimes called 'blue-green algae'). Cyanobacteria release highly toxic metabolites that are hazardous to humans, livestock and aquatic consumers (Huisman *et al.*, 2005; Chorus and Bartram, 1999). Methods for assessing cyanobacterial toxins in fresh water are becomingmore widely available, and discoveries of toxic blooms are more frequent. For example, a suvey of the surface waters from 10 Europeancountries revealed toxic blooms in about 50 per cent to more than 90 per cent of the samples tested (Smith, 2003).

Global phosphorus cycle

Among the major biogeochemical cycles (e.g. carbon, nitrogen, phosphorus and sulphur), the phosphorus cycle is most heavily altered by human action (Falkowski *et al.*, 2000). The annual flow of phosphorus to the sea has roughly tripled since pre-industrial times, and essentially all of this increase is attributable to human actions, including agriculture, mining and accelerated weathering resulting from land disturbance (Bennett *et al.*, 2001). The planetary boundary for the phosphorus flow from land to fresh waters is about 8.6 Tg/year, based on median data and a generous target concentration for phosphorus in fresh waters (Carpenter and Bennett, 2011). By definition, a planetary boundary is a normative, human-determined, maximum acceptable level of a variable that affects human well-being, computed for the planet as a whole (Rockstrom *et al.*, 2009). The median estimate of annual phosphorus flow from land to fresh waters is about 25.9 Tg/year, more than three times larger than the planetary boundary (Carpenter and Bennett, 2011). In other words, the total flux of phosphorus to fresh waters, averaged over the planet as a whole, is about three times larger than the level needed to maintain acceptable water quality.

However, these global averages belie substantial spatial heterogeneity in the phosphorus cycle (Fig. 2) (MacDonald *et al.*, 2011). Regions with positive phosphorus imbalances (accumulations of phosphorus, mainly in soil and fresh water sediments) are generally associated with impaired water quality. Most of the excess phosphorus accumulation is caused by the overuse of mineral fertilisers, although manure is an important driver of excess phosphorus in regions with high livestock densities (MacDonald *et al.*, 2011). In contrast to the regions of phosphorus surplus, phosphorus deficits occurred for about 30 per cent of the world's cropland area (MacDonald *et al.*, 2011). Phosphorus deficits were common in areas that produce forage crops used to feed livestock. They are also associated with places where soils are naturally low in phosphorus and farmers lack access to fertilisers. These imbalances suggest that phosphorus use around the world could be balanced to mitigate pollution in phosphorus-rich areas and stimulate crop production in phosphorus-poor areas.

Non-point nutrient pollution

Phosphorus hotspots are associated with non-point inputs of phosphorus pollution to fresh waters and coastal oceans (Carpenter *et al.*, 1998). Non-point sources may derive from extensive land areas that are distant from the receiving water body. Examples of non-point sources are runoff from agriculture, urban runoff from areas that lack storm sewers, runoff from non-agricultural activities, such as construction sites or mines, leachate from septic fields, or atmospheric deposition. Non-point inputs tend to be scattered and heterogeneous in both location and timing. In contrast, point sources through a pipe, such as sewage or industrial discharges, come from a focused location. Because point sources are linked to particular locations, they are relatively easy to locate, quantify and manage. Management of non-point pollution is much more difficult.

Agriculture is the major source of non-point phosphorus pollution to fresh waters (Carpenter *et al.*, 1998). Globally, phosphorus additions in fertiliser exceed the removal of phosphorus in food, and consequently phosphorus builds up in the soil or runs off to surface waters (Bennett et al., 2001). Nutrient runoff from agriculture has been recognised for decades, and it has proved to be a persistent environmental problem (Carpenter *et al.*, 1998).

Urban runoff can be an important local source of non-point pollution, even though its global magnitude is modest. In relatively wealthy municipalities, urban runoff has been controlled, for example by removing debris, establishing storm sewer systems and collecting sediment in retention basins (Carpenter *et al.*, 1998).

What can be done about it?

Managing the global phosphorus cycle

Because of human action, the phosphorus 'cycle' is no longer cyclic. Instead, it is a more or less linear flow of phosphorus from mineable rock to waste (Elser and Bennett, 2011). Until recently, fresh water degradation has motivated most of the concern about the disrupted phosphorus cycle. Now, however, there is growing concern about phosphorus shortages when mineable rock reserves are tapped out (Elser and Bennett, 2011; Cordell *et al.*, 2009). Emerging shortages of phosphorus should motivate the recovery and reuse of the mineral as a fertiliser for food production, to replace increasingly costly and scarce phosphate rock. Actions taken to improve phosphorus use efficiency and decrease waste will have benefits for water quality.

Many practices and technologies can contribute to the conservation, efficient use or recycling of phosphorus (Cordell *et al.*, 2011). Livestock densities, driven by demand for meat, account for a significant fraction of the excess phosphorus in the environment (MacDonald *et al.*, 2011). Phosphorus efficiency can be improved by changing the diets of humans and livestock to ones demanding less phosphorus, improving the efficiency of phosphorus transfers through the food chain to humans and improving agricultural practices. In addition, phosphorus can be recovered and re-used from crop residues, food waste, manure and human excreta (Cordell *et al.*, 2011).

Waste of food also wastes phosphorus. Estimates of the waste in the food production and distribution systems are around 40 per cent, though for some perishable foods waste can be 100 per cent at some places and times (Foley *et al.*, 2011). Only one-fifth of the phosphorus mined for food production is ever eaten by humans (Cordell *et al.*, 2009). The rest is accumulated in the soil, lost in runoff to fresh waters and coastal ecosystems, or discarded. Even a partial reduction in the magnitude of food waste would decrease water pollution, while increasing our capacity to feed a growing human population (Foley *et al.*, 2011).

Agricultural practices play a key role in improving the efficiency of the phosphorus cycle (Schröder et al., 2011; Suh and Yee, 2011). Applications of phosphorus fertiliser can be sharply reduced by

- Better matching of land and soil characteristics to crop needs.
- Preventing erosion.
- Building soil quality.
- Improving recommendations and guidelines for fertiliser use.
- Developing efficient methods for applying fertiliser.
- Creating crop varieties that use phosphorus more efficiently.
- Balancing phosphorus inputs and outputs at the farm scale.
- Exporting manure from phosphorus-rich sites to places that need more phosphorus.
- Adjusting livestock diets to decrease egestion and excretion of phosphorus (Schröder *et al.*, 2011).

Actions taken to improve phosphorus use efficiency and decrease waste will have benefits for water quality. Currently, many of these losses of phosphorus – for example erosion of soil, manure runoff, and unmanaged human waste – contribute to poor water quality. Unwanted phosphorus inputs to lakes, reservoirs and rivers will be decreased as less phosphorus is wasted through losses to the environment.

Watershed management

Although management of the phosphorus cycle is a global problem, many of the corrective actions are local. In wealthy countries with a long history of phosphorus pollution problems, many practices and policies have been developed to curtail phosphorus discharge to the environment. Foremost among these are improved sanitation and sewage treatment. These technologies have largely been successful, although the degree to which nutrients are controlled is variable from place to place depending on expenditures, infrastructure and other local factors.

Management of non-point phosphorus pollution has proved to be difficult. Even though many practices are capable of controlling non-point pollution, implementation of these practices has often been challenging. Practices that can potentially control non-point phosphorus pollution generally focus on agricultural lands (Carpenter *et al.*, 1998). Decreasing the phosphorus content of soils by limiting the applications of fertiliser and manure will decrease the amount of phosphorus that is in a position to be washed into surface waters. Even though decreases in fertiliser and manure application will eventually lead to decreases in soil phosphorus, 'legacy phosphorus' in over-enriched soils can persist for a long period (Kleinman *et al.*, 2011). Legacy phosphorus is a difficult message for planning and policy, because it means that yesterday's sinks of phosphorus may be tomorrow's sources (Kleinman *et al.*, 2011).

Transport of phosphorus by erosion and runoff can be reduced by vegetated buffer strips along shorelines, tillage practices that decrease erosion (such as contour tillage), cover crops and retention ponds. The concept of 'critical source areas' uses advanced mapping technologies to identify areas where high phosphorus levels coincide with conditions favourable to the transport of phosphorus (Sharpley *et al.*, 2011). These approaches have had mixed results. For example, conservation tillage to decrease erosion can cause vertical layering of phosphorus in soils which increases the loss rates of dissolved phosphorus (Sharpley *et al.*, 2011). In addition, outcomes at the scale of individual fields may not scale up to entire watersheds (Sharpley *et al.*, 2009). Despite these technical challenges, the greatest barriers arise in the implementation of phosphorus management policies.

Most phosphorus management practices involve changes in the ways that individual farms are operated. Implementation of these changes has proved to be difficult. Food production is an important priority for every country and so food producers enjoy great political power and significant financial subsidies in many countries. Producers think they are in business to generate food and not to control pollution or maintain water quality. Policies to mitigate phosphorus pollution from agriculture face many social and political obstacles (Perez, 2011; Mandelker, 1989; Harrington et al., 1985). Success, while possible, is rare.

From a global perspective, it is clear that we must conserve phosphorus in order to ensure food security, and we must balance phosphorus use around the world to mitigate water pollution, improve water security and address soil fertility deficiencies. The watershed approaches are intended to decrease phosphorus pollution of surface waters, an important goal, but, by itself, insufficient to address the interacting problems of food security, water security and sustainable phosphorus. In order to address the full set of global problems linked to phosphorus, we must go beyond merely stopping phosphorus pollution to recycling phosphorus and moving it from regions of excess to regions of need.

Management of fresh water ecosystems

Sometimes it is possible to mitigate eutrophication by direct intervention in the polluted water body. While in-lake methods may be viewed as 'treating the symptom not the cause', they sometimes provide the most cost-effective option for mitigating impaired waters and providing water security. An extensive literature addresses management of excess phosphorus and nuisance algae in lakes and reservoirs (Cooke *et al.*, 2005). Methods that have met with some success include dilution and flushing, withdrawal of polluted layers of water (hypolimnetic withdrawal), dredging and removal of polluted sediments, chemical inactivation of phosphorus and manipulation of the food web to increase the densities of grazers that consume algae (biomanipulation). The choice of methods depends on the specific ecological characteristics of the impaired water body as well as the engineering and financial resources that can be brought to bear on the problem (Cooke *et al.*, 2005). Well-funded and well-designed projects have often resulted in improvements in water quality.

Policy challenges

The global connections of food and water security raise many policy challenges, ranging from climate change to management of individual crop fields. Here I will focus more narrowly on the issues that relate to phosphorus and eutrophication.

Potential global shortages of phosphate rock raise important security issues because the element is irreplaceable and essential for food production (www.foreignpolicy.com/articles/2010/04/20/peak_phosphorus.html). Phosphorus rock supplies are controlled by only a handful of countries. Yet excess phosphorus in some regions drives severe degradation of fresh waters that impairs water security. Thus a principal need is for policies that moderate phosphorus use in regions of excess and provide adequate phosphorus in regions of insufficiency.

While many practices and technologies are capable of mitigating phosphorus pollution from agriculture, policies to implement these practices and technologies succeed only rarely (Perez, 2011; Mandelker, 1989; Harrington *et al.*, 1985). Clearly there is a need for new thinking and revision of policies to manage phosphorus pollution from agriculture.

A global perspective has important implications for the improved management of water quality and soil fertility, if shortages of phosphorus drive conservation and recycling. This is possible as prices rise. However, if political instability leads to short-term fluctuations in the phosphorus supply the consequences for food production and food security could be destabilising. In the long run, phosphorus shortage is likely to increase the prices of phosphorus, and if this happens rapidly there could be catastrophic consequences for food production, especially in developing countries with phosphorus-poor soils. A phosphorus tax could ease the transition in several ways. Producers would have time to adjust to high phosphorus prices. Tax revenues could be used to pay for practices and technologies to recycle phosphorus where it is abundant and transfer it to where it is needed. By raising the price to producers, a tax creates incentives for conservation and recycling. Thus a well-designed tax could create incentives that proactively solve the phosphorus problem.

In summary, we need to move from the current situation of a wasteful and highly vulnerable system for using phosphorus to a closed cycle that is efficient, mitigates excess, and addresses shortfalls. How can we increase the chances of a smooth transition to sustainable phosphorus? This challenge is at the heart of the phosphorus connection between food and water security.

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DR. BLANCA JIMÉNEZ-CISNEROS
Senior Researcher, Department of Environmental Engineering, National Autonomous University of Mexico

REVIEW OF NEEDS TO BETTER MANAGE URBAN WATER

This paper describes how cities worldwide are experiencing increasingly complex water challenges that are not being addressed by water utilities. Moreover, many of these challenges have not yet been identified as relevant problems to the water sector and, hence, who should be responsible for them has not been defined, even if they are obviously affecting water as a resource. This paper identifies some such problems, considering new types of urban settings, relevant geographical conditions and the impacts on water through the urban water cycle in different urban sectors. Based on this, a list of concepts that are to be considered as part of urban water management is provided, putting particular emphasis on developing countries.

Keywords: Megacities, urban water cycle, water services, cities of the future, climate change, IWRM

Introduction

Globally, the urban population is increasing, since cities are perceived as an option to improve the 'quality of life'. Cities concentrate economic resources, job opportunities, educational and cultural activities and, moreover, political power to gain access to public services. As a result, urban settlements have become more attractive than rural ones, and, therefore, nowadays, we experience an artificially increased 'need' to live in packed cities (urban areas are those with > 150 inhabitants/km^2, OECD, 2010). At the same time, the intensive use of densely populated land is affecting the environment and forcing urban planners to look for sustainable options for life in cities. This is one of the major modern concerns, as most of the world's population soon will live in cities. If urban growth maintains its current rate of increase, by the 2050s city dwellers will make up 90per cent of the global population (UN-HABITAT, 2010). Ninety five per cent of the urban population increase is expected to happen in cities in developing countries (UNESCO, 2009). Despite this, living in cities and achieving a better quality of life are not always straightforward in developing countries as the bulk of the population lacks services, notably those related to water.

At a world level, the concepts of urbanisation are being reviewed in order to define a new paradigm for the 'city of the future'. Considering this, it is worthwhile reviewing how urban water services are provided and how they can be improved to better manage water in terms of quantity and quality. Hence, the purpose of this paper is to identify concepts that are not considered within the scope of the conventional urban water services approach, but are necessary to manage urban water. The challenges to be faced are identified by analyzing the needs imposed by the different types of urban settings, the requirements set by different geographical regions, the urban water cycle concept and the impacts of different sectors on water. Based on this, a new definition of urban water management goals is proposed.

Identification of urban water management challenges

Cities represent small geographical areas in which there are high demands for resources, notably for water, energy and food. Simultaneously, they become areas in which pollutants are concentrated and discharged to the environment. As cities grow, these point source impacts become more and more significant, affecting wider areas. If several cities are located in the same geographical region these disturbances increase, perhaps in a non-linear way, and in such a manner that the environment may not be able to adapt to them. In this section, the challenges to be addressed through the integrated management of water are identified considering different conditions. These are summarised in Table 1.

Table 1. Challenges to address through the integrated management of urban water

Condition	Challenges
Type of urban setting	
City regions	• Harmonise the efficient use of water in urban and rural settings independently of different territorial policies, political levels of organisations and aims • Integrally manage water, urban floods and wastewater in different administrative areas • Combine safe on-site sanitation systems for rural hinterlands with wastewater collection and treatment systems for cities • Manage and revalorise sludge produced in urban areas
Urban corridors	• Harmonise the use of water supply sources and wastewater disposal sites along the urbanisation line • Control the non-intentional reuse of water
Megacities	• Provide supply from a combination of water sources • Provide the same level of services for the whole city
Mega regions	• Efficiently use water by optimising the use of different water sources for different activities in areas in different political territories • Properly manage water demand for municipal, agricultural and industrial uses • Properly provide the safe treatment and reintegration of used municipal and industrial water to the environment, including the management of sludge
Relevant geographical conditions	
Arid and semi-arid zones	• Deal with increasing conditions of water scarcity and per capita water availability • Combine conventional and non-conventional sources of water as supply • Control ground water overexploitation and associated problems • Efficiently use water, for instance by adopting toilets, taps and showers with low water consumption • Manage urban floods • Reuse wastewater • Manage the proper disposal of wastewater to the soil
Coastal regions	• Control saline intrusion by reducing overexploitation and recharging ground water • Protect and operate water infrastructure during hurricanes and floods • Properly dispose of wastewater to the sea
Mountain regions	• Provide a water supply service of sufficient quantity and with reliability in dry areas • Control sediment transportation to water sources and sewers in wet areas
Urban water cycle *Aspects that directly fall within the scope of water utilities or management institutions*	
Water supply	• Provide services that are efficient in terms of quantity, quality and reliability for an increasing population and under climate change scenarios • Provide water of drinking quality from water sources that are increasingly being polluted • Control leaks from the drinking water network (leaks in developing countries might be as high as 60 per cent of the total water supply) • Manage water demand through tariffs when there is flexibility • Protect urban aquifers from overexploitation and pollution • Control the unplanned reuse of water for drinking purposes
Urban flood control	• Promote urban design to reduce urban floods, for instance by using water ponds as part of the urban landscape • Implement programmes to control floods • Protect and operate urban water infrastructure • Promote public and private insurance for flood protection

Wastewater management	• Provide full coverage of sewage and wastewater treatment services • Implement pre-treatment programmes for industries discharging to municipal sewers • Control infiltration/exfiltration from sewers and rivers • Control leaks from septic tanks and latrines and safely dispose of their effluents • Promote clean production principles in small factories, businesses and services and introduce restrictions on the use of sewers as disposal sites • Control pollution from storm runoff • Reclaim water, nutrients and energy from wastewater and sludge • Safely introduce treated wastewater back into the environment
Aspects that do not directly fall within the scope of water utilities or management institutions	
Deposition of atmospheric pollutants	• Run programmes that control air and water pollution in parallel • Monitor air pollutants in water
Use of sewers as disposal sites	• Control the disposal of solid and liquid wastes from small factories, businesses and industries
Water pollution from residue washout in sewers as a result of the transport and transference of material	• Implement clean production practices and certification programmes in industries transporting chemical substances • Implement programmes to survey leaks from urban pipelines
Leakage from liquid storage tanks	• Implement monitoring programmes to follow up pollution from storage tanks • Implement clean production practices and certification programmes
Leaching from dumping sites, municipal landfills and hazardous waste confinement sites	• Replace dumping sites with municipal landfills • Monitor the quality of aquifers beneath municipal landfills that are relevant for municipal supply
Leachates from cemeteries	• Monitor the quality of aquifers beneath cemeteries that are relevant for municipal supply
Introduction to wastewater or aquifers of the residues from the application of de-icing substances	• Promote the selection of non-toxic compounds for de-icing
Sectors impacting water	
Land-use	• Develop joint strategies for the provision of housing and water services • Design cities with manageable urban population densities, with the types and heights of buildings based on the efficient use of water and energy • Design cities that maximise ground water recharge and the retention of storm water runoff • Promote urbanisation that reduces the heat island effect • Create zones with different water services and allow areas to locate hydraulic infrastructure to control floods and promote water reuse • Adopt a combination of centralised-decentralised water systems • Locate non-point sources of urban pollution at sites where they can be controlled
Transportation	• Design transportation infrastructure allowing storm water runoff to reduce unnecessary floods • Use fuels that demand smaller amounts of water for their production (L of water/km travelled) • Reduce fuel consumption in cities by reducing travel distances and promoting public transportation to save water for its production
Environmental	• Control deforestation in the higher part of the cities to increase ground water recharge, replenish water sources, reduce flood risks and sediment transportation to sewers and water sources • Control pollutants in the air that end up in water sources • Control solid waste dumping sites and non-point sources of pollution to water • Adapt water infrastructure to climate change impacts
Building construction	• Design buildings that reduce the per capita consumption of water and energy, considering water reuse systems, reclamation of pluvial water, promotion of ground water recharge and reduction of the urban water footprint
Energy	• Conjointly optimise the use of water and energy • Reduce energy consumption • Promote the recovery of energy from wastewater and sludge
Education	• Create awareness of unnecessary luxury uses of water and energy demands • Uncouple the concept of a better quality of life with the higher use of water and energy
Health	• Promote a good level of public health to reduce the content of pathogens in wastewater

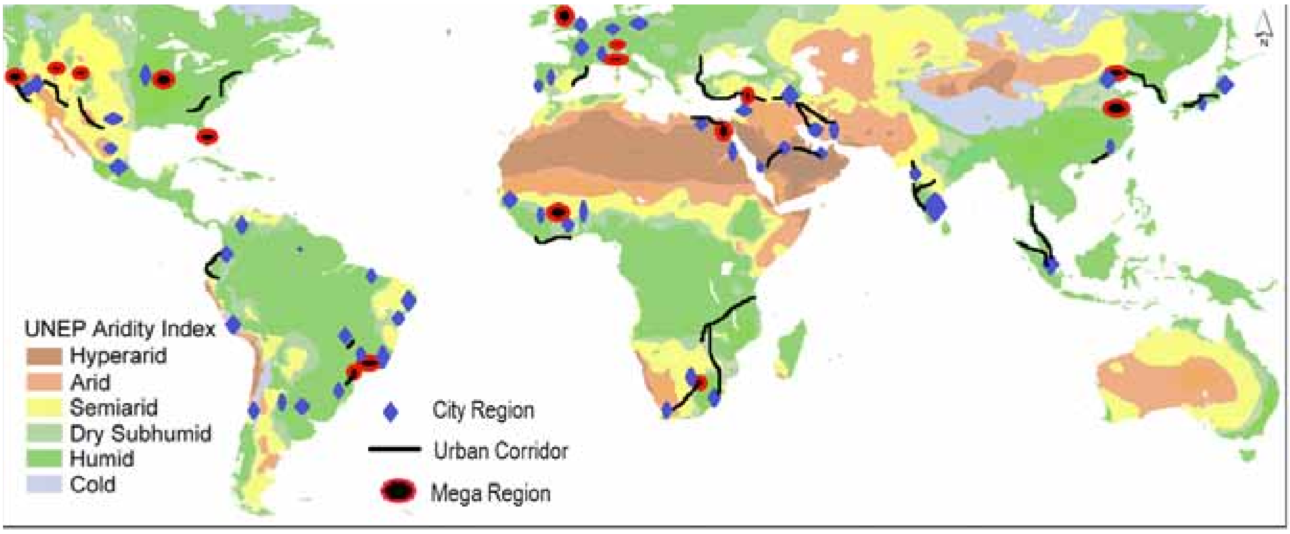

Figure 1. Selected city regions, urban corridors and mega regions and distribution of climatic zones, with information from UNESCO, 1979 and UN-HABITAT 2010

Type of urban setting

While in many cities the water sector is still trying to determine how to provide conventional water services – notably in developing countries – those in other urban settlements have become more complex. UN-HABITAT (2010), recognising the need to introduce additional classifications for urban settings (Fig. 1) provided definitions for city regions, urban corridors, megacities and mega urban regions with associated implications for the management of water. These are:

- *City regions* – Clusters of cities of different sizes, semi-urban areas and rural hinterlands. They extend beyond formal administrative boundaries and have developed over the last 20 to 30 years, as a result of the effects of the agglomeration of economies. In this mixture of urban and rural areas, people from different geopolitical regions share both water supplies and wastewater disposal sites, indistinctively using patterns not always clear to distinguish at a local level.
- *Urban corridors* – Urban spaces of different sizes that grow along highways, and are a consequence of the increased ease of communication. Linear urban spaces extend beyond administrative boundaries, basins and even geographical regions. They may also include megacities. Urban corridors create a linear demand for water and link cities through patterns of water supply and wastewater disposal sites. When cities are also connected by the same river, the non-intentional reuse of water for supply may occur.
- *Megacities* – As defined in the past, megacities are urban centres with more than 10 million people. Some are characterised by a large number of tall buildings while others (such as Mexico City) are extended urban areas with few tall buildings. Megacities are characterised by an enormous water demand and the production of a large volume of wastewater. By 2025, a total of 27 megacities are expected to concentrate 12 per cent of the world's urban population.
- *Mega regions* – Ensembles of metropolitan areas and other agglomerations with over 20 million people. They represent significant areas of economic output. The world's 40 largest mega regions concentrate 85 per cent of technological and scientific innovation, host 18 per cent of the world's population and account for 66 per cent of global economic activity. However, as they cover only a tiny fraction of the habitable surface of the world they are areas of intense water demand and used water discharges.

Relevant geographical conditions

Semi-arid and arid coastal and mountain regions have been identified as geographical conditions of particular relevance to the provision of water services.

Semi-arid and arid regions – These are regions generally characterised by low erratic rainfall of up to 700 mm per year, periodic droughts and an evapotranspiration rate higher than that of the precipitation (Goodin and Northington, 1985). They represent around 30 per cent of the global terrestrial surface area and host around 25 per cent of the world's population (Chalfoun, 2003). There are arid and semi-arid regions in both hot and cold climates. Hot semi-arid climates ('BSh' type) are located in the tropics and subtropics. In tropical semi-arid regions, extremely wet periods (known as monsoons in Asia) followed by several months of very low precipitation are characteristic (Goodin and Northington, 1985). Most arid and semi-arid areas are within the tropics. They cover most parts of the world's developing nations, including Latin America (the northern parts of Mexico and Brazil), most parts of sub-Saharan and West Africa, large portions of eastern and southern Africa and parts of India and Southeast Asia (Sygenta, 2012). Other examples are the Mediterranean region and a large part of Australia. Cold semi-arid climates ('BSk' type) tend to be located in temperate zones at a higher elevation than areas with hot semi-arid climates. They see some snowfall, though snow precipitation is much lower than locations at similar latitudes with more humid climates. These areas are sometimes subject to major temperature swings between day and night (as

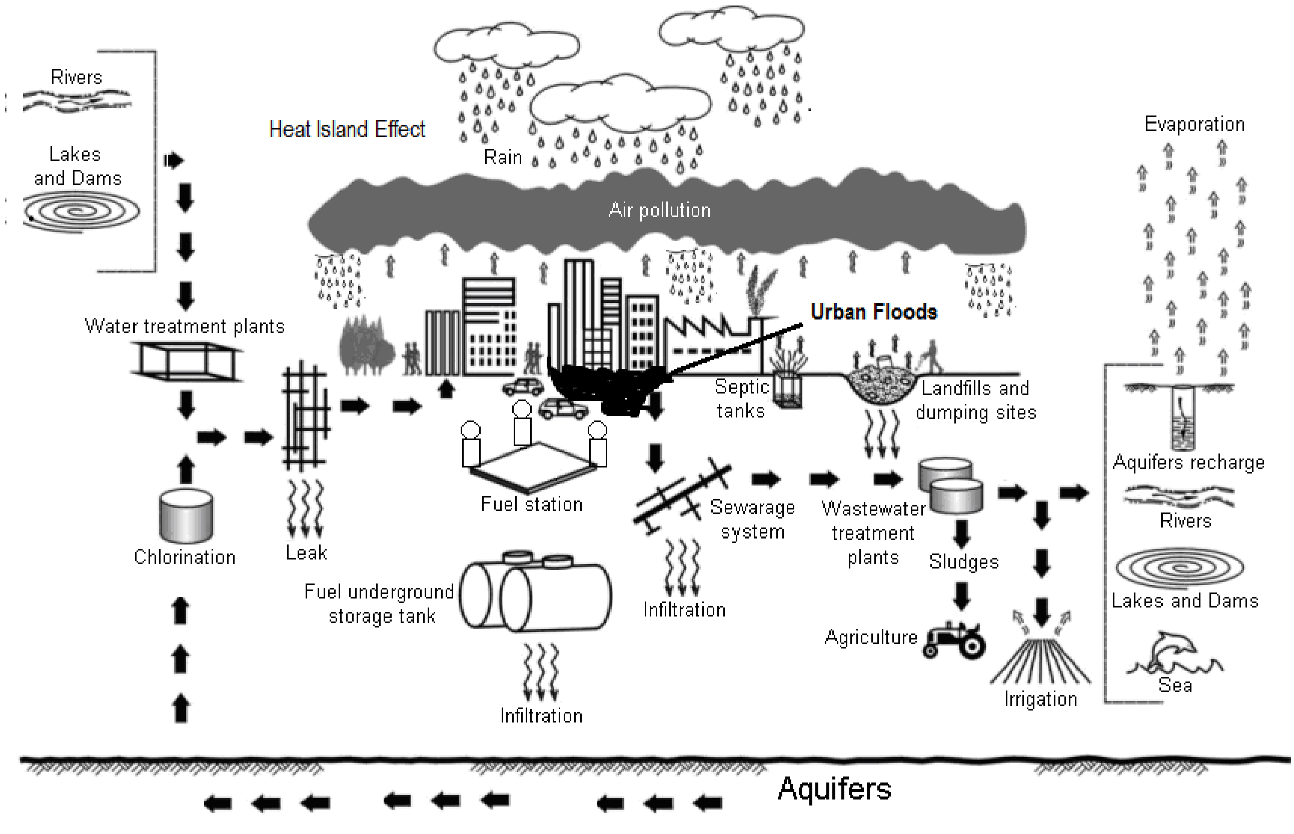

Figure 2. Urban water cycle (adapted from Jiménez 2008) Aspects that fall within the scope of urban water utilities or management institutions

much as 13°C). This climate can be found in Asia, northern Africa, southern Africa, Europe (primarily Turkey and Spain), parts of South America (mostly Chile and Argentina) and areas in the interior of southern Australia.

