CITIES OF THE FUTURE AND URBAN WATER MANAGEMENT

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ABSTRACT

Cities of the future are likely to experience difficulties in efficiently managing scarcer and less reliable water resources. To address these difficulties successfully, there is a need to change significantly the way we manage urban water cycle. There are several key concepts that underlie this change including: flexible and robust system design, interventions over the entire urban water cycle; reconsideration of the way water is used (and reused); and greater intervention of natural systems for water and waste water treatment. Clearly changes based around these concepts will substantially contribute to a reduction in the vulnerability of cities and an increase in their capacity and preparedness to cope with global changes. SWITCH is a research project that aims to create this change by developing scientific, technological and socio-economic solutions for the sustainable and effective management of water in the city of the future – 2050.

1.0 INTRODUCTION

It is widely accepted that one of the major challenges of the 21st century is to provide safe drinking water and basic sanitation for all. Presently, more than 1 billion people lack access to improved water sources, and over 2.6 billion people lack access to basic sanitation – nearly all of these people live in developing countries (Elimelech, 2006; UNICEF/ WHO, 2004).

Providing adequate water supply and sanitation, particularly in urban areas, is a challenging task for governments throughout the world. This task is made even more difficult because of the predicted dramatic global changes such as: climate change, predicted to cause significant changes in precipitation patterns and their variability affecting the availability of water; the technological and financial challenges of maintaining and upgrading the infrastructure assets to deliver water to all sectors while maintaining the quality of water distributed to the various users; population growth, urbanization, industrial activities are leading to a dramatic increase in water consumption and wastewater discharge.

It is generally recognised that there is a need for change in the way we manage urban water; and cities are now faced with difficult future strategic decisions (e.g. the choice between centralised and the decentralised options; the choice regarding the level of involvement (consultation, joint planning, joint decision making) of individual citizens, NGOs and companies; the choice between an institutional framework where separate institutions are responsible for a certain element of the urban water system or moving to a more integrated institutional set-up).

This paper presents the challenges faced by the cities today and possible future challenges to be faced due to global change pressures in relation to urban water and presents a research project SWITCH, that proposes a way forward.

2.0 EXISTING SITUATIONS

2.1 Urban Water Supply

It has been reported that in 2002 about 1.1 billion people were using water from unimproved sources, with two thirds of them from Asia. The problem of water scarcity in urban areas is of particular concern. For example, it is estimated that by 2050, half of India's population living in urban areas will face acute water problems (UNICEF/ WHO, 2004).

Since the water quantity available for supply generally is not sufficient to meet the demands of the population, and hence water conservation measures are essential. One of the most common methods of controlling water demand is the use of intermittent supplies, usually by necessity rather than design. The Asian Development Bank (ADB, 2004), reported that, in 2001, 10 of the 18 cities studied in Asia, supplied water for less than 24 hours a day (see Figure 1 (McIntosh, 2003). The situation is similar in other regions of the world, for example in Latin America 10 major cities receives rationed supplies and in Mombasa the average duration of the service is 2.9 hours a day (Hardoy *et al.,* 2001).

Intermittent supply leads to many problems including, severe supply pressure losses and great inequities in the distribution of water. Another serious problem arising from intermittent supplies, which is generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of interruption of supply due to negligible or zero pressures in the system (Vairavamoorthy *et al.*, 2007a). In India, eighty-five per cent of urban population has access to drinking water but only 20 per cent of the available drinking water meets the health and quality standards set by the WHO (Singh, 2000).

Although in many cites water is limited and hence rationed by the application of intermittent supplies, these systems still allow excessive losses. Figure 2 (McIntosh, 2003), shows non-revenue water for the same 18 Asian cities reporting intermittent supply. What is interesting to note from Figure 1 & 2, is that it is the same cities with high intermittency that have the highest non-revenue water (i.e. where the greatest rationing of water takes place is where utilities are wasting the most water).

