TEC BACKGROUND PAPERS NO. 16

# *Integrated Urban Water Management*

By Akiça Bahri

**Global Water Partnership**
**Technical Committee (TEC)**

**Global Water Partnership,** (GWP), established in 1996, is an international network open to all organisations involved in water resources management: developed and developing country government institutions, agencies of the United Nations, bi- and multilateral development banks, professional associations, research institutions, non-governmental organisations, and the private sector. GWP was created to foster Integrated Water Resources Management (IWRM), which aims to ensure the co-ordinated development and management of water, land, and related resources by maximising economic and social welfare without compromising the sustainability of vital environmental systems.

GWP promotes IWRM by creating fora at global, regional, and national levels, designed to support stakeholders in the practical implementation of IWRM. The Partnership's governance includes the Technical Committee (TEC), a group of internationally recognised professionals and scientists skilled in the different aspects of water management. This committee, whose members come from different regions of the world, provides technical support and advice to the other governance arms and to the Partnership as a whole. The Technical Committee has been charged with developing an analytical framework of the water sector and proposing actions that will promote sustainable water resources management. The Technical Committee maintains an open channel with the GWP Regional Water Partnerships (RWPs) around the world to facilitate application of IWRM regionally and nationally.

Worldwide adoption and application of IWRM requires changing the way business is conducted by the international water resources community, particularly the way investments are made. To effect changes of this nature and scope, new ways to address the global, regional, and conceptual aspects and agendas of implementing actions are required.

This series, published by the GWP Global Secretariat in Stockholm, has been created to disseminate the papers written and commissioned by the Technical Committee to address the conceptual agenda. See the inside back cover for a list of publications in this series.

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# Integrated Urban Water Management

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## *FOREWORD*

Urban water management is now on the verge of a revolution in response to rapidly escalating urban demands for water as well as the need to make urban water systems more resilient to climate change. Growing competition, conflicts, shortages, waste and degradation of water resources make it imperative to rethink conventional concepts – to shift from an approach that attempts to manage different aspects of urban water cycle in isolation to an integrated approach supported by all stakeholders.

This timely Background Paper by Dr. Akiça Bahri, Technical Committee member, helps understand the changes and their main drivers. It provides a detailed overview of Integrated Urban Water Management (IUWM). It shows us how IUWM, nested within the broader framework of integrated water resources management (IWRM), can contribute to water security in a basin or catchment by aligning the urban water sector with rural water supply, agriculture, industry, energy and the environment. And it provides guidance on implementing IUWM – covering policy, financing and management options and technological advances.

Akiça, who is the Coordinator of the African Water Facility at the African Development Bank, has a long-standing interest in how a more integrated approach to managing water and wastewater can contribute to meeting water demand and protecting the environment. In her home country of Tunisia and elsewhere, Akiça worked in the field of water reclamation and reuse and biosolids application for food crop production and advised on policy and legislation to guide water reuse and biosolids management. She has authored numerous papers and reports on the topic, including Managing the other side of water cycle: Making wastewater an asset (GWP Technical Paper No. 13).

I would also like to recognise the contribution of Technical Committee member Professor Kalanithy Vairavamoorthy, whose expert knowledge on urban water systems operating under future global change pressures and their implications on water governance greatly enriched this paper. In addition to serving as the Director of the Patel Centre for Global Solutions at the University of South Florida, where he is also a tenured professor, Kalanithy is a Professor of Sustainable Urban Water Systems at UNESCO-IHE and TU Delft and was the director of the EU project, SWITCH: Managing Water for the City of the Future.

Mohamed Ait Kadi
Chair, GWP Technical Committee

## *EXECUTIVE SUMMARY*

The challenges facing today's major cities are daunting, and water management is one of the most serious concerns. Potable water from pure sources is rare, other sources of water must be treated at high cost, and the volume of wastewater is growing. City dwellers in many areas of the world lack good-quality water and fall ill due to waterborne illnesses. As cities seek new sources of water from upstream and discharge their effluent downstream, surrounding residents suffer the effects. The hydrologic cycle and aquatic systems, including vital ecosystem services, are disrupted.

This is the situation today; tomorrow will bring intensified effects from climate change and the continued growth of cities. Extreme weather events, from prolonged droughts to violent tropical storms, are poised to overwhelm urban water infrastructure and cause extreme suffering and environmental degradation.

Integrated urban water management (IUWM) promises a better approach than the current system, in which water supply, sanitation, stormwater and wastewater are managed by isolated entities, and all four are separated from land-use planning and economic development. IUWM calls for the alignment of urban development and basin management to achieve sustainable economic, social, and environmental goals.

Planning for the water sector is integrated with other urban sectors, such as land use, housing, energy, and transportation to overcome fragmentation in public policy formulation and decision-making. Cross-sectoral relationships are strengthened through a common working culture, the articulation of collective goals and respective benefits, and the negotiation of differences in power and resources. The urban informal sector and marginalised populations are specifically included.

The process begins with clear national policies on integrated water management, backed by effective legislation, to guide local councils. IUWM encompasses all aspects of water management: environmental, economic, social, technical, and political. A successful approach requires engaging local communities in solving the problems of water management. Collaborative approaches should involve all stakeholders in setting priorities, taking action, and assuming responsibility.

IUWM includes assessments to determine the quantity and quality of a water resource, estimate current and future demands, and anticipate the effects of climate change. It recognises the importance of water-use efficiency and economic efficiency, without which water operations cannot be sustainable. It also recognises that different kinds of water can be used for different purposes: freshwater sources (surface water, groundwater, rainwater) and desalinated water may supply domestic use, for example, and wastewater (black, brown, yellow, and grey water) can be treated appropriately to satisfy the demands of agriculture, industry and the environment. With efficient new desalination technologies, saltwater has become an accessible water source.

Water reclamation and reuse close the loop between water supply and wastewater disposal. Integration of these two water management functions requires forward-looking planning, a supportive institutional setting, coordination of infrastructure and facilities, public health protection, wastewater treatment technology and siting appropriate to end uses, treatment process reliability, water utility management, and public acceptance and participation. New technologies for wastewater treatment and new business models, such as public-private partnerships and cooperation with the private sector, are options.

Under IUWM, water prices and allocations reflect the true costs of developing and delivering water supplies and maintaining the system. The price signals the value of water. Accurate prices will encourage wise water management by all users, consistent with an integrated urban water management strategy. Differential tariffs that account for water quality can be incentives for agricultural, commercial, municipal and industrial users to reduce consumption of surface water or groundwater in favour of reclaimed water.

Tariffs, taxes, and subsidies can be used to transfer benefits without diminishing the economic productivity of water resources. If tariffs are set low to favour poor users and cannot support effective operations and maintenance, the system may inadvertently contribute to greater inequality. Pricing instruments can be designed such that users pay more for higher levels of consumption or higher water quality. Financial incentives, such as rebates, subsidised retrofits and water audits, seasonal pricing, and zonal pricing can also be used. Polluter-pay schemes, which base fees on the amount of effluent users generate, can improve the cost-effectiveness of treatment and reuse and even fund new facilities' construction.

IUWM projects require significant levels of funding for both capital and operations and maintenance costs. For countries with limited ability to invest in water infrastructure, appropriate policies and well-functioning institutions make fundraising easier.

Adopting IUWM and its adaptive, iterative processes will help cities significantly reduce the number of people without access to water and sanitation by providing water services of appropriate quantity and quality, thereby improving the health and productivity of urban residents.

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## 1. INTRODUCTION

The world's population has reached 7 billion, and more people live in cities than in rural areas. Yet the benefits of city life are not available to all. In places, rapid population influx, inadequate public services, and out-of-date urban planning models have marginalised vast numbers of new arrivals into informal settlements or slums, exacerbating inequality and urban poverty, and compromising efforts to achieve and sustain water security.

Water is a critical natural resource for the world's growing urban areas. Commercial, residential, and industrial users already place considerable demands on this resource, which often requires treatment, may be located at great distance from the city, and is almost always in demand by multiple sectors. Water scarcity is leading to conflict over water rights. In urban watersheds, competition with agriculture and industry is intensifying as cities expand in size and political influence. With industrial and domestic water demand expected to double by 2050 (UNDP, 2006), competition among urban, peri-urban, and rural areas will likely worsen.

At the same time, because of climate change, more frequent and extreme weather events are expected to alter the quality, quantity, and seasonality of water available to urban centres and their surroundings. Cities located near water bodies may be at risk of climate change-related disasters. In response to such threats, water managers are revisiting conventional practices as they search for efficient ways to ensure human well being while safeguarding the integrity of the resource base.

### 1.1. Integrated urban water management

The goals of urban water management are to ensure access to water and sanitation infrastructure and services; manage rainwater, wastewater, stormwater drainage, and runoff pollution; control waterborne diseases and epidemics; and reduce the risk of water-related hazards, including floods, droughts, and landslides. All the while, water management practices must prevent resource degradation.

Conventional urban water management strategies, however, have strained to meet demand for drinking water, sanitation, wastewater treatment, and other water-related services. Some cities already face acute water shortages and deteriorating water quality.

Integrated urban water management (IUWM) offers a set of principles that underpin better coordinated, responsive, and sustainable resource management practice. It is an approach that integrates water sources, water-use sectors, water services, and water management scales:

- It recognises alternative water sources.
- It differentiates the qualities and potential uses of water sources.
- It views water storage, distribution, treatment, recycling, and disposal as part of the same resource management cycle.
- It seeks to protect, conserve and exploit water at its source.
- It accounts for nonurban users that are dependent on the same water source.
- It aligns formal institutions (organisations, legislation, and policies) and informal practices (norms and conventions) that govern water in and for cities.
- It recognises the relationships among water resources, land use, and energy.
- It simultaneously pursues economic efficiency, social equity, and environmental sustainability.
- It encourages participation by all stakeholders.

Under IUWM, supply management and demand management are complementary elements of a single process. There is no one-size-fits-all model nor is any single method sufficient. Rather, the mix of approaches reflects local socio-cultural and economic conditions.

Transforming entrenched institutional practice in large cities can be difficult. The greatest opportunities for IUWM to achieve results lie instead with small- and mid-sized cities (fewer than 500,000 inhabitants), whose effects on water resources will become increasingly important in coming decades. Instilling a different approach to resource management in the governance of these cities is both possible and beneficial.

## 1.2. Structure of the paper

A range of recent programmes – including the Managing Water for the City of the Future programme (known as SWITCH), UNESCO International Hydrological Programme's work on urban water, the World Bank's research on the impacts of urbanisation on water resources and management, and the International Water Association (IWA) Cities of the Future initiative – have experimented with demand-driven, context-appropriate, and cross-cutting urban water management measures. This paper contributes to the literature by further refining the concept of IUWM.

Section 2 considers how cities are growing and changing. Section 3 focuses on the implications of these changes for urban water resources: in the past, water security efforts focused on water quantity, but new concerns about water quality are now emerging. A changing climate also demands that water management be approached in a different way, and section 4 suggests that IUWM can contribute to cities' resilience in the face of climate change.

Section 5 considers the shift from urban water management to IUWM, and section 6 describes an enabling environment for the change. Section 7 details practical approaches to building green cities that are inclusive, productive, well governed, and sustainable. Section 8 concludes by describing the promise of IUWM. Throughout, boxes present case studies that explore the ways in which aspects of IUWM have been put into practice, since every city faces a different challenge and requires context-appropriate solutions.

## 2. THE CHANGING URBAN CONTEXT

Urbanisation is clearly underway in the Global South, and human settlement patterns are becoming more complex and more interconnected. According to the United Nations Population Fund, 3.3 billion people currently live in cities and this number is expected to rise to 4.9 billion by 2030 (UNFPA, 2007). This expansion will be concentrated in Africa and Asia, where the urban population will double between 2000 and 2030. Latin America and the Caribbean, in turn, will be more than 80 percent urbanised. By 2050, 70 percent of the global population is expected to live in urban areas (UN-Habitat, 2009).

Megacities, with populations in excess of 10 million, are becoming more common – and larger (Cohen, 2004). By 2025, there will be 27 megacities, of which 21 will be in the Global South (PRB, 2012). Already, some large cities and megacities are facing acute water problems; by 2030, 47 percent of the world population will be living in areas of high water stress (OECD, 2008). Megacities in arid and semi-arid areas, which account for one-third of the world's total megacity inhabitants, increasingly rely on water of marginal quality, which most people consider unusable unless first treated (Abderrahman, 2000).

Indeed, megacities have garnered much of the attention in the debate on sustainable urban development. Urban planning – particularly in the global South – continues to be concerned primarily with large metropolitan areas (Cohen, 2004; UN-Habitat, 2009). Yet today, 52 percent of the world's city dwellers live in cities and towns with fewer than 500,000 people (UN-Habitat, 2009). It is these cities that are expected to expand most rapidly in the coming decade (UN WWAP, 2009), presenting an opportunity to integrate resource management and basic service provision.

Cities with populations between 2,000 and 50,000 require infrastructure that is neither purely urban nor strictly rural. Rather, they need a mixed approach that addresses both core areas (which may rely on piped water supply and sewerage systems) and peripheral areas (which may require alternative technologies). They may also experience unpredictable expansion in water demand and spatial spread (Pilgrim et al., 2007).

## 2.1. Expanding city limits

Informal or slum settlements account for the bulk of urban expansion in the most rapidly growing cities in sub-Saharan Africa (UN-Habitat, 2008). About 830 million people, around one-third of the world's urban population, live in slum conditions.[1] These settlements tend to emerge on peripheral land that provides the city with critical, but often unrecognised, services, including flood control. Here, land tenure arrangements are frequently insecure and housing quality is poor (AfDB, 2011). The settlements often lack access to electricity, solid waste management, sanitation, and water supply.

As cities grow, they may swallow outlying towns and erase the rural-urban boundary (Cohen, 2004). This phenomenon is exemplified by the *desakotas* ('village-cities') of Southeast Asia (McGee, 1991) that are economically active areas at the edges of cities with both urban and rural features (Ginsburg et al., 1991). Nonagricultural activities are the main sources of income for desakota populations. Some members of these communities work in village and cottage industries, others commute to work in the city, and still others are based in the city and send remittances to their family members in the periphery. Much of the land in these zones remains under cultivation, but there is a shift away from subsistence crops towards market-oriented and high-value crops (McGee, 1991).

This urban sprawl poses a range of challenges for urban planners. It causes congestion and environmental degradation and increases the costs of service delivery (UN-Habitat, 2009). In several middle- and low-income countries, urban sprawl is exacerbated by urban primacy – the tendency of a significant segment of the national population to reside in a single urban centre, often the capital city (Cohen, 2004; UN-Habitat, 2009).

Although cities tend to have better sanitation facilities and drinking water sources than their rural counterparts, they struggle to keep up with population growth and sprawl (WHO-UNICEF JMP, 2010). As a result, the periurban poor rely on informal practices that lie outside formal support strategies and mechanisms, whether centralised supply policies or market-based approaches (Allen et al., 2006).

[1] As highlighted in the keynote address by Anna Tibaijuka, Under Secretary General and Executive Director of UN-Habitat, at the Chatam House Future of Cities Conference, London, 8 February 2010.

## 2.2. Consequences of globalisation

In today's integrated global economy, with its innovations in telecommunications and transportation, spatial proximity is no longer a prerequisite for economic activity, and financial deregulation has made capital mobile (Cohen, 2004). 'World cities' (Hall, 1966; Friedmann and Wolff, 1982) have emerged as centres that provide financial and other specialised services for firms and businesses, environments for innovation and manufacturing, and markets for end products (Sassen, 2001).

In some regions, 'growth triangles' and 'urban corridors' are emerging as economic engines for chains of cities. In South Africa, the Gauteng corridor forms an axis through Pretoria, Johannesburg, Witwatersrand, and Vereeniging (UN-Habitat, 2008). Urban corridors can span national boundaries: in West Africa, the Ibadan-Lagos-Cotonou-Lomé-Accra corridor is developing into a megacity region, offering sites for residential and industrial development that are removed from the pollution, congestion, and high land prices of city centres, yet have ready access and logistical connections to markets and services (UN-Habitat, 2008).

In other parts of the world – often those with lower initial levels of per capita income – urbanisation appears less associated with economic development. In some countries in Africa, for instance, urbanisation is described as driven by poverty, as opposed to industrialisation and economic growth (Cohen, 2004, UN-Habitat, 2008). In such areas, urban populations may become socially polarised, and certain communities may become marginalised. This situation may be exacerbated under the current global economic climate if there is less funding for urban development projects, which are capital-intensive. Furthermore, unemployment is expected to rise, particularly in sectors associated with urban areas, such as finance, construction, manufacturing, tourism, services, and real estate. Rising inequality and poverty often follow.

## 2.3. Special challenges for some cities

Water management is often affected by a city's geographical location. Coastal cities, which account for three-quarters of all large cities and half the world's population (UNEP & UN-Habitat, 2005), often pollute local waters, salinise aquifers, and the destroy ecosystems, such as mangroves, that serve as barriers to erosion, storm surges, and tsunamis. The environmental consequences extend beyond the boundaries of the city itself. For example, in Maputo, Mozambique, pollution from industrial activities and poor sewage management, mangrove destruction and coastal erosion, and agricultural and shipping activities threaten fisheries, tourism, and quality of life around Maputo Bay.

The water situation for large and growing cities becomes even more challenging in water basins shared by more than one country. Two in every five people are estimated to live in such transboundary basins, which cover more than 15 percent of the world's land surface (UNDP, 2006). Cities in transboundary basins place heavy demands on urban water infrastructure; where management institutions are inadequate or unresponsive, the integrity of water resources is compromised and public health endangered (Shmueli, 1999). Cities that share a common water body, such as Lake Victoria in Tanzania, pose a special threat to freshwater quality and aquatic ecosystems. Border cities are also often affected by pollution problems stemming from industrial growth, urbanisation, and agriculture in the upper part of the basin. An estimated 1.4 billion people now live in river basin areas that are 'closed', meaning that water use exceeds minimum recharge levels, or nearly closed (UNDP, 2006).

## 3. WATER RESOURCES AND URBANISATION

Water availability is not a matter of quantity alone; water quality can, in equal measure, determine how much is available for particular uses. Degraded urban water resources, often caused by inadequate treatment of wastewater, have consequences for ecosystems, health, and water-reliant livelihoods. Throughout history, sufficient water supply and an ability to deal with waste have been critical for urban settlements to flourish (Box 1). This section looks at the relationships among the components of water management systems.

**Box 1: Lessons from the past**

Human settlements are dynamic entities, whose sizes and structures change over time. Some early urban settlements relied on decentralised solutions and reuse, as well as resource recovery – all practices that today are components of IUWM.