In terms of water supply, cities in arid and semi-arid climates face greater challenges because of water scarcity and lack of reliability. Surface water resources are generally scarce and highly unreliable; with the result that ground water is frequently the primary source of water and, therefore, commonly overexploited (Scalon et al., 2006). In addition, arid and semi-arid regions with intense periods of rainfall have to deal with large amounts of storm runoff and often experience urban floods. As many arid and semi-arid cities are located in closed drainage basins (Sygenta, 2012), a further challenge is the need to designate proper wastewater disposal sites.

Coastal regions – Half the global population lives in coastal regions, with 18 of the world's 27 megacities located there. It is thought that these regions will have to face the largest migration pressures in the next 20 years (UNESCO, 2012). Coastal cities experience challenges in supply when fed from coastal aquifers that are threatened by saline intrusion, a phenomenon caused by overexploitation. Risk of salinisation is increased under the rising sea level scenarios. In addition, water infrastructure is at risk from hurricanes and floods. Coastal cities frequently suffer from flood and sewer discharge problems (Bates *et al.*, 2008).

Mountain regions – Between one-third and one-half of all freshwater flows come from mountain areas. More than half the human population relies on mountain water for drinking and domestic use (FAO, 2012). Mountain areas are under pressure from deforestation, agriculture and tourism, endangering the water supply. The presence of glaciers on mountains has an effect, as their size, durability and the volume of snow cover determine their capacity to act as reservoirs during the dry season. According to the literature, the proportion of discharge contributed by mountains varies between 40 per cent and 95 per cent according to the region, as a result of geographical conditions. For arid and semi-arid areas, the significance of the water provided from mountains is much higher than for humid ones. For instance, Egypt, India, and China are countries that rely heavily on mountain discharge. It is worthwhile highlighting that the mean values do not reflect the real importance of mountain discharge in individual spatio-temporal terms, in particular in arid areas with their high rates of climatic variation. Moreover, in humid areas mountains play a crucial role, not for the amount of water they contribute, but with respect to the sediments transported down to the lowlands that may end up collecting in sewers as a result of the collection of storm runoff (Viviroli *et al.*, 2003).

The urban water cycle

The urban water cycle (Fig. 2) is the part of the hydrological cycle that occurs in cities. To be precise, it is that part of the natural water cycle that occurs and is modified by urban settings. In the past, these modifications have not been recognised, but as cities have increased in size and number many negative consequences resulting from modifications made to the natural water cycle have become evident. A detailed description of the urban water cycle may be found elsewhere (Marsalek et al., 2006); here only the challenges identified through its analysis are presented. These challenges are classified into two groups that are not always clearly distinguishable. The first are those that are directly related to conventional urban water services (i.e. water supply provision, urban flood control and the collection, treatment and disposal of wastewater) and, hence, are easy to identify. The second are those that originate elsewhere, and for which it is not clear who is responsible for their remediation and how they should be dealt with.

These services are provided through water utilities and can be grouped into three broad areas – the supply of water, urban flood control and the management of wastewater. In the next sections, the activities that should be considered under the scope of these areas are described.

a) Water supply – The supply of water is the major task that is performed by water utilities worldwide. The attributes of this service have changed over time, and are different between developed and developing countries. Water quantity, water quality and the reliability of the service are the main issues, with the first of these being the most important.

Already by the mid-1990s, 40 per cent of the world's population was suffering from water shortages, with this estimated to increase to 66 per cent by 2025, considering only population and economic growth (Vörösmarty *et al.*, 2000). In fact, the future availability of urban water will depend not only on the two mentioned variables, but on a combination of many of them, acting independently and somewhat randomly according to local conditions. Of these, only some are within the scope of control by water utilities. In terms of demand, the increase in urban population and the water use patterns are dominant. In terms of availability, climate variability and climate change, in that order, are of the greatest importance (Bates *et al.*, 2008).

The challenges faced by cities with regard to water availability will differ depending on the type of water source (surface or ground water, or a combination of both). Many cities are currently sharing surface water resources, competing not only for water in quantity terms, but also for wastewater discharge sites. It is estimated that more than 1.5 billion urban dwellers currently rely on ground water (Foster *et al.*, 2010). The fact that ground water is an 'invisible' source frequently leads to its overexploitation. The most critical situations occur in semi-arid and arid areas where overexploitation is leading not only to higher costs to extract water from the subsoil, but also to the deterioration of its quality, and problems related to soil subsidence (Jiménez, 2008).

b) Urban flood control – An increasing number of urban floods are reported in many cities. Urban floods originate from several factors acting either in combination or alone. The expansion of impermeable urban pavements, the construction of urban infrastructure which blocks the natural drainage of storm runoff and an increase in the intensity of showers as a result of the heat island effect (Jauregui and Romales, 1996; IPCC; 2001) are among these. Floods may short-circuit transformers and disrupt energy transmission and distribution, damage households, paralyze transportation, disrupt aircraft landings and takeoffs, compromise clean water supplies and treatment facilities, disrupt the operation of gravity-fed sewers and accelerate the spread of water-borne pathogens. These problems affect cities in both developed and developing nations. For instance, in 2011 alone, in Mexico City there were registered cases in which families lost their possessions four times in the same year. In London, flash floods caused approximately 600 incidents on the underground between 1992 and 2003. A single flooding incident in the borough of Camden in 2002 caused traffic disruption amounting to losses of at least GBP 100,000 per hour of delay on each main road affected, not including the cost of infrastructure damage (OECD, 2010).

Coastal cities are particularly prone to urban floods. Many of the world's largest cities are located in coastal areas and suffer from increased vulnerability because of sea level rise and storm surge. This results in an unprecedented risk to livelihoods, property and urban infrastructure.

c) Wastewater management – In terms of the management of wastewater, the activities to be performed by water utilities are less well defined. It is clear that water utilities are responsible for providing sewage services and the treatment of wastewater. Less clear is their responsibility to provide on-site sanitation (notably the associated services, such as the cleaning and emptying of pits), sludge treatment and revalorisation, the reuse of water and the safe disposal of treated or untreated wastewater and septic tank and latrine effluents. Moreover, the responsibility of the water utilities to control the pollution of water has been limited to the operation of wastewater treatment plants. The list of pollution sources relevant to hydraulic resources is long and increasing.

Another aspect that is worth reviewing in detail is the practice known as wastewater disposal. Independently of whether wastewater is treated, at some point it must be returned to the environment in a practice referred to as disposal. Even if treated, wastewater does not recover the quality it had prior to its use. This is proved by the widespread presence of emerging pollutants in water sources (Wang *et al.*, 2011) that eventually affect the environment. The disposal of used water into surface water sources has resulted in several cases of de facto reuse, in which downstream populations are using their own effluent or those of neighbouring cities, even when exploiting the aquifer (Dillon and Jiménez, 2008). Another situation occurs in the developing world, where, in order to reduce the impact on water sources, urban wastewater is frequently disposed of to the soil through agricultural irrigation. It is estimated that at least 20 million ha in 50 countries (around 10 per cent of the total irrigated land) is fed with raw or partially treated wastewater (WHO, 2006).

Aspects that do not directly fall within the scope of water utilities or management institutions

Many urban activities are affecting water as a resource in cities. The problem is that they do not clearly fall within the scope of any governmental institution. Among these, the following are notable (Jiménez, 2008):

a) *Atmospheric deposition* – Some air pollutants are transferred to water through atmospheric deposition or solubilisation in pluvial water. As an example, in Mexico City nearly 19,889 t of particles smaller than 10 μm, 22,466 t of sulphur dioxide, 1,768,836 t of carbon monoxide, 205,885 t of nitrogen oxides and 465,021 t of hydrocarbons are discharged each year (Jiménez, 2008). Atmospheric pollution with sulphur and nitrogen oxides is the cause of acid rain. Other air pollutants that have been reported to be transferred from air to water are mercury, methyl tert-butyl ether, nitrogen compounds, sulphur compounds and pesticides (US EPA, 2001).

b) Dry discharges from industries, small factories, businesses and services – Industries handle liquid, gaseous and solid products that are discharged into sewers often separately from the discharge of water. Industries, and more frequently, small factories, businesses and services, mostly in developing countries, simply pour different type of wastes directly into the drains. As this is done occasionally and intermittently and sources are dispersed throughout the city they are difficult to detect and control. 'Dry' industries or small businesses are often not registered by water utilities as sources of water pollution, as they do not discharge 'wastewater'. Relevant pollutants include chlorinated solvents, aromatic hydrocarbons, pesticides and pharmaceuticals that can have catastrophic consequences for public health when discharged into sewage systems. Risks may be reduced with industrial pre-treatment and monitoring programmes. The associated risks are not only a concern for human health. For example, Louisville, Kentucky, experienced a series of serious industrial chemical catastrophes in the late 1970s and early 1980s as a result of this type of discharge, which led to the development of programmes now considered 'best practice' models for risk reduction in the United States (Garner, 2009).

c) *Residues from transport and transference of materials* – In cities, a wide range of materials is transferred and transported. This may take place via pipelines, trucks or trains. Leaks and spillages from oil pipelines have been reported as sources of pollutants to soil and water bodies with localised effects.

d) *Leaks from liquid storage tanks* – These are tanks constructed above or below ground to store different substances, such as oil, gasoline, etc. Because of corrosion, bad connections and ageing, these tanks frequently leak, especially if they do not receive appropriate maintenance. Fuelling station tanks are a major problem. The consequences do not necessarily depend on the size of the leaks, but on how long they have been occurring, and such tanks are refilled frequently.

e) *Leachates from dumping sites and municipal landfills* – In developing countries, dumping sites still exist and are a threat to surface and ground water sources because of leachates conveying pathogens and toxic chemicals. Even when dumping sites are replaced with landfills, leachates are still a potential source of pollution of water bodies, particularly aquifers, but to a lesser extent.

f) *Leachates from cemeteries* – Human bodies are a source of microbiological and organic pollution of water of particular significance in crowded cities.

g) *Application of de-icing substances* – Besides water, melted ice also contains suspended solids, heavy metals, phosphorus, calcium and chlorides and has a variable pH that affects water sources if uncontrolled.

Impact of different urban sectors on water

In addition to what has been discussed previously, many activities from other sectors have an effect not only on water quality, but also on the demand for and the efficiency of its use. It is up to the water sector, as it is frequently the first to become aware of the impacts, to at least promote their control.

The way in which urban land is used determines ground water recharging volumes and the amount of storm runoff. It brings about the heat island effect, determines the water distribution demand, defines the potential sites for diffuse sources for pollution and dictates the availability of land for hydraulic infrastructure. The transportation sector is at the origin of much urban infrastructure. It modifies storm runoff patterns, generating urban floods, and is indirectly related to the urban water footprint through the types and amounts of fuels used. The environmental sector is relevant in terms of the effectiveness of detecting and controlling the diffuse sources of pollution and the protection of the quality and quantity of water sources. Building codes determine the efficiency of water use that is achievable in urban settings. More details of these impacts are presented in Table 1.

The need to redefine the water services

Based on the previous discussion, new institutional mechanisms to properly manage water are needed and the public water service concept should be broadened. So far the integrated water resources management (IWRM) concept has been more a useful academic tool to understand and analyze water problems than to manage water in practice. However, at the urban scale, changes may be successfully implemented by clearly defining who should be in charge of the different challenges that urban water imposes. When designing the solutions, the following aspects should be taken into consideration (Neuman, 2005; Reiter, 2009; de Graff and van der Brugge, 2010; MacKay and Last, 2010):

- The expected characteristics of the city of the future.
- The proper design of local, regional and even national institutions to jointly manage water, together with the participation that different stakeholders are to have.
- Economic, social and institutional limitations.
- The importance of recognising hydraulic urban infrastructure as a public good, as is done for historic buildings, museums, parks and streets.

- The need to replace the concept of the disposal of wastewater with one of its safe return to the environment.
- The combination of soft and hard solutions and treatment or non-treatment options.
- Increasing resilience of the infrastructure to climate change.
- The relative importance of the water sector contribution to mitigation policies (1.5 per cent of the global carbon dioxide emissions and 5-7 per cent of the total emissions of greenhouse gases, (McGuckin, 2008)).

In addition to the previous recommendations, it is important for developing countries to:
- Better plan, implement, operate and manage water systems.
- Select technologies that are cost-effective/efficient.
- Design and build water systems in steps.
- Provide funds for running facilities.
- Conjointly manage wastewater and solid wastes.

Conclusions

Together with the current tasks of urban public water services (i.e. water supply, urban flood control and wastewater management) there is a need to integrally manage water, which has not yet been considered in many countries. When considering the additional problems observed in the management of urban water, that are specific to the local context of cities (type of urban settings, geographical conditions) or apply to any city (disturbances caused through the modification of the natural water cycle in urban settings or by activities in different urban sectors) the need to define additional targets for governmental institutions can be perceived. The definition of the targets should be performed under the current vision of the 'city of the future' concept, which requires a change in the paradigms of all sectors and the contributions of different disciplines to design urban infrastructure. This will demand considerable financial and social contributions and it will take several decades before tangible benefits are realised (Neuman, 2005; de Graaf and van der Brugge, 2010). In addition, a further question which needs to be addressed is whether cities should have an optimal size based on water demand. Urban planners have addressed similar problems in terms of transportation and the health costs of climate change, but not always with reference to water (UNESCO, 2009; OCDE, 2010).

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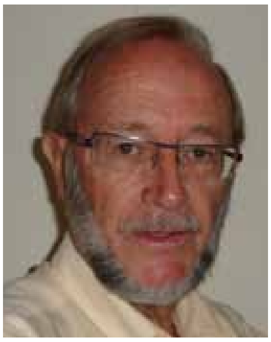

Dr. Stephen Foster
Immediate Past President
International Association of
Hydrogeologists (IAH) and
Senior Adviser Global Water
Partnership (GWP).
GW-MATEfoster@aol.com

Dr. Ricardo Hirata
Professor and Director of
Groundwater Research Center
(CEPAS), Universidade de
São Paulo, Brazil.
rhirata@usp.br

GROUND WATER USE FOR URBAN DEVELOPMENT: ENHANCING BENEFITS AND REDUCING RISKS

Ground water is often a critical but unappreciated resource for urban development. This article analyses the benefits to the water-user community, the risks in terms of compromising resource sustainability and of the public-health hazard arising from urban pollution, and the implications as regards public water-utility investments. It is based primarily on World Bank Groundwater Advisory Team (GW-MATE) supported projects in Brazil, India and, more widely, in Latin America and Asia, together with preliminary information from a number of African cities. Key policy issues are identified, and appropriate institutional and management approaches to promote more rational and secure resource use are discussed.

Keywords: Urbanisation, urban water-supply, urban ground water resources, urban sanitation, conjunctive use

Urbanisation and ground water – the context

Modes and drivers of urban ground water use

Urbanisation has been the predominant global phenomenon of the 20th century and is predicted to continue at ever-increasing rates for the foreseeable future. Ground water has been a vital source of urban water-supply since the very first settlements – when it was captured at springheads and by shallow, manually excavated waterwells. In modern times the means of ground water capture have expanded to include deeper waterwells, with a major growth of urban ground water use in industrialised nations from the 1950s, and in the so-called 'developing world' from the 1980s. Today many countries exhibit a high level of dependence on ground water for urban water-supply (e.g. from Denmark and Germany to Brazil, Nigeria, Pakistan, Peru and Vietnam). The principal modes of ground water use in urban areas are summarised in Fig. 1.

To understand the dynamics of urban water-supply development and water-resource accounting it is important:

- To distinguish within utility use between waterwells constructed in urbanised areas (on a piecemeal basis in response to new demand centres) and protected 'external wellfields or springheads' (developed as part of a long-term water-supply strategy) (Foster *et al.*, 2010a).
- To appreciate that most utilities in the developing world (and some more widely) have high levels of 'unaccounted for' water (often more than 30 per cent and in some cases 50 per cent of the original supply), and that this includes a significant component of physical losses from the distribution system to ground water, in addition to illegal connections and other non-revenue losses.
- Not to overlook the potential significance of private self-supply from ground water, not just for industrial purposes (which is more traditional), but also by residential and commercial users.
- To recognise that any given urban area is in a continuous state of evolution on a time-scale of decades (Fig. 2) (Foster *et al.,* 1998).

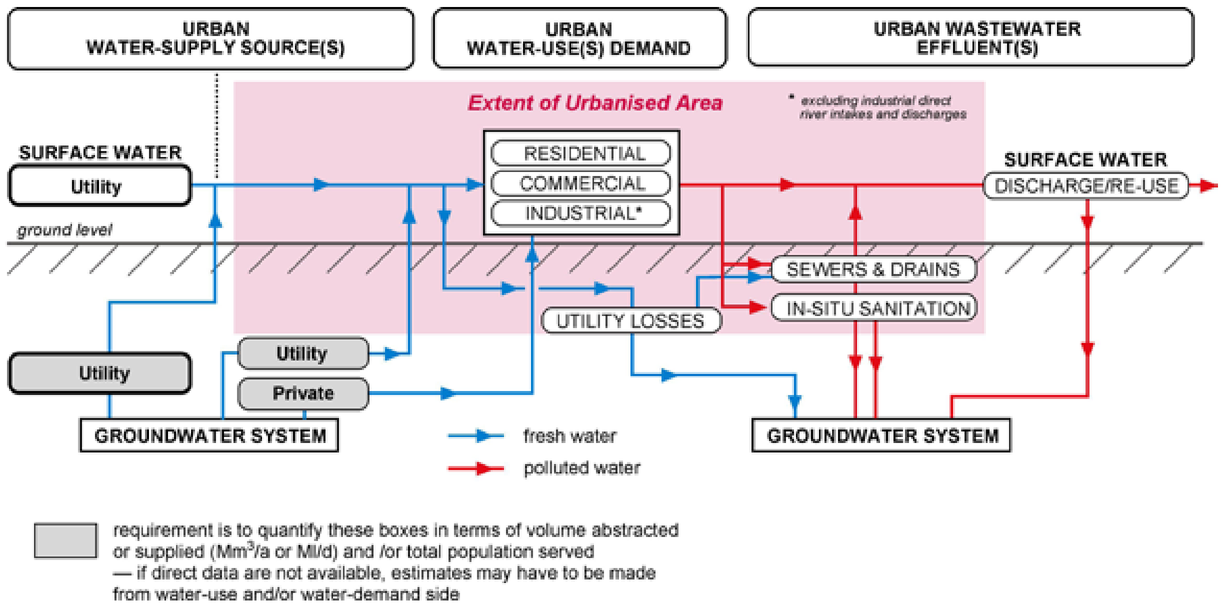

Figure 1. Sources and uses of urban water-supply and their generation of 'downstream' wastewater flows

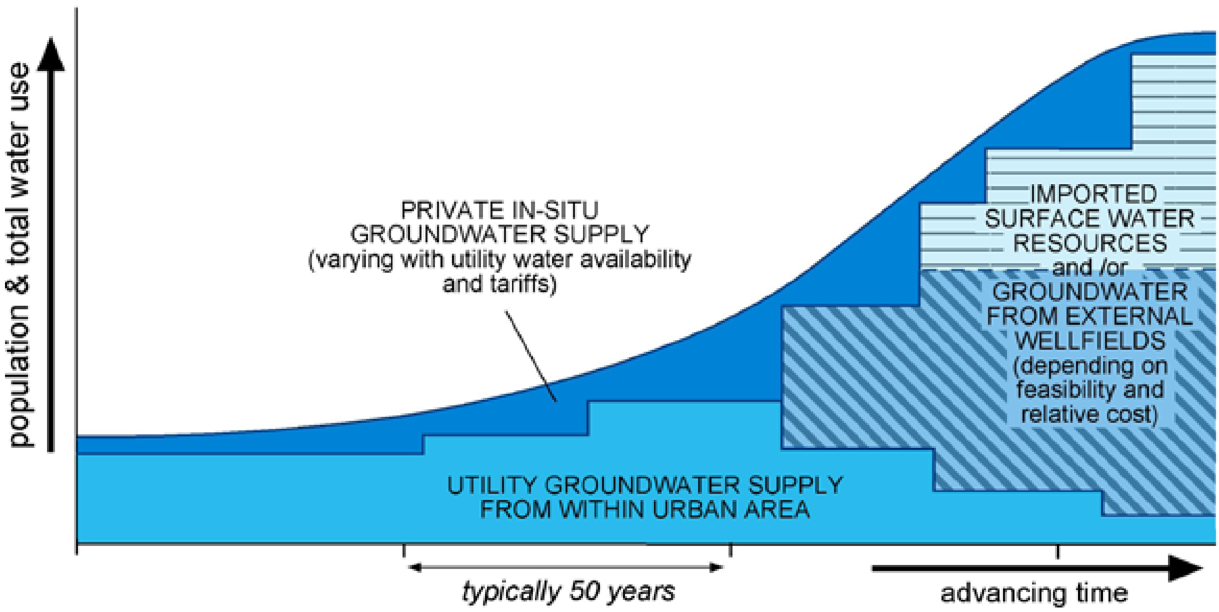

Figure 2. Typical temporal evolution of water-supply sources with large-scale urban development in areas surrounded by a high-yielding aquifer

Those urban centres surrounded by high-yielding aquifers (with sufficient potential to allow utilities to expand water-supply production incrementally in response to rising demand) usually have better mains water-service levels and lower water prices. While there are significant regional (and indeed local) variations in the evolution of urban water-supply provision and dependence upon ground water, the 'critical common factors' influencing use have been resource reliability for municipal supply and resource accessibility for private supply. Additionally, present-day drivers of urban ground water use include accelerating rates of urbanisation, increasing per capita water use, higher ambient temperatures and reduced river-intake security with climate change, and the generally low relative cost of waterwell construction (Foster *et al.*, 2010a).

In situations where the municipal water-supply service is (or has been) inadequate:

- Private operators sometimes develop local domestic water distribution systems (reticulated or tankered) based on water-wells (e.g. Asunción, Paraguay/Foster and Garduno, 2002).
- There is often a mushrooming of private in situ waterwell construction as a 'coping strategy' (e.g. Fortaleza, Brazil; Aurangabad and Bangalore, India) (Foster *et al.,* 2010a; Gronwall *et al.*, 2010).

Private supplies from ground water widely represent a significant proportion of the total urban water-supply 'actually received by users', and their presence has major implications for planning and investment in municipal water utilities. Although the 'economy of scale' can be poor, the cost of water-supply from this type of source often compares favourably with the tariffs implied by full cost-recovery from new utility surface water-supply schemes. The growth in private urban ground water use is not restricted to cities with ready access to high-yielding aquifers, but is often even more pronounced where minor shallow aquifers occur.

Ground water and the city – an intimate but fragile and neglected relationship

Urbanisation greatly modifies the 'ground water cycle' – with some benefits and numerous threats. The processes characteristic of urbanisation and industrialisation usually have a marked impact on aquifers underlying cities, and in turn man-made modifications in the ground water regime can have equally serious impacts on the urban infrastructure (Howard 2007; Foster *et al.*, 1998).

In general terms, urbanisation processes interact with ground water through:

- Substantially modifying, and generally increasing, ground water recharge rates through
  - The reduction in natural rainfall recharge through land-surface impermeabilisation usually being more than compensated for by physical water-mains leakage.
  - By infiltrating pluvial drainage.
  - By the 'return' of wastewater via in situ sanitation and leakage from faulty or ageing sewer systems.
- Greatly increased contaminant loading, as a result of
  - In situ sanitation and, to a lesser degree, sewer leakage and also inadequate storage and handling of 'community' and industrial chemicals.
  - Disposal of liquid effluents and solid wastes.

While in one sense ground water systems underlying cities represent 'the ultimate sink' for urban pollutants, the extent to which this applied subsurface contaminant load affects ground water will vary widely with the vulnerability of the aquifer system concerned.

Very rapid urbanisation, consequent upon large-scale migration of the rural population, is now occurring widely. This has lead to both escalating urban land prices from a construction industry boom and to major increases in the extension of informal unplanned slum dwellings. This is placing a heavy burden on municipal authorities for the expansion of the water-service infrastructure because it is 'by-passing' land-use planning and building regulations (e.g. Bangalore, India and Lusaka, Zambia) (Gronwall *et al.*, 2010). The latter, in turn, will frequently provoke ground water resource degradation and further complicate water-supply provision. Ways have to be found to get to grips with this situation.

Despite the frequent phenomenon of increased urban ground water recharge rates, there are rarely sufficient ground water resources within an urban area itself to satisfy the entire water-demand of larger cities. Other water-supply sources need to be introduced (Fig. 3). Otherwise, resource sustainability will become an issue (Foster *et al.*, 2010a; Foster *et al.*, 1998), and serious localised urban aquifer depletion (especially, but not only, in semi-confined systems) can result. This brings with it the risk of quasi-irreversible side-effects, such as induced seepage of contaminated water, land subsidence or coastal saline intrusion.