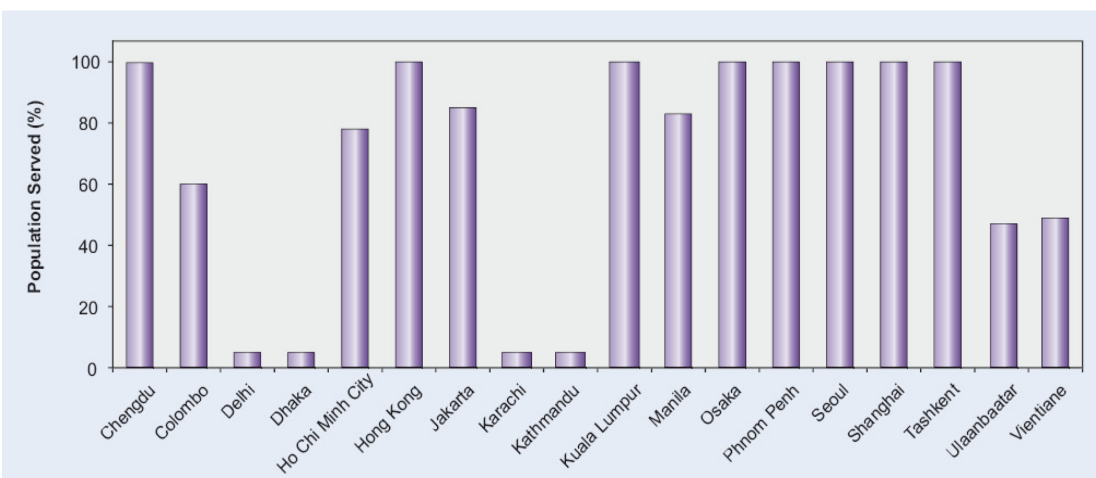

Figure 1: Population with 24-hour water supply in major cities of Asia (McIntosh, 2003)

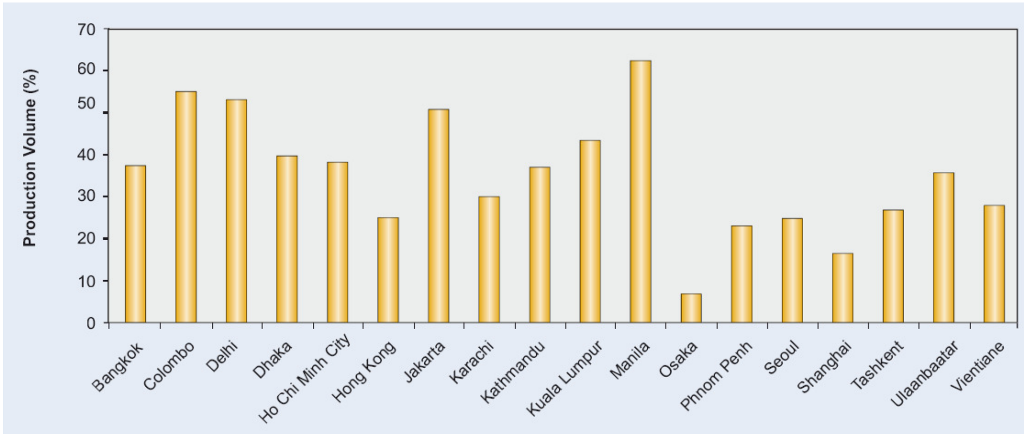

Figure 2: Mean unaccounted-for water in selected Asian cities (McIntosh, 2003)

2.2 Urban Sanitation

Only 59% of the world population had access to any type of improved sanitation facility in 2004 – in other words, 4 out of 10 people around the world have no access to improved sanitation. These people are obliged to use unsanitary facilities, with a serious risk of exposure to hygiene-related diseases.

Some 2.6 billion people, half of the developing world, live without improved sanitation (compared to 2% of the developed world). In sub-Saharan Africa the coverage is a mere 36 per cent, and in China and India there are nearly 1.5 billion people without access to improved sanitation services (WHO/UNESCO, 2006). The number of deaths attributable to poor sanitation and hygiene alone may be as high as 1.6 million a year. In order to meet the Millennium Development Goal sanitation target, 1.6 billion more people need to gain access to improved sanitation over the coming decade. Unfortunately, it is unlikely that this target will be met (it will fall short by approximately 600 million).

In developing countries, providing sanitation services especially for the urban poor who are living outside the designated residential areas like illegal settlements or slums is more challenging. The World Bank estimates that almost 26% of the global urban population, over 400 million people, lack access to the simplest latrines (World Bank, 2000). Moreover, the drainage, sewerage and solid waste collection services in these urban areas are not adequate. The systems are poorly planned, designed and operated or poorly maintained. Most of the wastes from these urban areas, are dumped and discharged directly to the open environment, and this creates unpleasant living conditions, public health risks and environmental damage (GHK, 2002).