Records from Greece show that between 300 BC and 500 AD, public latrines drained into sewers that transported sewage and stormwater to a collection basin outside the city (Mays et al., 2007). From there, wastewater was transferred through a system of brick-lined channels to agricultural lands to irrigate and fertilise crops and fruit orchards.

The Romans constructed a central, covered sewer system – the Cloaca Maxima – circa 600 BC. The system had seven branches to serve customers across Rome in return for a connection fee. The sewers also drained the streets during rains. Those who could not afford the service relied on indoor human waste containers, which were emptied into public cesspits. The contents of the cesspits were emptied daily by labourers, who were paid by the city, and the contents used as fertiliser. Urine was collected in public urinals and sold to dyers, tanners, and other users.

Reuse and resource management concepts were also familiar in early industrial Europe. Several German cities constructed sewers, which were channelled into a system of ponds and fields for direct reuse in agriculture and aquaculture (Prein, 1990). In early 20th-century Copenhagen, a dry sanitation system served as a source of fertiliser for agriculture (Wrisberg, 1996).

Today, the urban water management has become more integrated in its outlook as cities grapple with unprecedented patterns of urbanisation and the continued uneven spread of water and sanitation services, along with an emerging water quality crisis that threatens water security in many parts of the world (Corcoran et al., 2010).

### 3.1. Wastewater

Urban wastewater represents a significant pollution load. Where sanitation facilities are inadequate, all available channels become a means for wastewater disposal. Only an estimated 8 percent of Africa's city dwellers use sewered sanitation (Strauss, 2006) The WHO-UNICEF Joint Monitoring Programme (2010) report shows that, in 2008, about 255 million (or 84 percent) urban residents in sub-Saharan Africa had onsite sanitation technologies, consisting mostly of pit latrines, pour flush toilets, and septic tanks – and these numbers are increasing. Open defecation is also common. Consequently, faecal sludge is degrading streams and rivers, especially in the Global South.

Most disposed wastewater remains untreated. Urban wastewater becomes particularly hazardous when mixed with untreated industrial waste, a common practice in many parts of the world. In most cities of sub-Saharan Africa, greywater – water from bathing, laundry, washing, which can be reused without treatment for some purposes – is channelled into drains, where it mixes with highly polluted stormwater, solid wastes, and excreta from open defecation before entering natural water bodies (Jiménez et al., 2010).

Inadequate wastewater treatment is a major risk for human health in Africa. In Europe, the flow of nutrients into coastal waters is reducing productivity and creating anoxic dead zones (Corcoran et al., 2010). Microbial pollution, caused by exposure to animal wastes, inappropriate wastewater disposal and inadequate sanitation facilities, is the most important contaminant affecting human health. Indeed, achieving the sanitation target of the Millennium Development Goals is proving a greater challenge than expected and universal sewerage is thought to be an unattainable goal, even in the long term.

Between 1990 and 2006, the proportion of people without improved sanitation fell by only 8 percent. In Africa, an estimated 500 million people still do not have adequate sanitation (UN-WWAP, 2009; WHO and UNICEF JMP, 2010). In Pakistan, a mere 2 percent of cities with populations in excess of 10,000 had wastewater treatment facilities; in these cities, less than 30 percent of wastewater received treatment. In general, the development of sewage treatment lags behind the extension of sewer connections.

In many parts of the world, wastewater regulation is complicated by overlapping lines of authority between health, agriculture, and water supply and sanitation agencies. Moreover, local circumstances often limit the types of treatments or risk-reduction strategies that can be realistically put in place. In many parts of Global South, for example, waterborne sanitation systems and pollution mitigation facilities may not be sustainable. World Health Organization guidelines (WHO, 2006a) provide an integrated preventive management framework for safety along the chain from wastewater generation to the consumption of products grown with the wastewater and excreta and recognise that wastewater treatment is one possible component in an integrated risk-management approach. Strict and expensive treatment technologies, however, are not universally feasible or reasonable (UN-WWAP, 2009).

### 3.2. Water quantity

Worldwide, irrigated agriculture may account for 70–80 percent of water withdrawals. Industrial use (including energy) amounts to an estimated 20 percent of total water use, although this is increasing in urbanising economies. The proportion of domestic water use is approximately 10 percent of the total. With industrial and domestic water demand expected to double by 2050 (UNDP, 2006), competition over water sources will escalate.

Given the pressure on the water resource base, use of existing supplies must become more efficient. Service providers lose large volumes of water to leaks in the distribution system, an estimated 32 billion cubic metres per year worldwide; and illegal connections or shortcomings in water billing account for another 16 billion cubic metres per year (Kingdom et al., 2006). The difference between the amount of water that goes into the distribution system and the amount that eventually reaches – and is billed to – the customer is referred to as nonrevenue water.

The cost of nonrevenue water to utilities is estimated at US$141 billion per year worldwide (Kingdom et al., 2006). Nonrevenue water compromises the financial viability and, thus, the continued service of a utility. Reducing such losses can help extend urban water supply coverage and ease pressure on water resources.

As cities grow, the rate of increase in water consumption quickly outpaces population growth. Between 1900 and 1995, global water consumption grew sixfold – more than two times the rate of population growth (WMO, 1997). A comparative study of cities shows that urban water needs invariably get priority over water demands in outlying areas (Molle and Berkoff, 2006).

## 3.3. Water quality

Water scarcity problems, exacerbated by poor water quality, may limit the volume of water available for specific uses. Degradation often results from human activity – intensive agriculture, resource-heavy industries, and rapid urbanisation – that distorts natural water cycles and processes across the rural-urban spectrum. In cities, for example, the concentration of built-up impermeable areas means that less water infiltrates to groundwater. The base flows of streams are affected and the volume of surface runoff increases. The resulting stormwater flows can convey greater amounts of pollutants, which reduce water quality (Palaniappan et al., 2010).

Nonpoint source pollution (e.g., agricultural or mining runoff) can seep undetected into aquifers, damaging downstream ecosystems and drinking water sources. The effects of heavy metals are not limited to the degradation of downstream drinking water supply; they can also affect the quality of food intended for urban markets. The use of effluents from zinc mines for irrigation, for example, can lead to the accumulation of cadmium in rice grain (UN-WWAP, 2009).

The most common water pollutants are microbes, nutrients, heavy metals, and organic chemicals. Eutrophication is the predominant water quality concern worldwide. It is caused by excess concentrations of nutrients – mainly phosphorus and nitrogen – from agricultural runoff, domestic sewage, industrial effluents, and the atmospheric derivatives of fossil fuel burning and bush fires. Mercury, lead, and other heavy metals from industrial and mining activities, coal-fired power plants and landfills, can accumulate in the tissues of humans and other organisms. The substances in pharmaceuticals and personal care products – including birth control pills, painkillers, and antibiotics – are showing up in water in increasing concentrations.

These emerging pollutants are the next challenge in urban water systems. With advances in science and technology has come knowledge of new contaminants and their impact on human health and the environment. A number of emerging contaminants (e.g., endocrine disrupting chemicals, pharmaceutically active compounds, personal care products and disinfectant resistant microorganisms) have been identified. Their long-term effects on humans and ecosystems are unknown, although some are thought to imitate the actions of natural hormones in various species and cause public and environmental health concerns (UN-WWAP, 2009). These contaminants become more concentrated in low-water conditions. As the knowledge of emerging contaminants and their impacts advances, more stringent water quality standards will be put in place and in turn will increase the pressure on water utilities.

The world is said to be on the brink of a water quality crisis (Corcoran et al., 2010). Comprehensive data on pollution loads and water quality changes are lacking in many parts of the world, however, so the full scope of damage remains unknown (UN-WWAP, 2009).

### 3.4. Ecosystem services

Urban centres rely on wetlands and aquatic ecosystems for services, such as oxygen production, carbon storage, natural filtering of toxins and pollutants, and protection from coastal flooding or landslides and other storm-related disasters (UN-Habitat, 2011). Aquatic systems dilute and transport pollution away from human settlements, maintain the quality of freshwater sources, and, in some cases, permanently remove pollutants from the atmosphere.

Unsustainable water resources management and excess pollution are eroding these services, however, compromising clean water supplies and food production (UN-WWAP, 2009; Corcoran et al., 2010; Mafuta et al., 2011). Freshwater ecosystems are among the most degraded on the planet (UN-WWAP, 2009). Because of the interconnectedness of aquatic systems, changes in local aquatic ecosystems can have downstream consequences.

### 3.5. Policy responses

Despite the interconnections among water quality, water consumption, wastewater, and the ecosystem services provided by aquatic systems, each of these issues is frequently addressed independently (Van der Merwe-Botha, 2009). The resulting strategies may be inefficient and unsustainable. Some cities, for example, have created large-scale transfer schemes that convey water from rural agriculture, ecological reserves, and surrounding aquifers, or have constructed large dams. Where ecosystems have been degraded, cities have often turned to engineering solutions – large water storage and treatment facilities or river basin transfer schemes – to compensate for the lost services. These projects are expensive, however, and do little to halt unsustainable and polluting water use.

Approximately 20 million hectares of agricultural land today are irrigated by untreated or partially treated wastewater (Scott et al., 2004; Keraita et al., 2007). Farmers derive various benefits from the practice:  wastewater flows tend to be more reliable than freshwater sources, and wastewater irrigation increases crop yields and the range of crops that can be grown, including high-value crops, such as vegetables (Keraita et al., 2008; UN-WWAP, 2009). Efforts to install wastewater treatment facilities may therefore face resistance, even though wastewater irrigation can also harm human health (Bayrau et al., 2009; Obuobie et al., 2006) with its potentially high levels of heavy metals, organic toxic compounds, and pathogens (Abaidoo et al., 2009; Hamilton et al., 2007).

Now, however, stormwater capture and storage, desalination, and wastewater reuse are garnering more interest. Indeed, as cities exhaust their most accessible water resources, their water supply profile becomes more diverse (Asano, 2005). San Diego, CA, USA, for example, brings about 85 percent of its water from hundreds of miles away. With overall water demand expected to rise 25 percent by 2030, San Diego is planning to simultaneously tighten its water demand-management measures and tap new sources, such as desalinated water (Figure 1).

Wastewater represents one of the few readily available sources of water, particularly in arid and semi-arid areas (Jiménez et al., 2010; Keraita et al., 2008). Sewage treatment can remove physical, chemical and biological contaminants from wastewater. The treated effluent and sewage sludge can then be safely discharged or even reused – for urban landscaping,

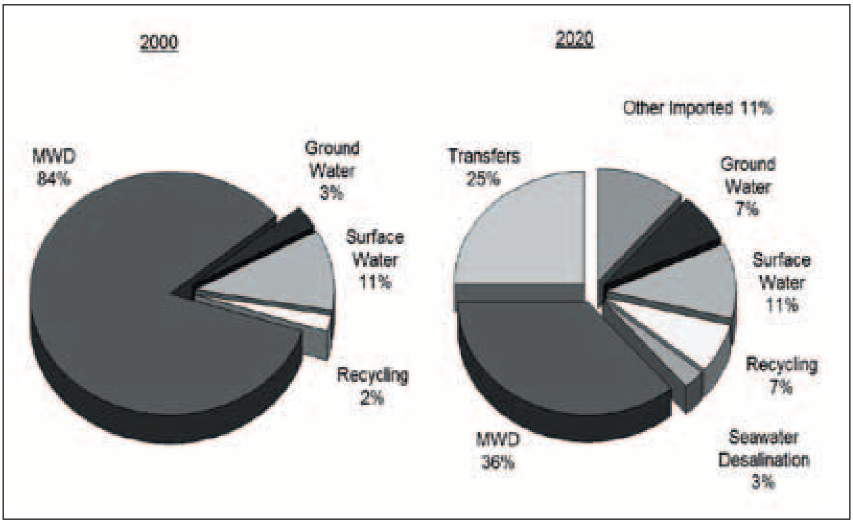


*Figure 1. San Diego's past and projected water supply profiles*
*Note: MWD = Metropolitan Water District.*
*Source: Asano, 2005 (after City of San Diego, California)*

recreational and environmental uses, industrial cooling and processing, potable reuse, indirect potable water production (e.g., through groundwater recharge), and agricultural irrigation (Asano, 2002).

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Singapore has led efforts to treat sewage to a standard that allows it to be used for drinking purposes (Box 2). Although the process is currently energy intensive (UNEP, 2011), technological advances are making direct potable reuse an increasingly cost-effective solution (Schroeder et al., 2012).

**Box 2. Singapore: State-of-the-art Integrated Water Resources Management**

The water management solutions of Singapore have evolved over several decades and clearly reflect its unique circumstances as a small city state. Nevertheless, the principles that underpin its water management offer lessons for other cities and countries.

The driver behind Singapore's water management scheme was the desire to reduce dependence on water sources in neighbouring Malaysia. Under the Four National Taps strategy, Singapore uses a range of measures to improve water-use efficiency, curtail waste, diversify the water supply, and manage water demand.

Singapore relies on advanced technologies. Membrane-based water purification has enabled the large-scale production of reclaimed water (NEWater). Since production began in 2003, the take-up rate of NEWater for human consumption and nondomestic use has increased steadily, thanks to its low cost and high quality. The water utility ensures reliable supply by drawing on alternative sources and supplying customers with storage tanks. Reclaiming water, however, has high energy requirements.

Singapore has also instituted measures to manage water demand. It resisted artificially lowering the price of water to subsidise lower-income water users and instead offers targeted financial assistance in the form of rebates. The water utility also hands out water-saving devices for households with above-average water consumption. The price of water in Singapore allows for the full cost recovery and also reflects the water scarcity situation and the costs of developing additional supplies. The revenue is channelled into the development

**Box 2.** ***Cont.***

of alternative water treatment and supply technologies, and infrastructure maintenance. The water utility, a statutory board under the Ministry of the Environment and Water Resources, has been pivotal in ensuring the success of these measures. It enjoys a high degree of autonomy and integrates the management of water supply, water catchment, and sewerage. The utility aligns its activities with other urban institutions, including the Urban Redevelopment Authority and the National Parks Board. The water recycling programme is the result of a public-private partnership.

High-level political commitment to integrated urban water management is another element of success. Before becoming the prime minister, Lee Kuan Yew prioritised the development of sustainable water resources management strategies. Once in office, he set up a unit to coordinate water and sanitation issues across government departments. Water policy topped the political agenda and all other sector policies were scrutinised for their alignment with the aim of long-term water security. Lee's support has ensured sustained investment.

*Source: ADB, 2010.*

### 3.6. Economic costs and benefits

Economic losses from water pollution and excessive water withdrawals cost the Middle East and North Africa an estimated $9 billion a year, or 2.1–7.4 percent of gross domestic product (GDP) (Hussein, 2008). Moreover, the cost of disasters, such as floods and droughts, as a share of GDP is markedly higher in poor countries than in rich countries (Delli Priscoli and Wolf, 2009). Freshwater degradation also raises costs for consumers by forcing service providers (whether formal or informal) to find alternative water sources. The restoration of ecosystems in greenhills and watersheds surrounding cities may provide cheaper and more efficient alternatives or complements that are also more resilient to extreme weather events (Mafuta et al., 2011).

Unsafe or inadequate water and sanitation – combined with inappropriate hygiene practices – cause some 1.7 million deaths annually (WHO, 2002). Microbial contaminants and the diseases that they cause are at the root of the majority of health threats posed by poor quality water in the Global South. The human health-related costs of poor water quality can be considerable: economic losses (including productivity losses and health treatment costs) from mortality and morbidity caused by lack of water and sanitation in Africa have been estimated at US$28.4 billion. This is equivalent to 5 percent of Africa's GDP (WHO, 2006b).

The return on investment in better water management varies by region and technology. The World Health Organization calculates that for each US$1 invested in safe drinking water and basic sanitation, the returns can range between US$3 and US$34 (Hutton and Haller, 2004). Safeguarding human and environmental health, improving workplace productivity, and encouraging school attendance and educational attainment (particularly among girls, who spend significant time collecting water) are among the benefits of sustainable water management and the provision of safe water (UN-WWAP, 2009).

## 4. THE CLIMATE CHANGE CHALLENGE

The water management crisis is unfolding against a backdrop of climate change. The latest Intergovernmental Panel on Climate Change (IPCC) Assessment Report (2007) called the evidence for global warming 'unequivocal' and forecast warming of 1.8°C to 4.0˚C by 2100. Land areas may experience warmer temperatures, more frequent heat waves, less precipitation, and more intense precipitation. The areas affected by drought are expected to expand. Some regions will see intense tropical cyclones, and coastal areas will face rising sea levels. Low-elevation coastal zones account for a mere 2 percent of the world's total land area, yet host an estimated 13 percent of its urban population (UN-Habitat, 2011). Box 3 summarises the effects for major world regions.

**Box 3. Regional climate predictions**

As climate temperatures rise, central and eastern parts of sub-Saharan Africa may experience more flooding and associated damage to water supply and sanitation infrastructure. Southern Africa, which has a significant amount of piped water supply and sewerage, is expected to experience declining average rainfall; urban areas will have to manage demand and reduce leaks and other lost water. Reduced rainfall also poses a threat to the Sahel and south western sub-Saharan Africa.

Northern Africa and the eastern Mediterranean regions – that are already dry – are also likely to experience further declining average rainfall. The region has high rates of piped water and sewerage and will have to prevent unsustainable rates of groundwater abstraction, particularly for urban water supply. Desalination is becoming more common in these regions; future energy supply and costs, as well as greenhouse gas emission targets, will influence the continued contribution of desalination for water supply.

South Asia is likely to see increased average precipitation and more intense five-day wet weather events. The consequent risks of flooding have serious implications for most types of water supply. Elsewhere in the region, glacial meltwater may be threatened by accelerated warming.

In Central America and north eastern South America, the climate is expected to become drier. Simultaneously, piped water coverage is expected to increase from its current levels of 75%. The region will have to devise strategies to secure water supply under drought risk.

*Source: WHO and DFID, 2009.*

Given their high concentrations of people, industries, infrastructure, and economic activity, urban areas will face both immediate and slow-onset threats from climate change (UN-Habitat, 2011): disruptions of water supply, transport networks, ecosystems, energy provision, and industrial production; damage to physical infrastructure; inability to continue basic services; collapse of local economies; exacerbation of existing urban inequalities; and dispersal of urban populations. Sudden natural disasters displaced an estimated 20 million people in 2008. By 2050, the number of people displaced by climate change-related events is expected to rise to 200 million (UN-Habitat, 2011). Low-income households – in both developed and developing countries – are the least prepared (UN-Habitat, 2011).