Later, in the evolution of major conurbations, there can be a 'sting-in-the-tail'. When pumping of ground water from the water wells in the central districts is abandoned there is a strong rebound in the water-table. (This results from the decline or migration of 'heavy industry', transformation from high-density residential to commercial use, ground water pollution fears, 'import' of major new water-supplies, etc.). This rebound can seriously consequences for established urban infrastructure, as illustrated by the experience of the past decades in Greater Buenos Aires, Argentina (Foster and Garduno, 2003).

Ground water resources near urban areas are thus influenced by a complex array of local development decisions, which are rarely viewed in an integrated fashion. These include:

- Authorisation of waterwell drilling and use (usually by water-resource agencies).
- Production and distribution of water-supplies (mainly by water-service utilities).
- Urbanisation and land-use planning (by municipal government offices).
- Installation of sewered sanitation, disposition of liquid effluents and solid wastes (by environmental authorities, public-health departments and water-service utilities).

Pragmatic strategies for risk management

Improving the sustainability of municipal utility use

In the developing world it will be important for the future that ground water be used more widely on an efficient and sustainable basis for urban water-supply. It can often play a key role in water-utility adaptation strategies with regards to climate change. In this context it will be vital that:

- Effective demand management measures are introduced to constrain inefficient and unnecessary use, and reduce 'unaccounted for' water.
- The large ground water storage of most aquifers is managed strategically (in some cases as the 'last reserve') and used conjunctively with surface-water sources to improve water-supply security (Foster *et al.*, 2010b), rather than for base-load municipal water-supply (Fig. 4).

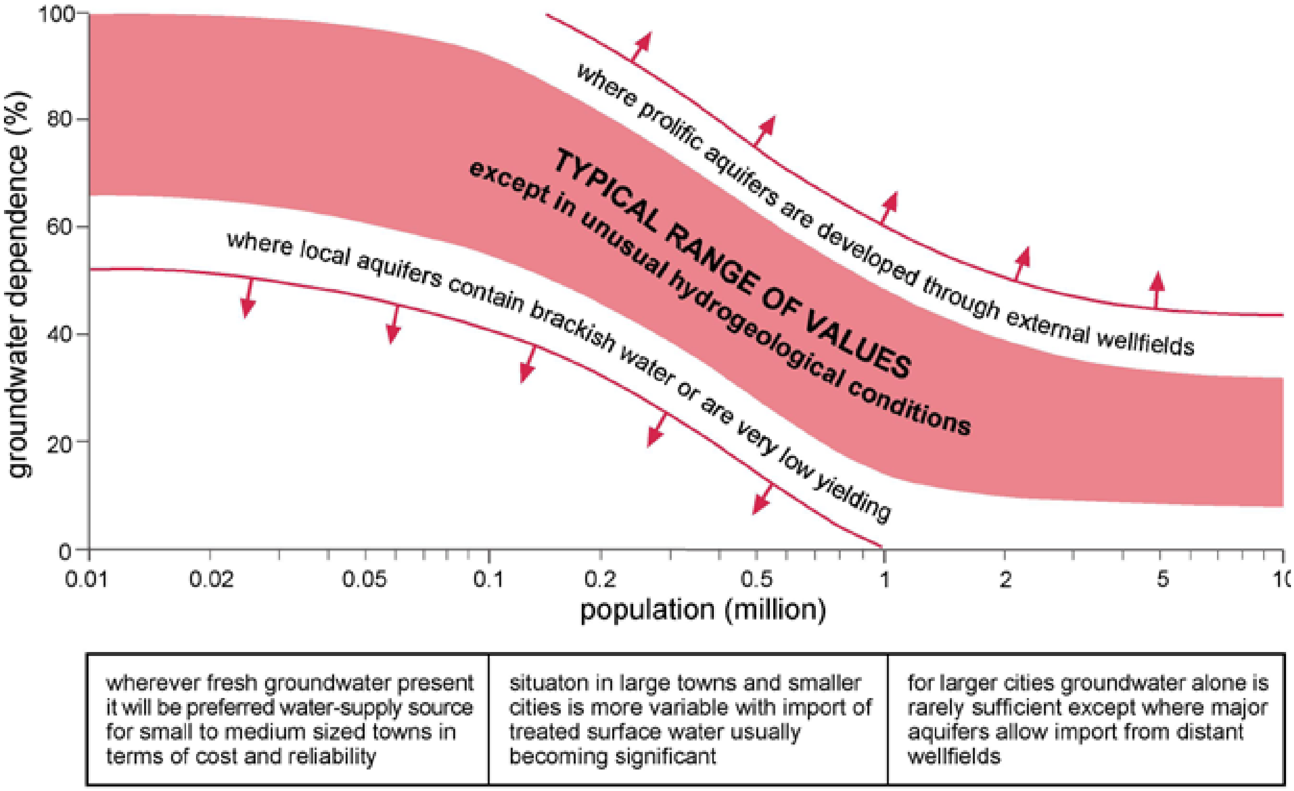

Figure 3. General relationship between ground water dependence for urban water-supply and the scale of urban development

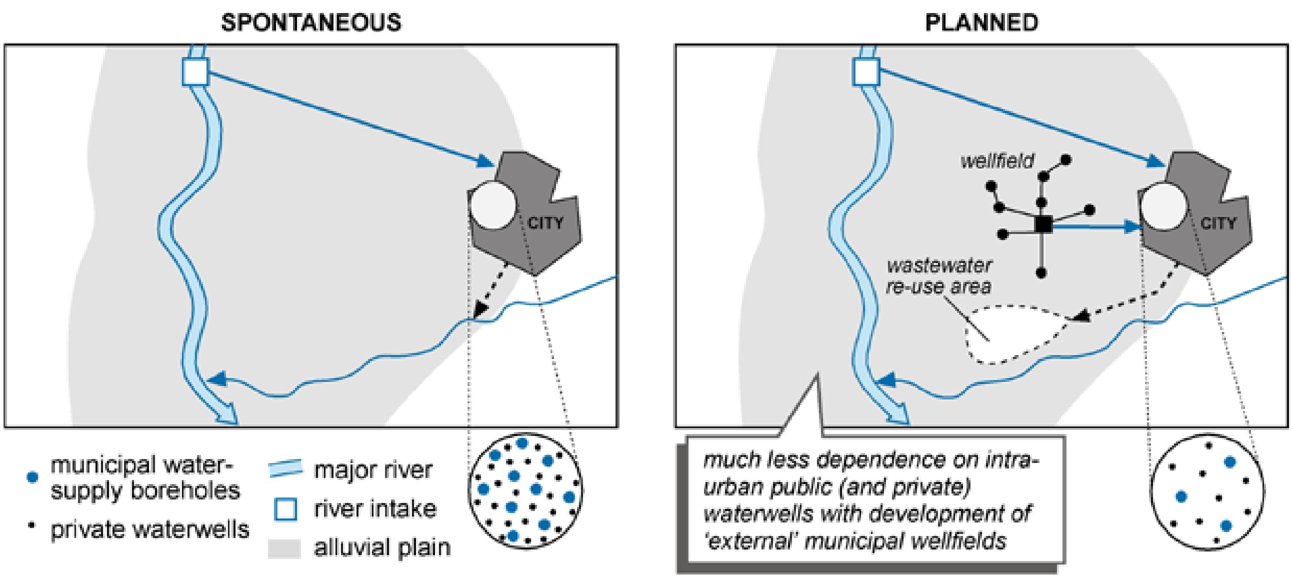

Figure 4. Schematic illustration of planned (as opposed to spontaneous) conjunctive use of ground water and surface-water sources for urban water-supply

But most conjunctive use presently encountered in the developing world amounts to a 'piecemeal coping strategy' (e.g. Lucknow, India) (Foster, 2010b) in which:

- Utility waterwells have been drilled ad hoc in newly constructed suburbs to meet their water demand at the lowest possible capital cost.
- Surface water has been recently imported from a major, new, distant source to reduce dependency on waterwells because of over-abstraction or pollution fears.

There are, however, a few examples of much more resource-optimised approaches (e.g. Lima, Peru and Bangkok, Thailand) (Foster *et al.*, 2010b). For more widespread promotion of such approaches a 'resource culture' needs to be generated with utilities. This may run contrary to some axioms of water-supply engineering that seek an operationally simple set-up (like a major surface water-source with large treatment works), rather than a more secure conjunctive resource management solution.

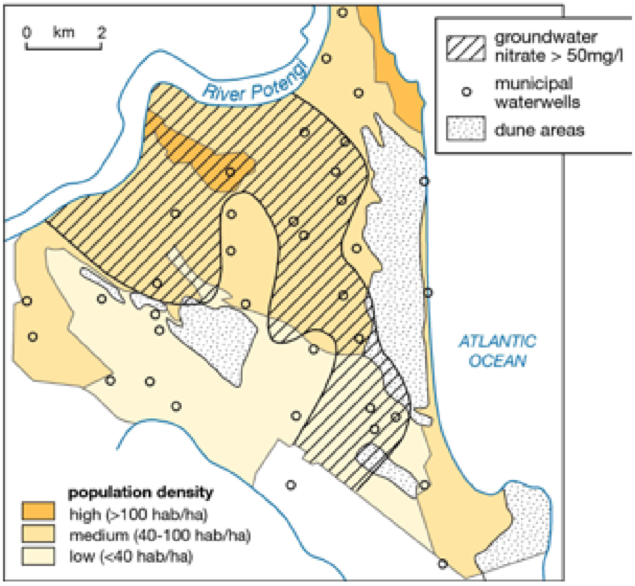

Figure 5. Excessive ground water nitrate concentrations in the coastal aeolian sand aquifer of Natal, Brazil (southern half) and their relation to population density. (The urbanised area is served by in situ sanitation except for a limited waterfront zone along the Potengi River)

Most importantly, establishment of utility wellfields outside cities (with capture areas declared as ecological or drinking-water protection zones) needs to be promoted as 'best engineering practice'. In the developing world it is either simply not considered at all or encounters administrative impediments related to fragmented powers of land-use and pollution control and between the numerous municipalities that comprise 'metropolitan areas' (Foster *et al.*, 2010a). Procedures and incentives need to be established for the ground water resource interests of a given urban municipality to be assumed by a neighbouring rural municipality. The procedures and incentives need to be such that adequate protection can be offered for the capture area of an 'external municipal wellfield' providing water-supply to the main urban area.

Given the continuous evolution of ground water use in 'urban aquifers', and the significant hydrogeologic uncertainty in predicting their precise behaviour, it is desirable to adopt an 'adaptive management approach' to urban ground water resources. This should be based on continuous monitoring of ground water levels and quality, and guided by a periodically updated, numerical aquifer model. This can also be used to evaluate future scenarios and for identifying the most suitable areas for 'external wellfield' construction.

Managing the sanitation-ground water nexus

The ground water sanitation nexus is especially relevant in developing nations, where in situ sanitation is much more extensive and presents a significant ground water quality hazard, which needs to be recognised and managed (Howard, 2007; Foster *et al.,* 1998). This threat is usually much more widespread than that posed by the inadequate handling of industrial chemicals and the disposal of industrial effluents.

In most aquifer types (except the most vulnerable and shallow) there will be sufficient natural ground water protection to eliminate faecal pathogens in percolating wastewater from in situ sanitation; these hazards increase markedly with sub-standard waterwell construction and/or informal or illegal sanitation and waste disposal practices (e.g. in numerous cities of Sub-Saharan Africa) (Foster, 2009). However, troublesome levels of nitrogen compounds (usually nitrate sometimes ammonium) and dissolved organic carbon in the ground water will also evolve to varying degrees, according to the population density served by in situ sanitation (Fig. 5). Such pollution can penetrate to considerable depths in the aquifer and persist after the contamination source is removed by the installation of mains sewerage or other alternative sanitation (Foster et al., 2010a). The most cost-effective way of dealing with this type of problem in municipal water-supplies is by dilution through mixing,. This requires a secure and stable source of high-quality water, such as that produced from protected 'external wellfields' (e.g. Natal, Brazil) (Foster *et al.*, 2010a).

In general, a much more integrated approach to urban water-supply, mains sewerage provision and urban land-use is required to improve the economic efficiency and security of urban water infrastructure. This improvement can be achieved, for example, by avoiding persistent and costly ground water quality problems (where local aquifers are providing a key component of municipal water-supply) that arise through piecemeal decision-making. There are numerous straightforward practical measures that can be taken by public administrations to improve the sustainability of urban ground water use. These include:

- Prioritisation of selected recently urbanised districts for mains sewer coverage to protect their good-quality ground water from gradual degradation. Also limit the density of new urbanisations served by in situ sanitation to contain ground water nitrate contamination.
- Establishment of ground water source protection zones around all utility waterwells that are favourably located to take advantage of parkland or low-density housing areas.
- Imposition of better controls for the handling and disposal of industrial effluents and solid wastes to reduce the risk of aquifer pollution.

Ground water pollution can also be reduced by deploying dry (eco-sanitation) units in which urine is separated from faeces and not discharged to the ground. However, while such installations are highly recommended for new urban areas overlying significant shallow ground water resources, their deployment as a universal solution to ground water contamination problems has limitations. Large-scale retro-installation in existing dwellings is not straightforward and it is less suitable for those cultural groups who use water for anal cleansing.

An important corollary that also needs to be addressed is how to make the best use of growing wastewater resources generated by increasing sewer coverage. This could be achieved through reuse for amenity and agricultural irrigation, which is spatially planned and appropriately controlled so as to minimise the risk of compromising ground water quality for potable use (Foster and Chilton, 2004).

Promoting rational private ground water use

The initial investment of private capital for in situ urban self-supply from ground water is usually triggered during periods of highly inadequate utility water-service or in the absence of such a service. This is essentially a 'coping strategy' (by multi-residential and individual properties, commercial and industrial enterprises). The well-researched Aurangabad, India example (Foster *et al.,* 2010a) reveals that all types of users tend to take water from multiple sources according to their availability and relative cost. These sources include subsidised water-utility mains supply, private and community in situ waterwells and, only as a last resort, much more expensive tankered water.

Private self-supply from ground water is widely practised by some users as a 'cost-reduction strategy' after the availability of utility supplies improves, The unit cost of ground water to private waterwell users is lower than the applicable municipal water-supply tariff (Foster *et al.*, 2010a) – albeit that many private waterwell operators do not consistently account for their running costs.

Intensive private ground water use alone (in the absence of large water-utility abstraction) does not necessarily cause serious resource overexploitation. Abundant aquifer replenishment from water-mains leakage and in situ sanitation seepage is often occurring. But whether private residential ground water use presents a serious threat to the user will depend on the type of anthropogenic pollution (or natural contamination) present,and the mode and type of water use concerned. Moreover, it can be argued that for the poorest in society, reliable access to any low-cost, parasite-free, water-supply is preferable to no water access at all (or to deploying scarce financial resources on expensive tankered supplies).

A broad assessment of urban waterwell-use practices is required by public administrations to formulate a balanced policy on private ground water resource use (Table 1).

If this assessment indicates serious hazards from ground water pollution or overexploitation, the following management actions could be considered (as appropriate to local conditions):

- Registering all commercial and industrial users, together with residential use for apartment blocks and other multi-occupancy housing estates and charging (directly by metering or indirectly by estimated sewer discharge) for abstraction, so as to constrain use
- Issuing water-quality use advice and/or health warnings to private waterwell operators. In severe pollution situations declaring sources unsuitable for potable and sensitive uses.

Equally, it will be necessary for the public administration to undertake an independent assessment of the benefits of private ground water use. This should help to relieve the pressure on municipal resources (especially for non-sensitive uses such as garden irrigation,

Table 1. A public-administration overview of the pros and cons of private residential in situ urban water-supply from ground water

Pros	Contras
• Greatly improves access and reduces costs for some groups of users (but generally not for the poorest because without help they cannot afford the cost of water well construction except in very shallow water-table areas)	• Interactions with in-situ sanitation can cause public health hazard and could make any waterborne epidemic more difficult to control, and also potentially hazardous where serious natural groundwater contamination present
• Especially appropriate for 'non quality-sensitive' uses– could be stimulated in this regard to reduce pressure on stretched municipal water-supplies	• May encounter sustainability problems in cities or towns where principal aquifer is significantly confined and/or main water-supply leakage is relatively low
• Reduces pressure on municipal water-utility supply and can be used to meet demands whose location or temporal peaks present difficulty	• Can distort the technical and economic basis for municipal water utility operations with major implications for utility finance tariffs and investments
• Incidentally can recover a significant proportion of main water-supply leakage	

laundry and cleaning, cooling systems, recreational facilities, etc.). It would also guard against the possibility of ground water table rebound and urban drainage problems should abstraction radically reduce. When large numbers of more affluent dwellers opt for in situ self-supply in urban areas, the knock-on effects are complex. It can, on the one hand, 'free up' utility water production capacity to meet the needs of more marginal low-income neighbourhoods. On the other hand it can 'reduce utility revenue collection', making it more difficult to maintain highly subsidised social tariffs for minimal use. And where a municipal water-utility has developed 'excess resources' and is subject to commercial incentives, it may market the substitution of mains water-supply for private self-supply, thereby distorting a 'rational policy dialogue'.

An important emerging policy question is under what circumstances the risks or inconveniences of private residential self-supply from ground water in the urban environment might justify an attempt to ban such practice completely (Foster *et al.,* 2011). Historically, 'urban private waterwell use bans' (or severe constraints) have been necessarily introduced as part of an effort to address:

- The control of a specific waterborne disease outbreak (e.g. cholera in 19th century London or in some Caribbean ports in the 1980s).
- Land subsidence and increased flood risk due to excessive ground water abstraction (e.g. Bangkok and Jakarta since the 1990s).

But they usually have high transaction costs and, alone, may only be partially successful. In Brazil, ground water abstraction constraints are currently imposed in specific zones of Ribeirão Preto and São José do Rio Preto (both in São Paulo State) to address problems of local overexploitation and continuous aquifer depletion. The restrictions apply to all classes of ground water user. In São Paulo City itself, use constraints are in place for zones of (proven hazardous) industrial ground water contamination. However, attempts are made to keep most existing waterwells functioning, since complete replacement by mains water-supply is not possible.

Urban ground water – responsibility for governance

Filling the institutional vacuum

Ground water is far more significant in the water-supply of developing cities than is commonly appreciated. Often it is also the 'invisible link' between various facets of urban infrastructure. Most urban ground water problems are very persistent and costly. Thus urban ground water tends to affect everybody, but all too often is the responsibility of 'nobody' (for reasons that will be analysed below). While many problems are 'predictable', few are actually 'predicted' because of this vacuum of responsibility (and therefore of accountability). Frequently 'one person's solution tends to become another person's problem'!

There is a clear need for ground water considerations to be integrated when making decisions on infrastructure planning and investment, whatever its use status. This is not as simple as it might at first appear, because institutional responsibility is at best split between various organisations, none of which take the lead. Regretfully, the reality is that:

- Water-resource agencies rarely have the operational capacity necessary to cope with urban development dynamics.
- Urban water-service utilities in the developing world widely remain 'resource illiterate'.
- Urban land and environment departments have a poor understanding of ground water.

It is important that the corresponding river-basin stakeholder committees (where these exist) are conscious of the need to incorporate ground water resources into watershed planning. They also need to be cognisant of the special problems that arise in this respect where major urban areas are present. However, the members of such committees rarely have enough knowledge of ground water issues or system behaviour to do more than 'flag' the issue for more detailed attention.

The importance of ground water for urban water-supply is not yet reflected by sufficient investment in the management and protection of the resource base. Governments, at all levels from national to local, need to seek realistic policies and effective institutional arrangements to address these issues. They will require the support of the political leadership, improved communication with, and participation of, stakeholders and be informed by sound hydrogeological science.

Moreover, the dynamics of urban development and its intimate relationship with ground water are such as to merit the formation of a 'cross-sector urban ground water consortium' (or standing committee) of all major stakeholders and regulatory departments/agencies. Such a consortium must be empowered and financed to define and implement a 'priority action plan'. Such consortia should be provided with a sound technical diagnostic, by an appropriate group of institute and university specialists. Perhaps the major challenge for such groups will be promoting acceptance of differential municipal land management for important recharge areas in the interests of ground water recharge quality. Also, they will have to confront the impediments resulting from the often geographically fragmented responsibility for land-use and environmental controls.

Confronting the challenge of escalating private use

Private waterwell use in urban areas poses a difficult challenge for water-resource agencies in developing nations. Modern waterwell drilling techniques provide rapid access to ground water for a modest capital investment. This makes it possible for a large numbers of users to exist whose 'hardware' is soon hidden from view. To date, effective management of this situation has often been beyond the capacity of public administrations.

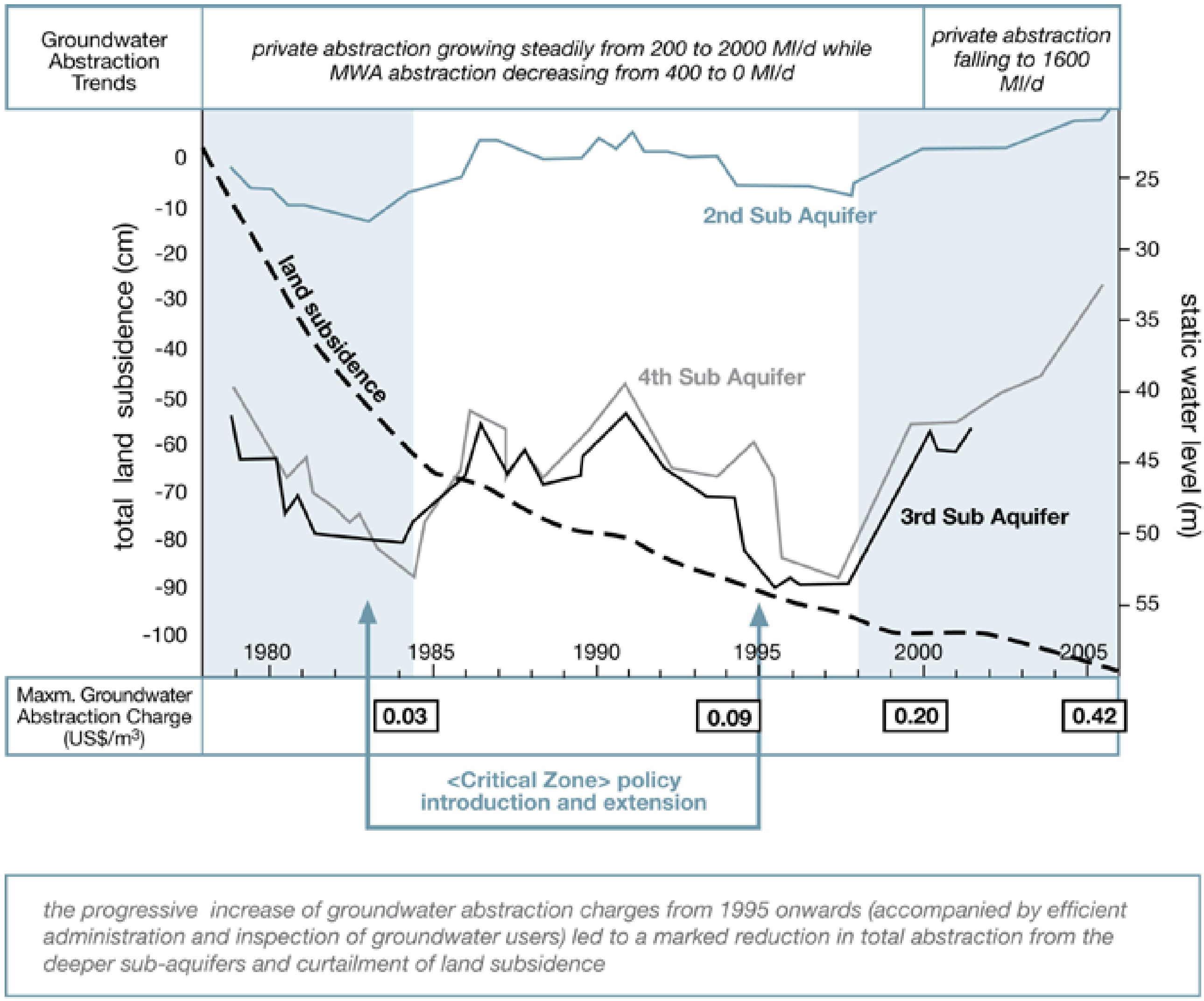

Figure 6. Evolution of ground water abstraction, water levels and land subsidence in Metropolitan Bangkok with improving resource management through waterwell licensing and charging

Most private waterwells are thus, at best, unregulated and at worst illegal. In the longer run this latter is counterproductive for the private user and the public administration and adds to the problem of stimulating a rational policy dialogue and action plan on urban water-supply. If this situation can be regularised, taking advantage of advances in geographical positioning and data-capture systems, it will have clear benefits for both public policy and private users. This will require strengthening the professional capacity and political mandate of water-resource agencies. A judicious use of sanctions may be necessary, but a greater emphasis must be placed on gaining civil-society commitment through effective participatory mechanisms with incentives for 'self-monitoring'.

In the developing world, concerted attempts to regularise private use of urban ground water have been made in a few places. For example in:

- Bangkok, Thailand (Buapeng and Foster, 2008) a combination of a regulatory approach with time-limited licensing of all larger multi-residential, industrial and commercial ground water abstractors is used. Constraints have been placed on privategroundwateruseincriticalareas.Aprogressiveabstraction charging plan has successfully stabilised ground water levels and curtailed serious land subsidence (Fig. 6)
- Recife and Fortaleza, Brazil (Foster *et al.*, 2010a) municipal utilities have (understandably) argued for a volumetric water charge to be levied in respect of mains sewer use by private ground water abstractors. This has resulted in a comprehensive inventory of private waterwells on multi-residential, commercial and industrial properties. Charging for sewer use is then by the type/size of property or by metering private waterwell use.

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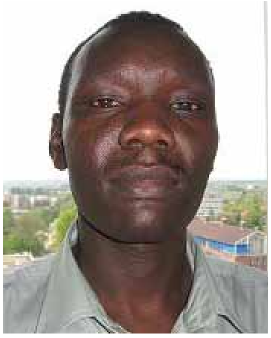

Mr. Sammy Letema
Department of Environmental Planning and Management, Kenyatta University, Nairobi, Kenya

Dr. Bas van Vliet
Chair, Environmental Policy Group, Wageningen University and Research Centre, Wageningen, The Netherlands

Dr. Jules B. van Lier
Sanitary Engineering Section, Department of Water Management, Faculty of Civil Engineering, Delft University of Technology, and UNESCO-IHE, Delft, The Netherlands.
Corresponding author
j.b.vanlier@tudelft.nl

INNOVATIONS IN SANITATION FOR SUSTAINABLE URBAN GROWTH: MODERNISED MIXTURES IN AN EAST AFRICAN CONTEXT

Urbanisation of poverty and informality in East Africa poses a threat to public health and environmental protection, perpetuating social exclusion and inequalities, while it creates service gaps. Neither conventional on-site sanitation nor modern centralised off-site sanitation provisions are tenable citywide, giving rise to the emergence of sanitation mixtures to meet sanitation demands. However, existing mixtures are not successful in meeting basic sanitary goals and show severe gaps in basic service provision and/or protection of human and environmental health. The evolved sanitation mixtures are theorised as a form of reflexive sanitary modernisation in tandem with local context variables. To achieve long-term sustainability in these mixtures, each sanitation option should undergo a modernisation process before it complies with specified sustainability criteria linked to 1) public and environmental health, 2) public accessibility, and 3) technological flexibility to adopt future amendments. The proposed modernised mixtures approach is helpful as an analytical tool for describing, mapping and assessing sanitation systems and their reconfigurations in societies where sanitation mixtures are a norm rather than an exception. It is also very helpful as a conceptual model for organizing a research agenda along the four categorised modernised mixtures dimensions, i.e. 1) its technical and spatial scale, 2) its scope of management (centralised – decentralised), 3) the nature of the flows (excreta – sewage), and 4) end-user participation. Translation of the proposed conceptual modernised mixtures model into a mathematical model is a challenge yet to be explored. Considering its intrinsic dynamic character of dependence on varying spaces, flows and scales of city development, a mathematical modernised mixtures model would provide a regulatory design tool for city planners for adopting amendments to existing sanitation solutions.