3.0 FUTURE CHALLENGES

Cities all over the world are facing a range of dynamic regional and global pressures (Figure 3) (Khatri & Vairavamoorthy, 2007; Kelay et al., 2006; Segrave, 2007; Zuleeg, 2006). Due to these pressures, providing safe water supply, basic sanitation and maintaining the environment is likely to be more difficult in the future.

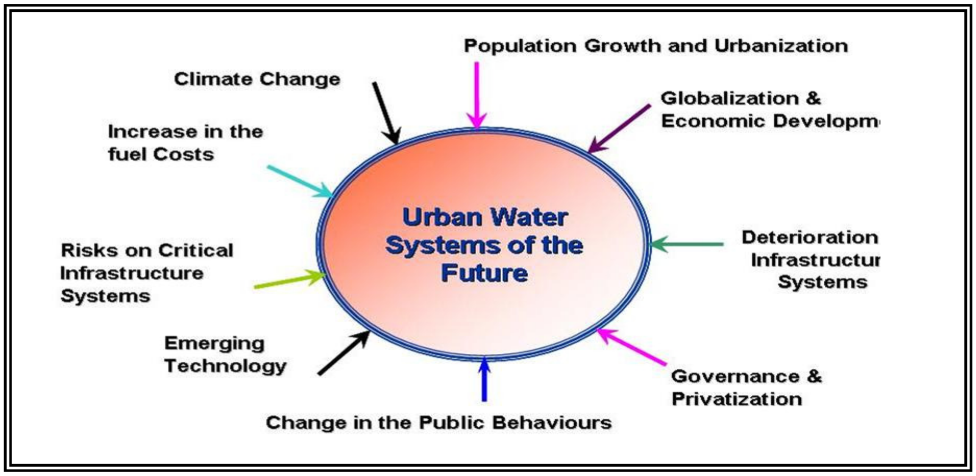

Figure 3: Global change drivers in the city of the future (Khatri & Vairavamoorthy, 2007)

Three of the major pressures are:

- Climate change: predicted to cause significant changes in precipitation and temperature patterns, affecting the availability of water and quality.
- Population growth and urbanisation: leading to a dramatic increase in high-quality water consumption, while the discharge of insufficiently treated wastewater increases costs for downstream users and has detrimental effects on the aquatic systems.
- Aging and deteriorating water related infrastructure: there is a technological and financial challenge to maintain and upgrade infrastructure in such a way that quality water can continue to be delivered to all sectors and wastewater can be adequately collected and treated.

In order to develop sustainable urban water solutions one must recognise these global change pressures.

3.1 Climate Change

There is little dispute that the earth system is undergoing very rapid changes as a result of increased human activities. Clearly these changes will severely impact the urban water cycle and how we manage it. Components of the urban water cycle, like water supply, wastewater treatment, and urban drainage etc. are generally planned for life-spans over several decades. Hence there is a need for us to pay attention to these changes in the context of how these systems will be designed and operated in the 'city of the future'.

Although the regional distribution is uncertain, the frequency and severity of droughts are likely to increase in some areas as a result of a decrease in total rainfall, more frequent dry spells, and higher evapotranspiration. Flood frequencies are also likely to increase in many areas, although the amount of increase for any given climate scenario is uncertain and impacts will vary among basins. The impact of climate change will be observed throughout the world; only the types and degree of vulnerabilities will be different.

In addition to water scarcity and flooding, water quality problems may increase where there is less flow to dilute contaminants introduced from natural and human sources. The potential increase in water temperature could alter the rate of bio-geo-chemical processes and lower dissolved oxygen concentrations. Also, increased runoff coupled with more frequent stormwater overflow activities will increase the load of pollutants into the water bodies. There are other more obvious impacts such as increased risk of damage to stormwater infrastructure and facilities (e.g. underground drains, levee, banks, pump stations etc) due to higher peak flows, and other less obvious ones such as increased risk of pipe failure and collapse due to drier soil conditions.

Climate change will affect different cities in different ways with some experiencing more frequent droughts and water shortage while others will have more intense storm events with subsequent flooding issues. Flexible and adaptable solutions are hence required to reduce the vulnerability of cities to these changes.

3.2 Population Growth and Urbanization

Population growth and urbanization will be one of the world's most important challenges in the next few decades. From 2007 the urban population of the world will exceed the rural population.

Urban settlements in the developing countries are, at present, growing five times as fast as those in the developed countries. In developing countries urban population is predicted to grow from 1.9 billion in 2000 to 3.9 billion in 2030, averaging 2.3% per year. On the other hand, in developed countries, the urban population is expected to increase, from 0.9 billion in 2000 to 1 billion in 2030 overall growth rate 1% (Brockerhoff, 2000).