Water is the main conduit for climate change effects in urban areas (UN-Water, 2010), and freshwater hydrology will be among the systems most affected by climate change (IPCC, 2007). Until recently, urban issues were largely absent from international climate change policy discussions. Now, cities across the globe are devising adaptation and mitigation measures, including strategies to improve the resilience of their water sector.

## 4.1. Climate change and water supply

Even as urban water demand increases due to growing populations, water supplies may become scarce as precipitation patterns, river flows, and groundwater tables change (UN-Habitat, 2011). Some sources may become unsuitable for certain uses (e.g., salinity may limit water for agricultural use), and the cost of water treatment may rise (e.g., eutrophication may require additional treatment of domestic water) (Sadoff and Muller, 2009). For some fast-growing desert and semi-desert megacities, water scarcity may be severe (Biswas et al., 2004).

Climate change is likely to affect water supply technologies, primarily through flood damage, increasing treatment requirements and reducing availability and operational capacity. Extended dry periods will increase the vulnerability of shallow groundwater systems, roof rainwater harvesting, and surface waters.

Most drinking water-supply technologies that are vulnerable to climate change show at least some adaptive potential. Among the technologies considered improved under the WHO-UNICEF Joint Monitoring Programme on Water Supply and Sanitation, tubewells (used mainly in Asia) show relatively high resilience to climate change; protected springs and small piped supplies appear to be resilient to a lesser degree; and dug wells and rainwater harvesting, even less so. Water supplies that are managed by utilities have high potential resilience and adaptive capacity – much of it not yet realised. Water supplies that are managed by small communities are considered highly vulnerable (WHO and UNICEF, 2009).

As water availability patterns shift, trade in virtual water (water-intensive products) may increase between water-secure and water-insecure regions. Virtual water trade may serve to sustain food security by transferring food production to high-potential areas. Nonetheless, recent fluctuations in food prices have highlighted the problem of access to staple foods (Sadoff and Muller, 2009).

## 4.2. Climate change and sanitation

Climate change can affect sanitation directly when water is essential to the process (such as sewerage) or indirectly if ecosystems are less able to absorb or mitigate wastes. In dry areas, water-dependent sewer systems will become more difficult to operate and maintain.

Where rainfall intensity and flooding increase, climate change will impose additional costs on stormwater drains, dams, and levees, and may render certain areas uninhabitable. Flooding may damage sewers. In cities with combined stormwater and sewage systems, flooding may overwhelm treatment facilities and create public health risks (Tucci, 2009). Rising groundwater levels may make pollution from pit latrines difficult to manage (WHO and DFID, 2009). Flooding may also contaminate water supplies, leading to increased incidence of diarrhoeal and respiratory illnesses (UN-Habitat, 2011).

Of the sanitation technologies classified as improved under the WHO-UNICEF Joint Monitoring Programme on Water Supply and Sanitation, pit latrines are more resilient because they can be redesigned. Individual facilities, in general, are less resilient. Where groundwater levels rise, however, pollution from pit latrines becomes difficult to control. Modified sewerage, which includes simplified options, such as 'small bore', 'shallow', and 'condominial' sewerage, is typically lower cost than traditional sewerage, functions with less water, and is expected to be more resilient in the face of a wider range of climate scenarios.

'Adaptation deficit' refers to the inadequacy of urban infrastructure, in some developing countries, in dealing with current conditions, let alone the new challenges posed by climate change (UN-Habitat, 2011). Many slums lack drainage networks or existing drains are choked with garbage. Heavy rainfall can trigger flooding with untreated wastewater from overflowing sewers (Twumasi and Asomani-Boateng, 2002).

In many countries, storage, treatment, and transport and distribution infrastructures are reaching the end of, or have exceeded, their design lifetime. Deteriorating infrastructure poses risks to human and environmental health, and public and private property, with heavy impacts on local economies. Climate change will further burden these systems (Khatri and Vairavamoorthy, 2007).

Table 1 shows the range of climate hazards that cities are likely to face, along with their effects on urban systems.

**Table 1. Climate hazards and their effects on urban systems**

| Climate hazard | Effect | Vulnerable system | Possible consequences |
|---|---|---|---|
| Decreased precipitation | Water scarcity | Water supply | Water shortages for households, industries, and services |
| | | Human health | Malnutrition and increase in waterborne diseases |
| | | Food production | Reduced availability of irrigation water and yield decreases: food import |
| | | Urban green space | Reduced biodiversity and ecosystem services |
| | Reduced streamflow | Energy supply | Reduced hydropower generation potential: disruption of thermal power plants cooling systemes |
| | | Food production | Negative impact on coastal fisheries due to decreases in the outflow of sediments and nutrients |
| Increased precipitation | Flooding | Water supply | Disruption of public water supply |
| | | Wastewater | Flooding of facilities damage and contaminate water bodies |
| | | Transportation | Damage to transport infrastructure |
| | | Built enviroment | Disruption of settlements, commerce, transport, and societies: loss of property |
| | Increased erosion and sediment transport | Water supply (reservoirs) | Sedimentation and decrease in water storage capacity and turbidity increase |
| Higher temperatures | Reduced water oxygen concentrations and altered mixing | Water supply (lakes, reservoirs) | Reduced water quality (e.g., algal blooms): increase in treatment requirements |
| | Changes in snow and ice cover | Water supply (rivers) | Change in peak-flow timing and magnitude |
| | Increase in bacterial and fungal content of water | Water supply infrastructure | Increase in treatment requirements to remove odour and taste |
| Sea level rise | Saltwater intrusion into coastal aquifers | Water supply (groundwater) | Decreased freshwater availability due to saltwater intrusion: abandonment of water source |
| | Storm surges, flooding | All | Damage to all coastal infrastructure: costs of coastal protection versus costs of land-use relocation: potential for movement of population and infrastructure |

*Sources: IPCC, 2007; Loftus, 2011.*

### 4.3. Urban contributions to climate change

Urban centres affect the carbon cycle and climate system by emitting greenhouse gases and generating solid waste, as well as through their land-use patterns. Wastewater treatment is a source of emissions of carbon dioxide, methane, and nitrous oxide (WHO and DFID, 2009). Methane emissions from wastewater are predicted to rise by almost 50 percent between 1990 and 2020 (although, at present, this is relatively minor) and the increase in nitrous oxide is estimated at 25 percent (IPCC, 2007).

Informal settlements and slums, which tend to emerge near rivers, streams, and coastlines that offer informal access to water, can disrupt aquatic systems and deprive the city of critical ecosystem services, including flood control. With the parallel increase in built-up areas and consequent imperviousness of urban land surfaces, natural infiltration and stormwater flows are disturbed (Tucci, 2009).

In 2011, for example, heavy monsoon rains and successive tropical storms caused protracted flooding in Bangkok. Over the years, rapid urbanisation and development in the city and its surroundings had shrunk flood retention areas and floodplains (UN-WWAP, 2009). The city is located in a flat, marshy delta, and several of its neighbourhoods lie below sea level, making it among the most vulnerable capitals in Southeast Asia (Yusuf and Francisco, 2009). The Bangkok case illustrates the struggle that many cities – particularly in the Global South – face in ensuring that urban growth does not undermine environmental protection and public safety.

Cities also contribute to greenhouse gas emissions outside their boundaries through their expansion and consumption. As cities expand into surrounding areas, often on land that was formerly covered by vegetation, sequestration of carbon dioxide is reduced. Cities' reliance on nearby forests, farmlands, and watersheds for consumer goods, food, and water leads to greenhouse gas emissions in the outlying support areas (UN-Habitat, 2011).

Quantifying the exact contribution of cities to climate change remains difficult. Various organisations have developed frameworks and standards for cities to calculate the volume of greenhouse gas emissions produced within their boundaries.[2] According to recent estimates, cities account for 75–80 percent of carbon emissions (Kamal-Chaoui and Robert, 2009; World Bank, 2010).

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[2] See, for instance, the Local Governments for Sustainability framework (International Local Government GHG Emissions Analysis Protocol) and the International Standard for Determining Greenhouse Gas Emissions for Cities.

Industrial sectors and individual corporations are beginning to conduct greenhouse gas emission inventories to assess the effects of their activities on the environment. Still, questions remain, including the choice between production- or consumption-based measurements and the delineation of urban boundaries for the purposes of calculating emissions (UN-Habitat, 2011).

### 4.4. Response options

Much of early climate change research and policy separated mitigation (curtailing the anthropogenic activities that intensify climate change) from adaptation (preparing for the consequences). Increasingly, though, they are interconnected and must be aligned with the broader goals of sustainable development (McEvoy et al., 2006; World Bank, 2010). Analysis of proposed measures can reveal potential synergies, conflicts, and trade-offs. The restoration of urban green spaces, for example, serves both urban mitigation and adaptation: not only do these areas sequester carbon, but they also protect urban areas from damage associated with extreme weather events (UN-Habitat, 2011).

Comprehensive action to deal with climate change must account for the temporal and spatial scales at which mitigation and adaptation occur: mitigation measures tend to be driven by international obligations and national targets, with benefits in the long term; adaptation is more local and immediate. The heavy concentration of people and economic activity in cities makes mitigation and adaptation programmes both feasible and necessary. Nevertheless, efforts to reduce the carbon intensity of urban water and sanitation systems have been comparatively rare, and climate-proofing urban water systems has lagged behind more urgent urban water management priorities, such as expanding coverage and stopping losses from nonrevenue water. Efforts to cope with immediate and extreme hydrological and climatic variability are often 'in the most preliminary stages and frequently ad-hoc in nature' (Danilenko et al., 2010).

Preparing for climate change requires an integrated approach. To determine climate vulnerability and improve resilience, for example, planners must view urban water management in conjunction with the regional built-up environment, pollution control policies, and solid waste and stormwater management. To update preparedness status, they must understand resource availability, anticipate demand, find infrastructure solutions, monitor operational procedures and planning processes, and take corrective action.

Several cities worldwide are beginning to manage their water systems with climate change in mind (Box 4).

**Box 4. Seattle, Melbourne, and Manila: Climate change adaptation and mitigation**

The Seattle (WA, USA) public utility teamed up with the University of Washington to develop methods to account for climate change in the utility's planning processes. This has involved downscaling global climate models to the local watershed level and modelling watershed hydrology and systems. The analyses are updated as new data become available. The utility has sponsored additional research with Cascade Water Alliance, Washington State Department of Ecology, and the local metropolitan authority to study the potential for operational improvements in its systems.

The Global Warming Action Team, formed in 2005, includes representatives of the budget office, water planning, solid waste, and other departments. In this way, the authorities have been able to capture the cumulative consequences of climate change across urban sectors and account for them in the county's climate plan (Danilenko et al., 2010).

Melbourne Water (in Victoria, Australia) is seeking to improve sensitivity assessments, extract lessons from high-risk and worst-case scenarios, and minimise uncertainties in climate and hydrological projections. It is also exploring desalination, recycling, and pricing as ways to improve the resilience of the city's water supply, with new planning criteria and 'no-regrets' policy options. Because south eastern Australia has suffered from drought for more than a decade, the city already has a public awareness campaign that distributes information on water conservation, reports river levels and reservoir volumes, and advertises in a range of outlets, including city taxis, to influence the public's water-consuming behaviour. In both Melbourne and Seattle, public outreach was used to communicate the possible effects of climate change on urban water systems to different stakeholder groups and to engage them in devising appropriate adaptation measures.

Melbourne is likely to experience further reductions in rainfall, leading to reduced water supply and availability. Because the city does not receive subsidies from the federal or state government for adapting its water supply system to climate change, all efforts are funded through charges on water customers (Danilenko et al., 2010).

The Manila (Philippines) Water Company emphasises mitigation in its climate change policy, launched in 2007. It is devising a carbon management plan to improve energy efficiency and use more renewable energy sources in its operations. The utility's waste-to-energy project will recover energy from wastewater sludge and use it to run the Ayala South Wastewater Treatment Plant, located in the metropolitan area's Makati City.

Timely adaptation measures will allow cities to reduce the costs and technical challenges associated with retrofitting buildings, changing infrastructure, and adjusting land-use plans in response to climate change. Local government has a critical role to play in installing and maintaining infrastructure and services that are climate proof. Yet, in many parts of the world, local governments lack the necessary resources and institutional capacity. Under these circumstances, community-based adaptation measures must build on local adaptive capacity. Neither government- or community-based approaches alone are sufficient; effective adaptation responses necessitate the participation of a wide range of stakeholders (UN-Habitat, 2011).

## 5. FROM RESOURCE USER TO RESOURCE MANAGER

Urban planners face a choice in their future approach to water resources: their cities can become increasingly dependent on rural support areas and enlarge their urban 'shadow', potentially damaging food production, nutrient flows, and water resources; or they can shift from being resource users to resource managers, altering their consumption patterns, waste management, and planning to better balance resource flows to and from cities.

This section charts the shift that is needed to usher in more sustainable water management for cities and their surroundings.

### 5.1. Conventional urban water management

Urban water management seeks to ensure access to water and sanitation infrastructure and services. It must also manage rainwater, wastewater, stormwater drainage, and runoff pollution, while controlling waterborne diseases and epidemics, mitigating floods, droughts, and landslides, and preventing resource degradation.

Even though conventional urban water-management strategies have been unable to respond to existing demands, more will be asked of urban water management in the future. Given the challenges posed by urban growth and climate change, conventional urban water-management practice appears outdated. Its tradition of managing the elements of the urban water system as isolated services has led to an unbalanced urban 'metabolism' (Novotny, 2010) and separated urban water issues from broader urban planning processes.

In the past, water supply, sanitation, wastewater treatment, stormwater drainage, and solid waste management have been planned and delivered largely as isolated services. A range of authorities, each guided by distinct policies and pieces of legislation, continue to oversee water subsectors at the city level. The traditional urban water-management model has failed to distinguish between different water qualities and identify uses for them. As a result, high-quality water has been diverted to indiscriminate urban water needs (Van der Steen, 2006). This issue is not confined to city boundaries: basin-level management often neglects to acknowledge the cross-scale interdependencies in freshwater, wastewater, flood control, and stormwater

(Tucci et al., 2010). Water is extracted from upstream sources and delivered to urban areas, where it is used and polluted, then rechanneled – often untreated – downstream.

Water issues often remain disconnected from broader urban planning processes. This problem is particularly evident in developing countries, where modern urban development, associated with the design of physical human settlements and land-use zoning schemes, still hold sway (UN-Habitat, 2009). Past efforts have focused on containing urban sprawl, a tack that is relevant for low-density, low-growth cities, but ill-suited to rapidly growing, high-density centres in many developing regions (Angel et al., 2011). This model has proved exclusionary: it fails to account for the vast numbers and high poverty of new arrivals. Where alternative frameworks are in place, city authorities and municipal managers frequently lack the institutional capacity required to implement them. The result: informal settlements and peri-urban sprawl.

## 5.2. Integrated urban water management

The urban transitions that are currently underway – and their reverberations beyond city limits – mean that urban centres are critical units of water management. A new approach is clearly needed.

Integrated urban water management is not a set of quick fixes for isolated urban water management problems. Rather, it reframes a city's relationships to water and other resources, and reconceptualises the ways in which they can be overseen.

In essence, IUWM:

- encompasses all the water sources in an urban catchment: blue water (surface water, groundwater, transferred water, desalinated water), green water (rainwater), black, brown, yellow and grey water (wastewater), reclaimed water, stormwater, and virtual water;
- matches the quality of different sources (surface water, groundwater, different types of wastewater, reclaimed water, and stormwater) with the quality required for different uses;
- considers water storage, distribution, treatment, recycling, and disposal as a cycle instead of discrete activities, and plans infrastructure accordingly;
- plans for the protection, conservation, and exploitation of water resources at their source;

- takes into account the other, nonurban users of the same water resources;
- recognises and seeks to align the range of formal (organizations, legislation, and policies) and informal (norms and conventions) institutions that govern water in and for cities; and
- seeks to balance economic efficiency, social equity, and environmental sustainability.

Table 2 compares past practice with the new approach.

**Table 2. Comparison of urban water management and IUWM.**

| Past urban water management | Future IUWM |
|---|---|
| Water and wastewater systems are based on historical rainfall records. | Water and wastewater systems rely on multiple sources of data and techniques that accommodate greater degrees of uncertainty and variability. |
| Water follows one-way path from supply, to single use, to treatment and disposal. | Water can be reclaimed and reused multiple times, cascading from higher to lower quality. |
| Stormwater is a nuisance, to be conveyed quickly from urban areas. | Stormwater is a resource to be harvested as a water supply and infiltrated or retained to support aquifers, waterways, and vegetation. |
| Human waste is nuisance, to be treated and disposed. | Human waste is a resource to be captured, processed, and used as fertiliser. |
| Linear approaches deploy discrete systems to collect, treat, use, and get rid of water. | Restorative and regenerative approaches offer integrated systems to provide water, energy, and resource recovery linked with land-use design, regulation, and community health. |
| Demand equals quantity. Infrastructure is determined by the amount of water required or produced by end-users. All supply-side water is treated to potable standards; all wastewater is collected for treatment. | Demand is multifaceted. Infrastructure matches characteristics of water required or produced for end-users in sufficient quantity, quality, and level of reliability. |
| Gray infrastructure is made of concrete, metal, or plastic. | Green infrastructure includes soil and vegetation as well as concrete, metal, and plastic. |
| Bigger is better; collection system and treatment plant are centralised. | Small is possible; collection systems and treatment plants may be decentralised. |
| Standard solutions limit complexity; water infrastructure consists of 'hard system' technologies developed by urban water professionals. | Solutions may be diverse and flexible; management strategies and technologies combine 'hard' and 'soft' systems devised by a broad range of experts. |
| Utilities track costs alone and focus on accounting. | Utilities evaluate the full array of benefits from investment and technology choices, and focus on value creation. |
| The standard is a business-as-usual toolkit. | An expanded toolkit of options includes high-tech, low-tech, and natural systems. |
| Institutions and regulations block innovation. | Institutions and regulations encourage innovation. |
| Water supply, wastewater, and stormwater systems are physically distinct. Institutional integration occurs by historical accident. | Water supply, wastewater, and stormwater systems are intentionally linked. Physical and institutional integration is sustained through coordinated management. |
| Collaboration equals public relations. Other agencies and public become involved only when approval of predetermined solution is required. | Collaboration equals engagement. Other agencies and public are actively involved in search for effective solutions. |

*Sources: Moddemeyer, 2010; Pinkham, 1999.*

Nested within the broader framework of integrated water resources management (IWRM), IUWM can contribute to water security in a basin or catchment by aligning the urban water sector with rural water supply, agriculture, industry and energy. Thus, IUWM is not an end in itself. Rather, it is a means of overseeing a subsystem of a basin to improve the availability of and access to water, and minimised conflicts over use.