Keywords: Modernised mixtures, on-site/off-site sanitation, sewerage, sustainability, East Africa

Introduction

The rapid rate of urbanisation in developing countries has created an overwhelming demand for housing, infrastructure and services (Taylor and Parkinson, 2005), while sanitary provision is lagging behind urbanisation rates. Many interventions have been sought in the past to address water and sanitation challenges, but globally, 2.6 billion people still lack access to improved sanitation (UNDP, 2006). In March 1977, the United Nation's member countries declared the period 1981-1990 the International Drinking Water Supply and Sanitation Decade. Despite the concerted efforts made during that period, the number of people not served by an adequate and safe water supply fell by approximately 450 million while those without appropriate means of excreta disposal remained almost the same (Loetscher, 1999; WHO, 192). Member countries of the United Nations once again met at the turn of the millennium and agreed on the Millennium

Development Goals (MDGs), where they set the targets of halving the proportion of people without access to basic sanitation by 2015 and significantly improving the lives of slum dwellers by 2020. Additionally, WHO and UNICEF have set a target of 'Sanitation for All' by 2025. To achieve this WHO/UNICEF target, 480,000 people would have to be provided with improved sanitation daily (Mara *et al.*, 2007). To give more impetus to the magnitude of the sanitation challenge, 2008 was declared the 'International Year for Sanitation' by the United Nation's General Assembly in December 2006. Dismal progress has been made towards achieving the targets, with most of sub-Saharan Africa – East Africa included – unlikely to meet the MDG target (WHO/UNICEF, 2010; UN-Habitat, 2008; UN 2006). Despite years of intervention measures between the Water and Sanitation Decade and the International Year of Sanitation, the proportion of the population using improved sanitation in sub-Saharan Africa increased only marginally from 28 per cent in 1990 to 31 per cent in 2008 (WHO/UNICEF, 2010).

To achieve adequate and sustainable sanitation in the rapidly urbanising areas, a proper institutional framework, adoption of appropriate technology and the embedding of sanitation solutions in the local socio-economic, cultural and spatial structures is imperative (Seghezzo, 2004; Ellege *et al.*, 2002; WECD, 1987). Technologies are considered appropriate when they fit within the boundary conditions determined by local conditions. Such boundary conditions consist firstly of standards and principles of engineering, which determine the way in which sanitary systems develop. Interestingly, most boundary conditions for sanitary services follow a conventional master plan of city development geared towards centralised systems and making available to all city residents planned and serviced land for new settlements. Secondly, most regulations, institutions and organisational frameworks for sanitary provisions are public oriented, and in line with the engineering master plan. Yet there are multiple providers of sanitary services in the rapidly developing cities. Thirdly, different spatial structures have different affinities for particular sanitary systems. So far, centralised sanitary systems, comprehensive urban planning and public provision in developing countries, especially East Africa, have had little impact, as between 50 per cent and 70 per cent of the urban population live in informal settlements that are neither planned nor serviced (UN-Habitat, 2008, 2003). Fourthly, socio-economic and cultural conditions – affordability, acceptability and accessibility – determine the feasibility of the sanitation options available for adoption. The picture of development efforts towards improved sanitary provision in East African cities is plagued by contradictory development strategies pursued by many agencies with relative degrees of autonomy. Consequently, there is a lack of a cohesive and wholly accepted strategy for sanitary provision in the cities of East Africa because of the co-existence of various sanitary solutions, spatial structures and multiple providers resulting in sanitary mixtures. To reach the goals as formulated in the MDGs, these sanitary mixtures are in need of a modernisation strategy. With the term 'modernised' we would like to differentiate between conventional systems that are often referred to as 'modern' on the one hand, and on-site systems that are often termed 'traditional' on the other. With 'modernised' we mean locally embedded solutions that merge the best options of both modern and traditional systems in fitting local conditions and complying with defined sustainability criteria (Segghezo, 2004). We, therefore, postulate that modernisation, in the situation of multi-modal sanitary systems and multiple providers as is the case in East African cities today, for example, can best be achieved through application of a "modernised mixtures approach". Such an approach calls for a mix of scales, strategies, technologies, payment systems and decision-making structures that better fit the physical and human systems for which they are designed (Letema, 2012; Oosterveer and Spaargaren, 2010; van Vliet, 2006).

This paper presents first the status of sanitation provision in urban East Africa (section 2). Then, in section 3, it explores the dominant socio-technical paradigms in sanitation provision, i.e. centralised, large-scale provision versus small-scale provision, and the common sanitation options and sanitation scales to which such paradigms lead. The section ends by presenting the mixed sanitary solutions that can be found in urban Africa nowadays. Section 4 presents the application of the modernised mixtures approach to assess and evaluate the range of existing sanitary configurations along spatial, technical and management dimensions. The paper concludes, in section 5, by assessing the value of the modernised mixtures approach in opening up the paradigmatic debate between centralised and on-site sanitation provision and by assessing and evaluating existing sanitation mixtures.

Urbanisation and sanitary provision status in East Africa

Although East Africa is the least urbanised African region, it is experiencing, and is forecast to experience, a rapid urbanisation of over 3.9 per cent annual growth between 2000 and 2015 largely because of natural growth (UN-Habitat, 2008). The urbanisation, however, is not driven by industrialisation, economic growth, spatial planning or investment in environmental infrastructures and, therefore, leads to the urbanisation of poverty and the growth of extensive informal settlements. The urbanisation of poverty poses a threat to environmental health, perpetuates social exclusion and inequalities, and creates service gaps (UN-Habitat, 2008).

Different sanitary approaches attributed to parallel sanitary solutions, pursued under different programmes, culminate in various stages of sanitary solutions, which all sit next to each other. The mixture comprises different sanitary systems having different coverage, quality and scale (Table 1), different institutional arrangements and servicing different urban spaces and clientele. The number of urban centres connected to modern sewerage accounts for about 14 per cent in Kenya, 12 per cent in Uganda (excluding Town Boards), 16 per cent in Tanzania and none in Rwanda and Burundi. Those that have modern sewerage, however, have low coverage, ranging from 5-36 per cent in Kenya, 0.9-20 per cent in Tanzania and 2-26 per cent in Uganda (Letema, 2012). The coverage and connection ratio are also not in tandem with water coverage. The status of sewage treatment works is

Table 1. Per cent of population coverage for different sanitation solutions in East African capital cities

City	Sewerage	Septic tank	VIP latrine	Pit latrine	No facility	Reference
Nairobi	36	<…………….. 64……………... >			n.a.	(AWSB, 2005)
Kampala	6	18	<………… 70………... >		6*	(NWSC, 2004)
Dar es Salaam	13	13	n.a.	70	4	(DAWASA, 2008)
Kigali	0	16	3	80	1	(Sano, 2007)
Bujumbura	0	n.a.	n.a.	100	1	(WSSINFO, 2008)

*Abbreviation: n.a. not available; * 3 per cent practise open defecation; 3 per cent use shared sanitation*

disappointing. For instance, in Kenya, out of 38 treatment works, 40 per cent are overloaded, 15.5 per cent are operating at design capacity, 2.5 per cent are not operating at all and 42 per cent are operating below capacity (MWI, 2008).

The treatment systems for conventionally collected sewage in gravity sewers are mostly waste stabilisation ponds (WSP), with few being mechanised processes, such as conventional trickling filters, oxidation ditches and aerated lagoons. In Kenya, WSP are used in 25 of 38 urban sewage treatment works (STW). In Uganda, 12 are WSP while two are conventional trickling filters. Stringent environmental standards, set by the National Environment Management Authority (NEMA), require nutrient removal in addition to carbon and pathogens, which make most conventional treatment process options non-compliant with effluent discharge standards. The very stringent legislation on the one hand and the socio-economic inabilities to meet the set requirement using up-to-date technologies on the other, paralyses any investment at the wastewater treatment level. Here a paradigm shift is urgently needed.

Paradigms of centralisation and decentralisation, on-site and off-site systems

Socio-technical paradigms in sanitation

Technology development framing in the context of the service

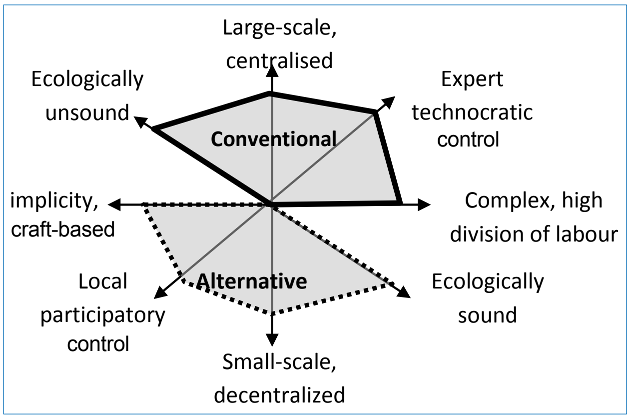

Figure 1. Classification of sanitary systems as 'conventional' and 'alternative' along multidimensional axes (adapted from Smith, 2005)

provision of water, waste(water), energy, housing and food over the last five decades has been characterised by a clash between two paradigms – a centralised (conventional) approach and a decentralised (alternative) approach. Centralised systems are viewed by the proponents of alternative approaches as large-scale, centralised, expert driven, complex, and ecologically unsound, whereas the alternatives as small-scale, decentralised, participatory, simple and ecologically sound (Fig. 1) (Smith, 2005).

The proponents of centralised systems argue that they have provided hygienic conditions, easy transport with little visibility, adequate handling of organic matter and nutrients, and little energy consumption (Harremoës, 1997). Moreover, low-technology craft systems are not necessarily sustainable at any cost and design, whereas appropriateness depends on local conditions (Grau, 1996).

Conventional systems have inertia and lock-in effects, which curtail the emergence of alternative decentralised options at the house-on-site and/or community level to develop and complement them (Hegger, 2007; Nilsson, 2006; van Vliet, 2006, 2002). Strikingly, so far, the centralised versus decentralised debates are often reduced to a competition between the proponents in an attempt to remain relevant and retain, access, or wrestle power. But each group possesses various, but always incomplete, levels of capital, scientific expertise and technology (Bijker, 1995 in Smith, 2005).

Urban systems for waste(water) often develop in a paradigmatic manner, where certain engineering practices, standards and technical knowledge come to prevail, which may deter technological changes (Ertsen, 2005 in Nilsson and Nyanchaga, 2008; Chartzis, 1999). Conventional sewerage is based on conservative design values that have undergone little change over a century. For smooth operation, the resulting gravity-based systems require high water flows, minimum pipe diameters, large numbers of household connections, sewerage passing both sides of the street, minimum velocity, minimum depth and slope of sewers, pumping stations at various stages of the sewer network and design periods of over 30 years (Mara and Alabaster, 2008; Paterson et al., 2007; IETC, 2002; Sundaravadivel *et al.*, 1999; Mara, 1996). The applied conservative design values result in deep sewerage, high capital costs, high operation and maintenance efforts, and inappropriateness in most types of urban settlements in East Africa (IETC, 2002; Sundaravadivel *et al.*, 1999; Otis et al., 1996). Conventionally designed urban sanitary systems comprise medium- to large-scale sewer collection and treatment systems characterised by large piping networks that convey wastewater from the place of generation to the treatment site, making use of pumping stations and/or complex siphons. Moreover, such systems are dependent on advanced water supply and electricity infrastructures being in place, and towns engineered into pipe-like networks (Newman, 2001; Graham and Marvin, 2001; van Lier and Lettinga, 1999). Large-scale systems, van Dijk (2008) notes, are too expensive to introduce on a large-scale in developing countries. Consequently, currently existing large-scale systems serve only a small population, are capital intensive in development and maintenance, and subsidise the more affluent groups (Oosterveer and Spaargaren, 2010; Toubkiss, 2010; Nilsson, 2006).

Besides the conventionally designed centralised systems, autonomously functioning satellite sewers or intermediate sanitary services are being installed, serving a designated city section, often covering part of a catchment in which only gravity sewers can be used. Such intermediate sanitary service levels are the semi-collective sewerage and treatment systems which serve clusters, communities and/or neighbourhoods (Toubkiss, 2010; Mara, 2008; Gómez-Ibáñez, 2008; Hunt et al., 2005). Various authors claim that intermediate infrastructures have a number of advantages (Toubkiss, 2010; Gómez-Ibáñez, 2008; Hunt et al., 2005; Kariuki and Schartz, 2005) since they increase access to sanitary services without being dependent on large-scale infrastructural works and institutional support. In various cases the private sector is involved in both sewage collection and treatment.

Alternative sanitary systems, applied in a decentralised mode are twofold – simplified sewerage, e.g. condominial, settled sewer systems (Fig. 2) to be combined with community on-site treatment, and (house) on-site systems coupled with off-site treatment of manually collected wastes or in situ waste valorisation linked with reuse practices.

On-site sanitary systems, e.g. pit latrines and septic tanks, are the cheapest and most appropriate for rural, low-density urban and low-income areas and can provide the same health benefits and user convenience as conventional sewerage systems provided the ground water is deep and the areas are not prone to flooding (Paterson *et al.*, 2007; Kalbermatten et al., 1982). Construction and management of traditional on-site systems, such as latrines, are well described in text books (e.g. Franceys *et al.*, 1992). Although developed for rural, low-density applications, on-site sanitary systems serve the majority of the urban population in developing countries, offering solutions to individual or a group of households, and accounting for between 80 per cent and 100 per cent of the population in cities (Kone, 2010). On-site sanitary systems are stand alone, site specific, individual plot-

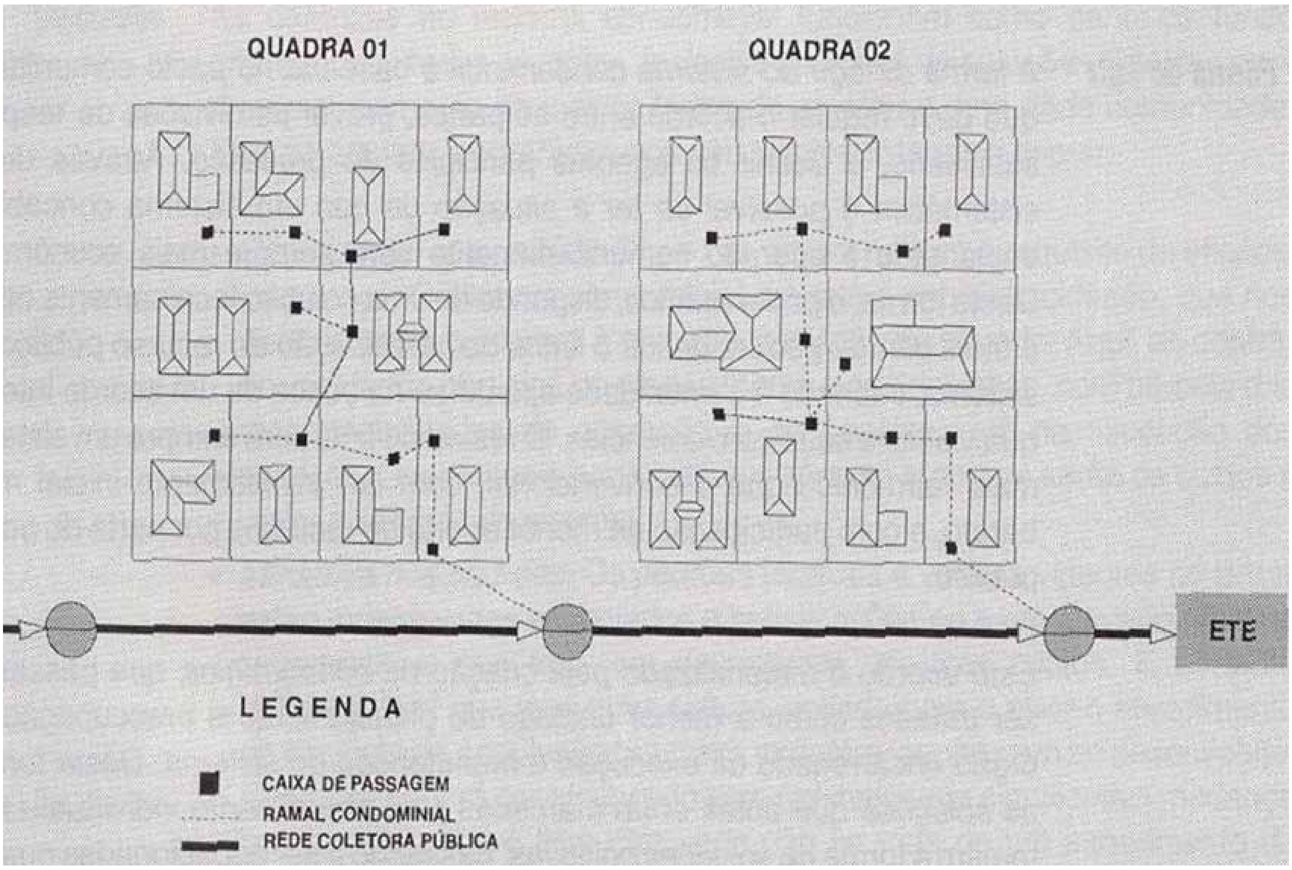

Figure 2. Construction plan of a simplified sewer system or condominial sewer, making use of already existing infrastructure, such as septic tanks, when available (from the urban sewerage plan, north east Brazil)

based, and very basic options that are often temporary facilities (Abbott, 2010). However, on-site systems are perceived as simple and second best options, useful in situations where the finances, technological capabilities and organisational capacities are severely limited for centralised systems, and compromising the needs and the abilities. Besides, they are supposed to be transient, i.e. replaced with more advanced systems as soon as the social, economic and technological conditions allow (Spaargaren et al., 2005). However, although often implemented, they are not feasible in (peri-)urban areas because of the high population densities, lack of space, poor drainage and risk of contamination of the water sources (Paterson et al., 2007). In addition, faecal sludge management is often absent leading to accumulating health problems. In most East African cities the dominant on-site sanitation systems are traditional pit (TP) latrines followed by shared latrines – public or community and either traditional or poor flushed – and then septic tanks and ventilated improved pit (VIP) latrines. Fig. 3 depicts the situations in Kampala, Uganda and Kisumu, Kenya.

Other options available, but in limited use, are ecological sanitation (eco-san), biogas latrines (bio-latrines) and bucket latrines. Although, not yet implemented in large numbers, the feasibility of improved on-site systems, such as bio-latrines, is the subject of many current studies. Novel sanitation options include additional drivers to sanitary provision, such as recovery of energy and/or useful resources from sanitary streams. The success of these systems is dependent on the effectiveness of the demand chain for the recovered resources and their adequacy to provide basic sanitary conditions. Indeed, current full-scale applications in the slums of Kibera, Nairobi, Kenya, serving from 300 to 600 persons/day (Fig. 4), show the potential for local energy provision, while providing proper sanitation services at fixed tariffs. Theoretically, the energy content of human excreta equals between 500 and 700 kJ/person/day (equivalent to up to 200 watt-hour/person/day), and the excreted nutrients (ammonium and phosphates) are of interest for agricultural purposes. The human waste collection at a single location in a densely populated area facilitates both bio-energy recovery in the form of biogas and the establishment of a demand chain for nutrients and stabilised organic matter for soil conditioning. New business models guaranteeing the demand chain, and thereby the hygienic and environmental sustainability of these innovations, need to be implemented and surveyed in other settings to adequately judge the viability of the resource-oriented sanitary facilities.

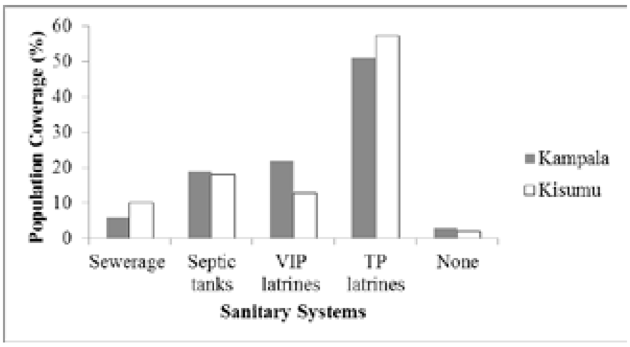

Figure 3. Sanitation coverage in Kampala and Kisumu (NWSC, 2008; KIWASCO, 2008)

Management of side flows, such as non-treated grey waters and digester effluents, are not yet sufficiently covered in existing pilot projects. Possible upgrades may for example include the establishment of a small bore sewer connecting the digester outlet to the city sewerage when local treatment is not tenable (Fig. 2). From projections, based on investments plans (NWSC, 2008, 2004), it is expected that over the next two decades, septic tank coverage will increase steadily and receive significant wastewater flows in Kampala as compared to sewers and latrines while implementation of shared and unshared latrines will be slowing down and stabilised by the 2030s.

The feasibility of septic tanks in densely populated areas depends on the emptying regime and ultimate treatment and disposal of septage. Septic tank systems serve (a) individual household housing units, (b) apartments on single standard plots, (c) apartment clusters and (d) a group of households as shared sanitation. Septic tanks for individual households generally consist of two chambers, with the second chamber being the soakage pit. Septic tanks are generally used in residential settlements in the medium density areas of, for example, Kampala

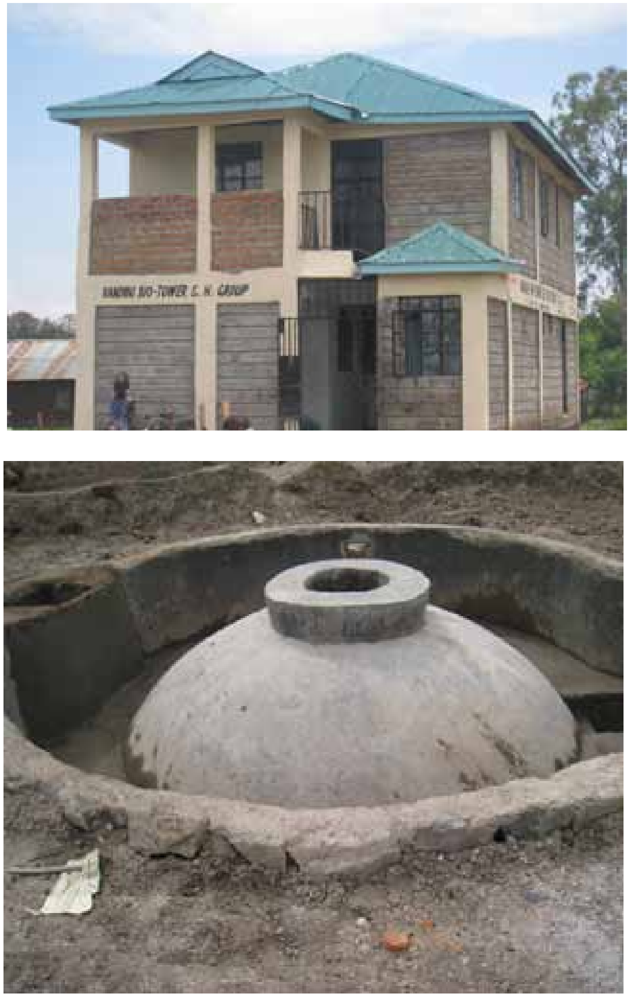

Figure 4. Biogas latrine facility in Kibera, Nairobi, Kenya, exploited by, for example, Umande Trust (www.umande.org). Left: multifunctional building with ground floor: latrines and showers; first floor: meeting rooms, offices, kitchen; top floor: open side for community gatherings, for example. Right: subterranean biogas digester underneath the multifunctional building.

and Kisumu township neighbourhoods that were established at the turn of the 20th century. In these areas, septic tanks have soakage pits, serve plots with an average size of between 500 m2 and 1000 m2, are located on high ground, and are well drained sites. An attempt to compulsorily connect these areas, such as the 2004–2006 campaign in Kampala, was deemed not necessary by the households, indicating that they still offer good services even at the turn of the 21st century, and thus have been operated as a non-transient permanent solution. Re-zoning of these areas into commercial and apartment buildings, however, leads to densification and a concomitant increase in wastewater flow, attaining sewerage thresholds. Following the one-dimensional approach to sewerage provision that applies conventional sewers only, could shift the septic tank application from being a permanent to a transient solution. However, the already installed septic tanks could be re-utilised, and become part of an alternative small bore settled sewerage system (Fig. 2), conveying the liquid to off-site treatment. In various African cities this approach has already been implemented, for example, in Dakar, Senegal.

Different population densities have a different affinity for some specific sanitary solutions (Mara, 2008). Density thresholds over which on-site sanitary application is prohibited and sewerage applied are set at 250 population equivalent/ha in Indonesia (Fang, 1999) whereas in Natal, Brazil, simplified sewerage was noted to be more cost-effective at a density of 160 population equivalent/ha (Sinnatamby, 1983). In alternative sewerage, design codes are more relaxed, resulting in the use of small-sewer pipe, significant reductions in water requirements, lower gradients and depths, and manholes replaced by inspection chambers or cleanouts, while maintaining sound design principles (Mara and Alabaster, 2008; Paterson *et al.*, 2007; IETC, 2002; Sundaravadivel *et al.*, 1999; Reed, 1995). Alternative sewerage is low-cost, flexible in location and layout, amenable to community participation, appropriate for planned and unplanned settlements, can be planned as decentralised networks and can adopt low-cost treatment systems (Mara and Alabaster, 2008; Paterson *et al.*, 2007; Sundaravadivel *et al.*, 1999; Pombo, 1996).

Sanitation system scales

Sanitary system scales, i.e. sewerage catchment coupled to a treatment facility, are generally based on expected sanitary flows and an urban spatial planning hierarchy (van Buuren, 2010; Hegger, 2007; de Graaf, 2006; Hasselaar et al., 2006; Mgana, 2003; Rijnsburger, 1996) (Table 2). However, there is no absolute delimitation of the maximum or the minimum number of users within a scale. Crites and Tchobanoglous (1998) classified treatment systems as small-scale and decentralised when they have a treatment capacity of < 3785 m^3/d (1 million gallon/day), which is equivalent to about 30,000 population equivalent. Following van Buuren's (2010) classification, the maximum capacity of a decentralised municipal system has been arbitrarily set at 50,000 population equivalent or an area of 250 ha, whereas a community sanitation system is 4000 m^3/day, which is about 20,000 population equivalent and a maximum area of 100 ha. More important than the actual population equivalent number, flows and/or serviced area is the extent of the coverage in relation to the entire urban area and its infrastructural complexity in relation to the socio-economic conditions. Table 2 lists sanitation system scales based on population equivalent and households.