Moreover, the numbers and size of the cities in developing countries are increasing due to the higher rate of urbanization. In 1950, New York City and Tokyo were the only two cities with a population of over 10 million inhabitants. By 2015, it is expected that there will be 23 cities with a population over 10 million of which 19 of these cities will be in developing countries. In 2000, there were 22 cities with a population of between 5 and 10 million; 402 cities with a population of 1 to 5 million; and 433 cities in the 0.5 to 1 million categories.

Cities in developing countries are already faced by enormous backlogs in shelter, infrastructure and services and confronted with insufficient water supply, deteriorating sanitation and environmental pollution. Population growth and rapid urbanization will create a greater demand for water while simultaneously decreasing the ability of ecosystems to provide more regular and cleaner supplies. Moreover, rapid increase in built-up areas disturbs the local hydrological cycle and environment by reducing the natural infiltration opportunity and producing the rapid peak storm water flow.

3.3 Deterioration of Infrastructure Systems

Protecting the infrastructure used to treat and transport water (including sources, treatment plants, and distribution systems) is an important step in ensuring safety in public health and the environment. However, in most cities worldwide, there has been years of neglected maintenance to water storage, treatment, and distribution systems. A large proportion of this infrastructure is over 100 years old, placing it at increased risk for leaks, blockages and malfunctions due to deterioration (see Figure 4). For example the UK has over 700,000 km of mains and sewers pipes, and these require over 35,000 maintenance works per month (Vahala, 2004). Higher rates of water leakage means higher water losses and higher chances of in-filtration and ex-filtration of water. This will create higher chances of drinking water contamination and outbreak of water-borne diseases (Vairavamoorthy et al., 2007a).

The cost of rehabilitation of water infrastructure system is increasing substantially due to their deterioration over the world. In Germany, for example, estimates are that over the next 15 years, 12€ billion per annum is required (6.5 for investments and 5.5 for operation and maintenance) to keep the urban wastewater systems operational (Hiessl *et al.*, 2001). Similarly, in North America, the trillions of dollars of infrastructure are failing prematurely and are in a need of costly repairs. The U.S. Environmental Protection Agency, in its 2002 Clean Water and Drinking Water Infrastructure Gap Analysis, estimates that the funding gap in water infrastructure investment is $534 billion over the next 20 years (EPA, 2002).

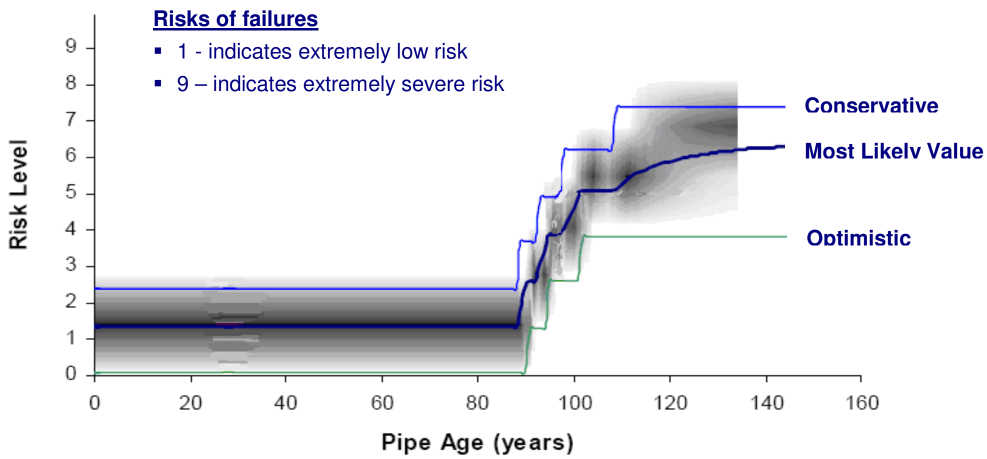

Figure 4: Risk of failure of buried water mains due to ageing (Kleiner *et al.*, 2006)

The deterioration processes is more severe for the developing countries, due to poor construction practices, little or no maintenance and rehabilitation activities, and operation at higher capacities than design. This is compounded by the lack of records and data about the location and condition of the infrastructure and the lack of efficient decision support tools or managing the infrastructure (Misiunas, 2005).