## 5.3. Toward a framework for Integrated Urban Water Management

The framework for IUWM is based on an integrated urban water cycle model (Figure 2), including approaches of system engineering. It includes both 'standard' urban water flows (potable water, wastewater, and runoff), as well as their integration through recycling schemes (greywater, reclaimed water, and rainwater harvesting).

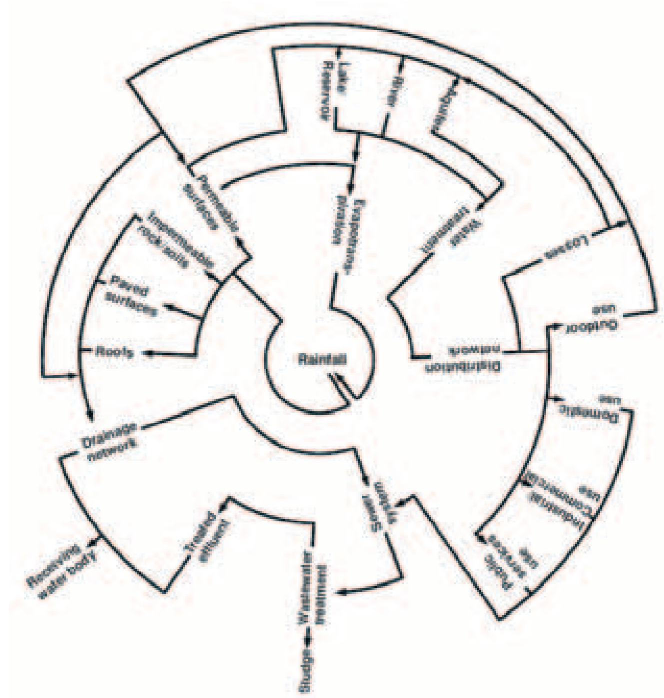


*Figure 2. Integrated urban water cycle model*
*Source: SWITCH, 2011.*

Linkages between different urban resource streams, such as the water, energy and nutrients nexus, have to be considered in the integrated model (Figure 3). The systems approach is not limited to the physical characteristics of the urban water cycle, but also includes institutional, financial and policy structures (Figure 4). Thus, humans and their various organisational forms


*Figure 3. Integration of different urban services*
*Source: SWITCH, 2011.*

are integral elements of the urban water system (van der Steen and Howe, 2009). The boundaries of the system model for IUWM should be wide enough to avoid externalities. Too narrow system boundaries could result in a harmful sub-optimization of individual subsystems.

The framework emphasises the linkages within the urban water cycle. When ignored, the interactions between the different elements of the urban water cycle can affect each other negatively, while at the same time, positive synergies can be missed. To capture the complex interactions and linkages, modelling tools for IUWM are required to predict the impacts of possible interventions throughout the system. There are a number of different decision support and scoping models (e.g., CITY WATER, AQUACYCLE, UVQ UWOT, MULINO, HARMONIT, DAYWATER) that can support IUWM by enabling the assessment of the dynamic balances of water, energy and pollutants at the city scale. These tools are designed to provide guidance on the potential short- and long-term impacts of innovative technologies and systems for urban water management (Bates et al. 2010) and can help identify system configurations that minimise water consumption, costs and energy.

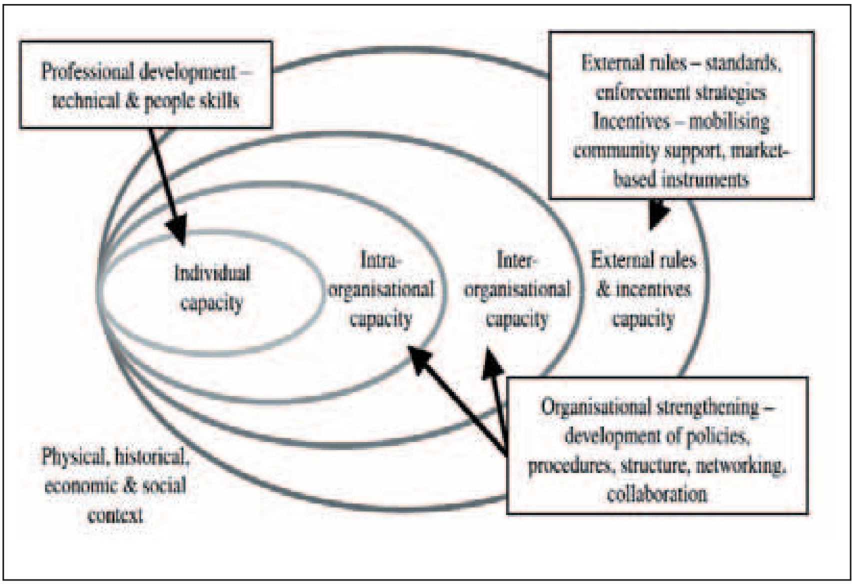


*Figure 4. Framework for institutional integration*
*Source: Brown et al., 2006*

There is no one-size-fits-all IUWM model. Water managers must consider the implications of the choice of scale: for example, when can catchments or basins be useful or appropriate scales to use, and when are municipalities or regions a better fit? What decisions are best made at the catchment or basin scale and what decisions are best made at other scales? There are various boundary options, depending on natural and social factors. Nonetheless, each will feature nested levels of management across municipalities, basins, nations and regions.

Table 3 provides an example of the goals and the practical tools through which they can be pursued, at different levels of management.

## Table 3. IUWM goals and tools at different levels of management

| Level | Goals | Tools |
|---|---|---|
| Household, community | *Conserve supplies* | In-factory and in-house recycling<br>Rainwater harvesting<br>Water-efficient consumer durables |
| | *Meet basic needs* | Small-scale community networks<br>Authorisation of private vendors |
| Municipality, city utility | *Conserve supplies and reallocate supplies* | Leak control and network maintenance<br>Planned reuse at urban scale<br>Dual supplies<br>Cost-based tariffs and metering<br>Retrofitting of water-use equipment |
| | *Improve health and meet basic needs* | Targeted subsidies<br>Education on water hygiene<br>Facilitating community-level provision<br>Removing land-tenure restrictions on provision<br>Preventing waste infiltration into supply |
| | *Increase investment* | Cost-based tariffs<br>Better revenue collection<br>Higher operating efficiency<br>Curbing illegal connections |
| | *Source protection or quality protection* | Groundwater abstraction controls<br>Leak control to curb infiltration<br>Land zoning<br>Industrial and domestic waste pollution controls |
| Basin | *Enhance supply* | Purchase of upstream water or waste disposal rights<br>Purchase of catchment protection services |
| | *Enhance supply and protect quality* | Physical enhancement (dams, recharge)<br>Regulation of catchment land use<br>Regulation of waste and stormwater discharges<br>Pollution taxes |
| | *Reallocate supplies* | Regulation of abstraction<br>Abstraction pricing<br>Water trading<br>Consultation, conflict resolution |
| Subnational or regional government | *Enhance municipality utility performance* | Monitoring, benchmarking, and publicity<br>Building of skills, human capacity<br>Public loans<br>Consultation, conflict resolution for land use |
| National government | *Prioritise goals* | Land and water allocation policy<br>Regulatory frameworks<br>Monitoring of subnational, basin-level agencies |

*Source: Rees, 2006*

Research on achieving sustainability in the urban water sector in Australia has yielded a typology of 'transition states', shown in Figure 5. Although the researchers are careful to emphasise that cities have unique socio-political and bio-physical circumstances, the typology does indicate how various drivers can influence the service delivery functions of urban water systems and provides a 'mental model' for decision-making for long-term, integrated urban water management.

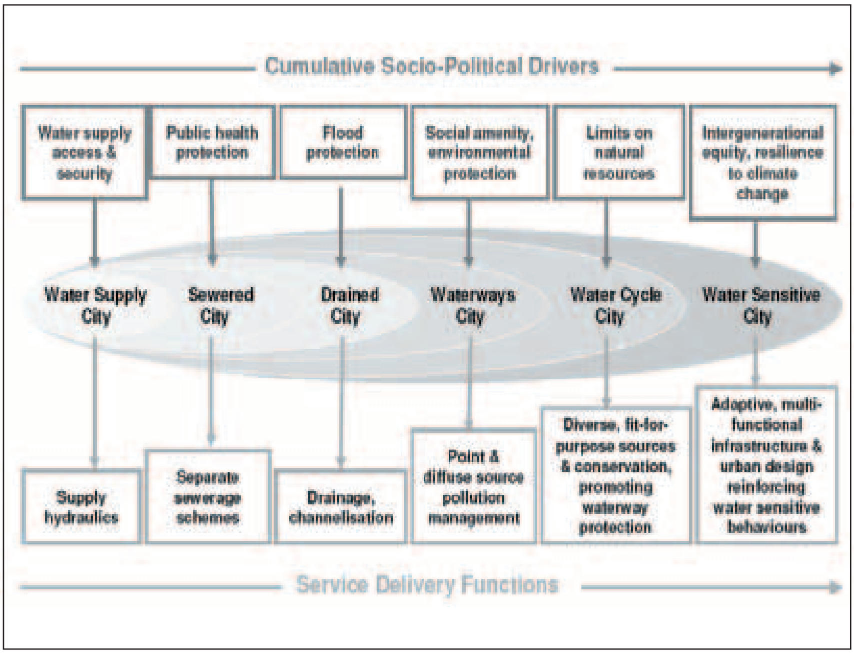


*Figure 5. Transitions from water-supply cities to water-sensitive cities*
*Source: Brown et al., 2008.*

## 6. CREATING AN ENABLING ENVIRONMENT FOR IUWM

At its core, integrated urban water management is about balancing objectives, prioritising goals over different timeframes, and taking practical measures deployed in concert by a range of organisations. It therefore requires an institutional context in which public and private actors can work together, supported by coherent legislative and policy frameworks.

Indeed, the success of IUWM rests on cross-scale and cross-sectoral linkages; it is not the remit of cities or the water sector alone. High degrees of internal integration and alignment between various levels of resource management are characteristic of emerging 'green' or 'sustainable cities'. These cities draw on a range of tools to catalyse coordination, including resource-wide budgets and city-wide integrated plans.

### 6.1. Roles for central governments

During the 1990s, when public service provision was deemed a failure in terms of efficiency, market approaches were expected to improve efficiency, create new financial flows, and deliver greater accountability (UNDP, 2006). Although the corporate sector has, in places, improved the efficiency of service delivery, it has been less capable of meeting equity goals. According to UN-Habitat (2009), the present global financial crisis has highlighted some of the limits of market-led approaches and re-ignited interest in stronger government involvement to ensure that basic needs are met. The fluctuations in global energy and food prices may compel central governments to exert a greater regulatory role over market forces, particularly where the cost of daily living has soared beyond the means of vast swaths of the population. As a whole, government measures complement – but do not replace – private efforts, whether formal or informal, or led by the community, civil society, or the corporate sector.

Central governments provide country-wide perspectives on urbanisation and water management by setting national policies on land, infrastructure services, and other issues that affect the entire urban-rural continuum. In choosing to make policy for broad economic areas that integrates villages, towns, and cities, governments can even out the differences in living standards between rural and urban areas (AfDB, 2011). Typically, central governments have the authority to convene stakeholders for deliberations.

IUWM necessitates closer relationships between upstream and downstream areas; this can entail crossing national borders, which presents technical and political challenges. Northern Ghana and Burkina Faso, for example, compete with the urbanised society of Southern Ghana for water resources (Giesen et al., 2001). Ideally, efforts to establish cross-border frameworks on water management will enhance collective action for the conservation, protection, and development of the common resource base; balance the rights of use by the countries sharing a common resource base, including their social and economic needs; and account for the availability of alternative sources.

Where informal actors provide basic water services, central governments play an important regulatory role, working with local governments to promote equitable pricing and better quality – and not cutting off informal service provision.

## 6.2. Roles for local governments

Urban governments devise policies and strategies for prioritising, sharing, and managing available resources, while taking into account local demands. To be successful, they must look beyond the water sector in isolation. Policies on housing, energy, land use, urban and rural agriculture, and waste management all have a bearing on the sustainable management of water.

Urban governments can engage the various water users in analyses, choices, and decisions related to water resources. They can ensure that decisions about new water sources, particularly for cities with high water demands, do not deprive surrounding areas. Local governments need to foster a culture of long-term planning that looks beyond short-term financial calculations (Box 5).

**Box 5. Johannesburg and Gauteng Province: Planning ahead**

When gold was found high on South Africa's central plateau in the 1880s, miners needed more water to retrieve the gold. The local springs were insufficient during the dry winter months. A more reliable source was found in the waters of nearby dolomite aquifers and the Vaal River, 80 kilometres south of the future city of Johannesburg. In 1904, a public utility, Rand Water, was formed to supply water to the mines and expanding towns.

In 1938 the Vaal Dam was built to supply water through the worst droughts, but this, too, proved insufficient: the Vaal River alone could supply only 10% of the needs of what is now Gauteng Province. This is a collection of three cities with a combined population of nearly 10 million people, accounting for over 60% of South Africa's economy.

Water was sought further away. A pumped transfer scheme brought water from the Thukela River in the province of KwaZulu-Natal, 250 kilometres distant. When this water is not needed for other purposes, it generates peak-period electricity for the country's national grid.

The Lesotho Highlands Water Project was implemented to transfer water from a neighbouring country by capturing water high in the catchment and bringing it under gravity to the Vaal, rather than pumping it long distances. Lesotho is paid a share of these cost savings, rather than for the water itself. There are plans to expand this scheme to ensure supplies to 2030 and beyond.

Many South African cities are allowed to abstract water from rivers, only on the condition that they treat wastewater and return it to the river for downstream use. Direct recycling is still more expensive than other alternatives. If water is not properly treated, recycling can create water quality problems of its own, particularly inland.

Over the years, water quality management has proved just as much of a challenge as water supply in South Africa. Current water management operations aim to maintain the salinity of Vaal river water within acceptable levels; the dam system is operated with this objective, occasionally releasing fresh water to reduce salinity. In addition, much of the water used and treated by Johannesburg is transferred into the Limpopo River basin, where it supplies the fast-growing platinum mines of the North West Province. Since the mining industry and surrounding towns need water, they are prepared to pay part of the costs of treatment and transfer, a win-win situation.

The planning of this system is long term, continually looking 20–30 years ahead. It evaluates likely changes in consumption, as well as pollution loads. It considers the different options to meet water needs, not just new water supplies, but greater efficiency and water reuse. Even the operations of the system are undertaken on a multiyear basis.

Two countries, five provinces, eighty towns and cities – the story of South Africa's water demonstrates that effective water resource management in situations of water stress inevitably go far beyond city boundaries. Managing water as part of a multibasin system brings greater efficiencies, as well as economic and social opportunities, than can be achieved by attempting to manage water within the city's boundaries alone.

*Source: Mike Muller*

The remit for managing the urban water system, however, is often fragmented across several departments and agencies. Moreover, the transition toward sustainable water resource use and management practices takes time and may exceed the tenure of elected officials and other stakeholders. Some cities lack information on existing and projected water resources availability, levels of water use, environmental hazards and risks, and settlement patterns. Structural impediments may create conditions for corruption that limit access to basic services.

IUWM depends on decentralisation: beyond the devolution of administrative functions, local governments must also have political and fiscal authority. A strong local government can forge new relationships with rural authorities, national decision makers, and the public and private sectors.

### 6.3. Private sector involvement

In parts of the Global South, public utilities often lack the financial resources for maintenance and operate their water infrastructure 20 and even 50 years beyond its intended life span. Uncoordinated planning further aggravates the situation: new infrastructure is built on outdated networks that cannot withstand the expansion of demand for water and wastewater services (Danilenko et al., 2010).

Greater private sector involvement in urban water management is one way to deliver more efficient services, extend service coverage, and operate financially sound utilities. Private sector involvement can take the form of leases, concessions, management contracts, service contracts, or subcontracting of specific activities (Kingdom, et al., 2006). Under performance-based contracting, companies are paid not only for the services delivered but also for achieving specific performance measures; they therefore have incentive to deliver results (Kingdom et al., 2006).

Companhia de Saneamento Básico do Estado de São Paulo, Brazil, for example, has leveraged private sector capacity to strengthen its commercial management. Its operations were hampered by leaks, thefts, and faulty meters, until the utility recruited five private contractors to engineer, supply, and install new meters for large-account customers. The contractors were expected to finance the investment, and payment was based on the average increase in consumption volume – as opposed to meter fittings alone. In three years, the volume of metered consumption increased by 45 million cubic metres, while revenues increased by US$72 million. Of this, US$18 million was paid to the contractors (Kingdom et al., 2006).

The effort succeeded because the contract offered strong incentives for the contractor while guaranteeing profit for the utility. In addition, the contractors had flexibility to determine the way in which they would meet the terms (Kingdom et al., 2006).

Appropriate regulation, and the ability to enforce it, can help ensure high-quality, sustainable, and equitable services by both state- and non-state actors. Independent regulators – overseeing stable and predictable regimes of tariffs, service standards, and other factors – can instil confidence in new entrants and encourage existing providers to make reforms.

### 6.4. Business opportunities along the entire value chain

Entrepreneurs, often informal, already provide the bulk of some cities' on- site sanitation services, such as latrine construction, maintenance, and desludging. Such business opportunities are expanding as more people demand improved water and sanitation products and services.

Food security is heavily dependent on fertilisers. The rising price of artificial fertilisers and dwindling phosphate reserves have created a market opening for organic fertilisers from animal manure, human excreta, and other biowastes. In Malawi, for example, private on-site service providers give credit to households that are otherwise unable to build composting toilets, against future 'manure' sales. These activities contribute toward 'closing the loop' in managing nutrients, land, and water, thereby helping rebalance distorted urban metabolisms (Figure 6). Ouagadougou, Burkina Faso, is one of the cities that has tested the viability of a value chain for recycling urine and excreta (Dagerskog et al., 2010).

### 6.5. 'Urban' and 'basin' management

Hydrologic boundaries rarely coincide with administrative ones. Urban catchments – overseen by city authorities – may lie within basins that cross state, or even national, borders. The relationship is reciprocal: practices within the basin influence the quantity and quality of water available for cities, and urban population growth and economic development shape water flows beyond city boundaries (Bahri et al., 2011). Saõ Paulo has explored various governance mechanisms to integrate its management of water resources with efforts at the broader basin level (Box 6).