In addition to spatial scales, sanitary mass flows determine the actual types of technologies that are perceived as feasible at a certain location. Sanitary mass flows consist of human excreta and urine, possibly supplemented with flushing water for transport of these wastes. The availability of water is questionable in large parts of the urban areas; also the need for water borne sanitation in areas where wastewaters cannot be conveyed or treated is presently widely questioned. Local sanitary options are, therefore, dependent on both population density and actual wastewater flows as depicted in Fig. 5.

Table 2. Sanitation system scales based on population equivalent and households

Reference: Mgana (2003) Rijnsburger (1996)	*Reference:* Hegger (2007); de Graaf (2006); Hasselaar et al., (2006)	*Reference:* van Buuren (2010) (p.e.)
Housing unit, 10-40 p.e. Pit latrines/septic tanks	Dwelling 1 Hh	Individual on-site/cluster, 5-50
Housing block 40-200 p.e. or 4-10 Hh and mostly septic tank	Houses/apartment cluster of 2-25 Hh	Community 50-2,500
Neighbourhood unit, 100-2000 p.e. and mostly wastewater collection and treatment	Neighbourhood 25-250 Hh > 2,500-50,000	Small-scale,
	City quarter 250-10,000 Hh	Medium-scale, > 50,000-500,000
	City or large >10,000 Hh	Large-scale, > 500,000

Abbreviation: p.e. population equivalent; Hh household

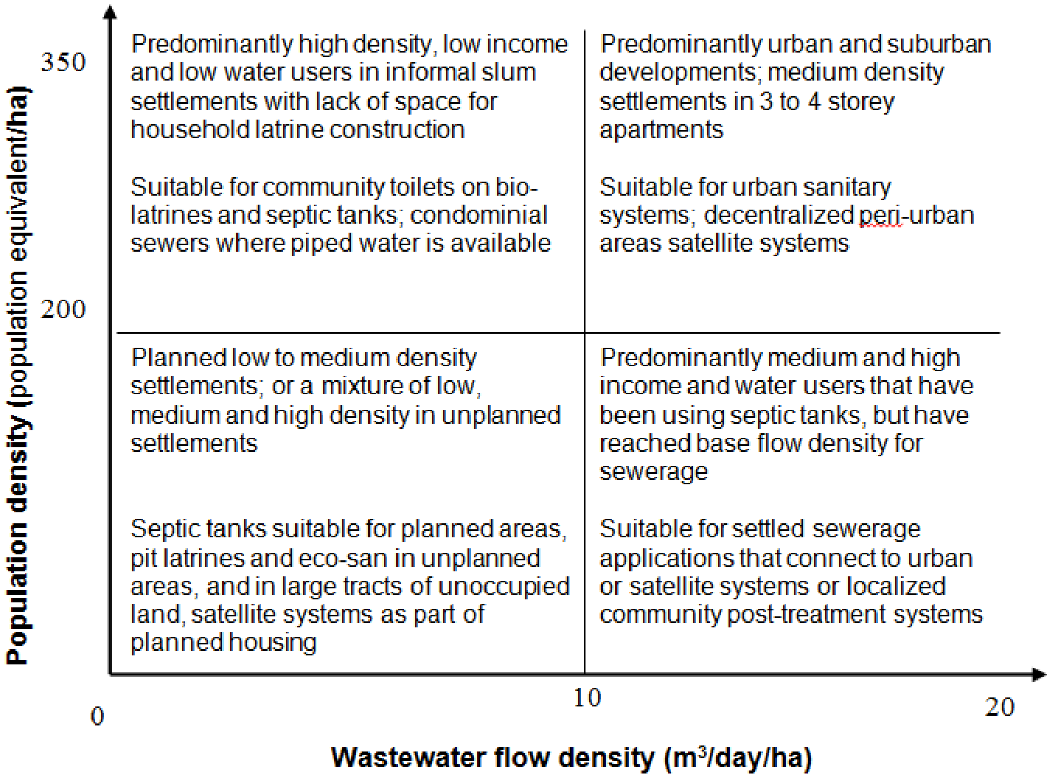

Figure 5. Population density as a determinant of the sanitary systems to apply (Modified from NWSC, 2004)

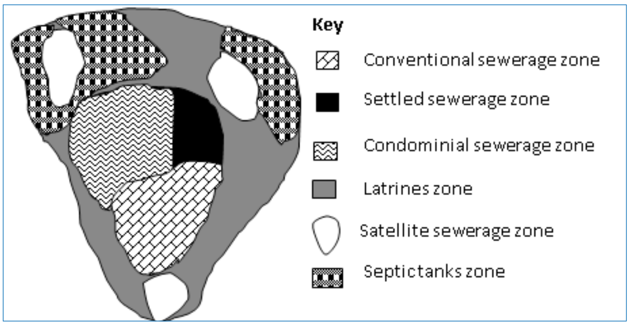

Figure 6. Illustration of mixed sanitation provision in cities with spatial variability

Mixed sanitary solutions

Sanitary provision development in Africa is determined by the prevailing socio-economic conditions, severely limiting both capital and operational exploitation costs. The above analysis reveals that if sanitary provision is to succeed it should be based on mixed solutions and at multiple scales. A mixed sanitary structure can be conceptualised spatially as illustrated in Fig. 6 – a parallel development of different systems at different scales serving different parts of the population.

Each sanitary system's service level can have its treatment scale and technology option. Adoption of mixed sanitary solutions may introduce complexity, which may lead to increased operation and maintenance costs, personnel and problems because of a lack of standardisation, lack of up-to-date infrastructure records, and weak enforcement. Alternatively, recognition of these mixed solutions gives ample possibilities for full coverage of sanitary services, provided the solutions offered meet agreed sustainability criteria. Therefore, in order to include all available sanitary structures in a strategic urban master plan, each applied system and technology requires modernisation, which is defined above and further elaborated in the next section. Solutions that cannot meet these criteria, thus cannot be modernised according to agreed definitions, should then be discarded as a potential option for that specific location. At the city level, the proposed modernised mixtures approach offers a new view to sanitation which does not preclude or exclude any of the developed sanitary systems, but sets sustainability demands on its functionality.

4. Assessment based on the modernised mixtures approach

The process of modernisation of the current sanitary mixtures to the 'modernised mixtures' level provides an approach for analysing, structuring, and improving sanitary infrastructures and institutional arrangements in such a way that it results in a mix of scales, strategies, technologies, payment systems and decision-making structures (Spaargaren et al., 2005) that comply with specified sustainability criteria linked to:

1) Public and environmental health
2) Public accessibility (physical, institutional, social)
3) Technological flexibility to adopt future amendments (technical, institutional, social).

If implemented, such mixtures would lead to socio-technical arrangements of technical systems, institutional arrangements and payment systems that take the best features from both (modern) centralised and (alternative) decentralised systems. This is achieved by combining the features of large-scale, high-technology and technocratic approaches, with small-scale, low-technology and participative approaches into new forms in order to better fit the local conditions characterised by different spatial structures (Oosterveer and Spaargaren, 2010; Hegger, 2007; van Vliet, 2006).

In characterising the existing sanitary provisions in the East African cities of Kampala, Uganda and Kisumu, Kenya, each sanitary system is evaluated along four dimension and six scale categories. Each scale along the dimension is mapped by shading and the resultant configurations are presented in Fig. 7. The dimensions of sanitary provision espoused by the modernised mixtures concept (Fig. 7) are:
1) Technical and spatial scale dimension, between a large-scale and a small-scale systems
2) Management dimension between centralised monopolistic organisation and decentralised organisation by multiple providers
3) Nature of flows dimension, between combination and separation of water and waste flows
4) End-user participation dimension, between technocratic control and a participatory approach.

The categories of the sanitation scale dimension can be defined in relation to the technical scale of implementation, i.e. coverage expressed in population equivalents (Table 3).

The management dimension can be defined in relation to the organisational service level, which is assed as follows:
- Household
- Community e.g. non-governmental organisations, community-based organisations, faith-based organisations, neighbourhood associations and cooperatives
- Private
- Quasi-public institutions e.g. universities, institutes, schools, hospitals
- Semi-public authorities, public limited companies, local authorities and corporations
- Public authorities e.g. ministries, departments, directorates.

In the nature of flows dimension, the assessment scales are:
- Urine separation, with or without flush water i.e. yellow or brown water
- Excreta collection
- Grey water collection
- Black water collection, i.e. urine, faecal matter including flush water
- Domestic wastewater collection
- Combined sewage collection, i.e. industrial and domestic or domestic and storm water or all three.

The assessment scales for end-user participation between participatory and technocratic dimension are:
- End-user construction and use without approval, design consideration and help of local artisans
- Artisan construction together with end-users without authority approval
- Expert planning and design and artisan construction, with the help of community service organisations
- Expert planning, design and construction, with sanitation authority supervision
- Planning, design, construction, operation and maintenance by a firm of experts, and monitoring and evaluation by end-users and the authority
- Planning, design, construction and operation and maintenance by a sanitation authority.

Table 3. Assessment scales for the technical scales of sanitary provision

Rank	Settlement size	Sanitation type	Population (p.e.)
1	Household Dwelling unit Housing cluster	Pit latrines Septic tanks Eco-san	5-50
2	Community	Septic tanks Bio-latrines	50-1500
5	Neighbourhood	Decentralised sewerage Centralised sewerage	1500-5000
4	Small urban	Decentralised sewerage Centralised sewerage	5000-50,000
5	Medium urban	Catchment Centralised sewerage	50,000-250,000
6	Large urban	Centralised	> 250,000

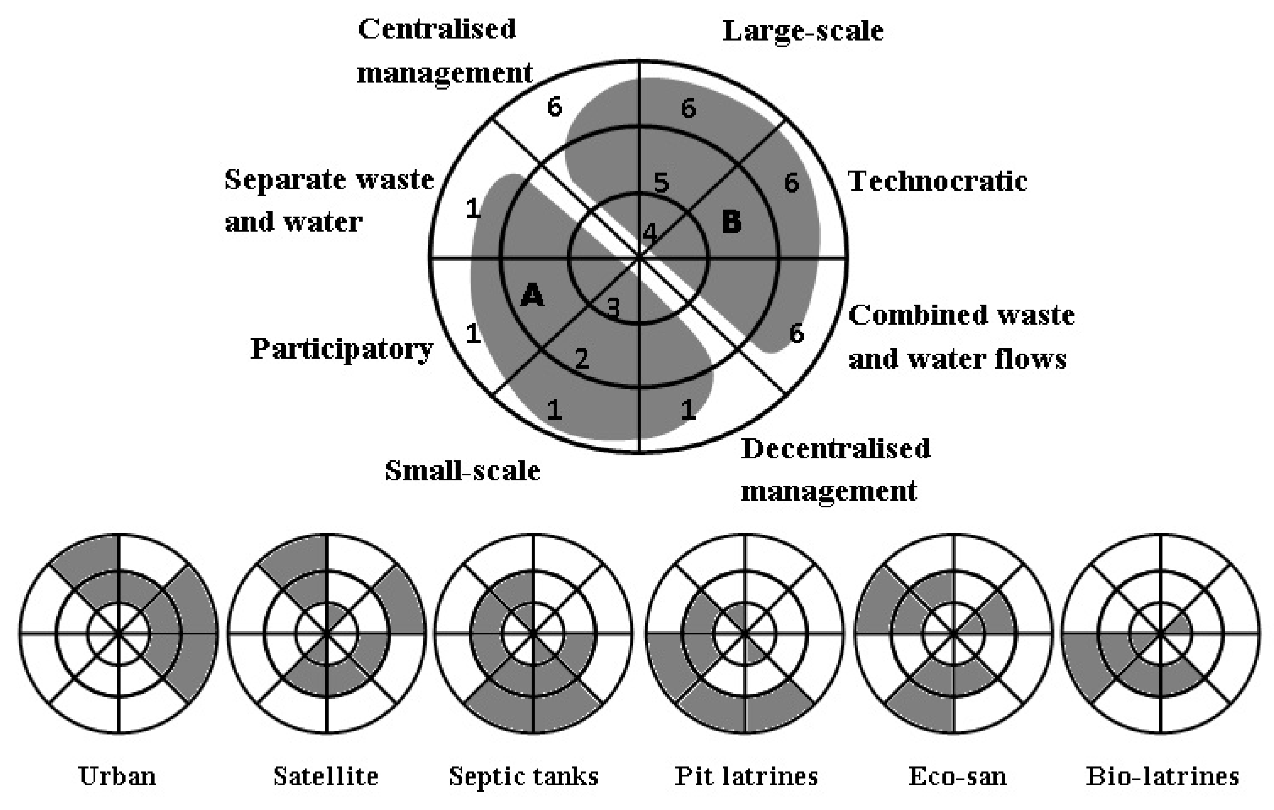

Figure 7. Assessment of sanitary configurations in Kampala and Kisumu along modernised mixtures dimensions against centralised (A) and decentralised (B) represented by six axes. Numbers refer to assessment scale categories as explained in the text

The different sanitary configurations (Fig. 7) are attributed to the existence of the differentiated spatial structures, providers and service levels inherent in Kampala and Kisumu cities (Letema, 2012). Sanitary mixtures constitute a multiplicity of sanitary solutions exhibiting different configurations. Different sanitary configurations require different spaces and institutional arrangements in order to fit the local conditions. Therefore, different sanitary systems have their own merits, but they have to meet general assessment criteria that apply across systems.

A next step is the analysis of the degree of compliance with the sustainability criteria of public and environmental health, accessibility and flexibility, and elucidating the most critical performance indicator t a specific location. Also in this analysis the proposed modernised mixtures approach could be a useful analytical and assessment tool. As a result of such an assessment, the limiting factor of a specific sanitary provision that is responsible for inadequate system performance will become transparent. Restructuring and improving the sanitary provision can then be economically quantified against opting for a complete novel service provision, such as a centralised sewer system.

In our current research, the modernised mixtures approach has been used to analyse sanitary system configurations in Kampala and Kisumu (Letema, 2012). Suffice to say that this is the development of assessment indicators and ranking scales for sanitary systems along the four modernised mixtures dimensions of scale, management, flows and participation (Fig. 7).

From the present analysis, six systems are discernible:

- Centralised urban sewerage
- Satellite sewerage
- Septic tanks
- Pit latrines
- Eco-san
- Bio-latrines.

Bio-latrines and eco-san, which are relatively recent technological options in the East African landscape, are shared sanitation schemes. We assume that the analysed and assessed systems apply across East African cities. As an assessment tool, the modernised mixtures approach has demonstrated that sanitary configurations can be conventional (centralised), traditional (decentralised) or mixed (hybrid). Besides, the assessments are not restricted to local conditions or site specific factors, thus are generic and can apply to sanitary systems in any East African city. Our present work (Letema, 2012) also shows that the modernised mixtures approach is a prescriptive tool with the assessment highlighting which social, technical or spatial dimensions are modernised and which ones are not. However, this is only the first part of making the modernised mixtures approach operational – it is necessary to describe the modernised contexts, assess the sanitary systems, map the sanitary configurations and define their boundary conditions. The second step should entail development of a mathematical model for the modernised mixtures approach based on the boundary conditions and configurations espoused in this paper. The third step should be to validate the conceptual and mathematical model through statistical survey data to generalise it for developing and transition economies.

Concluding remarks

Sanitary provision in East African cities is a mixture and a flux of technical and spatial scales and institutional arrangements. The proposed modernised mixtures approach is based on the premise that in an East African context, and implicitly in other developing countries with similar socio-economic and spatial structures, sanitary provision will be rather a mixture, comprised of different technical and spatial scales, multiple service providers and diverse institutional arrangements. Such mixtures, however, ought to be brought up to date using the modernised mixtures criteria of public and environmental health, accessibility and flexibility to attain sustainable urban development and meet the MDG of halving the number of people without improved sanitation by 2015 or the WHO/UNICEF Sanitation for All by 2025.

Sanitary mixtures are theorised as the co-existence of different phases of modernity; in tandem with local context variables. Therefore, there is no one-size-fits-all paradigmatic way to sanitary provision if the local contexts, like spatial structure, socio-economic conditions and level of environmental infrastructure development, are apparently different even within the same city. However, a shift of the centralised-decentralised dichotomy to the modernised mixtures paradigm offers a better impetus for enhancing the environmental health, accessibility and flexibility of sanitary mixtures as it optimises the advantages of both centralised and decentralised provisions.

The modernised mixtures approach is helpful in analysing, characterising, assessing, and prescribing sanitary systems in cities where sanitation mixtures are the norm rather than the exception. It is also very helpful as a conceptual model for organising a research agenda which can be developed along the four modernised mixtures dimensions, of scale, management, flows and participation, as well as in searching for appropriate modernisation pathways along one or more of the modernised mixtures provision dimensions. It is helpful to understand not only the scope and nature of the modernisation debates, but also to contextualise the modernisms of sanitary provision. As an assessment and decision-making tool, it is helpful to find out which aspects highlighted in the assessment need to be restructured and which need improvement in order to be modernised. However, more research is needed on the process of score assignments along the modernised mixtures dimensions and applied scales, followed by validation of the conceptual model in actual urban planning.

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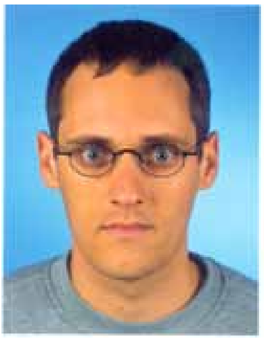
Mr. Seneshaw Tsegaye
Research Fellow
seneshaw@mail.usf.edu



Mr. Jochen Eckart
Research Fellow
jocheneckart@mail.usf.edu

Dr. Kala Vairavamoorthy
Executive Director
vairavk@usf.edu
Patel School of Global Sustainability, University of South Florida

URBAN WATER MANAGEMENT IN CITIES OF THE FUTURE: EMERGING AREAS IN DEVELOPING COUNTRIES

With increasing global change pressures (urbanisation, climate change etc.), coupled with existing un-sustainable factors and risks inherent to conventional urban water management, cities in the future will experience difficulties in efficiently managing scarcer and less reliable water resources. In order to meet these challenges, there needs to be a paradigm shift. This paradigm shift is based on several key concepts of urban water management including: resilience of urban water systems to global change pressures; interventions over the entire urban water cycle; reconsideration of the way water is used (and reused); greater application of natural systems for treatment. Rapid urban growth in the emerging urban areas of developing countries provides great opportunities to implement a paradigm shift. Often these areas don't have legacy infrastructure and governance structures, and urban planning has not yet happened, hence they provide real opportunities to implement innovative solutions for the provision of water and sanitation.

Keywords: Integrated urban water management, uncertainty, clustered approach

Challenges and opportunities of urban water in cities of the future

Urban water challenges

It is widely accepted that one of the major challenges of the 21st century is to provide a safe water supply and basic sanitation for all. Safe water supply and reliable sanitation are fundamental to a community's health and development. Water and sanitation are fundamental requirements in the fight against poverty, hunger, child mortality and in achieving gender equality. Worldwide, almost 900 million people still do not have access to safe drinking water and some 2.6 billion, almost half the population of the developing world, do not have access to adequate sanitation (WHO/UNICEF, 2006). Unsafe water and poor sanitation are one of the major causes of disease in the world. Over half of the world's hospitals beds are occupied with people suffering from illnesses linked with contaminated water (Corcoran et al., 2010). Every year, unsafe water coupled with a lack of basic sanitation is responsible for the death of at least 1.6 million children under the age of five years (WHO/UNICEF, 2006). Consequently, over a billion people are locked in a cycle of poverty and disease (UNICEF/ WHO, 2004).

Providing adequate water supply and sanitation, particularly in urban areas, is a challenging task for governments throughout the world. Already, half of the world's population lives in cities, most of which have virtually no infrastructure or only inadequate infrastructure, and limited resources to address water and wastewater management in an efficient and sustainable way. Due to inadequate infrastructure almost 85 per cent of all wastewater is discharged to water bodies without treatment, resulting in one of the greatest health challenges, restricting development and increasing poverty through costs to health care and lost labor productivity (Corcoran *et al.*, 2010)

This task is made even more difficult due to predicted dramatic global changes. Climate change is predicted to cause significant changes in precipitation patterns and their variability, affecting the availability of water. In addition, technological and financial constraints are challenges in maintaining and upgrading infrastructure assets to deliver water to all sectors while maintaining the quality of water distributed to the various users. Furthermore, population growth, urbanisation and industrial activities are leading to a dramatic increase in water use and wastewater discharge. The global population is expected to exceed nine billion by 2050 (UN 2010). The urban population is projected to rise, nearly doubling from the current 3.4 billion to 6.4 billion by 2050, with the number of people living in slums rising even faster, from 1.0 to 1.4 billion in just a decade (UN 2010). Water scarcity coupled with inadequate infrastructure and management systems for the increasing volume of wastewater that we produce are at the heart of the water and sanitation crisis.

Under the aforementioned circumstances, current models of urban water management and their corresponding infrastructure have already failed or are on the verge of collapse from the perspective of cost effectiveness, performance and sustainability. Cities are now faced with difficult future strategic decisions – do they continue business as usual, following a conventional technical, institutional and economic approach for water and sanitation; do they tinker, where they follow the conventional approaches while trying to optimise and fine tune them; or do they look for a new paradigm, that considers: interventions over the entire urban water cycle that provide security through diversifying water sources; reconsideration of the way water is used (and reused); viewing wastewater as a valuable resource; governance structures, covering the entire urban water cycle; and resiliency of water and sanitation to global change pressures.

Urbanisation offers great opportunities

Urbanisation, while challenging, also offers opportunities to implement a new paradigm for urban water management. This is particularly the case in the many emerging towns and villages in developing countries. It is in these emerging areas where most of the rapid expansion in urbanisation is taking place (UNFPA, 2007). Pilgrim (2007) reported that for every large town there are an estimated ten small towns, which are expected to increase four-fold in the next 30 years. The fact that these emerging urban areas often don't have mature infrastructure and governance structures, and urban planning has not yet happened, provides real opportunities to implement innovative solutions for the provision of water and sanitation. Development plans in these emerging areas are urgently required and may allow direct implementation of radically different system configurations: where surface water, groundwater and storm water are combined as potential sources; where innovative solutions are applied that allow source separation of wastes and implementation of reclamation schemes (wastewater recycling, nutrient and energy recovery schemes); and where mixed land-use development that promotes cascading water uses between domestic, industry and agriculture sectors are considered. Although the potential to do things differently in these emerging areas exist, the window of opportunity to create a more sustainable pathway is relatively small (5-15 years), hence quick action is needed if one is going to create a paradigm shift (World Bank 2009).

Compared to emerging towns, existing cities provide limited opportunities to rethink urban water management as the built environment already exists and they often have locked-in, legacy infrastructure operated by isolated institutions. In these cities a paradigm shift will be harder to implement. However, there are opportunities to apply new approaches for water supply and sanitation in urban areas, growing on the boundaries of existing cities, by conceptually 'ring-fencing' the infrastructure of the existing city (and not extending it further into the growing areas), and then considering the growing areas as independent clusters that can be developed according to the integrated paradigm (presented for the emerging cities).

An integrated paradigm for urban water management

In order to meet the future water and sanitation challenges there is the need for a fundamental change in the way we manage urban water systems – a paradigm shift. The key principles for the proposed integrated paradigm are presented in the following sections. These principles provide the chance to transform threats into opportunities and to address the challenges of urban water management in developing countries.

Integrated urban water management (IUWM) framework

It is important to contextualise domestic water and sanitation provision within an integrated urban water framework, as this allows us to understand and articulate the relationship between the various components of the urban water system. For example, experience has shown that poor sanitation has a major impact on the pollution of potential water sources and treated drinking water. An integrated framework exposes these negative interactions. In addition to exposing some of the negative impacts, an integrated framework also highlights positive interactions such as the potential for providing more people with water and sanitation services, while using less resource. For example, it highlights opportunities for reuse, recycling and the potential of alternative sources for water, such as stormwater. Hence, by understanding these interactions, we can maximise the opportunities and minimise the threats to urban water management. For further information on the principles of IUWM see Mitchell (2004) and SWITCH (2011).

The integrated framework has to be applied at different spatial scales, specifically at the neighborhood/cluster scale and at the city scale. The consideration of the different spatial scales facilitates the assessment of the different threats and opportunities for urban water management (see Figure 1 for the nested structure of the different frameworks). It is expected that optimal solutions are likely to be a combination of interventions across these scales.

Neighborhood/cluster scale - this scale allows water and other resource flows to be described between the various components of the urban water system. It allows negative interactions between components to be articulated (e.g. cross-contamination of treated water by dysfunctional or poor sanitation systems, impact of septic tanks, pit latrines etc. on ground water sources, receiving water bodies etc.) and helps to identify the root causes of many of the threats to urban water management. In addition, this scale allows identifying positive interactions between components (e.g. opportunities for addressing competing needs for water and other resources by exploring and maximising recycling, reuse of water and recovery of energy and nutrients) and facilitates the identification of opportunities. Figure 2 presents an integrated framework for water systems in low-income neighborhoods in developing countries (illustrating typical elements such as onsite sanitation and negative interactions such as the cross-contamination).

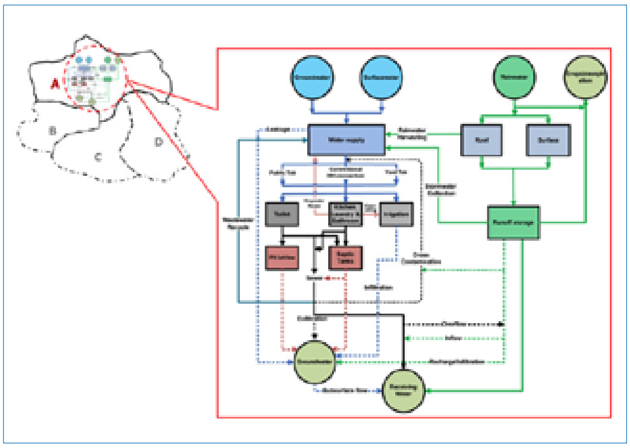


Figure 1: Nested structure of the integrated urban water framework (Vairavamoorthy et al. 2012)

Urban/city scale – this scale describes water and other resources flows between different neighborhoods and clusters within an urban space/city. For example, negative interactions on the city scale include: lack of drainage provision in one cluster (e.g. a slum) impacting the performance of drainage in the entire city; lack of sanitation in one cluster (e.g. slum) degrading the quality of water sources in other clusters etc. Positive interactions that could be articulated at this scale include: cascading use of water between clusters (e.g. wastewater from one cluster being used for urban agriculture in another cluster); arguments for integrated infrastructure provision among clusters (i.e. all communities including low income groups and slums), where service provision for the entire city benefits both individual clusters and the greater city (i.e. an integrated drainage network that includes all clusters makes more sense than one that intentionally avoids some clusters (i.e. slum clusters). The Figure 3 presents a diagram of the flows between clusters which illustrate the mentioned positive and negative interactions.