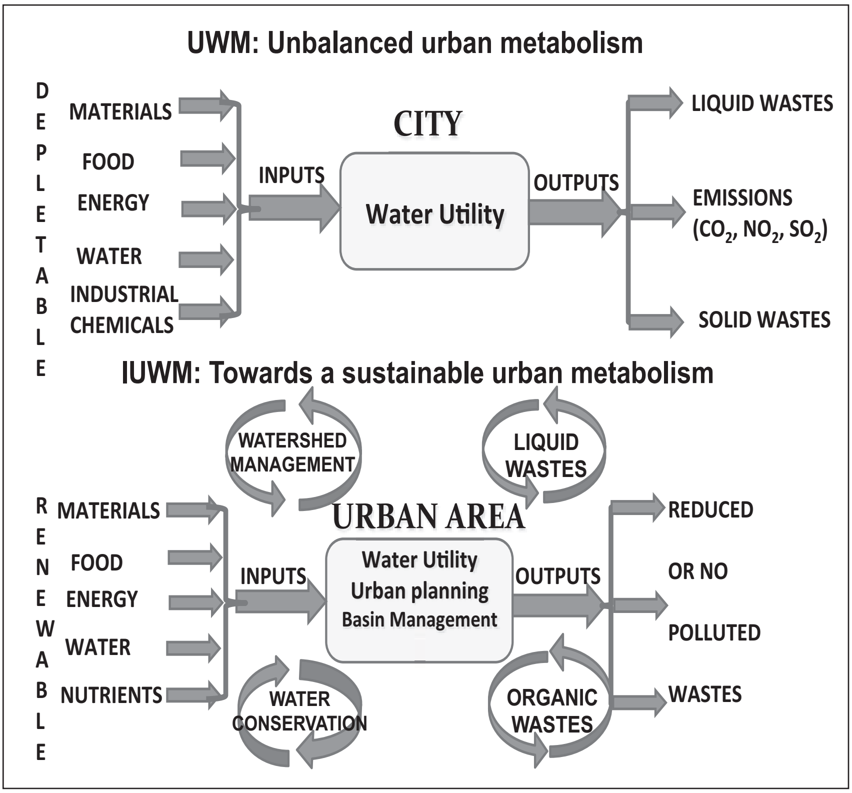


*Figure 6. IUWM Contributions to rebalancing the urban metabolism*
*Sources: Novotny, 2010; Browder, 2011.*

Cities produce large quantities of wastewater and other forms of waste. Where waste treatment is inadequate – or, indeed, entirely absent – waste disposal sets in motion a cascade of events that reverberates across a range of ecosystems. Wastewater flows, for example, can spill onto agricultural fields and into surface water bodies. Seasonal flooding may amplify the effect as wastewater mixes with stormwater (Bahri et al., 2011). The loss of permeable soil in built-up areas further diverts the flow of polluted stormwater into agricultural lands and downstream environments (Van Rooijen et al., 2005).

In Accra, an estimated 80 percent of the total volume of water used becomes wastewater, much of it used to cultivate vegetables. Without appropriate safeguards, the practice can pose considerable health risks both to irrigators and consumers. However, if appropriately treated and managed, they may encourage new resource uses and users along the entire urban-rural continuum (Bahri et al., 2011).

**Box 6. São Paulo: Experimenting with new forms of urban water governance**

São Paulo and its surrounding areas form an important urban centre and industrial complex in Latin America. In response to higher demands, São Paulo has begun to experiment with alternative forms of urban water governance that involve stakeholders beyond the urban confines.

The water supply system of the São Paulo metropolitan region is operated by the Companhia de Saneamento Basico do Estado de São Paulo, S.A. (SABESP). This public utility provides water and sewage services for 25 million residential, commercial, and industrial customers. It relies on three main surface water systems: two lie within the Tietê River basin and supply 56% of demand, and the third, the Cantareira System, is in the neighbouring Piracicaba basin, which supplies the remainder.

The cost of treating water intended for drinking purposes has increased 133% in recent years, and the potential for expanding the water supply system is highly constrained. Further water transfers from neighbouring basins may be unavoidable, but in the absence of interbasin collaboration, the political and social costs would be considerable.

In addition, wastewater collection and treatment continues to fall short in the metropolitan region. Water quality remains substandard. Ill-planned or unrestrained land use in the basin has diminished water quality and compounded severe flooding.

To integrate and coordinate water management within the basin, a watershed committee, comprising diverse stakeholder groups, negotiated the Upper Tietê Basin Plan in 2009. This ambitious plan proposes action at three levels. First, to better link water quantity and quality management, water systems (water supply, wastewater treatment, flood control, and irrigation) and activities that affect water sources (industrial use, energy use, and solid waste disposal) are being interconnected. The authorities have strengthened enforcement measures for compliance with water withdrawal and discharge permits, economic incentives for demand management, and user-pay and polluter-pay charges.

Second, the plan seeks better alignment between sectors related to land-use management (housing, transportation) to prevent development of vulnerable areas (water supply regions, floodplains) and limit the imperviousness of urban development. Revenue from the user-pay and polluter-pay charges is invested only in projects that have committed to watershed protection. State, municipal and private sector actors are thus encouraged to improve protect sources and floodplain areas, manage water demand, and manage solid wastes and groundwater.

Third, the plan calls for integration with neighbouring basins to address interbasin transfers of water, pollution loads, and downstream flooding. The watershed committee has emphasised the need for shared information systems, including peer-to-peer monitoring of compliance with agreed-upon targets. A critical component of interbasin collaboration is the preparation of emergency plans so that neighbouring basins can respond in unison.

The implementation of the scheme is complicated by institutional history: the municipalities are in charge of land-use planning, urban housing and transportation, but the state is in charge of water resources management. Nevertheless, the permitting process and user fees are being phased in. The information system comprising data on all users is completed, although not yet public. The cross-sectoral actions remain an important

**Box 6. *Cont.***

challenge – the water sector lacks authority to influence land-use regulation and institutional mechanisms for effective metropolitan governance are inadequate – but the evolution toward integrated urban water management across water basins is beginning.

*Sources: Braga et al., 2006; FUSP, 2009; Porto, 2003.*

Under IUWM, cities align the management of housing, energy, landscape and waterscape design, agriculture, and waste management, and all sectors address shared risks and opportunities.

## 6.6. Stakeholder participation

The IUWM approach depends on stakeholders' engagement in designing and managing urban water systems. Although widely accepted in principle, stakeholder engagement can vary substantially. In some cases, it entails genuine involvement in decision-making; in others, it amounts to informing people about decisions already taken.

All user groups should participate in designing or restructuring systems for basic services. Participation in project planning, municipal planning, and budgeting can ensure appropriate design and informed contributions that improve living conditions, particularly in low-income settlements.

Legal mechanisms may be needed to define the roles for stakeholders and set the conditions for the involvement of groups not traditionally considered relevant for urban decision-making (UN-Habitat, 2009), such as upstream farmers' associations, industry representatives, and energy utilities (UNDP, 2006). In addition to forging upstream–downstream linkages, legislation can also be a vehicle for cross-sectoral integration. Laws guaranteeing the right to wastewater encourage farmers to install appropriate treatment and irrigation infrastructure; they also establish standards for water quality and monitoring authority for public health purposes.

Water users typically have different agendas that need to be reconciled. Capacity to resolve disputes must be accompanied by transparency.

Karachi, Pakistan – a pioneer in the implementation of IUWM within a context of a megacity – has put in place a public-private partnership to manage its water resources in a more coordinated, equitable manner (Box 7).

### Box 7. Karachi: Participatory water resources management

Karachi – whose population of approximately 18 million is expected to double in another decade – faces serious water management challenges. Unsafe water is estimated to contribute to the deaths of 30,000 people annually; 40% of the water in the city is lost through leaks; and private vendors, mainly supplying poor consumers, may charge 12 times the price of water of the public systems. Water quality and supply have declined, wastewater management is inadequate, and water conservation measures have been poorly planned. The urban water system had tariff rates that were often set below provision and operation and maintenance costs..

Against this backdrop, concerned individuals came together in 2000 to float the concept of a water partnership for the city. These prime movers – officials from the Karachi water and sewerage board; experts in urban water, water conservation, and marine wetlands; and a farmer from the city's peripheral lands – set up a joint initiative of government officials and private citizens to promote water conservation and improve water and sewerage management. Some people said Karachi was too large and too politically, socially, and ethnically divided, but the Karachi Water Partnership (KWP) was officially launched in 2007.

The partnership was intent on moving away from discrete, technical interventions that made up Karachi's urban water infrastructure. Instead, it would address human capital, urban governance, and systems of resource allocation between social groups and water-use sectors. Participants turned to the concept of integrated water resources management (IWRM) for institutional designs and governance and implementation practices. IWRM had previously been viewed as framework for basin-scale water resources management; few attempts had been made to deploy it at the level of a city, and the concept was unfamiliar to city managers and politicians.

The Karachi Water Partnership (KWP) went beyond conventional public-private partnership models and sought to involve the general public in its activities. This not only created more stakeholders but also set the tone for their mode of engagement. Working closely with the Global Water Partnership, the KWP provides a neutral platform for competing urban user groups to deliberate the management of water issues (Figure 7).

Women formed an important constituency, given their often central roles in managing daily domestic water use. Industry involvement in waste mitigation and treatment measures was essential. Academics contributed capacity building and generated a knowledge base for resource management policy. Government was also enrolled in the KWP. Finally, the media also became involved as the main channel for reaching the citizens of Karachi, via documentaries and public service announcements. The partnership secured the involvement of some stakeholders through memoranda of understanding. Additional partnerships were set up at sub-city levels to ensure that decisions would be made as close as possible to those whom they affected.

**Box 7. *Cont.***

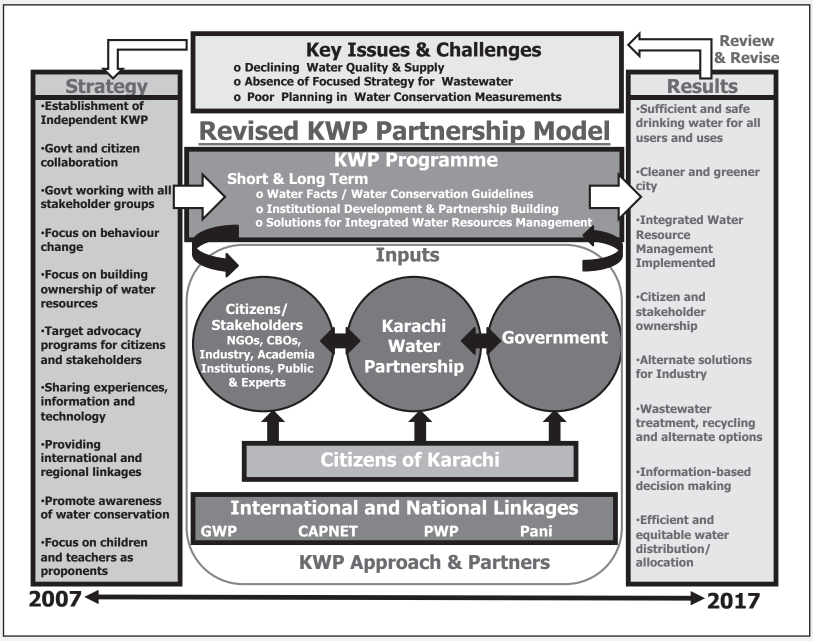


*Figure 7. Karachi Water Partnership model*
*Source: Baxamoosa, 2009.*

To put the IWRM concept into practice, the partnership sought to instil a sense of ownership among stakeholders and then translate this into more conscious consumption and management of water resources. Each institutional stakeholder was asked to contribute money to carry out partnership commitments. Moreover, stakeholder groups held each other to account in fulfilling the roles and responsibilities that were expected of them.

Facilitating local-level activities is important for catalysing work at sub-city levels. For example, with support from the partnership, the Area Water Partnership in Gulshan-e-Iqbal, one of 18 administrative towns in Karachi, has developed water conservation and management guidelines in English, Urdu, and Sindhi for homes, schools, industries, and mosques. These were distributed with water bills. Water bill distributors and teachers received training in water conservation measures, and water supply and sanitation systems were built in 20 government schools.

Many public-private partnerships targeted at urban water and sanitation focus on creating alternative service delivery mechanisms – parallel structures, effectively – that become detached from established channels. KWP is different. It has sought from its inception to work with what is already in place, engaging with stakeholders from all water-use sectors and along the entire spectrum of urban governance, to establish more efficient, equitable, and sustainable urban water management practices.

*Sources: GWP, 2010; Siddiqui, 2011; Baxamoosa, 2009.*

## 6.7 Fostering a new culture of urban water management

IUWM offers a socio-technical transformation: it advances both technological solutions for water management and simultaneous modifications in behaviour, attitudes, institutions, financing mechanisms, and training. Institutional capacity building is crucial for updating and integrating knowledge in the natural sciences, engineering, environmental biology, economics, finance, and sociology.

Professional cultures need to change so that they reward cross-sectoral and cross-scale cooperation. Building and maintaining collaboration among stakeholders is no simple feat, however. Ideas must be conveyed across institutional languages and operational cultures. Different levels of power, influence, and resources have to be bridged. Common goals, and the benefits of mutual action, must be clearly articulated.

Such transformations must be accompanied by robust monitoring mechanisms that update authorities, service providers, and users. Successful management approaches are adaptive and nimble, so that water management systems can respond promptly to unexpected changes. Indeed, IUWM involves learning how to act in conditions of uncertainty and imperfect knowledge. Problem definitions and underlying assumptions must be continuously revisited for their relevance (SWITCH, 2011).

Sectoral integration within government and scalar integration between levels of government are becoming increasingly important. Transforming entrenched practices can be especially difficult in megacities. Small and medium-sized cities, on the other hand, can plant the seeds of integration now.

Managing urban water resources and integrating all aspects of water source and quality will require public education and collaboration to realise the necessary cultural and behavioural changes (Najjar and Collier, 2011), as well as coordination among land and water management entities, resource and regulatory agencies, local governments, and nongovernmental organizations (Watson et al., 2011). New York City supplies 9 million people with safe drinking water by collaborating with surrounding municipalities to protect upstream sources (Box 8).

**Box 8. New York City: Upstream source protection of drinking water**

New York City supplies its 8 million residents, plus another 1 million people in surrounding counties, with safe drinking water simply by protecting its upstream sources in two watersheds in the Catskill Mountains. Once, these waters required little or no treatment. By the late 1980s, however, land-use practices upstream – dairy and livestock farming, in particular – had begun to erode water quality. The challenge was to secure the quality of drinking water supply to the city without burdening upstream water users. Farmers were concerned about how watershed protection measures would affect their livelihoods.

New York City was highly motivated to find a workable solution for watershed protection because the Environmental Protection Agency was threatening to require filtration systems at a cost of several billion dollars. But if water quality was high, regulators would issue a 'filtration avoidance determination', exempting the city from filtering its drinking water, as would otherwise be required under the US Safe Drinking Water Act.

The agency and the New York State governor's office convened all stakeholder groups from the watershed areas for negotiations and, in 1997, a memorandum of agreement was signed. Under its authority, revenues collected from water users would help finance activities to protect the watersheds and their environmental goods and services (Pagiola and Platais, 2002 and 2007).

The agreement has three major elements. First, under the land acquisition programme, New York City has acquired environmentally sensitive, largely undeveloped land from willing sellers. In the first decade, 85,000 hectares of land was bought, for US$260 million. The city is willing to make available another US$320 million over the next 10 to 15 years. This programme sets aside some areas for growth; the priority areas for acquisition are near reservoirs, streams, and wetlands.

Second, under the watershed regulatory programme, new regulations to control pollution were negotiated among watershed counties, water-use communities, New York City, New York State, the agency, and environmental groups.

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**Box 8. *Cont.***

Third is the watershed protection and partnerships programme. It mandates that New York City will pay to upgrade upstream treatment systems; the city also provides payments to 'good neighbour' municipalities that join the scheme. Additional money is dedicated to replacing failing and ageing septic systems, extending sewers, and improving stormwater and wastewater treatment infrastructure in upstream areas.

Although the efforts are funded by New York City water users, several are implemented by the non-profit Catskill Watershed Corporation, whose board of directors consists of locally elected officials. Committees of stakeholders, such as recreational users, address specific watershed management issues, and a public affairs office organises outreach events and produces educational material to raise awareness.

Agricultural stakeholders make important contributions to the watershed protection endeavour and have a separate partnership with the city. Under this voluntary Watershed Agricultural Programme, New York City has committed more than US$100 million to develop a 'whole farming approach' that will help farmers reduce pollution by switching to environmentally sound farming practices. More than 95% of watershed farmers have pledged to participate.

The watershed protection measures adopted by New York City and its neighbours provide an example of how robust formal institutional measures – the Safe Drinking Water Act and the Environmental Protection Agency's power to withhold or grant exemptions – can prompt action by cities with sufficient resources, taking advantage of a clearly delineated balance of powers among authorities and citizen access to accountable government.

*Sources: Grumbles, 2011; Office of Water, 2010; Pagiola and Platais, 2002 and 2007.*

## 6.8. Game-changing technologies and approaches

IUWM aims to make use of innovative technological solutions for urban water systems. Practical applications of a variety of innovative technologies, such as membrane filtration systems, including membrane bioreactors, advanced oxidation, hybrid systems of natural and advanced treatment, microbial fuel cells, electrochemical processes, and source separation of different waste streams (separation of greywater, black and yellow waters) have led to new ways of managing urban water systems. The potential of more efficient reuse of water and nutrients and the recovery of energy is a major advantage of the new treatment technologies (Bieker et al., 2010). Those new technologies are, in many cases, instrumental in the concept of integrated management approaches.

Moreover, IUWM offers different innovative approaches to cope with the challenges for urban water management. IUWM ensures that the technology innovations in urban water management are coupled with comprehensive system changes of the urban water system. The new approach should consider the whole urban area as unit of management with application of other new approaches, such as cascading uses of water, beneficiation of water (use of water-machine concepts and semi-centralised systems), decentralised systems, analyses of quantity and quality aspects in a single framework, and flexible and adaptable urban water systems, etc.

## 7. IUWM TOOLS AND MANAGEMENT STRATEGIES

Integration in an IUWM approach requires efficiency, equity, and environmental sustainability. Efficiency is the need to optimise the use of an increasingly vulnerable and scarce resource. Equity means ensuring access to water across all socioeconomic groups, so that they have the quantities and qualities needed to sustain human well being. Finally, environmental sustainability entails management that protects the resource and associated ecosystems and ensures its availability for future generations (GWP TAC, 2000).

These three core approaches can, at times, come into conflict. The efficiency principle, for instance, may give advantage to certain users over others and compromise equity and environmental sustainability, if pursued solely through pure market pricing. To maintain balance among the three, central governments can enact legislation that makes water a state property and provides a unified framework for water allocation. A government then grants water withdrawal permits as elements of a formal water economy. Legislation in itself is not, of course, enough: it must be accompanied by enforcement and monitoring to guard against the exploitation of unequal power relations (UNDP, 2006).

Indeed, IUWM involves balancing a range of objectives and employing a range of tools, from appropriate technology and financial structures to favourable institutional contexts – all while promoting cross-sectoral and cross-scale dialogue. A great number of not-necessarily compatible goals can simply halt progress. Goals may need to be simplified and prioritised over different timeframes. 'Tool packages', which typically involve concerted actions from different institutional levels by several nonwater actors, can also help planners integrate multiple goals.

It is often informal urban settlements – those outside administrative jurisdictions and formal governance structures – that face the most acute water and sanitation crises. Here, bold political processes are necessary to help articulate a new vision of water as a universal entitlement, rather than a market-based commodity, and to build consensus and collaboration across stakeholder groups.

Each city requires its own set of water management practices, but they have universal goals. Cities must deliver water in appropriate quantities and qualities and at appropriate times, without compromising the availability of the resource for others. They promote efficient water use and alternative sources of water, including wastewater, to provide economic incentives that yield results. And they must build in resiliency to handle anticipated disruptions caused by climate change.

IUWM provides cities a new framework for planning, designing and managing urban water systems. An IUWM perspective enables all stakeholders to look at the urban water system holistically, as an integrated, cooperative venture, and together supply the capacity to predict the impacts of interventions across broad resource management units. By doing so, the framework facilitates the development of innovative solutions for urban water management and the prioritisation of resources.

## 7.1. Water audits and efficient use

The intensifying cycle of urbanisation and resource depletion is causing water stress. The knee-jerk reaction, to augment supply, is not a long-term cure, and it may even exhaust water resources at the expense of the environment and access to water for future generations (UNDP, 2006).

Water resource assessments, such as water audits, quantify a given water resource base and the demands placed upon it. They are the basis for water policy, water management approaches, and investment decisions. In an IUWM approach, they examine not just surface and groundwater supplies but also previously overlooked sources, such as stormwater and wastewater. In Perth, Australia, for example, the local authority (the Tamala Park Regional Council) decided to integrate urban water cycle management approaches into a new urban development. The use of water balance modelling allowed the authority to design a water system that minimised demand on imported water and maximised water reuse (Barton et al., 2009).

Domestic supply systems often lose 50 percent of their water to leaks. Reducing water loss involves changing the design, construction, and operation and maintenance of systems, as well as user behaviour. It may also include introduction of water-saving measures. In Zaragoza, Spain, water savings have been a major focus since 1996. The municipality has improved its water loss management with water-saving devices and by the monitoring of flows and pressures with a supervisory control and data acquisition system, linked to a geographic information system and simulation model (SWITCH, 2011).

Singapore has achieved significant reductions in unaccounted-for water and now has one of the world's lowest nonrevenue water rates. Laws that prohibit illegal connections to the water supply system are vigorously enforced. New water-supply infrastructure uses high-quality materials, and existing works are upgraded to minimise physical losses. A sophisticated system detects leaks and pipes are fixed promptly. Faulty meters are also replaced. Collectively, these measures reduce both wastage and operating costs (ADB, 2010).

## 7.2. Water reclamation and reuse

Reclamation and reuse are essential elements of any sustainable urban development strategy. Used water is harvested and treated to different quality standards for reuse in agriculture, industry, and other sectors. Cities can thereby improve human and environmental health, while supporting economic activities (Brown, 2009), and the recycling creates a multiplier effect, whereby a given volume of water can be made more productive.

In some peri-urban areas, treating and reusing reclaimed water for food production is an option for increasing food security (DST, 2008). Farmers derive a range of benefits from the use of wastewater for irrigation (Bahri, 2009): it is a reliable source that is usually free and readily accessible, and available near their urban market. In addition, wastewater tends to contain significant levels of nutrients, thereby reducing the need for chemical fertilisers. The use of wastewater in agriculture supports the livelihoods of farmers, traders, and other actors along the agricultural value chain. It reconciles the public health and environmental resource protection interests of a city with the local farming community's desire to maintain an agricultural way of life.

Wastewater can be reused in aquaculture and for irrigation of parks, green spaces, golf courses, and other urban areas. It can recharge groundwater and contribute to restoration of water bodies and wetlands. Wastewater flows from Mexico City have, over time, led to the incidental recharge of downstream aquifers. These new groundwater supplies can help meet the water demands of the city's 21 million inhabitants (Box 9).

### Box 9. Mexico City: Replenishing downstream aquifers

Mexico City historically relied on groundwater to satisfy its water needs. When withdrawals exceeded recharge rates, the resulting soil subsidence damaged the sewer system, mixing stormwater and wastewater, and causing structural problems in buildings. In response, Mexico City turned to water transfers from surrounding basins to augment its supply, but this strategy is also reaching its limits. New transfers will be required over greater distances and along steeper gradients, all with high social, environmental, and economic costs.

This megacity also produces vast volumes of wastewater. Today, 12% of its wastewater is treated and reused in landscape and agricultural irrigation, industrial processes, commercial activities, and aquifer recharge. Untreated wastewater is also reused extensively. Traditionally, the city's wastewater has flowed downstream to the Tula Valley, where it has been used for agricultural irrigation. Downstream farming communities value the productivity gains and year-round cultivation opportunities afforded by this readily available and nutrient-rich water source.

Where the soil is permeable, aquifers in the Tula Valley have been recharged by wastewater, which is stored in unlined holding areas. Studies have estimated that the aquifer recharge rates in the downstream areas are 13 times the natural rate.

Various physical, chemical, and biological processes purify the wastewater as it is transported, stored, and reused for irrigation. Over the past two decades, water quality assessments have indicated that the quality of the groundwater is equivalent to the upstream water sources that supply Mexico City. Still, there are signs of emerging pollutants and high salt concentrations in some of the sources, clearly indicating the need for further evaluations.

The recharged aquifer in the Tula Valley may become a new source of water for the greater Mexico City area. The 2007 Water Sustainability Programme launched by the National Water Commission envisions importing groundwater from downstream areas to supply the city. In the long-term, the city will have to take a more comprehensive and coordinated approach, and find holistic solutions to all its water management problems:  groundwater overexploitation, land subsidence, flood risks, deteriorating water quality, unreliable supply, inefficient water use, scarce wastewater treatment facilities, and cost recovery for water services.

The Federal District of Mexico City is seeking a better balance between groundwater abstraction and recharge. In 2007, it launched a 15-year, multisectoral plan to promote water-saving measures for consumers (metering all users and improving bill collection), curtail network losses (by bringing illegal connections into compliance), and increase wastewater treatment and reuse (by constructing tertiary treatment plants to produce recharge water). With these measures, the Green Plan seeks to reduce groundwater abstraction by 10% and the overdraft by 25%.

*Sources: Jiménez and Chavez, 2004; Jiménez, 2008; Jiménez and Chavez, 2010; CONAGUA, 2011.*

Wastewater can also be deployed in industry (in cooling towers and boilers, and as process water) and for toilet flushing (Asano, 2002, 2005; Bahri, 2009). Technological innovations are enabling water reclamation and reuse in novel ways. Advanced membrane and nanotechnologies are increasingly cost-effective and energy-efficient, and reclaimed water can even be made potable.

Indeed, in many parts of the world, direct potable reuse is expected to be the most economical and reliable means of meeting future water demand. Wastewater that has been treated by conventional means is further treated to remove any remaining suspended and dissolved matter, including trace organics; once purified, it enters water treatment plants or goes directly into the water distribution systems (Schroeder et al., 2012). Windhoek, Namibia, has been practicing direct potable reuse since 1968 with highly treated wastewater blended with other drinking water sources. Reclaimed water makes up close to 35 percent of the city's drinking water. Potable reuse, despite its potential difficulties elsewhere, is an indispensable element of the Windhoek water system and has proven to be a reliable and sustainable option. A case study of Southern California shows that its wastewater stabilises water supplies for a large urban population and a major agricultural region; creates energy savings, ranging from 0.7 to 1 terawatt hours per year; and saves approximately US$50–$87 million annually (Schroeder et al., 2012).

## 7.3. Stormwater management

Stormwater management can mitigate intense rainfall events and enhance local water sources. Cities that suffer from flooding have several options for urban stormwater management, such as using retention ponds, permeable areas, infiltration trenches and natural systems to slow the water down. Lodz, Poland, and Belo Horizonte, Brazil, both use such systems, and Birmingham, England, is experimenting with green roofs to achieve the same effect (SWITCH, 2011). Green areas take up water and provide ecosystem services at lower costs than conventional stormwater drainage systems (Bolund and Hunhammar, 1999), in which urban runoff and stormwater become polluted and must be treated.

### *7.3.1. Rainwater harvesting*

Rainwater harvesting can help address water scarcity at the household level and may be easy and cost-effective to implement. Flow- or roof-water harvesting provides a direct water supply and can recharge groundwater, while reducing flooding. Such measures may be an immediate solution to accompany long-term infrastructure improvements in water supply and drainage. To date, comprehensive documentation of the design criteria, costs, benefits, impacts, and constraints of large-scale adoption is generally lacking and would be needed to evaluate the viability of scaling up.

### *7.3.2. Desalination*

Desalination of brackish water and seawater is becoming increasingly economical, thanks to advanced membrane technologies and improved energy efficiency (Bergkam and Sadoff, 2008; Blue Plan-MAP-UNEP, 2007). The cost of producing desalinated water is estimated at $0.60-$0.80 per cubic meter (Blue Plan-MAP-UNEP, 2007). In countries that have exhausted most of their renewable water resources, desalinated water meets both potable and industrial demand. Although its use in agriculture remains limited, desalinated water is increasingly supporting the cultivation of high-value crops in greenhouses (Blue Plan-MAP-UNEP, 2007).

## 7.4. Technologies that support IUWM

A range of innovations – not just new technologies, but new ways of using existing technologies – is being used in IUWM.

### *7.4.1. Membranes*

Advanced treatment technologies are increasingly becoming the preferred choices for water, wastewater, and stormwater treatment. They help cope with stringent standards, enhance capacities (hence, reduce their footprints), and address contaminants that cannot be managed with conventional technologies. Due to their better capabilities and performances, membrane-based technologies and membrane bioreactors are penetrating the markets in many water-scarce regions because they enable recycling of wastes and use of alternative sources (such as brackish water and seawater).

The cost of membrane systems has dropped dramatically in the last decade. Robust and durable membrane materials, as well as low-energy membrane systems (in some cases, gravity driven) are being developed. Other technologies, such as photovoltaic systems with a renewable power source (solar driven) and oxidation processes, which can be enhanced with catalytic processes in combination with membrane systems, are coming into the market. This trend will enable utilities to upgrade their systems.

### *7.4.2. Nanotechnology and microbial fuel cells*

Nanotechnology concepts are being investigated for higher performing membranes with less fouling properties, improved hydraulic conductivity, and more selective rejection/transport characteristics. Microbial fuel cells, a potential breakthrough technology that will be able to capture electrical energy directly from organic matter present in the waste stream in the process of microbial activities, are emerging. Although these technologies are still in the early stages of development, and significant advances in process efficiency, demonstration, and production to commercial scale are necessary, they have the potential to enhance treatment-process performances and improve efficiency of resources use.

### *7.4.3. Natural treatment systems*

Natural Treatment Systems (NTSs) use natural processes to improve water quality, to maintain the natural environment, and to recharge depleting groundwater sources. For example, NTSs are increasingly being used to treat and retain stormwater, wastewater, and drinking water flows. NTSs have the advantage of being able to remove a wide variety of contaminants at the same time, which makes them a total treatment system on their own, and they are increasingly being used for water reclamation.

### *7.4.4. Source separation of waste streams*

Key to the application of the most of the new treatment technologies is the separation of the different flows of wastewater according to their pollution load. Most of the contaminants of concern in wastewater are contained in black water. For example, most of the organic and microbial contaminants are generated from faecal matter (which accounts for only 25 percent of domestic waste), while most of the nitrogen and the emerging contaminants, such as pharmaceutically active compounds and endocrine disrupting compounds, are present mainly in urine.

New technologies, such as vacuum sewage systems and urine separation toilets, which reduce most of the nitrogen and trace organic contaminants, have made it possible to handle a small and concentrated amount waste. These technologies create opportunities for reuse of grey water at the source and recovery and reuse of nutrients. They also reduce the cost of extensive sewer systems and minimise (even avoid) use of clean water to carry waste.

An overview of innovative technologies that support IUWM is provided in Table 4.

**Table 4. Innovative technologies and their benefits for IUWM**

| Innovative technology | | Benefits for IUWM |
|---|---|---|
| 1 | Natural treatment system | • Adds multi-functionality (integrated treatment and environment functions).<br>• Improves environmental quality.<br>• Utilises natural element, features and process (soil, vegetation, microorganisms, water courses, etc.).<br>• Is robust and flexible/adaptive.<br>• Minimises the use of chemicals and energy.<br>• Promotes water reuse and nutrient recovery. |
| 2 | Nanotechnology and microbial fuel cells | • Provide access to a cheap 'green' energy source (enables the capture of electrical energy directly from organic matter present in waste stream). |
| 3 | Membrane bioreactors (wastewater) | • Enhance new strategy for water management to move towards water reuse.<br>• Reducing plant footprint.<br>• Can easily retrofit wastewater treatment processes for enhanced performances.<br>• Offers operational flexibility (amenable to remote operation).<br>• Manages environmental issues (visual amenity, noise and odour). |
| 4 | Membrane technologies (both water and wastewater) | • Promote decentralised systems which minimise environmental footprint.<br>• Enhance contaminants removal and encourage water recycling.<br>• Minimise the use of chemicals.<br>• Improve system flexibility and permit small-scale treatment systems. |
| 5 | Source separation | • Promotes water reuse and nutrient recovery.<br>• Promotes small (decentralised) systems that can be easily managed.<br>• Avoids the complications and cost of dealing with mixed wastes. |
| 6 | Anaerobic fermentation (UASB) | • Produces biogas.<br>• Promotes the recovery of energy from wastewater. |

## 7.5. Finding the appropriate scale

Implementing these technologies at appropriate scales allows urban water-management systems to make the most of every drop of water. In semi-centralised systems, water is abstracted, used, treated, reused, and discharged over short distances. The semi-central systems encourage advanced treatment technologies for wastewater, which enable grey water recycling, as well as closing the black water loop in a decentralised setting (Otterpohl et al., 2003).

Key to the application of most new treatment technologies is the ability to separate the different flows of wastewater according to their pollution load. For domestic users, brown water (faecal matter), yellow water (urine), greywater (wastewater from sinks, showers, washing machine, etc.) and stormwater (runoff from rainfall) are managed independently.

Semi-centralised systems have water saving potentials of up to 80 percent of fresh water consumption (Bieker et al., 2010; Otterpohl et al., 2003). Hence, semi-centralised systems can help address the problems arising from water scarcity, as well as rapid urbanisation. In addition, the technologies that enable the minimising of the energy demand for water transport and the recovery of energy from wastewater (such as heat recovery from greywater and the production of biogas from brown water) can be employed. The concepts of semi-central treatment systems are already in place in Qingdao, China, and Hanoi, Vietnam (Bieker et al., 2010).

## 7.6. Flexible and adaptable urban water systems

Given the various uncertainties and pressures associated with population growth and climate change, cities need flexible systems that are able to cope with uncertainties and adapt to new or changing requirements (Ashley et al., 2007; Schmitt, 2006). The key is building in 'flexibility options'. These options may relate to the technical aspect of the design that enables the system to adapt to its environment or to management decisions during the planning and operation of the system (de Neufville, 2002).

A modular approach to urban water system design increases the number of possible configurations from a given set of inputs (complex adaptive systems). SWITCH (ICLEI, 2011) has developed a diverse repertoire of alternative options for urban water systems, which have internal degrees of freedom that optimise their flexibility and sustainability over time. For example, in relation to stormwater management, small-scale decentralised measures, such as infiltration devices, have the ability to respond to changes in boundary conditions.

In relation to flexible sanitation systems, there is a progressive shift from centralised mixed systems to decentralised systems, based on source control and separate treatment of concentrated and diluted household wastewater flows. In relation to process technologies for water and wastewater treatment, the use of natural systems is becoming more popular. One of the main features of these natural systems is their adaptability to almost all conceivable applications, and improved renewal and readjustment opportunities (essential for flexibility).

## 7.7. Tariffs, payments, and other economic tools

Water services tend to be local government responsibilities (Serageldin, 1994). However, in the Global South, local government revenues are often insufficient to keep pace with demographic changes and physical developments. At the same time, the cost-recovery potential of commercial service providers is constrained by users' low average incomes.

In addition, the willingness to pay for water often varies with the quality of service, thus insufficient revenue for operation and maintenance can lead to a cycle of deteriorating service and decreasing cost recovery.

While water prices that reflect water scarcity conditions and the true costs of developing and delivering water supplies can encourage more efficient water management by all water users, water pricing must also continue to account for the role of water as social good. This needs to be kept in mind when planning water tariffs, so that the rights of vulnerable groups are protected (Visscher et al., 1999; Peña, 2011). The charging mechanisms adopted must be appropriate and reflect both local socio-cultural and economic conditions.

### *7.7.2. Financial and investment tools*

Investments by national governments to develop water resources have traditionally been overshadowed by investments in transport, energy, telecommunications, and the military. International agencies have had limited budgets for urban water and sanitation (Hardoy et al., 2001). The share of private financing in water infrastructure projects has also been relatively small; of the total private infrastructural investments between 1990 and 2002, a mere 5.4 percent went into the development of water systems (OECD, 2003). Fiscal transfers and cross-subsidies may be needed to tackle resource depletion and inequality (UNDP, 2006).

### *7.7.3. Payment for ecosystem services*

Some financing strategies have sought to capitalise on the value of ecosystem services for the health, food security, and livelihoods of both urban and rural communities. One approach gaining currency is payment for ecosystem services. Landowners and users are given incentives (often monetary) to engage in land-use practices that provide an ecological service.