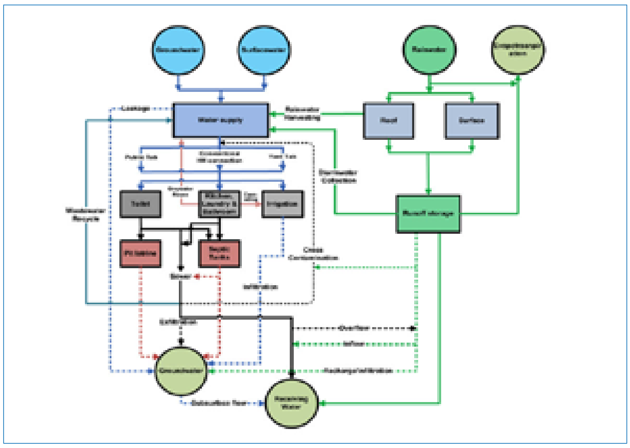


Figure 2: Integrated urban water framework for low-income urban areas (Vairavamoorthy et al. 2012)

The integrated framework facilitates a structured and integrated analysis of strategies to improve water and sanitation provision. By improving the understanding of the highly complex interactions between the different parts of the urban water cycle, it allows for an integrated decision-making process.

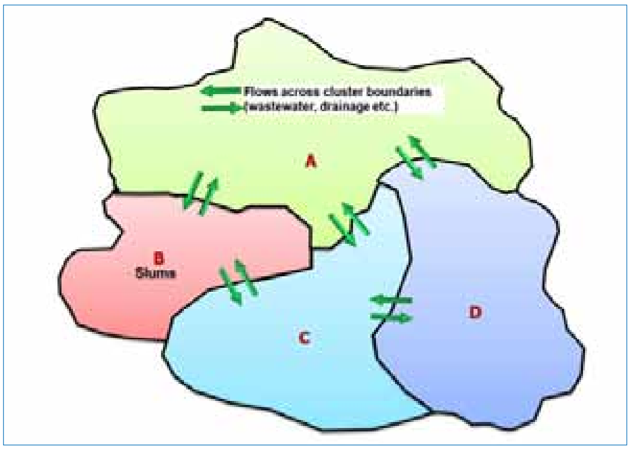


Figure 3: Schematic depicting flows between neighborhoods/clusters in an urban area (Vairavamoorthy et al. 2012)
Water security through diversity

One of the major challenges is to meet the future water and sanitation goals in a situation where competition for water will be stiffer and the availability of fresh water will be more uncertain. This requires the consideration of a portfolio of water sources options such as groundwater, surface water, storm water, leakage reduction, and treated greywater. In addition, there is a need to critically look into the way we use and reuse water to improve water use efficiency. These solutions need to be a combination of end-use efficiency, system efficiency (low leakage rate), storage innovations (using aquifer recharge options), and reuse strategies that would reduce the demand for fresh water. Stormwater and wastewater need to be viewed as potential sources as opposed to burdens. Balancing the demands for water between the various sectors could ensure that water can be used multiple times, by cascading it from higher to lower-quality needs and by treatment for recycling and reuse. This should be coupled with a multiple barrier approach and water safety plans safeguarding water quality from the source to the tap. The integrated approach is essential for the identification of the portfolio of conventional and unconventional water sources. Compared with the reliance on single conventional water sources, the proposed portfolio of water sources provides a higher resiliency of the water supply against extreme events and future change drivers.

Wastewater is a valuable resource and not a burden

One of the major opportunities to addressing the global sanitation challenge is to change mindsets about wastewater – viewing it not as waste and a burden, but rather as a resource (Bieker *et al.*, 2010; Cornel *et al.* 2011 Verstraete *et al.* 2009). Smart and sustained investment in wastewater management could generate multiple dividends in society, the economy and the environment. Wastewater treatment and reuse in agriculture can provide benefits to farmers in conserving fresh water resources, improving soil integrity, preventing discharge to surface and groundwater waters, and improving economic efficiency. Key is the safe reuse of water, while reducing the risk for public and environmental health. Reclaimed water can play an important role in ecosystem restoration. In addition to non-potable reuse applications, wastewater has potential from the perspective of extraction of renewable energy and nutrients. The expected solutions will convert current liabilities (e.g., energy required for wastewater treatment) into assets (e.g., energy from wastewater treatment). New technologies that promote wastewater as a resource need to be tailored for the unique conditions that exist in low-income countries. These include: low cost membrane filtration systems including membrane bioreactors, hybrid systems of natural and advanced treatment, microbial fuel cells, electrochemical processes and source separation of different waste streams. The integrated approach is key to identify and exploit the opportunities provided by the recovery of resources from wastewater.

Integrated approach fosters decentralised urban water systems

The successful application of an integrated approach to urban water management appears to foster a more decentralised approach to urban water management as:

- Water reuse fosters decentralisation – Key for the recycling and reuse of wastewater is to reduce the distances between the households and the treatment units to minimise energy demand for pumping and minimises capex for sewer and pipe systems (Bieker 2009; Cornel *et al.* 2011).
- Energy recovery fosters decentralisation – as above, the possibility for biogas recovery from wastewater should be provided as close as possible to the user. In addition, the recovery of heat energy from hot grey water is more efficient when the distance between the user and the treatment units is short.
- The use of local water sources fosters decentralisation – the potential of small local water sources (such as small streams, rainwater harvesting or local groundwater), which are often neglected in central schemes, could be utilised in decentralised systems.

A clustered approach to urban development

The effective implementation of the decentralised urban water systems and their associated opportunities requires a clustered approach to urban development.

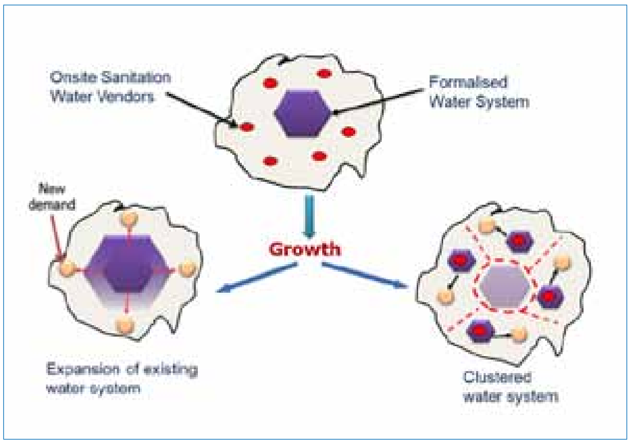


Figure 4: A clustered development approach for emerging urban areas (Vairavamoorthy et al. 2012)

The traditional approach to deal with the expected urban growth would be to extend the existing centralised water system to the new emerging areas (see Figure 4). Past experiences illustrate that such an approach leads to a highly complex, interconnected, dysfunctional system. Hence, it is proposed that instead of simply expanding the centralised urban water system, a clustered water and sanitation system is envisioned where the central inner core of the city will be 'ring-fenced' (as shown in Figure 4). For the new emerging areas on the outskirts of the inner core, several clusters of a decentralised water and sanitation system will be developed. Such an approach could be implemented more quickly than a conventional approach (as the planning and implementation process is easier to manage) and it provides flexibility by allowing infrastructure provision to be staged in a way that traces the urban growth trajectory more carefully. In addition, it could be implemented in an incremental fashion, which reduces the investment costs and makes the project easier to manage.

Case study: Mbale

The new integrated approach to urban water management has been proposed in a recently prepared feasibility study for Mbale Town, Uganda, funded by the World Bank (Vairavamoorthy et al., 2012). Comparable concepts are discussed for the case studies Arua, Uganda and Nairobi, Kenya or in the case studies on semi-central treatment systems in Xing Dao and Xi'an China. Mbale is one of the emerging towns in Uganda. It is located at the foot of Mount Elgon in Eastern Uganda. The population of Mbale is expected to grow from 107,602 in 2012 to 218,218 by 2032 with an annual growth rate of 3.6 per cent. By the year 2032, the water demand in Mbale is estimated to rise to 16,893 m^3/d exceeding the capacity of the existing surface water sources of 11,500 m^3/d (Vairavamoorthy et al., 2012). In addition to the water shortage problem, Mbale also lacks adequate sanitation provision. Areas outside the central business district have onsite sanitation systems. Many of the pit latrines are dysfunctional and overflowing during the rainy season, posing both health risks and water pollution risks. It has become clear that the current practice of urban water management in Mbale is not sustainable, and hence in order to address the current and future water and sanitation challenges there is a need for a paradigm shift.

The rapid urban growth of Mbale provides great opportunities to implement innovative approaches to urban water management. Hence a paradigm shift for urban water management in Mbale, based on the integrated urban water management frameworks, the principles of providing security through diversity, considering wastewater as a valuable resource and semi-central, and clustered approaches, is proposed. A template for the development of strategies was created. This template provides a structured approach to: identify cluster boundaries; identify additional water sources and prioritise their selection; select appropriate treatment technologies for promoting integrated water use; assess and balance water flows and contaminant fluxes and optimise the cost-benefits. Based on a detailed analysis of the existing and projected urban growth patterns, using the developed template, Mbale town and its emerging areas were divided into 7 clusters (M1-M7) (see Figure 5). Several criterion were combined to support the identification of the clusters including: topographical features, natural drainage patterns, potential for a portfolio of water sources, planned future development, extent of existing infrastructure etc.

An integrated framework is applied at cluster scale to understand flows within the cluster such as water supply, stormwater and wastewater, and to assess different strategies for improving water and sanitation in Mbale town. Based on the assessment, different technologies are proposed for the emerging areas, such as Decentralised Wastewater Treatment Systems (DEWATS) for greywater and black-water; Soil Aquifer Treatment (SAT) for treatment of greywater effluent; advanced water treatment for treatment of greywater effluent;conventionalwatertreatmentfortreatingsurfacewaterormixed surface water and greywater effluent and disinfection for treatment of groundwater. Figure 5 shows one of the proposed treatment units for the emerging area, which treats surface water, groundwater and greywater to potable water, and black water to the effluent quality. In addition, flows between clusters are analyzed by applying the framework at the city scale. One of the recommendations for Mbale is to use the effluent from upstream clusters in downstream clusters (through river as a natural buffer).

The new approach offers water security for the Mbale town through diversified water sources and recognises wastewater as a valuable resource. Figure 6 shows the proposed technology and the flows for cluster M5. In this cluster, different water streams such as surface water, groundwater and greywater are considered in an integrated way to optimise the provision and use of water from various sources. The proposed portfolio of sources for cluster M5 includes surface water (1244m^3/d), groundwater (38m^3/d) and greywater (732m^3/d). The applied integrated approach recognises wastewater in Mbale as a valuable resource by recycling greywater and providing opportunity to produce energy from blackwater. In addition, the treated blackwater of 477 m^3/d is discharged into the Namatale River, as a natural buffer, which serves as a water source for downstream clusters. The study recommended a clustered development approach for Mbale where existing central district be 'ring fenced' in terms of its infrastructure, so that its centralised water supply system is not further expanded into the new emerging areas around its boundaries. The emerging areas on the boundaries can be viewed as urban clusters that have their own autonomous decentralised water and wastewater systems.

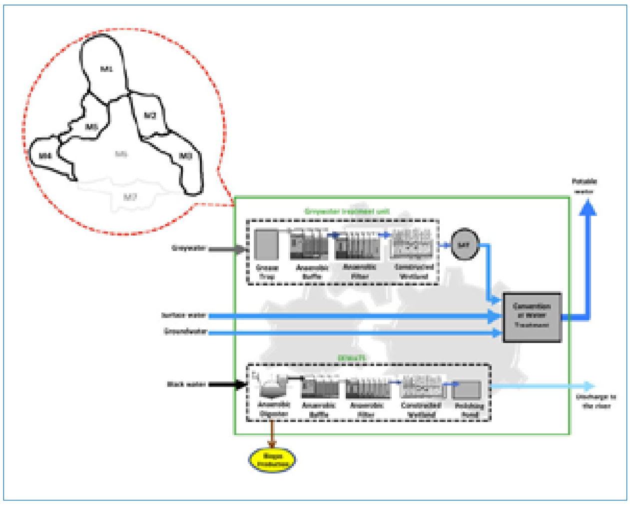


Figure 5: Proposed treatment technologies for emerging areas in Mbale (Vairavamoorthy et al., 2012)

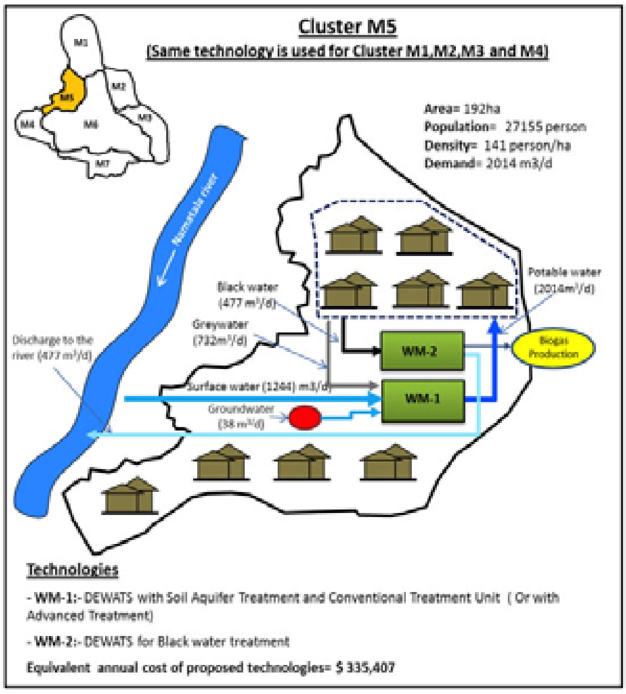


Figure 6: Water flows in Cluster M5 of Mbale (Vairavamoorthy et al. 2012)

To evaluate the cost-benefits offered by the integrated approach, a 'business as usual' scenario and a 'cluster' scenario are compared. The 'business as usual' scenario considers expansion of the existing water supply system, increasing the abstraction capacity of surface water from a further distance, the management of wastewater by centralised sewerage systems and onsite sanitation systems without recycling options. The 'clustered' scenario includes the integrated options described above by combining surface water, groundwater and recycled wastewater and providing decentralised sanitation systems. Annual costs for the full development of infrastructure (including operation and maintenance; based on African cost figures) for the 'business as usual' and the 'clustered approach' for Mbale are estimated to be USD 3,489,700 and USD 3,113,300, respectively. The corresponding average unit costs are USD 0.57/m^3 and 0.50 USD/m^3, respectively (Vairavamoorthy *et al.*, 2012).

This case study illustrates that there is a huge potential in emerging urban areas like Mbale. The proposed approach exposes the opportunities to provide adequate water services without a corresponding increased pressure on freshwater sources. It also explores the potential to satisfy the water needs of communities at the lowest cost while minimising adverse environmental and social impacts. In addition, the approach enables the understanding of the interactions that take place between different components of the urban water system. This is crucial to provide and maintain effective and efficient water and sanitation services.

Conclusions

It has become obvious that the current practice of urban water management in developing countries is not sustainable and the need to adopt innovative approaches is evident. In particular, there are great opportunities to implement innovative approaches in emerging urban areas similar to those presented in the Mbale case study. Development plans, in these emerging urban areas, may allow direct implementation of radically different water system configurations, where surface water, groundwater and storm water are combined as potential sources, where innovative solutions are applied that allow source separation of wastes and implementation of reclamation schemes. In the case study, a portfolio of water sources for Mbale was recommended that combine surface water, groundwater and recycled wastewater. To achieve the recycling potential of wastewater, the study recommended the application of innovative decentralised treatment options that are well suited to conditions in developing countries. The innovative approach has an important role in promoting a sustainable solution based upon a portfolio of sources (important from the perspective of security by diversity). Associated with this is a change in mindset about wastewater – we should stop viewing it as waste and a burden, but rather as a resource that could be effectively utilised to augment water sources. Hence, wastewater treatment has to be viewed from the dual perspective of providing improved sanitation and generating additional water sources. There are opportunities to apply the innovative approaches in emerging urban areas that are developing on the boundaries of existing cities. To achieve this, it is first important to conceptually 'ring-fence' the infrastructure of the existing city (and not extend it further into the emerging areas), and then to consider the emerging areas as independent clusters. The conclusion is that the innovative approach exposes the potential of alternative water sources to meet the growing demand and enables the prioritising of the distribution of use from a cost-benefit perspective. In the case study of Mbale it is estimated that the average unit costs for the proposed IUWM scenario are 0.50 USD/m^3 while the unit cost for the conventional approach is 0.57 USD/m^3.

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Mr. Kevin L. Shafer
Executive Director
Milwaukee Metropolitan Sewerage District, 260 W. Seeboth Street, Milwaukee, Wisconsin 53204-1446, United States
kshafer@mmsd.com

CASE STUDY

SUSTAINING OUR FUTURE WITH GREEN INFRASTRUCTURE APPROACHES: THE MILWAUKEE EXPERIENCE

Positioning the Milwaukee region for a more sustainable infrastructure future has been an emphasis of the Milwaukee Metropolitan Sewerage District (MMSD) since its inception (MMSD, 2012). Initially, to meet regulatory requirements, the emphasis was on 'grey' infrastructure. In 1999, while still building grey infrastructure, MMSD enhanced the grey infrastructure approach with a more sustainable approach using green infrastructure. To make this modification, MMSD using watershed-based planning to identify water quality impacts to the region's waterways. Since there was limited capital cost information available on green infrastructure, MMSD also initiated a series of pilot projects to help fill this gap for capital, operation and maintenance costs. These pilot projects also sought to identify the multiple benefits that this new sustainable approach provides. These benefits looked beyond the improvements to water quality; they also considered the aesthetic benefits and the advantage of being more prepared for a changing climate. To date, the Milwaukee experience has shown that sustainable, green infrastructure is a cost effective approach to deal with water quality challenges. Using the economic data and watershed-based water quality planning helped to align non-traditional partners in support of the green approach with common goals of improving the region's quality of life and buoying the economy. Green infrastructure is now accepted as a critical element in the movement toward sustainability, but many pieces had to be assembled prior to launching this effort, and there is more yet to accomplish.

Keywords: Green infrastructure, sustainable infrastructure, regional collaboration, Greenseams®, renewable energy, energy efficiency

Background

Milwaukee, Wisconsin is the 28th largest city in the United States. It was established in 1846 on the shores of Lake Michigan, one of North America's Great Lakes (Fig. 1.) The Great Lakes are a collection of freshwater lakes located in north-eastern North America, on the United States-Canadian border. Consisting of Lakes Superior, Michigan, Huron, Erie and Ontario, they form the largest group of freshwater lakes on earth by total surface area – 80,5 square miles. The Great Lakes hold 21 per cent of the world's surface fresh water.

Because it is a natural harbour on the western shores of Lake Michigan, Milwaukee became a centre for trade and shipping. Shipping was joined by meat packing, leather tanning and brewing, which turned Wisconsin's agricultural bounty into useful products. In the late 1800s, manufacturing was the city's lifeblood, and Milwaukee became known for the variety of steam engines, agricultural machinery, electrical equipment, mining shovels and automobile frames it produced. The City of Milwaukee and surrounding region quickly became known as the brewery capital of the world. The industrialisation of this once undeveloped area quickly started to stress the water resources of the local rivers and Lake Michigan.

Figure 1. Location map for Milwaukee

Throughout its history, the city and the region surrounding Milwaukee have relied on the bountiful freshwater supplies that the lake has provided. With this reliance, regional leaders understood that they needed to protect this precious water body for the obvious economic benefits as well as the environmental and human benefits into which this translates.

Initially, Milwaukee built sewers just to keep up with population growth. Sewers were extended along the rivers reaching the neighbourhoods to convey the sewage to the water reclamation facilities. While this approach met the public health and safety needs of the residents, it did not manage storm water runoff or the pollutants within that runoff. This network of sewers has, over the years, formed the grey backbone of the region's infrastructure future.

Over the years, the chosen approach transformed the network from the initial 'grey' infrastructure, urban centric philosophy to a more dynamic approach that is integrated with 'green' infrastructure across the entire watershed. This new dynamic has fostered a paradigm shift in how the Milwaukee region constructs, manages and considers water in its future infrastructure plans.

Milwaukee Metropolitan Sewerage District

The Milwaukee Metropolitan Sewerage District (MMSD) is a state-chartered, regional government agency that provides water reclamation and flood management services for approximately 1.1 million customers in 28 communities in the greater Milwaukee area. MMSD serves 411 square miles that cover all, or segments of, six watersheds in south-eastern Wisconsin.

Sustainable infrastructure has been woven into the fabric of the Milwaukee region's infrastructure since its inception. In 1913, nearly 100 years ago, the State of Wisconsin passed an act creating the Milwaukee Sewerage Commission, providing the means for raising funds to build Milwaukee's first water reclamation facility. When the Jones Island Water Reclamation Facility (JIWRF) was constructed in 1926, MMSD also began converting its biosolids to a renewable lawn fertiliser known as Milorganite®. This environmentally beneficial re-use has helped to offset operating costs and has been the lowest cost means of disposal of the biosolids.

Soon after JIWRF was built, MMSD's sustainability efforts focused on cleaning up the region's black and septic rivers and lakes, protecting the public's health, and, even then, finding ways to use waste as a resource. In the late 1960s, a second water reclamation facility was built, South Shore Water Reclamation Facility (SSWRF). At this facility, MMSD included anaerobic digestion as a means of producing biogas, which it used to generate electricity, offsetting operating costs and continuing MMSD's sustainability record.

With the passage of the United States Clean Water Act in 1972, MMSD embarked on a 20-year program to reduce its environmental impacts by managing combined and separate sewer overflows with the construction of a deep tunnel storage system. There has been a

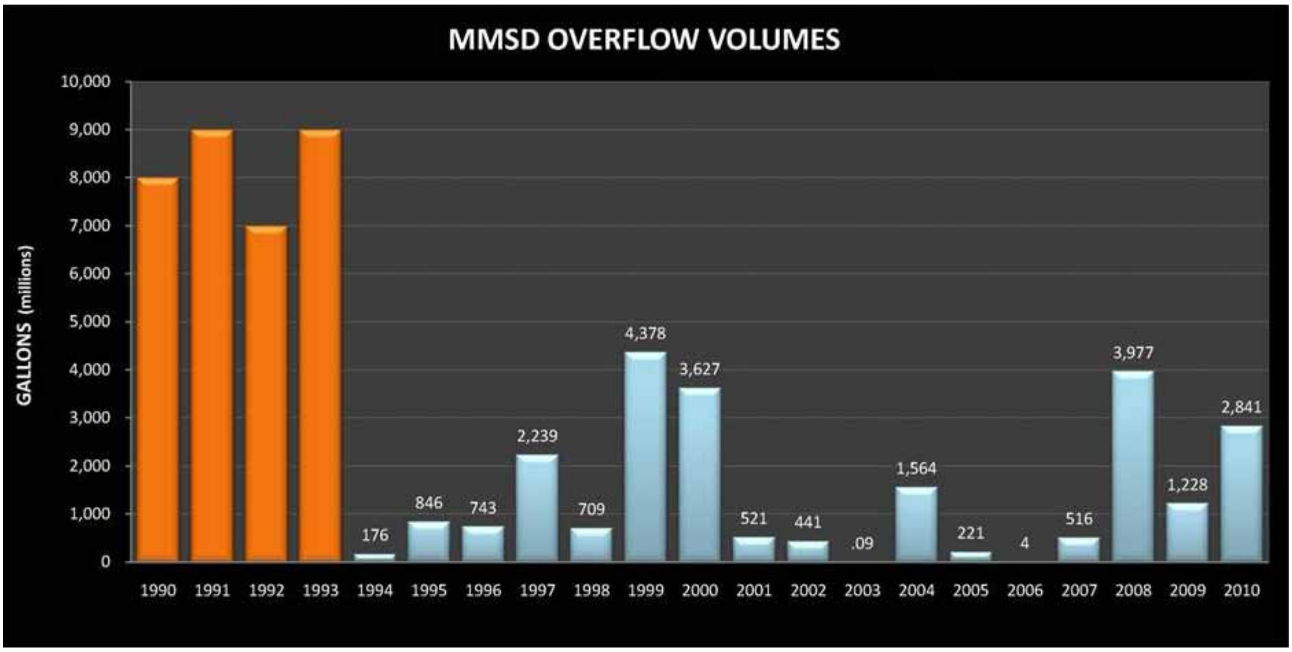

Figure 2. MMSD overflow volumes

marked reduction in overflows since the implementation of the Deep Tunnel. The average volume of overflows has been reduced from between eight and nine billion gallons per year to 1.1 billion gallons per year (Fig. 2). Additionally, the number of overflows has been reduced from an average of 50 to 60 per year down to 2.2 per year. Having this strong history of good overflow management has provided the environmental baseline necessary to examine other means of developing sustainable infrastructure.

Another metric that MMSD analyses to determine the success of its water management system is the per cent of water captured and treated annually. The United States Environmental Protection Agency (USEPA) requires that MMSD treats a minimum 85 per cent of all the flow coming into its sewer system (USEPA, 2012). Since the Deep Tunnel system became operational in 1993, MMSD has always captured and treated 94 per cent of flow (Fig. 3).

Since becoming operational, the Deep Tunnel system has outperformed all Federal and State regulatory requirements and provided a noticeable improvement in the area's rivers and Lake Michigan.

Regularly monitoring the health of the rivers and lakes since then has enabled MMSD to identify areas that need protection and/or restorative action. Today's increased interest in environmental health was founded in Wisconsin's strong environmental tradition, fuelled by federal environmental legislation in the 1970s.

Setting the table

Although compliant with regulations, the Milwaukee region still faced a plethora of water quality and quantity problems in 2002. Many problems presented themselves to the general public in visible fashion, and this pressured MMSD to look at the region's water resources through a more practical lens and not simply through a regulatory lens. Throughout the summer months, beach closures were common, and warnings about swimming in the rivers following a rain event and even about fish consumption were believed to be indications of infrastructure failures. These problems created a public outcry that something must be done to protect the water resources.

Many causes of these public problems were beyond the jurisdiction of the MMSD, but MMSD leadership understood that they needed to address these more widespread issues in their own infrastructure decisions if they were to succeed. MMSD understood that, in the current environment, they must be cognisant of the variety of drivers that constituents faced. These included limited financial resources, more severe storms because of changing climate, and increased scrutiny on governmental initiatives. Therefore, the leaders adopted a multi-phased approach that would add resiliency to the urban environment, striving for improved water quality and less flood risk. This multi-phased approach would still include investment in the Deep Tunnel, but would be supplemented with an investment in green infrastructure.

The Deep Tunnel is often characterised as grey infrastructure. Grey infrastructure is usually a defined, designed approach that includes the construction of man-made structures to manage large volumes of water. Green infrastructure is an approach that strives to mimic nature by using more geographically diffuse approaches to store and infiltrate smaller volumes of storm water (United States EPA Water Division; Green Infrastructure, 2012). MMSD fosters the belief that green infrastructure helps its grey infrastructure work more efficiently.