Within the water sector, payment models are designed in the context of the watershed. Downstream communities, for example, pay upstream water users to refrain from practices that undermine the integrity of water flows and quality. Payment for ecosystem services thus amounts to a tool for joint management of natural resources across city boundaries (DST, 2008; Mafuta et al., 2011).

## 7.8. Resilience to climate change

Practical measures to promote IUWM – including efforts to integrate the urban water cycle and urban management sectors, improve the efficiency of water use and distribution, and ensure wastewater recycling, flood protection and transboundary management – also help cities build resilience against climate change (UN WWAP, 2011).

As with all practical IUWM approaches, the costs and benefits of tools to climate-proof the water sector must be carefully weighed. Natural and artificial water storage, for instance, controls flooding and secures access to water during dry periods (WHO and DFID, 2009), but not all countries can afford water storage infrastructure. If transport and delivery networks are inadequate, water storage facilities themselves do not ensure water security. Moreover, building water storage without simultaneously improving water use efficiency may create a false impression of abundance and inadvertently hasten depletion of the resource (Sadoff and Muller, 2009).

In the past, cities favoured large-scale infrastructure solutions, but these ‘hard’ systems, and the institutional rigidity that supports them, struggle to accommodate unexpected circumstances. ‘Stationarity’ is the assumption that changes in natural systems will not exceed what has been seen in historical observations; spare capacity in supply, wastewater, and stormwater infrastructures is built accordingly (Loftus, 2011). Anthropogenic climate change is now undermining the basic assumption of stationarity and the management approaches that it supports (Milly et al., 2008).

Demand management, development of alternative sources, and other flexible approaches are likely to be less vulnerable to changed circumstances. Decentralisation is another: several small-scale natural treatment systems in different locations may represent less risk than a single large wastewater treatment plant, for example. In certain contexts, decentralised systems may be easier to install and more cost-effective to maintain (Loftus, 2011).

## 8. THE FUTURE OF URBAN WATER GOVERNANCE

Sound urban water governance is fundamental to ensuring human and environmental health. It requires robust national policies, plans, and programmes, as well as instruments to measure and benchmark progress. Urban areas need to move from a status of water users to that of water suppliers and managers. With today's technologies and management options, water quantities and qualities can be managed more effectively and efficiently for different purposes.

Integrated approaches can deliver water to specific users in appropriate quantities, qualities, and at appropriate times, without compromising the availability of the resource for others. Managers can tackle existing, or prevent impending, water scarcity by promoting water use efficiency and alternative sources of water, including wastewater and stormwater. New approaches to the collection, transport, treatment and management of sewage can improve resource recovery and mitigate the strain on water resources under challenges such as high population density, urban sprawl, and climate change.

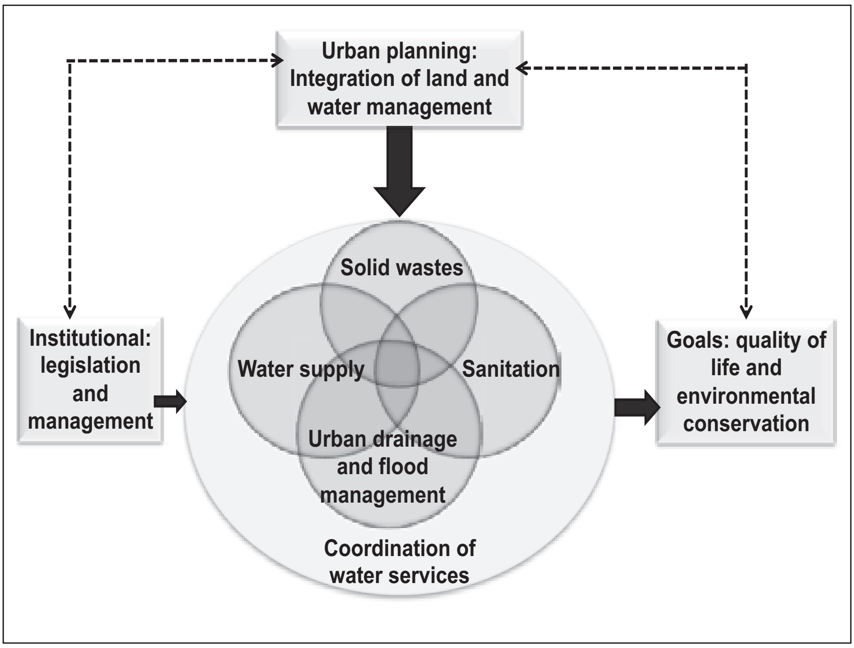


*Figure 8. Integrated Urban Water Management*
*Source: Tucci, 2009.*

IUWM requires the development of planning and management for all components of urban water services (Figure 8). These services are interconnected and require a high level of integration. Coordinating structures and forums will ensure communication between departments, between levels of government, and with communities and stakeholders.

Urban planners have an important role in helping governments overcome fragmentation in public policy formulation and decision making by linking planning with the activities of other policy sectors, such as infrastructure provision, and adopting collaborative approaches that involve all stakeholders in determining priorities, actions, and responsibilities (Figure 9). This may involve new methods for interagency coordination and control of water use, such as a new institution or executive committee that has the authority and capacity to regulate and enforce standards and procedures.

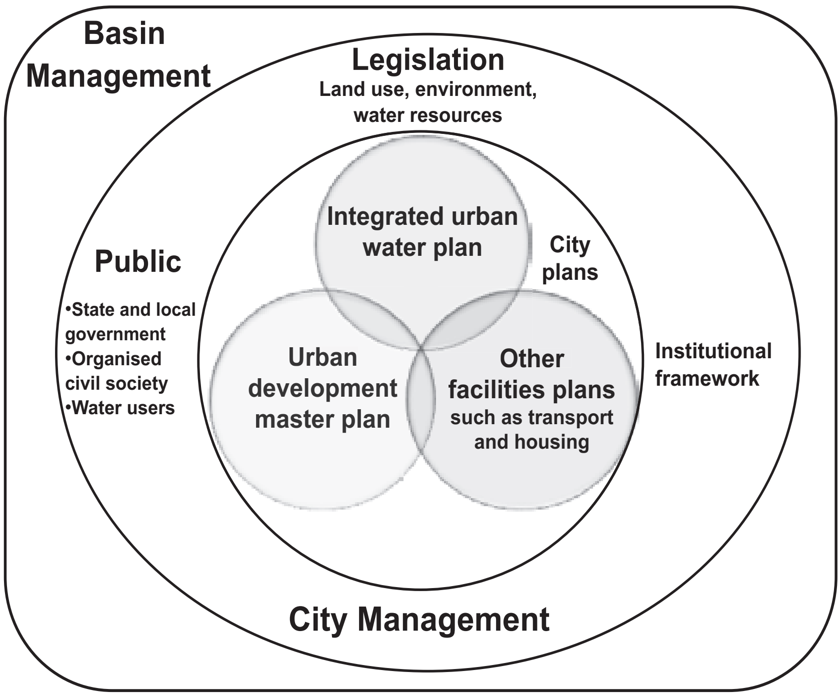


*Figure 9. Framework for integrated urban water management and land use planning*
*Source: Adapted from Tucci et al., 2010.*

Integrated urban water policies based on participatory, democratic, and pluralistic governance can secure sustainable development, particularly if governments adopt clear urban policies as an integral part of their economic policies (UNEP, 2002). Changes will be necessary to shift attitudes and stimulate innovative, efficient, and sustainable ways to manage the water resource.

## 8.1. Key messages

### *8.1.1. IUWM*

1. IUWM is the improved and efficient management of various water quantities and qualities for different purposes within the urban area. It encompasses conventional and alternative water sources: freshwater (surface water, groundwater, rainwater, desalinated water), wastewater (black, yellow, brown, grey, and reclaimed water), and stormwater within the resource management structure, i.e. the urban area.
2. IUWM calls for the alignment of urban development and basin management agendas in order to ensure sustainable economic, social, and environmental relations along the urban-rural continuum.
3. IUWM is an adaptive and iterative process that allows cities to respond to change.
4. IUWM encompasses environmental, economic, social, technical, and political aspects of water management. A successful IUWM approach requires a structured process engaging communities to reflect their needs and knowledge of water management.

### *8.1.2. Institutions, policies, and regulations*

*Cross-sectoral relationships*

1. Achieving sutainable urban development requires attention to the relationships between water resources, energy, and land use.
2. The development of eco-cities can enable the use of waste products to satisfy urban energy and material needs.
3. City-wide budgets and resource-wide plans can facilitate cross-sectoral relationships. But, their maintenance demands establishing a common working culture, clearly articulating collective goals and respective benefits, and negotiating differences in power and resources.

*Role of governments*

1. Governments should take on a more central role in cities and towns, in order to lead development initiatives and ensure that basic needs are met.

2. Special attention needs to be given to supporting the urban informal sector, which is vital for a sustainable urban economy.
3. In cooperation with both public and private sector partners, policies and strategies should be developed to facilitate the implementation of IUWM at the local and national levels. These policies and strategies should be supported by financing strategies, technological developments, and tools for decision making for IUWM.

*Urban planning*

1. Urban planning has an important role to play in assisting governments to meet the urban challenges. It can help overcome governance fragmentation in public policy formulation and decision-making, by linking planning with the activities of other policy sectors, such as infrastructure provision.
2. Climate change predictions should be incorporated into urban water-supply planning.
3. Urban planning and management can be improved by adopting collaborative approaches that involve all key stakeholders and enable agreement on priorities, actions, and allocation of responsibilities between relevant agencies.
4. Most cities in the developed world have followed a linear process of providing water supply systems, then piped sewers, and finally drainage systems. However, in the many emerging small urban towns and cities, which lack full infrastructure systems, there are opportunities to implement innovative, cost-effective approaches that would enable an IUWM approach from the outset.

*Capacity-building*

Capacity-building of personnel and institutions engaged in IUWM is needed to ensure they can deliver what is expected from them. Where there are no clear national policies on water management, IUWM can guide local and urban councils in devising policies that clearly state the direction of water management. Water policies must be backed by effective legislation to give life to the policies.

### *8.1.3. Technologies and practices*

1. Advanced technologies, such as membrane technologies, nanotechnology and microbial fuel cells, natural treatment systems, and treatment systems with source separation, have great potential for IUWM. Similarly, some of the innovative approaches to urban water system planning, including planning for multiple benefits in urban water uses

and semi-centralised and decentralised system design, enable efficient resources use, reuse, and recovery in an urban area.

2. Design of adaptable and flexible infrastructure systems that are responsive to future changes, pressures, and associated uncertainties will ensure improving the systems performance, reduce risks of systems failures, and optimise life-cycle costs in development.

3. There is a range of technology and management options that can be implemented (small piped water works; affordable and sustainable local or on-site water supply; sanitation services and technologies along the value chain; rainwater harvesting techniques; new technologies and approaches for wastewater treatment and recycling; and new business models).

*Water savings*

1. Water resources assessments determine the quantities and qualities of water in a given water resource base, and the current and expected demands that are placed upon it.
2. The sustainability of operations and investments for water, wastewater, and stormwater require improving the economic efficiency of services.
3. Efficiency measures minimise water losses during transport, storage, and use. Reducing water loss involves aspects related to design, construction, and operation and maintenance of systems, as well as changes in user behaviour.
4. Nonrevenue water reduction is an important strategy for conserving scarce water resources. In places, this may be achieved through increased cooperation with the private sector – whether small-scale entrepreneurs and enterprises, or large-scale contractors. Different types of partnership arrangements are available; their appropriateness must be assessed on a case-by-case basis.

*Multiplying and diversifying sources for future reliability*

1. Diversifying the urban water supply portfolio is a central feature of IUWM. A critical component of future reliability is the development and management of local supplies and conservation programmes. Water conservation, local runoff, imported water, desalination, and groundwater may offer some opportunities in the future. But cities must diversify their sources of water and increase the use of locally produced water (through rainwater harvesting and water reuse) to assure an adequate and reliable supply for the future.
2. Water reclamation and reuse provides an opportunity to augment tra-

ditional water supplies and to use the city's water supplies efficiently. Water reuse can help to close the loop between water supply and wastewater disposal. Effective water reuse requires integration of water and reclaimed water supply functions. The successful development of this water resource depends upon an integrated approach and careful consideration of the institutional, organisational, regulatory, socio-economic, policy pricing, environmental, and technical aspects.

*Participation*

1. Participatory planning at the project level can result in more appropriate design and significant resident contributions, leading to improved living conditions in low-income settlements.
2. Participation by residents in planning and implementation of practical improvements in areas where they live and work, in municipal budgeting, and in local plan preparation has positive outcomes and can be scaled up to play a role in city-level planning.
3. Participatory processes engage with urban water supply and sanitation for poor or otherwise marginalised communities.

***8.1.4. Financing***

*Business opportunities along the entire value chain*

Business opportunities exist along the entire value chain. Encouraging small-scale entrepreneurs to seize these business opportunities through provision of credit and information may also enhance the sustainability of services.

*Tariffs*

1. A sound pricing policy can encourage revenue generation. Such policies must take into account existing incentives and practices. Differential tariffs that account for water quality can serve as incentives to limit the use of surface water or groundwater in favour of reclaimed water, for example.
2. Water prices and allocations should reflect the true costs of developing and delivering water supplies. Accurate prices will encourage wise water management by all water users, consistent with an integrated urban water management strategy.
3. Tariff systems, taxes, and subsidies can be used to transfer benefits to vulnerable groups without diminishing the economic productivity of water resources. If tariffs are too low to support sustainable operation and maintenance, instead of favouring poorer consumers, the system may contribute to greater inequality. Pricing instruments, such as

increasing block-rate structures and charges for excess use, are set so that users pay more for higher levels of consumption. Other financial incentives, such as rebates, subsidised retrofits and water audits, seasonal pricing, and zonal pricing, can also be used.

*Investments*

1. IUWM projects require significant levels of funding for both capital and operation and maintenance costs. Public agencies in many countries, however, have limited ability to invest in water infrastructure. Appropriate policies and well-functioning institutions can facilitate fund-raising. Programs that generate revenue by charging water users a fee per unit of effluent they generate (the polluter pays principle) can improve the cost-effectiveness of treatment and reuse, particularly when the revenue is fed into the construction of facilities for collecting, treating, and reusing wastewater.

## REFERENCES

Abaidoo, R., Keraita, B., Drechsel, P., Dissanayake, P. and Maxwell, A. 2009. Soil and crop contamination through wastewater irrigation and options for risk reduction in developing countries. In P. Dion (Ed.) *Soil Biology and Agriculture in the Tropics*. Springer Verlag, Heidelberg.

Abderrahman, W. 2000. Urban water management in developing arid countries. *Water Resources Development*. Vol. 16. pp. 7–20.

ADB (Asian Development Bank). 2010. *Every* Drop Counts: Learning from good practices in eight Asian cities. Asian Development Bank, Mandaluyong City, Philippines.

AfDB (African Development Bank). 2011. Rapid urbanization and the growing demand for urban infrastructure in Africa. *Market Brief*. Vol. 1. Issue 1. pp. 1-12.

Angel, S., Parent, J., Civco, D.L. and Blei A.M. 2011. Making Room for a Planet of Cities. Lincoln Institute of Land Policy, Cambridge, MA.

Asano, T. 2002. Water from (waste)water – The dependable water resource, Water Science and Technology 45/8 (2002) 23–33.

Asano, T. 2005. Urban water recycling. *Water Science and Technology*. Vol. 51. No. 8. pp. 83–89.

Ashley R., Blanksby J., Cashman A., Jack L., Wright G., Packman J., Fewtrell L., Poole T. and Maksimovic C. 2007. Adaptable Urban Drainage: Addressing change in intensity, occurrence and uncertainty of stormwater (AUDACIOUS), in: Built Environment, 33: 70 – 84.

Bahri, A. 2009. Managing the other side of the water cycle: Making wastewater an asset. *Global Water Partnership (GWP) Technical Committee (TEC) Background Paper No 13*. Global Water Partnership, Stockholm.

Bahri, A., Sally, H., McCartney, M., Namara, R., Awulachew, S., Van Koppen, B. and Van Rooijen, D. 2011 "Integrated Urban Watershed Management: Towards sustainable solutions in Africa" In Garrido, A.; Ingram, H. (Eds.). Water for food in a changing world. London, UK: Routledge. pp. 50-70. (Contributions from the Rosenberg International Forum on Water Policy).

Barton, A.B., Smith, A.J., Maheepala, S. and Barron, O. 2009. Advancing IUWM through an understanding of the urban water balance. 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009. http://mssanz.org.au/modsim09. 7 p.

Baxamoosa, S. 2009. Karachi Water Partnership. Review of Phase 1 (January 2007- December 2008). Hisaar Foundation. 38 p.

Barton, A.B., Smith, A.J., Maheepala, S. and Barron, O. 2009. Advancing IUWM through an understanding of the urban water balance. 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009. http://mssanz.org.au/modsim09. 7 p.

Baxamoosa, S. 2009. Karachi Water Partnership. Review of Phase 1 (January 2007- December 2008). Hisaar Foundation. 38 p.

Bayrau, A., Boelee, E., Drechsel, P. and Dabbert, S. 2009. Wastewater Use in Crop Production in Peri-urban Areas of Addis Ababa: Impacts on health in farm household, *Environment and Development Economics* (in press).

Bergkamp, G. and Sadoff, C. 2008. Water in a Sustainable Economy. In State of the World: Innovations for a Sustainable Economy. Washington, DC: Worldwatch Institute.

Bieker, S., Cornel, P., and Wagner, M. 2010. Semi-centralised supply and treatment systems: integrated infrastructure solutions for fast growing urban areas. Water Science and Technology, Vol. 61(11), pp. 2905-2913.

Biswas, A., Lundqvist, J., Tortajada, C. and Varis, O. 2004. ”Water management for megacities” *Stockholm Water Front*. Vol. 2. pp. 12–13.

Blue Plan, MAP (Mediterranean Action Plan), and UNEP (United Nations Environment Programme). 2007. Water Demand Management, Progress and Policies: Proceedings of the 3rd Regional Workshop on Water and Sustainable Development in the Mediterranean. Zaragoza, Spain, 19-21 March. MAP Technical Reports Series 168. Athens: United Nations Environment Programme.

Bolund, P. and Hunhammar, S. 1999. Ecosystem services in urban areas. *Ecological Economics*. Vol. 29. pp. 293-301.

Braga, B., Porto, M. F. A. and Silva, R.T. 2006. Water Management in Metropolitan São Paulo. International Journal of Water Resources Development. , Vol. 22, pp.337-352.

Browder, G. 2011. Blue water, green cities. An initiative from the World Bank for integrated urban water managemenmt in Latin America. Presentation at the 2011 World Water Week. August 24, 2011.