Figure 3. Per cent of water captured and treated

Recently, MMSD embarked on a variety of projects that were atypical of a wastewater utility, but were the first step toward a more integrated sustainable infrastructure portfolio. These projects can be categorised as:

1. Continuation of improvements to MMSD's grey infrastructure
2. Development of water quality research
3. Development of entire watershed water quality plans
4. Completion of environmentally friendly flood management facilities
5. Implementation of green infrastructure practices.

Continuation of improvements to MMSD's grey infrastructure

MMSD has developed a strong technical staff of scientists and engineers. Knowing that sanitary sewer overflows would always be a public concern, MMSD used this staff's expertise and entered into an agreement with the State of Wisconsin to design and construct additional grey infrastructure facilities that would address the public outrage and go beyond any regulatory requirements. Since 2002, an additional USD 1 billion investment in sanitary sewers, tunnel expansion and water reclamation facility infrastructure improvements were completed to manage sanitary sewer overflows. Two recent projects that highlight the grey infrastructure improvements are the Harbor Siphons project and the JIWRF Aeration Improvement Project.

The recently completed Harbor Siphons project added new sewer siphons under the Milwaukee Harbour, delivering additional water to JIWRF during wet weather events. This project adds 50 years of service life to the sewer system, improves the operations of the system and eliminates a hydraulic bottleneck. The project has helped MMSD reduce the volumes of its overflows to the area's rivers and will reduce the energy footprint at JIWRF by maximising the amount of flow that is delivered to the facility without using the Deep Tunnel system.

The JIWRF Aeration Improvement Project consists of replacing the aeration diffusers in aeration basins and upgrading the process air compressors with new higher efficiency units. This project will improve the air distribution in the existing aeration basins and reduce energy usage and greenhouse gas emissions.

Development of water quality research

It was understood early that the abundance of water problems that the region was experiencing was mostly a consequence of a widespread set of causes. To assess these causes in the most cost effective manner, MMSD began investing in water quality research that was more watershed focused. This water quality research soon formed the basis for future capital investments throughout the region. One of the first research efforts was targeted at determining why the public beaches along Lake Michigan were closing when there were no

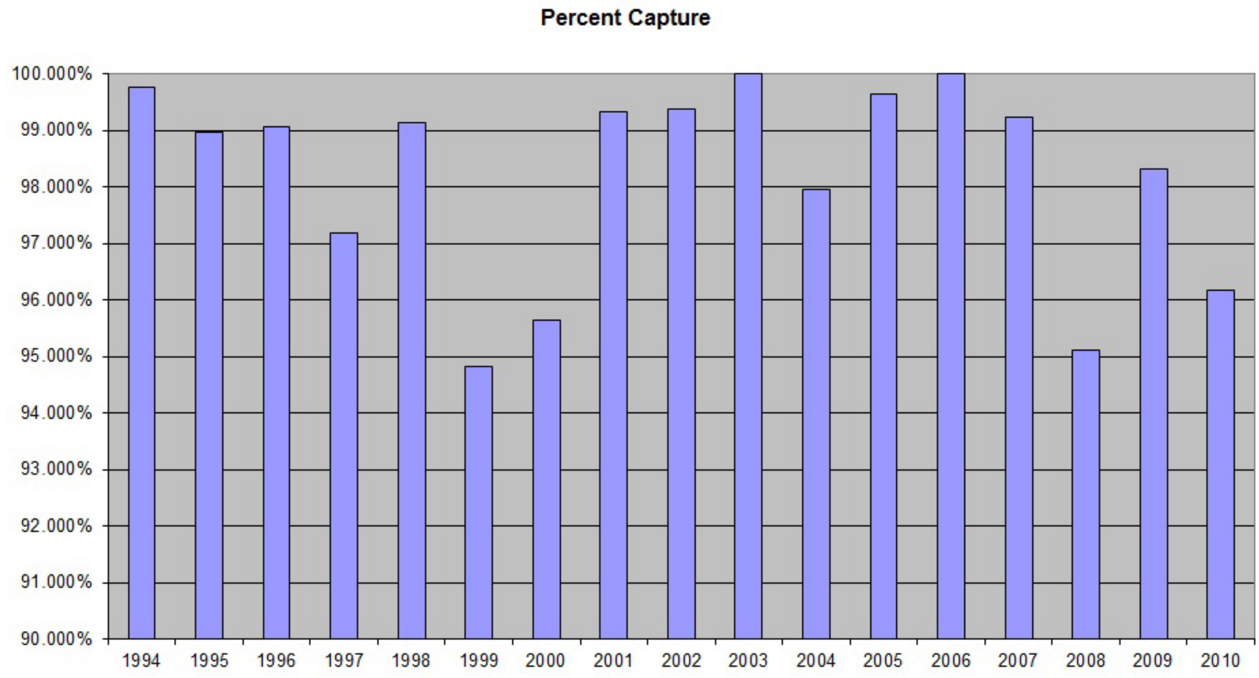

Figure 4. Promotional material for Menomonee River Channel initiative

sanitary sewer overflows. Through some innovative DNA analysis, the University of Wisconsin-Milwaukee's Great Lakes Water Research Institute (GLWRI) linked the high bacteria counts that were measured at the beaches to seagull faeces (GLWRI, 2012). Through a variety of meetings, symposiums and targeted efforts with the media, this information was widely disseminated and, over time, was accepted.

Another problem facing MMSD was the high faecal coliform measurements in the rivers. MMSD took these measurements and was concerned that they occurred when there were no sanitary sewer overflows. For this problem, MMSD commissioned GLWRI to sample the water that was discharged to the rivers through storm water outfalls. The results of this analysis showed that, through time, the old municipally-owned and privately-owned sanitary sewer pipes in the area had begun to leak. Additionally, several direct connections from the sanitary sewers to the storm sewers were identified. Based on this research, MMSD and the State of Wisconsin worked with municipalities to initiate infrastructure improvements to reduce faecal coliform loading to the rivers.

Development of entire watershed water quality plans

Armed with innovative science, MMSD next developed collaborations with a variety of partners, both public and private, and embarked on a long-term planning process that used USEPA's watershed approach. In south-eastern Wisconsin, regional planning performed for municipalities is accomplished by the regional planning entity, the Southeastern Wisconsin Regional Planning Commission (SEWRPC) (SEWRPC, 2012). Using the skills of SEWRPC, MMSD became the cornerstone agency for a five-year planning process that analyzed sources of point and non-point pollution to the region's rivers. This effort was known as the Regional Water Quality Management Plan (RWQMP) (SEWRPC, 2012).

Completed in 2007, this update to the RWQMP became the roadmap for MMSD's future efforts. While the plan's goals and objectives considered several pollutants, the plan focused on bacteria (faecal coliform) as the primary indicator of water quality. This integrated roadmap of scientific data led to the key findings that:

1) Non-point pollution (e.g. storm water runoff) is the largest source of faecal coliform bacteria, a primary pollutant of concern, and of total suspended solids. The analysis of pollutant sources and loadings revealed that storm water pollution was primarily responsible for the region's inability to fully comply with the State of Wisconsin's water quality bacterial standards in the region's rivers.

2) Reducing (or even eliminating) sanitary sewer overflows would result in little or no water quality improvement on an annual basis. As a result of the past investments in the Deep Tunnel and improvements to the water reclamation facilities, MMSD had reached a point of diminishing returns in terms of the water quality improvements that would result from additional capital investment to further reduce sanitary sewer overflows.

3) Significant improvements to water quality could only be achieved through regional implementation of widespread measures to reduce pollution from non-point sources. Until this time, polluted storm water runoff had largely been ignored. The plan's comprehensive, integrated watershed approach helped the region's leaders understand that more could be accomplished by focusing efforts on better management techniques for storm water runoff.

4) Green infrastructure is a cost effective tool that should be phased into the future infrastructure investments. From a large-scale perspective to individual private homes, the plan demonstrated that green infrastructure was the best next step toward sustainable infrastructure for the Milwaukee region.

In short, this comprehensive roadmap showed that, while the Milwaukee region had performed very well on managing and reducing sewer overflows, it needed to take the next step if it was to realise additional improvements in the water environment.

Completion of environmentally friendly flood management facilities
In 1999, MMSD initiated a series of flood management projects that strived to mimic nature. These environmentally friendly projects removed concrete liners from waterways, purchased structures, expanded natural floodplains, incorporated habitat restoration features and looked at the entire watershed as opposed to just a certain reach of a river. This comprehensive approach required extensive public involvement and collaboration.

The results have been amazing (Fig. 4) – many rivers have been returned to nature where possible, and this has expanded the variety of recreational opportunities in the region. With the habitat improvements, there has been a resurgence of fish migrations through the rivers, and water quality is improving. The health and wellbeing of the residents along the rivers are improving.

Implementation of green infrastructure practices

In 2002, MMSD leadership knew that a new path needed to be explored for water infrastructure. They understood that the type of problems with which the public was concerned required the approach to infrastructure to change. It needed to be more visible to the public and to address a more comprehensive set of concerns beyond just water. MMSD leadership knew there was little scientific data on the benefits of green infrastructure, but they also believed that some of these approaches made sense. MMSD initiated a series of green infrastructure pilot programmes that ranged in size from efforts that dealt with the small residential property owner to the larger land owners along the rivers.

Figure 5. Promotional material for the Greenseams initiative

Figure 6. Promotional material for the rain barrel programme

One of the larger scale initiatives was the Greenseams® programme, which began in 2000 (MMSD, 2012c). The original objective of this programme was to acquire buffers along the rivers to reduce the impervious areas along the waterways that contributed to flooding downstream. This objective was closely connected to the parallel efforts being implemented for construction of improved flood management facilities. Approximately 15,000 acres of low, floodplain property was initially identified as potentially meeting this objective. Implementation of this programme was initially met with a great deal of distrust. Landowners were concerned that MMSD would use its eminent domain powers to take their land without adequate compensation. Several heated public meetings brought this concern forward; therefore, MMSD decided to only use voluntary property sales for land purchases. This nationally acclaimed programme morphed into one of the premier efforts sponsored by MMSD. Since 2002, approximately 2300 acres (15 per cent of the total 15,000 acres) have been purchased.

The completion of the RWQMP in 2007 substantiated the need for the region to take steps to reduce non-point pollution sources. Greenseams® was originally targeted to reduce flooding, but the benefits of reducing pollutants in storm water runoff quickly became apparent. MMSD is using the Greenseams® programme to meet this need and hopes that, by expanding the programme upstream, future expenditures for constructed flood management projects will be diminished.

On a smaller scale, MMSD started a rain barrel programme in 2002 (MMSD, 2012e). Partnering with a local inner city youth group, MMSD salvaged food-grade barrels from landfills and converted them to 55-gallon storage vessels that homeowners could use to capture storm water runoff from their roofs. This programme has been hugely successful with the public. MMSD has sold approximately 16,000 barrels, or an average of approximately 1700 per year, since the programme's inception (Fig. 6). Totalling more than 880,000 gallons, this distributed storage network has provided relief to localised flooding and has cost a fraction of comparably sized infrastructure. Additionally, the public has accepted these barrels and has learned the importance of managing the rainwater that falls on their property.

Figure 7. Promotional material for the green roofs programme

Looking to the future, MMSD is analysing the benefits of enhancing this programme by using larger storage vessels for larger commercial developments. MMSD believes that it might also introduce a real-time operational system to these storage vessels and coordinate the filling and draining of the vessels with the operation of the MMSD's Deep Tunnel system.

MMSD also started a green roof programme in 2002 in a very limited fashion (MMSD, 2012d). While a few roofs were converted to green plants, a more concerted green roof initiative started in 2010. Since then, MMSD has worked with private and public property owners to build over seven acres of green roofs in the urban centre (Fig. 7). These roofs act as natural sponges in an otherwise sea of impervious cover. One roof built by this programme has recorded 460,000 gallons of water diverted out of the combined sewer system in its first year of construction. This public-private partnership is reaping huge benefits for the MMSD system and is proving to be a very good measure for reducing energy costs for the building owners, since green roofs act as natural insulation for the roof and reduce air conditioning costs.

In 2009, MMSD realised that there was still a lack of understanding of the importance of green infrastructure, so it created the Fresh Coast Green Solutions document, which provides a comparison of the various green initiatives that MMSD has initiated (MMSD, 2012b). In 2010, MMSD also introduced the website www.h2ocapture.com, which allows residents to input their green infrastructure improvements into a database that MMSD tracks.

The key to the transition to a more sustainable approach to infrastructure hinged on two key elements, (1) watershed-based water quality modelling that showed that more work was necessary for storm water management and (2) the cost differential between the grey and green infrastructure approaches. The first step was to meet with the public and elected officials. At these meetings, MMSD representatives talked about how the watershed-based planning identified the need for more emphasis on improved storm water management. MMSD representatives also discussed green infrastructure, what it is, and how it could improve storm water management. Additionally, MMSD knew that the aesthetics of green infrastructure would sell themselves. The elected officials easily understood the benefits and became the champions of the efforts because of the strong environmental message tied to lower costs.

Charting a new course

The years 2007 through 2009 were milestones in the development of an integrated infrastructure approach to the Milwaukee region's future infrastructure investments. With the completion of the RWQMP update, MMSD could reference a regional plan that identified the need for better storm water runoff management and indicated that green infrastructure was the tool to accomplish this. Given the dispersed nature of storm water, the MMSD leadership realised the need for a broader coalition to work outside jurisdictional limits.

This coalition became the Southeastern Wisconsin Watersheds Trust (SWWT) (SWWT, 2012). Founded in 2008, this non-governmental group is comprised of environmental, governmental and regulatory organisations. SWWT has become a collaborative forum that provides an opportunity for all interested parties to come together, to voice their concerns, and to support water resources improvements. From this joint collaboration, the region started to discuss improved storm water runoff management on a watershed scale.

In addition to SWWT, MMSD leadership developed a long range 2035 Vision (MMSD, 2012). Within this Vision statement are two strategic objectives – integrated watershed management and climate change mitigation/adaptation with an emphasis on energy efficiency. Under the integrated watershed management objective, MMSD set 2035 goals of zero sewer overflows and has called for an integration of rural and urban storm water runoff management. The second objective identifies the need for MMSD to be more efficient with its energy needs and to strive to use 100 per cent renewable energy sources. One result of these actions will be a reduced carbon footprint, and the Vision calls for this to be reduced by 90 per cent over the 2005 baseline.

For MMSD, the 2035 Vision became the first building block to the future. While broad in context, it allows the region to coalesce around a set of defining objectives that will sustain the region through the changing climactic cycles being experienced. The 2035 Vision was adopted in December 2010 and has launched many new initiatives.

Energy sustainability

Several initiatives will bring MMSD very close to meeting the 2035 Vision goals. One effort is the Landfill Gas Pipeline project. This project, currently under construction, will allow MMSD to capture methane gas currently being flared off at a landfill. The landfill is projected to produce enough landfill gas for at least 20 years of energy production. This gas will be piped 17 miles to JIWRF and will be burned in turbines producing between 13 and 15 megawatts of power. The project is scheduled to be completed in early 2013 and will reduce the greenhouse gas emissions at JIWRF by approximately 95 per cent. Additionally, MMSD analyzes all uses of its energy and is pursuing energy conservation, improved energy efficiencies and maximisation of the use of renewable fuels. Several ongoing projects highlight this effort.

At SSWRF, MMSD is updating the mixing mechanisms in its over 40-year-old anaerobic digesters. This improvement will provide a 17 per cent reduction in sludge production and will increase the methane gas production by 20 per cent. The additional methane gas will be used at SSWRF by engine generators to power the facility or it will be sold back into the local electric grid. In conjunction with Marquette University, MMSD has determined that the direct injection of high strength wastes into SSWRF anaerobic digesters will also increase gas production (Marquette University, 2012). These two projects will lower costs, reduce greenhouse gas emissions, and produce Milorganite® in a more cost effective manner. Additionally, at JIWRF, MMSD installed 20 kilowatt solar panels in 2006. While just a fraction of the total energy load, these solar panels have provided over 96,400 kilowatt hours of electricity since they were installed. Through these various efforts, it is believed that MMSD will meet its climate change mitigation/adaptation objective much earlier than 2035.

Partners for sustainable infrastructure

Along with the efforts of MMSD, the Milwaukee region has become recognised as one of the world's most significant hubs for water research and the water industry. Officially formed in 2009, with approximately 130 water technology companies, the Milwaukee Water Council has led the efforts to have Milwaukee recognised internationally as a centre of freshwater expertise (The Milwaukee Water Council, 2012). Through the Water Council's efforts, the United Nations has designated Milwaukee as a United Nations Global Compact City because of this expertise (United Nations, 2012). The Water Council was created by leaders in the business and education sectors, who understand the importance of developing education programmes to train talent and building partnerships that cut across all sectors and geographic boundaries (The Milwaukee Water Council, 2012). Beside many other advances, the Water Council has brought a business sense to the on-going water discussion. The Water Council has implemented a workforce training effort that will develop the leaders of tomorrow. They have also initiated the implementation of a water business accelerator, which will assist new technological advances to mature and develop as viable businesses of the future.

Success in Milwaukee

The success green infrastructure has garnered in Milwaukee has a lot to do with the success of grey infrastructure. MMSD's overflow reduction programme has been very successful. MMSD did not abandon its grey approaches, but rather educated the public about how the grey and green approaches need to work together. MMSD was also successful in identifying how the newer, more sustainable approach could be achieved at a lower cost. Several large storms during the transition period also afforded opportunities for the public to learn more about green approaches. Finally, one of the most important factors to success was local leadership that helped to propel green infrastructure forward as a solution and then to continually reminded the public of the important roles it plays.

Conclusions

Over 100 years of aggressive work has laid the foundation for a more sustainable future for the Milwaukee region's infrastructure. Green infrastructure combined with grey infrastructure has been determined to be the best next step. The use of both these approaches will allow a continued stellar regulatory compliance record and will help the region to become more resilient to changes in climate. With the assistance of the environmental community, local business leaders and the Milwaukee academic community, MMSD's past work on environmental stewardship will prove to be a great foundation to make the region's transition to a greener, sustainable future more accessible.

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Dr. Joan Clos
Under-Secretary General United Nations, Executive Director, UN-Habitat

Dr. Graham Alabaster
Chief, Urban Waste Management, UN-Habitat

REFLECTIONS

URBAN PLANNING AND DESIGN: THE CRITICAL ROLE OF BASIC INFRASTRUCTURE

The growth of cities is not spontaneous and uncontrolled but is guided and shaped by human interaction, which is governed by, inter alia, physical infrastructure. Urban expansion around the world is characterised by uncontrolled urban sprawl, leading to inefficient use of space and natural resources. Interactions between humans, and opportunities for innovations are constrained by low density and social segregation. Cities can present opportunity for improving the quality of life, rather than being seen as a negative consequence of population growth. If cities are organised and planned properly they can provide improved well-being for society at large and be more efficient in resource use with limited environmental impact. By considering relevant physical aspects and how they related to human activities and social dynamics, sustainable urban development can be fostered. There is without doubt a need to adopt a more positive and optimistic perspective. This chapter proposes a new approach to urban planning and infrastructure layout that can facilitate and promote a desirable socio-economic development of cities.

Key words: Critical infrastructure, physical planning, layout, density versus sprawl,

In 2011, the world reached the seven billion population mark, with more than half of this population living in urban areas. By 2050, this number is expected to increase to more than 9 billion people (UN-DESA, 2010). It is remarkable that only a century ago, two out of ten people in the world were living in urban areas. In the least developed countries this proportion was as low as 5 per cent, as the overwhelming majority lived in rural areas. Since then the world has been rapidly urbanising and in some countries and regions, at an unprecedented pace. It was only two years ago when the urban population outnumbered the rural population thus marking the advent of a new "urban millennium". By the middle of this century it is expected that seven out of every ten persons on the planet will be urban dwellers. The 21st Century will therefore be known as the century of the city. Virtually all this growth (some 90 per cent) will take place in the developing world. Many of the cities will flourish generating wealth and prosperity, but many others will be or remain poor.

Patterns of urbanisation

The patterns of urbanisation across the world vary. In the economically developed parts of the world, which is 85-95 per cent urbanised, the key challenge of urbanisation today is urban sprawl. As more land is allocated to cities, the result is diminishing density, and increasing per capita cost of providing basic infrastructure such as water and sanitation.

In Asia, the process of urbanisation that began in the post – World War II period, has taken place over the last 50 years, characterised by the rapid industrialisation of Japan, and Korea, and more recently, China and India. Through this process, billions of people have become urbanised concurrently with economic growth, particularly growth in manufacturing. Although the process has been new historically, in terms of the space and numbers that have been involved, it falls very much within the classical theory of urbanisation as experienced in the West. Industrialisation was accompanied by the development of supportive institutions, social contracts, and social relationships. The financial and economic surplus generated from the process of industrialisation provided the capital for building basic infrastructure.

The kind of urbanisation taking place in Africa and South East Asia is characterised by slums, unemployment and the dominance of the informal economy. Urbanisation in large parts of the developing world is non-industrialised, supported mainly by the primary production sector comprising mainly agriculture, the extractive industry, and informal trade.

In social terms, this kind of urbanisation is associated with high rates of unemployment (an estimated 60 per cent or more of the youth in slums being unemployed). The majority of those who are excluded from opportunities in the formal sector are engaged in various activities in the informal sector which accounts for up to 70 per cent of GDP in some cases (Daniels, 2004). If urbanisation goes ahead without industrialisation and without formal sector activities, there is a lack of surplus capital to improve the living environment by improving basic infrastructure such as water, sanitation and transport. While there is a growing demand for these services, there is a lack of interest in potential investments. The challenge is therefore how to develop infrastructure and services in non-industrialised but heavily urbanised cities into bankable projects.

Historical perspectives on planning: Learning from history

The critical role that infrastructure and the physical form play on the development of cities is sometimes overlooked. Ancient cities such as Giza in Egypt, Babylon in modern Iraq, Miletus in Greece, Rome in Italy, or Sanggyong in Korea, to name just few cities, all started by laying down their streets that in most cases were straight and intersecting at right angles; some of them were paved with bricks and bitumen. Early texts and laws guided the design and construction of hundreds of cities such as the Kaogong in China (770 BC), the Castra city planning in the Roman Empire (550 BC) and the Law of Indies in Latin America (1573) that prescribed a critical chain in the production of the city (Cristallinks, 2011). European towns and cities were planned using similar grid plans since the beginning of the 12th Century. Philadelphia in 1682 and the visionary proposal for New York City in 1811 were designs that safeguarded against overcrowding fire and disease. These cities' physical layouts served an important purpose, namely to support the organisation of further development, including infrastructure, construction, transport, amenities and public services in an orderly manner.

The Plan of Manhattan in New York City is a good example. It was originally formulated in February 1807 when the City Council , with State help, set about planning future streets. The Council said its Goal was"...laying out Streets... In such a manner as to unite regularity and order with public convienience and benefit and in particular to promote the health of the city..."

In March 1807 the council appointed a 3 member commission to establish the comprehensive street plan (Morris, Rutherfurd and De Witt). A month later state legislature gave the commissioners exclusive power to lay out streets, roads and public squares. There was much hostility but the plan was published in March 1811. It was based on goals of «free and abundant circulation of air to stave off disease». Right angles were also favoured in the construction of buildings as straight-sided and right-angled houses were the most cheap to build. Each Avenue was to be 30m wide. Even though vehicular traffic had yet to be established, there was the foresite to create a network of roads which continues to serve the residents of Manhattan even today.
A study of the factors which influenced the provision of household level water supplies in US cities is also interesting (Whittington *et. al.*, 2008). Throughout the nineteenth and the first half of the twentieth century, the provision of urban water supply in the US was financed by property taxes paid by water users. This principle relied on well-developed local government finance systems. . Property owners were willing to pay higher property taxes in return for access to piped water. This willingness to pay was due to the fear of fires in urban areas. Wood (timber) was widely used for buildings in American cities, and fire was a constant threat in much of 19th Century. Having a piped water supply in a street made it possible to install fire hydrants. This led to improved property values and reduced fire insurance rates.

There was also a misplaced belief in the "miasma" theory of disease. In fact, the belief that "bad air" caused illnesses such as cholera, which could be overcome by flushing streets could only be accomplished if the property was served by piped water. Even today it is not an uncommon practice to see streets being "flushed" this way in the early morning.

Thus, two of the main perceived benefits of piped water were conveniently reflected in improved property values and financing mechanism not related to specific quantity of water consumed.

Kibera – Social inclusion through poverty mapping

In a recent UN-HABITAT project in the low-income settlement in Nairobi Kenya, known as "Kibera" the influence that basic infrastructure in the form of roads and water and sanitation, has on the quality of life and in boosting economic potential is impressive (UN-HABITAT, 2008). Kibera is one of the main slums in Kenya, with the highest population density and which experiences poor water supply and sanitation service provision. Because of its transient nature, the population of Kibera fluctuates from 200,000 – 500,000 people. Most residents are still practicing open defecation and use "the flying toilet", since the number of pit-latrines available are totally inadequate, further more they are in dilapidated state mostly overflowing into open drains which are also the only spaces for channeling other basic services such as water pipes. According to a poverty mapping study conducted by UN-HABITAT in 2004 in Soweto East Village (which is one of the 12 villages of Kibera) over 70,000 people were sharing 110 dilapidated pit-latrines (Kagiri, 2008). Due to lack of planning and accessibility into the settlement, the movement of goods and services are largely through improvised handcarts and wheelbarrows complicating the possibility of conventional sludge exhaustion, drainage of storm/grey water and solid waste management. Water supply in most parts of the settlement is through "spaghetti pipes" which are generally of poor quality, illegally connected, leaking and laid along waste water drains posing a high risk of contaminated water, at the point of collection.

In 2004 Community members were invited by UN-HABITAT to draw a map of their village. It shows the layout of their settlement in terms of boundaries, neighbouring villages and shared resources. It also highlights the location of homesteads, types of houses, all the services available and the physical infrastructure. This map shows that the community members had a clear understanding of their village and their resources, e.g. water points and physical infrastructure. As a result, it was recognised that community members easily understood the best ways to plan their settlement. Based on community preferences facilities were provided in the form of basic water and sanitation facilities, and the construction of a metaled road through the centre of the village. The facilities were complimented with initiatives on drainage and solid waste management. To date, seven communal sanitation facilities are accessible to 21,000 residents of one of the villages in Soweto East (showers and toilets). Running cost for the daily use of the facilities is affordable and the cost of providing the facilities is approximately, 8 USD per capita. This is very cost effective compared to provision of water and sanitation in urban areas which can range from 30-70 USD per capita. Each of the seven facilities is managed by a community-based group which on average collects – Kshs 46,800 (600 USD) per month. The facilities are thus financially sustainable and socially accepted and managed.

The construction of the 1.5 km tarmac ring road across Soweto East and the provision of 600m of improved drains has greatly increased access from the outside, security and economic development. The street has provided a focus for social activity and has become a hive of activity, particularly in the evening hours. When asked about what is the biggest impact, the residents often remark that the air feels fresh and the road has assisted in this respect. The economic development is impressive and there is a marked difference between the quality of vendors stalls and establishments at the beginning of the road (the first part to be constructed) as compared to the more recently completed section.

In addition, a component on waste management is included with the youth-organised door to door garbage collection for 400 homesteads. This was initiated with support from well-established community groups, with income generation as a main driver. Waste recycling has now become a key source of income, including recycling waste paper for resale. The provision of improved surface water drains has also encouraged reduced garbage littering. The youth-led initiative on solid waste is likely to be extended to surrounding villages in the near future.

Lessons learnt

Streets and open spaces – meeting places and economic assets

The lessons we have learned from such examples provide important clues on addressing the critical issues of infrastructure and their role in urban planning. In modern and well-functioning cities, adequate land must be allocated for streets and physical space. This is to allow for investments to be made in the transport and delivery of goods and services for the common good such as water, gas, electricity, telephones, etc. In an urbanised setting, the street directs the accumulation of public capital. The street and the open space it ensures is thus not only a symbolic meeting place but also an economic asset.

In a typical slum, only 2-3 per cent of the land is allocated to streets and thoroughfares. This can be compared to Manhattan where 30 per cent of the land is occupied by streets. Without the basic physical infrastructure provided by the street, there is no physical space where public capital can be accumulated over time. Whereas in the West, investment in public capital took several centuries, cities in the developing world cannot afford such luxury. They are expected to achieve within five to ten years what cities in the developed countries achieved in several centuries. There is a need for a massive infusion of capital required to provide the basic infrastructure needed to make private sector investment flow. It is critical therefore to understand the need for streets and thoroughfares, in the context of urban planning, the provision of basic services, and the potential for the accumulation of public capital around such urban systems.

The economies, resources stewardship and innovations of density

Often, the spatial expansion of cities is faster than population growth, which translates into a reduction of population density. In secondary urban centers, the urban sprawl continues unchecked, due to poor planning and low availability of cheap transportation. These area show the highest per capita investments and operating costs. As the sprawl increases, so does the cost of providing and maintaining infrastructure. For the same infrastructure, in both urban and rural spaces, the capital cost naturally declines with density. In a recent study on the cost of infrastructure in urban areas showed that, at the highest density, the cost of a bundle of high-quality services is 325 USD per capita; for medium- density cities, it is 665 USD; for the rural hinterland 2,837 USD; and for isolated areas 4,879 USD (African Development Bank, 2011). Population density also affects the possibilities to pay for such infrastructure. In rural areas the cost of a high quality infrastructure bundle is 10 to 20 times the annual household budgets so unaffordable. This ratio falls steeply in urban areas, where the cost of the bundle is typically one to three times the annual household budget.

Creating the city of the 21st Century: Promoting an urban paradigm shift

To address the challenges and to make use of the opportunities of urbanisation, it is necessary to revisit approaches to urban planning. For the last 30 years, urban planning has been out of fashion. In economies that have urbanised rapidly without an industrial base, and with weak or poorly enforced planning laws, it has been further diluted. To ensure the sustainable development of future cities will require new thinking.

There is a need to move away from the current perspective of the kind of city, which evolved since the Second World War Cities have developed based on the availability of cheap fossil fuel, with a high dependence on the motor vehicles. These cities are often characterised by low densities, long distances, and poor connections that also foster social divisions. Planning standards have promoted a highly segmented urban form with strict land use controls and segregated spaces. This has served private interests rather than the variety and dynamics of social and cultural initiatives.

Creating cities of the 21st Century is based on the need to move away from features of a mono-functional city. Singapore is a good example of where effective urban planning has led to the reduction of slum areas and the development of a more inclusive and functional city. The perspective adopted for the development of Singapore has promoted social diversity and the use of multi-functional spaces, creating a more compact city that minimises transport and service delivery cost, and optimises the use of land, and supports the protection and organisation of urban open spaces (see Box 1).

Box 1 The Planning of Singapore

According to Vivian Balakrishnan, Singapore's minister for environment and water resources,(about 80 per cent of people globally will live in cities by 2050. This may represent positive opportunities rather than a burden if governments plan well. Elaborating, Balakrishnan) pointed out that dense, open, well-connected and well-planned cities are the greenest, most sustainable, and a focal point for opportunities. One issue for governments to contend with here is housing though. "In Singapore, we provide subsidised housing, and not only do citizens live in public housing, they also own the space they live in and hence will take care of it," he said, adding the country does not have slum communities that are a feature in other cities. When the quality of a country's environment is of a high standard, this becomes a source of enduring competitive advantage, the minister stated. This is because a destination that attracts people to locate their families and money in will beget other investments. Companies would see this and build their regional or even global headquarters in such places, with Singapore an example of this, he added. He did urge other governments to invest in good governance and maintain and renew infrastructure. As cities become engines of growth and a magnet for people seeking better economic opportunities, this would create enormous pressures on urban infrastructure. "Build a beautiful city; conserve energy and water; tap new, innovative technologies, especially with private sector partners; and have good, honest and competent leaders," Balakrishnan advised.

Adapted from (Teo 2012).

Future cities should strike a balance with favours efficient public transport, walkability, green areas and open spaces and the promotion of an efficient use of energy and natural resources. The vision needs to move from private interests of a few to the collective interest of the majority. The way in which space is deployed and shaped; how proximity and connectivity are enhanced, public transport improved, land and place value is developed and captured, as well as use and function are streamlined are central to the process of urbanisation and city development.

Developing a vision for cities is an important first step and will require new and radical thinking in terms of physical components and inclusion of human resources and potential in policy and institutional arrangements.

Physical planning components

Going back to basics

Amidst the complexity of urbanisation as a process, urban planners and designers need to focus on the "core planning issues" and assign the remaining 'collateral issues' to collaboration with partner institutions and agencies. The challenge is to identify critical levers of intervention – which can assist in the transition for a "business as usual" approach to vibrant liveable cities. 'Going back to basics' concentrates on providing some basic guiding principles for planning interventions. These interventions must first and foremost pay attention to the preconditions for physical aspects for the building and running basic services. These are pre-requisites for meeting day-to-day human needs and, thus, to the functioning of the city and well-being of its citizens. Equally important, the physical interventions need to be combined with efforts to promote and guide human and social potentials.

Scale matters

In an urban world with growing demands in energy, transport, infrastructure, land and housing, among others, there is a need to plan at the scale of the challenges –old and new–, that cities are facing, particularly cities of the global South that are confronted with rapid urban growth rates. Strategies and related plans need to be commensurate with the size and magnitude of problems, proposing solutions that have the ability to deliver adequate responses that can trigger changes according to desired outcomes.

Planning for density and mixed land-use

More and more cities in the world are growing spatially outside their boundaries to satellite or dormitory cities and suburban neighbourhoods. Greater population mobility, better commuting technologies and services, lower land prices, and the desire of better quality of life are some of the factors that explain the preference for a suburban lifestyle. But this model is expensive and resource intensive. Suburbanisation in poor countries is also generated by poorly managed cities, land regulation crises, lack of control of peri-urban areas, weak planning control over land subdivisions and speculative factors (UN-Habitat, 2010a). Planning mixed-land uses is crucial to making density work and produce beneficial effects that result in economies of agglomeration. Adequate density, combined with diversity (residential and socio-economic) and better connectivity, is fundamental to produce a higher concentration of economic activities and employment density, which contribute to generate wealth and development.

The critical role of infrastructure and basic services

The importance of urban basic services for the sustainable development of cities can hardly be overstated. As engines for economic growth, cities are dependent on basic urban services to create wealth. Transport networks, for example, connect people to jobs, goods and services. The growth of industrial and service sectors is dependent on the quality, reliability and cost of services such as water supply, sanitation, energy and transport. Basic urban services also sustain the health, livelihood and the general living environment of the city workforce. Equally important, basic urban services are the cornerstone of a municipal government's compact with its residents. They are the most tangible result for which city residents hold their elected officials accountable.

Despite efforts being made by many governments and local authorities to provide urban basic services, the numbers of people in urban areas without proper access to the basic services of water supply and sanitation is increasing. According to the 2010 WHO UNICEF Joint Monitoring Programme (JMP) report in 2000, 662 million people living in urban areas did not have access to improved sanitation; in 2008 this figure had increased to about 800 million. Similarly, in 2000, 115 million urban dwellers did not have access to improved water supply; in 2008 this figure was close to 135 million (WHO/UNICEF, 2010).

These figures do however mask the real situation amongst the most disadvantaged. In the poor areas of cities, and in particular the smaller urban centres, coverage levels of less than 20per cent are common (UN-HABITAT, 2010b).

Mayors, city planners and utility managers are still confronted with a rising urban population resulting in increased demand for basic services, increasing urban poverty, growing financial resource constraints, and uncertainties and risk implications of climate change. The problem is complicated by dilapidated infrastructure, lack of clearly defined urban development policies and legislation, weak institutional capacity, low investments and lack of pro-poor financing mechanisms. The goals of infrastructure and provision in cities is threefold to:

i) rehabilitate and expand urban infrastructure and services to keep pace with growing demand for urban basic services;

ii) ensure institutional efficiency and effectiveness in the provision of services; and

iii) provide adequate levels of service for the urban poor.

Urban waste management

Managing waste is one of the biggest challenges of a city. Available data show that cities spend a substantial proportion of their budget on waste management, yet waste collection rates for cities in low- and middle-income countries range from a low of 10 per cent in peri-urban areas to a high of 90 per cent in commercial city centres (UN-HABITAT, 2010c). To enhance the capacity of local actors in solid waste and waste water management. In fact, critical to the success is the integration of formal and informal waste management actors, which can only be managed by the city authorities.

Urban energy

In the urban energy cluster, focus is on increasing access to modern, clean and reliable energy services for the urban poor. Emphasis is also on energy efficiency and the use of renewable energy technologies by promoting renewable energy technologies, for instance, solar power and water heating and mainstreaming energy efficiency measures into housing policies, building codes and building practices. Key activities include demonstration projects, advocacy and awareness creation on the importance of energy for sustainable development and engagement in policy and legislation (UN-HABITAT, 2012).

Planning in phases

The cities that follow an 'urban layout', or 'spatial structure', can gradually adapt to the needs of the inhabitants using a coherent network of streets that operates as a basic framework for planning and for the future evolution of the city. This basic support system can evolve overtime according to the availability of resources of public administrations and the financial capacities of the population. The same philosophy moved the World Bank to create in the 1970 and 1980s a worldwide programme of "Sites and Service" that aimed to provide new tracks of urbanised land with the basic supporting services as a way to produce viable low income communities (World Bank, 2006).

Planning in phases enables good management of time, costs, changes and risks. There is a need to start with very basic designs that can be affordable on a larger scale. The street is the first public common good to be built. It is a public space that promotes social and economic exchange, encourages human contact and has the potential to foster symbolic and identity values. After planning the streets, the supply of water and sanitation must follow, and thereafter other infrastructure and services. This setting of priorities starting with basic requirements allows creating an 'urban layout' that serves as a platform for organised development in the future.

In the water and sanitation cluster, the goal of UNHABITAT as well as many other organisations is to support efforts by governments in developing countries in their pursuit of the Millennium Development Goals (MDGs) for water and sanitation. This achieved through city-level demonstration projects, institutional strengthening of water operators and engagement in national policy and reform processes. Focus is also on advocacy and support to water and sanitation-related political processes and events to raise the profile of pro-poor urban water and sanitation issues and their integration in urban sector policy and practices.

Social and human components of planning

Focus on the poor

Capacity building and technical assistance are provided to local authorities, water operators and other service providers to improve their capacity to deliver effective and efficient services to cater for the needs of the urban poor, which is the most challenging group who frequently gets forgotten in city-planning. New opportunities exist in terms of, for instance, poverty mapping (cf. example of Kibera above), development of strategic business plans, gender mainstreaming and women empowerment, preparation and implementation of performance improvement plans, water demand management, billing and revenue collection. Peer-to-peer exchange mechanisms have also created opportunities for practical exchange of experiences among service providers (UN-HABITAT, 2009).

The potential of diversity

Cities from the 21st Century are characterised by increased numbers of minorities, ethnic backgrounds, intergenerational workers and different lifestyles (Florida, 2002). Urban planners and city managers have realised that the extent to which these demographic and cultural differences are effectively and efficiently managed are not only good for fairness, but also for economic development and competitiveness. New urban planning needs to take into consideration the local context, history, climate and social fabric of the city. When streets and neighbourhoods are more heterogeneous and multifunctional, cities develop a unique and distinctive nature that is an expression of their soul. Planning for diversity advances the notion of 'quality of place' that does not only increase site and land values, but also help to fuel the local economy, generating local jobs. Most new jobs happen in dense and well-connected areas that have the right mix of land uses; physical urban planning can create the conditions to improve and diversify the local economy.

Urban mobility

In the urban mobility cluster, focus is on promoting sustainable mobility options. The central task is to encourage transport policies and investments that contribute to improved urban productivity across social groups, reduced per capita energy consumption and better living and working conditions for all urban residents by catering for their mobility.

Policy and institutional components

Strategic partnerships with financing institutions

Partnerships are established with development banks and international financing institutions which fund huge infrastructure projects. Providing pre-investment planning and capacity development to partner countries, ensures that such projects benefit from faster appraisal and preparation, stronger focus on integrating the poor into formal secotr activities, greater ownership by recipient cities and sustainability of investments through capacity building.

Policy and institutional reforms

Technical and advisory support given to partner cities through policy dialogue, sector review and strategy development. Many developing countries are plagued with out-dated legal systems, an uncontrolled informal sector, inappropriate policies, weak institutions and the absence of strong community-based organisations to articulate the needs of consumers, especially the poor. Accordingly, governance reform, long term institutional development and capacity enhancement are prioritised as central pillars for long term service improvements.

Integrating physical and infrastructure planning processes

Integrated infrastructure planning is promoted to ensure that cities are planned and built to avoid costly and resource intensive urban sprawl. Integrated planning is important in reducing consumption of land and natural resources (including water and energy) as well as reducing greenhouse gas emissions. Long-term environmental, demographic, financial, and managerial considerations need to receive up-front assessment and incorporation into the design and implementation of basic urban infrastructure and services.

Focus on green economy

The drive towards a green economy and "greener" production and consumption patterns is crucial in saving resources, reducing operating costs and protecting the environment. Activities center on ensuring optimum efficiencies in the use of water and energy resources, improving wastewater treatment and reuse, maximising opportunities to recover energy from waste, creating new "green" jobs, and supporting 'intelligent transportation systems" that not only reduce traffic congestion but also lower CO_2 emissions. Renewable energy technologies and energy efficiency offer additional opportunities for job creation and sustainable urban development. Mainstreaming energy efficiency in public services through energy audits are some of the measures to be promoted in order to reduce greenhouse gas emission.

Where is the intervention most critical ?

The smaller urban centres and poverty pockets in bigger cities are the areas where intervention is critical. Not only to reverse the trend but also to prevent unsustainable urban development. The smaller cities in developing countries are currently experiencing explosive growth. They are also the areas where there is the least capacity to plan and develop services. Understanding the dynamics of urbanisation and the flexibility and opportunities in planning infrastructure is critical. The UN-HABITAT initiatives in the Lake Victoria and Mekong regions are good examples (see www.unhabitat.org). In these initiatives, capacity-building interventions have been carefully planned and targeted, which has enabled revenue generation significantly. Similarly, by linking this approach to infrastructure investment packages, the prospects for long-term sustainability are improved. Small towns present great opportunities to reuse and recycle wastes, due to the close proximity to agricultural hinterland. In bigger cities, focus is on the unserved and underserved sections delineated through poverty mapping and needs assessment exercises.

At the global level, advocacy and awareness creation through support to international campaigns and events is intended to help to raise the profile of pro-poor urban basic services. At the regional level, support is provided to regional political processes and events to gain political commitment in prioritising pro-poor urban basic services in regional programmes. At the national level, engagement is with national governments, national sector players and local communities in city-level demonstration projects and in policy and institutional reforms.

Conclusions

Embracing new approaches to urban planning will pave the way for improved infrastructure. Examples such as the original grid plan for New York, and indeed Kibera in the slums of Nairobi, underscore the critical importance of integrated approaches.

Ultimately, the challenge is anything but technical. Affordable and sustainable technology for the delivery of water and sanitation and waste management services is available. Technologies to introduce efficient energy and sustainable transport are also available. The challenge is how to develop institutions and social contracts by which we can convert existing needs for basic infrastructure into bankable projects. This requires a paradigm shift away from the usual focus on governance to a focus on developing social and political institutions, strong enough to guarantee the viability of projects. A political evolution, if not revolution is necessary for this to be realised. On a global level, funding is available and at a local level, cities need to invest in improving basic infrastructure for their residents. How do we bridge the two realities? We need combine the two in the form of bankable projects. To do this, we shall need to be extremely innovative, open ourselves to new ideas, and focus on solutions that address future needs of the city with a more holistic approach. The examples in Kibera, Nairobi and in the Lake Victoria and Mekong regions, clearly indicate that the integrated approach pays off with results. Combining new approaches in urban planning with provision of basic services will enable both existing cities to right the wrongs of earlier interventions and new rapidly expanding cities to face the realities of today in planning the future.

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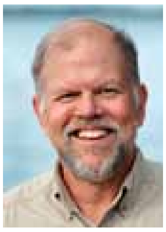
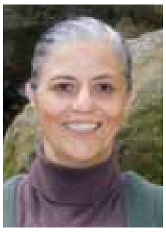
BIOGRAPHIES

Dr. Steven Carpenter



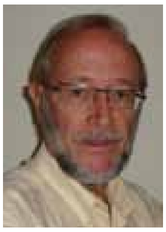
Dr. Carpenter is one of the most cited ecologists in the world, and currently serves as the Director of the Center for Limnology at the University of Wisconsin-Madison, USA. He received the 2011 Stockholm Water Prize for his groundbreaking research that showed how lake ecosystems are affected by the surrounding landscape and human activities. He is a member of the US National Academy of Sciences, a fellow of the American Academy of Arts and Sciences, a foreign member of the Royal Swedish Academy of Sciences, and an affiliate of the Chinese Academy of Sciences.

Dr. Blanca Jiménez Cisneros



Dr. Jiménez Cisneros is Senior Researcher at the Department of Environmental Engineering, in the National Autonomous University of Mexico, in Mexico City. She is co-chair of the team producing the Freshwater Resources chapter under the Adaptation theme for the IPCC. She was awarded in 2010 with the Global Water Award by the International Water Association and in 2009 the Mexican National Science and Arts Prize. She has produced over 400 publications (books and book chapters, papers in journals, norms, standards and patents). Her fields of expertise include: water and wastewater treatment and reuse technologies; water and health, urban water, and public policies.

Dr. Stephen Foster

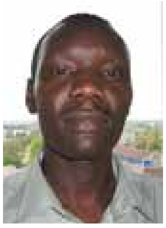


Dr. Foster has extensive experience in groundwater work, with a wide variety of practical application both in his native Britain and worldwide. His more recent professional posts include World Health Organisation-Groundwater Advisor for Latin America & Caribbean (1986-89), British Geological Survey-Divisional Director (1990-99) and World Bank-Groundwater Management Team Director (2000-10). He is also a very active member of IAH (the worldwide groundwater association) having been Vice President-Western Europe (2000-04) and President (2004-08). In 1993 he was named University of London-Visiting Professor and Spanish Real Academia de Ciencias-Foreign Member, and has received numerous awards from British, American and international professional societies, including the IAH Presidents Award (2004) and Geological Society of London-William Smith Medal (2008).

Dr. Ricardo Hirata

Dr. Hirata is a Certified Geologist from UNESP, Brazil. He is currently a Professor at the University of São Paulo (USP), aside from being the Director of CEPAS (Groundwater Research Center, USP). Dr. Ricardo Hirata is a former member of the Groundwater Management Advisory Team of World Bank (GWMATE), an adviser for the International Atomic Energy Agency (IAEA) and UNESCO, and a member of the Hydrogeologist Without Boarder Council in addition to being a 1B-Level Brazilian CNPq Research Fellow. Dr. Hirata has 29 years of experience working intensively in many aspects of groundwater and water resources for private and government companies in more than 20 countries in areas that include, among others, groundwater contamination, groundwater resource development, water resource management and governance, and groundwater protection policy.

Mr. Sammy Letema



Sammy C. Letema, a Kenyan national, has worked as a consultant in the formulation of municipal strategic plans and integrated solid waste management plans and a lecturer in environment and spatial planning in the Department of Environmental Planning and Management, Kenyatta University. In 2007, he joined Wageningen University in the Netherlands for his PhD work where he is drafting a mathematical model on sanitation selection based on the modernised mixtures approach. This work won an innovation prize in 2011 from 5 S-NL Society of The Netherlands.

Dr. Bas van Vliet

Dr. van Vliet is assistant professor of the Environmental Policy Group at Wageningen University since 2002. His main field of research concerns sustainable consumption and production with a particular specialisation in environmental management of urban infrastructures (water & sanitation, waste, energy) as they are linked to social aspects of technological environmental innovations and systems of provision. His academic background combines environmental sciences with environmental sociology, which he has brought into an effective relationship by analysing water, energy and waste services consumption-production patterns in Europe, East Africa and Vietnam.

Dr. Jules B. van Lier

Dr. van Lier is full professor of "Wastewater Treatment/Environmental Engineering" at the Section Sanitary Engineering of Delft University of Technology, with a 0.2 fte posted position at UNESCO-IHE. He received both his MSc and PhD from Wageningen University, The Netherlands, and is specialised in Anaerobic Treatment technology. He (co-)published nearly 300 publications in double refereed journals and conference proceedings from 1988 onwards. His research interest comprises the development of cost-effective technologies for (waste)water treatment, recovering resources such as water, nutrients, biogas, elements from waste streams. Research projects are focused on closing water cycles in industries and sewage water recovery for irrigated agriculture.

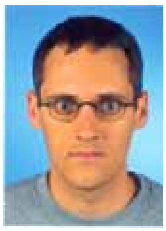
Dr. Kala Vairavamoorthy

Dr. Vairavamoorthy is an internationally recognised expert in water resource management and urban water systems. He is the Founding Director of the Patel School of Global Sustainability, and a tenured Professor at the University of South Florida (USF). In his career, Dr. Vairavamoorthy has led group of researchers studying the future of sustainable water systems for cities and how urban areas might respond to water issues in face of climate change and population growth. He was the Director of SWITCH, an EU research project for Sustainable Urban Water Management. Dr. Vairavamoorthy Co-Chairs IWA's 'Cities of the Future' program and is a member of UNESCO-IHP's Task Force. He has a strong international profile working closely with World Bank, UN-Habitat, UNEP, UNESCO-IHP and IWA. Currently he sits on the scientific program committees for both the World Water Week in Stockholm and Singapore International Water Week.

Mr. Seneshaw Tsegaye

Dr. Tsegaye is research fellow at the Patel School of Global Sustainability at the University of South Florida. His research areas are integrated urban water management as well as resilient and adaptive infrastructures. Currently, he is doing research on Flexible Urban Water Distribution Systems. He received B.Sc in Civil Engineering from Addis Ababa University, Ethiopia, and an M.Sc degree in Integrated Urban Engineering from UNESCO-IHE, Institute for Water Education, The Netherlands. Prior to joining the University of South Florida, he worked as a researcher at University of Birmingham, United Kingdom and has been involved with multiple projects related to urban water management.

Mr. Jochen Eckart



Dr. Eckart is research fellow at the newly founded Patel School of Global Sustainability at the University of South Florida. He is doing interdisciplinary research in the field of sustainable and resilient cities as well as the integration of spatial planning and infrastructure management. He has a master degree in Spatial and Environmental Planning at the University of Kaiserslautern. From 2006 to 2009 he worked at the HafenCity University Hamburg. He was project manager of the work package 'Water Sensitive Urban Design' within the research project 'SWITCH Managing Water for the City of the Future'. His research was mainly about the combination of urban planning and water management.

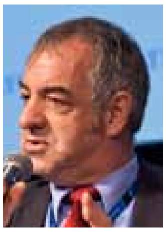
Mr. Kevin L. Shafer, P. E.

Mr. Shafer is the executive director at the Milwaukee Metropolitan Sewerage District (MMSD) in Milwaukee, Wisconsin (USA) and is responsible for the overall management, administration, leadership and direction for MMSD in meeting short- and long-term goals and objectives. Since becoming executive director, Shafer has worked diligently on MMSD's USD 1 billion Overflow Reduction Plan. He has been instrumental in providing the regional leadership in implementing green infrastructure in MMSD facilities and on private property. Mr. Shafer holds a bachelor's degree in science and civil engineering with a specialty in water resources and a master's in science and civil engineering.

Dr. Joan Clos

Dr. Clos is the Executive Director of the United Nations Human Settlements Programme (UN-HABITAT) at the level of Undersecretary-General by the United Nations General Assembly. Prior to joining the United Nations, he was twice elected Mayor of Barcelona serving two terms during the years 1997-2006 and was appointed Minister of Industry, Tourism and Trade of Spain from 2006-2008. He has also served as Spanish ambassador to Turkey and Azerbaijan. At the international level, he has been previously elected as the President of Metropolis, the international network of cities, and of the World Association of Cities and Local Authorities. He has also served as Chairman of the United Nations Advisory Committee of Local Authorities. He has received a number of awards, including the gold medal from the Royal Institute of British Architects and the UN-HABITAT Scroll of Honour Award.

Dr. Graham Alabaster



Dr. Alabaster is an internationally recognised expert on water, sanitation and environmental infrastructure within the context of human settlements development, who has over 25 years experience in 30 countries globally, covering policy development & analysis, project conceptualisation, project management, applied research and consultancy services. With a foundation in developing sustainable infrastructure for the poor, his expertise widened to cover social development issues and hygiene behavior. An accomplished professional who represents UN-HABITAT on many interagency bodies and developes and manages flagship, cutting-edge programmes in urban and rural settings. his particular interest relates to fostering linkages with the regional development banks and bilateral donors, to provide support in the form of critical pre-investment capacity-building. This has been demonstrated in the development of regional projects funded by Asian, African and European Investment Banks. He has particular research interests in monitoring water and sanitation coverage and works closely with WHO and UNICEF to support the Joint Monitoring Programme.

ON THE WATERFRONT VOLUME 3

On the Water Front vol. 3 offers a collection of innovative and important insights on that were presented at the 2011 World Water Week in Stockholm, which was held under the theme "Responding to Global Changes: Water in an Urbanised World". This compendium is a must-read for those interested in the latest knowledge, tools and strategies to resolve the planet's most pressing urban water challenges.

Each chapter in this publication is authored by prominent and experienced colleagues from science and public policy and builds upon research presented at the 2011 World Water Week in Stockholm, August 21-26, 2011. The texts submitted have been peer reviewed by the members of the World Water Week Scientific Programme Committee (SPC) and other colleagues who are familiar with the topics discussed in the articles in line with the procedures applied in Scientific Journals.

SIWI

Stockholm International Water Institute, SIWI
Drottninggatan 33, SE-111 51 Stockholm, Sweden
Phone +46 8 522 139 60 ✦ Fax +46 8 522 139 61 ✦ siwi@siwi.org ✦ www.siwi.org