Brown, R.R., Mouritz, M. and Taylor, A. 2006. Institutional capacity. In: Wong, T.H.F. (ed.) Australian Runoff Quality: A Guide to Water Sensitive Urban Design. Engineers Australia, Barton, Australian Capital Territory, pp. 5-1–5-22.

Brown, R., Keath, N. and Wong, T. 2008. Transitioning to Water Sensitive Cities: Historical, Current and Future Transition States. *11th International Conference on Urban Drainage*. Edinburgh, Scotland, UK, 2008.

Brown, P. 2009. The changing face of urban water management. *Water 21*. February 2009. pp. 28–30.

Cohen, B. 2004. Urban Growth in Developing Countries: A Review of Current Trends and a Caution Regarding Existing Forecasts. *World Development*. Vol. 32. No. 1. pp. 23–51.

CONAGUA, Comisión Nacional del Agua. National Water Commission. 2011.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D. and Savelli, H. (Eds). 2010. Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal.

Dagerskog, L., Coulibaly, C. and Ouandaogo, I. 2010. The emerging market of treated human excreta in Ouagadougou. In: UA Magazine no 23 - Urban nutrient management, pp. 45-48.

Danilenko, A., Dickson, E. and Jacobsen, M. 2010. Climate change and urban water utilities: challenges and opportunities. *Water Working Note No. 24*. Word Bank, Washington, D.C.

Delli Priscoli, J. and Wolf, A.T. 2009. Managing and Transforming Water Conflicts. International Hydrology Series. Cambridge University Press, Cambridge, UK.

de Neufville, R. 2002. Architecting/Designing Engineering Systems Using Real Options. Monograph, Engineering Systems Division Internal Symposium, Massachusetts Institute of Technology.

DST (Desakota Study Team). 2008. Re-imagining the Rural-Urban Continuum: Understanding the role ecosystem services play in the livelihoods of the poor in desakota regions undergoing rapid change. Research Gap Analysis prepared by the Desakota Study Team (DST) for the Ecosystem Services for Poverty Alleviation (ESPA) Program of Natural Environment Research Council (NERC), Department for International Development (DfID) and Economic and Social Research Council (ESRC) of the United Kingdom. Institute for Social and Environmental Transition-Nepal (ISET-N), Kathmandu, Nepal.

Friedmann, J. and Wolff, G. 1982. World city formation: an agenda for research and action. *International Journal of Urban and Regional Research*. Vol. 6. No. 3. pp. 309–344.

FUSP. 2009. Plano da Bacia do Alto Tietê. Comitê da Bacia Hidrográfica do Alto Tietê. São Paulo. Brasil.

Giesen, N., Andreini, M., Edig, A. and Vlek, P. 2001. *Competition for water resources of the Volta Basin. Regional Management of Water Resources,* Maastricht, IAHS Publ. No. 268.

Ginsburg, N., Koppel, B., and McGee, T.G. (Eds.). 1991. *The extended metropolis: settlement transition in Asia*. University of Hawaii Press, Honolulu.

Grumbles, B.H. 2011. Managing One Water. Water Resources Impact. Vol. 24. pp. 25-27

GWP (Global Water Partnership) TAC (Technical Advisory Committee). 2000. Integrated Water Resources Management. *TAC Background Paper No. 4*. Global Water Partnership, Stockholm.

GWP (Global Water Partnership). 2010. Briefing Note: IWRM Principles and Processes: From Advocacy to Action. Accessed online (19.10.2011):http://www.gwp.org/Global/The%20Challenge/Resource%20material/Briefing_Note_Changing%20Lives.pdf

ICLEI (Local Governments for Sustainability). 2011. SWITCH Training kit module 1 SWITCH, Delft, The Netherlands.

Hall, P. 1966. *The world cities*. London: World University Press.

Hamilton A.J., Stagnitti F., Xiong X., Kreidl S.L., Benke K.K. and Maher P. 2007. Wastewater irrigation the state of play. *Vadose Zone Journal*. Vol. 6. No. 4. pp. 823-840.

Hardoy, J.E., Mitlin, D. and Satterthwaite, D. 2001. Environmental Problems in an Urbanizing World: Finding Solutions for Cities in Africa, Asia and Latin America. Earthscan, London.

Hussein, M. A. 2008. Costs of Environmental Degradation: An Analysis in the Middle East and North Africa Region. *Management of Environmental Quality*. Vol. 19. No. 3. pp. 305-17.

Hutton, G. and Haller, L. 2004. Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level. World Health Organization, Geneva.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Synthesis Report. *Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva.

Jiménez, B. and Chavez, A. 2004. Quality assessment of an aquifer recharged with wastewater for its potential use as drinking source: 'El Mezquital Valley' case. *Water Science and Technology*. Vol. 50. No. 2. pp. 269–273.

Jiménez, B. 2008. Water and Wastewater Management in Mexico City. In Mays, L. (Ed.) *Integrated Urban Water Management in Arid and Semi-*

*arid Regions around the World*. Taylor & Francis Group Ltd., Paris, France. pp. 81-112.

Jiménez, B. 2010. The unintentional and intentional recharge of aquifers in the Tula and the Mexico Valleys: The Megalopolis needs Mega solutions. Paper presented at Rosenberg Symposium, Buenos Aires, Argentina.

Jiménez, B., Drechsel, P., Koné, D., Bahri, A., Raschid-Sally, L., and Qadir, M. 2010. Wastewater, Sludge and Excreta Use in Developing Countries: An Overview. In Drechsel, P., Scott, C.A., Raschid-Sally, L., Redwood, M., and Bahri, A., (Eds.) *Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-Income Countries*. Earthscan, London.

Kamal-Chaoui, L. and Robert, A. 2009. Competitive Cities and Climate Change. *OECD Regional Development Working Papers 2009/2*. OECD Public Governance and Territorial Development Directorate, Paris.

Keraita, B., F. Konradsen, P. Drechsel, and Abaidoo, R. C. 2007. Effect of Low-Cost Irrigation Methods on Microbial Contamination of Lettuce Irrigated with Untreated Wastewater. *Tropical Medicine and International Health*. Vol. 12. Issue. 2. pp. 15-22.

Keraita, B., Jiménez, B. and Drechsel, P. 2008. Extent and implications of agricultural reuse of untreated, partly treated and diluted wastewater in developing countries. *Agriculture, Veterinary Science, Nutrition and Natural Resources*. Vol. 3. No. 58. pp 1-15.

Khatri, K., and Vairavamoorthy, K. 2007. Challenges for urban water supply and sanitation in the developing countries. Symposium 13-15 June, 50th Anniversary UNESCO-IHE, Delft.

Kingdom, B., Liemberger, R. and Marin, P. 2006. The challenge of reducing non-revenue water (NRW) in developing countries. How the private sector can help: A look at performance-based service contracting. *Water and Sanitation Sector Board Discussion Paper Series*. No. 8.World Bank: Washington, D.C.

Loftus, A. 2011. Adapting urban water systems to climate change: A handbook for decision-makers and the local level. ICLEI, UNESCO-IHE and IWA.

Mafuta, C., Formo, R. K., Nellemann, C., and Li, F. (Eds.). 2011. Green Hills, Blue Cities: An Ecosystems Approach to Water Resources Management for African Cities. *A Rapid Response Assessment*. United Nations Environment Programme, GRID-Arendal.

Mays, L.W., Koutsoyiannis, D. and Angelakis, A.N. 2007. A brief history of urban water supply in antiquity. *Water Science and Technology: Water Supply*. Vol. 7. No. 1. pp. 1–12.

McEvoy, D., Lindley, S. and Handley, J. 2006. Adaptation and mitigation in urban areas: Synergies and conflicts. *Proceedings of the Institution of Civil Engineers. Municipal Engineer 15*9. Issue ME4. pp. 185-191

McGee, T.G. 1991. The emergence of desakota regions in Asia: expanding a hypothesis. In N. Ginsburg, B. Koppel, & T. G. McGee (Eds.) *The extended metropolis: settlement transition in Asia*. University of Hawaii Press, Honolulu. pp. 3-25.

Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P. and Stouffer, R.J., 2008. Stationarity Is Dead: Whither Water Management? Policy Forum, Science, Vol. 319, pp. 573-574. http://aquadoc.typepad.com/waterwired/files/milly_et_al.pdf

Moddemeyer, S. 2010. Generating demand for integrated urban water management. *Water 21*. pp. 13-14.

Molle, F. and Berkoff, J. 2006. Cities versus Agriculture: Revisiting Intersectoral Water Transfers, Potential Gains and Conflicts. *Comprehensive Assessment Research Report 10*. International Water Management Institute, Colombo.

Najjar, K.F. and Collier, R. 2011. Integrated water resources management: bringing it all together. *Water Resources Impact*. Vol. 13. No. 3. pp. 3-8.

Novotny, V. 2010. Footprint tools for Cities of the Future: Moving towards sustainable urban water use. *Water 21*. pp. 14-16.

Obuobie, E., Keraita, B., Danso, G., Amoah, P., Cofie, O.O., Raschid-Sally, L. and Drechsel, P. 2006. Irrigated urban vegetable production in Ghana – Characteristics, benefits and risks. CSIR-INSTI, Accra.

OECD (Organization for Economic Cooperation and Development). 2003. OECD Global Forum on Sustainable Development: Financing Water and Environmental Infrastructure for All. OECD, Paris.

OECD (Organization for Economic Cooperation and Development). 2008. Environmental Outlook to 2030. OECD, Paris.

Office of Water. 2010. New York: New York City and Seven Upstate New York Counties – Effective Watershed Management Earns Filtration Waiver for New York. (4606M) 816F10031 January 2010. http://water.epa.gov/infrastructure/drinkingwater/sourcewater/protection/casestudies/upload/Source-Water-Case-Study-NY-NY-City-7-Upstate-Counties.pdf

Otterpohl, R., Braun, U., and Oldenburg, M. 2003. Innovative technologies for decentralised water-, wastewater and biowaste management in urban and peri-urban areas. Water Science and Technology, Vol 48 No 11 pp 23–32.

Pagiola, S. and Platais, G., 2002. Payments for environmental services.

Environment Strategy Notes. The World Bank, Washington, D.C. USA.

Pagiola, S. and Platais, G., 2007. Payments for Environmental Services: From Theory to Practice. The World Bank, Washington, D.C. USA.

Palaniappan, M., Gleick, P.H., Allen, L., Cohen, M.J., Christian-Smith, J. and Smith, C. 2010. Clearing the Waters: A focus on water quality solutions. UNEP, Nairobi.

Peña, H. 2011. Social equity and integrated water resources management. *Global Water Partnership (GWP) Technical Committee (TEC) Background Paper No 15*. Global Water Partnership, Stockholm.

Pilgrim, N., Roche, B., Kalbermatten, J., Revels, C. and Kariuki, M. 2007. Principles of Town Water Supply and Sanitation. *Water Working Note No. 13*. Word Bank, Washington, D.C.

Pinkham, R. 1999. 21st Century Water Systems: Scenarios, Visions and Drivers, An opening presentation for an EPA Workshop on 'sustainable urban water infrastructure – a vision of future', Rocky Mountain Institute, Snowmass, Colorado, http://www.rmi.org.

PRB (Population Reference Bureau). 2012. Human popuplation: Urbanization. http://www.prb.org/Educators/TeachersGuides/HumanPopulation/Urbanization.aspx

Porto, M. 2003. Recursos hídricos na Região Metropolitana de São Paulo: um desafio do tamanho da cidade. Série Água Brasil, Vol. 4. Banco Mundial. Brasilia.

Prein, M. 1990. Wastewater-fed fish culture in Germany. In Edwards, P. and Pullin, R.S.V. *Wastewater-Fed Aquaculture. Proceedings of the International Seminar on Wastewater reclamation and Reuse for Aquaculture*. Calcutta, India, 6-9 December, 1988.

Rees, J. 2006. Urban Water and Sanitation Services: An IWRM approach. *TEC Background Paper No. 11*. Global Water Partnership, Stockholm.

Sadoff, C. and Muller, M. 2009. Water Management, Water Security and Climate Change Adaptation: Early Impacts and Essential Responses. *TEC Background Paper No 14*. Global Water Partnership, Stockholm.

Sassen, S. 2001. The global city: New York, London, Tokyo. Princeton University Press, Princeton.

Schroeder, E., Tchobanoglous, G., Leverenz, H.L. and Asano, T. 2012. Direct Potable Reuse: Benefits for public water supplies, agriculture, the environment and energy conservation. *National Water Research Institute White Paper*. National Water Research Institute: Fountain Valley, CA.

Scott, C.A., Faruqui, N. I. and Raschid-Sally, L. (Eds). 2004. Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and

Environmental Realities. CABI Publishing, Wallingford, UK.

Serageldin, I. 1994. Water Supply, Sanitation and Environmental Sustainability. *Directions in Development.* World Bank, Washington, D.C.

Shmueli, D.F. 1999. Water quality in international river basins, Political Geography, 18 (1999) 437–476.

Siddiqui, A. 2011. KWP Karachi Mega-city Case Study. Background report.

SWITCH, 2011. *SWITCH 2006-2011*: Managing water for the city of the future. UNESCO-IHE Global Partnership.

Tucci, C.E.M. 2009. Integrated urban water management in large cities: a practical tool for assessing key water management issues in the large cities of the developing world. Draft paper prepared for World Bank, July 2009.

Tucci, C.E.M., Goldenfum, J.A., and Parkinson J.N. (Eds.). 2010. Integrated Urban Water Management: Humid Tropics. *UNESCO IHP. Urban Water Series.* CRC Press

Twumasi, Y.A. and Asomani-Boateng, R. 2002. Mapping seasonal hazards for flood management in Accra, Ghana using GIS. Geoscience and Remote Sensing Symposium. IGARSS apos; 02. IEEE International. Vol. 5, pp. 2874- 2876.

UNDP (United Nations Development Program). 2006. Human Development Report 2006. Beyond Scarcity: Power, poverty and the global water crisis. UNDP, New York.

UNEP (United Nations Environment Programme). 2002. Global Environmental Outlook 3. Earthscan, London and United Nations Environment Programme, Nairobi.

UNEP (United Nations Environment Program). 2003. Water resources management in Latin America and the Caribbean. *Contribution of the Inter-Agency Technical Committee (ITC) to the Fourteenth Meeting of the Forum of Ministers of the Environment of Latin America and the Caribbean.* Panama, November 20 – 25, 2003. United Nations Environment Program, Nairobi.

UNEP (United Nations Environment Program). 2011. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. UNEP, Nairobi.

UNEP (United Nations Environment Program) & UN-Habitat (United Nations Human Settlements Programme). 2005. Coastal pollution – The role of cities. UNEP & UN-Habitat, Nairobi.

UNFPA. (United Nations Population Fund). 2007. *State* of World Population 2007: Unleashing the potential of urban growth. UNFPA, New York.

UN-Habitat. 2008. State of African Cities: A framework for addressing urban challenges in Africa. UN-Habitat, Nairobi.

UN-Habitat. 2009. Planning Sustainable Cities: Global Report on Human Settlements 2009. Earthscan, London.

UN-Habitat. 2011. Cities and Climate Change: Global Report on Human Settlements 2011. Earthscan, London.

UN-Water. 2010. Climate Change Adaptation: The pivotal role of water. *UN-Water Policy Brief*. UN-Water, New York.

UN-WWAP (United Nations World Water Assessment Programme). 2009. The United Nations World Water Development Report 3: Water in a Changing World. UNESCO, Paris and Earthscan, London.

Van der Merwe-Botha, M. 2009. Water quality: A vital dimension of water security. *Development Planning Division Working Paper No. 14*. DBSA, Midrand, South Africa.

Van der Steen, P. 2006. Integrated Urban Water Management: Towards Sustainability. *Paper presented at the first SWITCH Scientific Meeting*. University of Birmingham, UK, 9-10 Jan 2006.

Van der Steen P. and Howe C. 2009. Managing Water in the City of the Future; Strategic Planning and Science. Reviews in Environmental Science and Bio-Technology, 8, 2, p 115-120.

Van Rooijen D., Turral H. and Biggs T.W. 2005. Sponge City: Water balance of mega-city water use and wastewater use in Hyderabad, India. *Irrigation and Drainage*. Vol. 54. pp. 81-91.

Visscher, J.T., Bury, P., Gould, T., and Moriarty, P. 1999. Integrated water resource management in water and sanitation projects: Lessons from projects in Africa, Asia and South America. IRC International Water and Sanitation Centre, Delft, The Netherlands.

Watson, A., Prickett, R., Taghavi, A. and West T. 2011. California's IWRM program: a regional framework for integrated water resources management. Water Resources Impact, Vol. 13, No. 3. pp. 9-13.

WHO (World Health Organization) and UNICEF (United Nations Children's Fund) Joint Monitoring Programme (JMP). 2008. A Snapshot of Sanitation in Africa. United Nations Children's Fund, New York and World Health Organization, Geneva.

WHO (World Health Organization) and UNICEF (United Nations Children's Fund) Joint Monitoring Programme (JMP). 2010. Progress on Sanitation and Drinking-water: 2010 Update. United Nations Children's Fund, New York and World Health Organization, Geneva.

WHO (World Health Organisation). 2002. World Health Report: Reducing

Risks, Promoting Healthy Life. WHO, Geneva.

WHO (World Health Organization). 2006a. Guidelines for the Safe Use of Wastewater, Excreta and Greywater. World Health Organization, Geneva.

WHO (World Health Organization). 2006b. Economic and Health Effects of Increasing Coverage of Low Cost Water and Sanitation Interventions. UNHDR Occasional Paper, World Health Organization, Geneva.

WHO (World Health Organisation) and DFID (United Kingdom Department for International Development). 2009. Summary and policy implications Vision 2030: The resilience of water supply and sanitation in the face of climate change. WHO, Geneva and DFID, London.

WMO (World Meteorological Organization). 1997. Comprehensive Assessment of the Freshwater Resources of the World. WMO, Geneva and Stockholm Environment Institute, Stockholm.

World Bank. 2010. Cities and climate change: an urgent agenda. Vol. 10. Washington, DC: The World Bank.

Wrisberg, S. 1996. Urinseparation i København; Genopprettelse af forbindelsen mellem land og by. Institut for Jordbrugsvidenskap. Sektion For Agroøkologi, Den KGL. Veterineer Og Landbohøjskole, Fredriksberg (in Danish).

Yusuf, A.A. and Francisco, H.A. 2009. Climate Change Vulnerability Mapping for South Asia. Singapore: EEPSEA.

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