Escalating deterioration of water and sewer systems threatens our ability to provide safe drinking water and essential sanitation services for the current and future generations and this is a challenge for the 'city of the future.'

4.0 INNOVATION IN URBAN WATER MANAGEMENT

Currently, providing safe water supply and basic sanitation services across the globe is a major challenge. With increasing global change pressures coupled with existing un-sustainability factors and risks inherent to conventional urban water management, cities of the future will experience difficulties in efficiently managing scarcer and less reliable water resources.

Realising the shortcoming of conventional UWS, there are calls for a paradigm shift in the way we manage urban water (Biswas, 1991; Bouwer, 2002; Pinkham, 1999; SWITCH, 2006). This paradigm shift should be based on several key concepts of urban water management including: resilience of urban water systems to global change pressures; interventions over the entire urban water cycle; reconsideration of the way water is used (and reused); greater application of natural systems for water and wastewater treatment (SWITCH, 2006).

4.1 Resilience of Urban Water Systems to Global Change Pressures

Projections of future global change pressures are plagued with uncertainties which cause difficulties when developing urban water management strategies that are insensitive to these global change uncertainties. Hence there is a need to develop processes that can generate optimal urban water management systems that are robust, adaptable and sustainable under these future global change pressures. These flexible systems will be characterized by their capability to adapt to new, different, or changing requirements and they will have the capability to cope with uncertainties associated with changing needs.

New techniques can be used to develop these flexible systems including exploratory modelling that combines the best features of traditional quantitative decision analysis with those of narrative scenario-based planning. Other techniques such as risk assessment and real-options analysis (Zhao & Tseng, 2003), also offers opportunities in this respect. Risk assessment is the process of identifying, evaluating, selecting, and implementing actions to reduce risks and manage uncertainties. Real-options-based decision making recognizes the value of flexibility, or flexible alternatives. It develops decision alternatives that may provide flexibility for future decision making or develop decision alternatives that may be exercised flexibly in time to cope with uncertainty.

All the above methods will promote flexible designs, capable of adapting to new, different, or changing requirements. The decisions generated from such an approach can be viewed as 'least regret' ones, that provide the best solutions in an uncertain world.

4.2 Integrated Urban Water Management

Traditionally urban water systems, their planning, development and management, are based on the consideration of their isolated components as opposed to the complete holistic or integrated system. An important aspect of urban water systems is the interactions that take place between different components of the system (e.g. foul water from leaky sewers entering into a drinking water distribution network (Vairavamoorthy *et al.*, 2007c). It widely recognised that it is important to consider these interactions in order to maintain an effective, efficient and safe service of water and sanitation (Vairavamoorthy *et al.*, 2007b).

For example:

- Leakage from water distribution systems often impact groundwater and this may result in increase infiltration into sewers. This may result in dilution of wastewater and increase hydraulic loads in the sewers and ultimately to the wastewater treatment works. On the other hand sewers often leak and this may result in contamination of water supplies in the distribution networks.
- Implementation of various demand control measures may affect the quantity and quality of wastewater entering into sewers. Factors like hydraulic retention time of the wastewater in the sewers, natural aeration within the sewers, extent of the period of anaerobic conditions etc. can have a direct impact on the change in qualitative characteristics of the wastewater during transport. This will affect the performance of the wastewater treatment plant.

An IUWM approach involves managing freshwater, wastewater, and storm water as links within the resource management structure, using an urban area as the unit of management. Urban areas are appropriate as units of management, as specific problems and needs faced by cities may transcend the physical and scientific boundary embodied by more traditional units of management of catchments and watersheds.

4.3 Reconsider Water Use

The challenge of servicing more people with same quantity of water, while maintaining a tight control over the adverse environmental impacts is a profound one. Hence it is important to critically look into water use practices and to develop strategies that maximize the benefits of water services while minimizing the usage as far as practically possible.

In a traditional urban water system, after water use, wastewater is treated to certain legalized quality levels and then discharged into receiving water bodies. Such a water use system is generally regarded as a once-through system. Water can be used multiple times, by cascading it from higher to lower-quality needs (e.g. using household grey water for irrigation), and by reclamation treatment for return to the supply side of the infrastructure .

In water stressed areas, balancing the demands for water between the various sectors will need to be accompanied by the use of new and alternative resources. Increased recycling of wastewater will ensure better access to safe water, reduced vulnerability to extremes and increased adaptive capacity. Demand management and water reuse opportunities are real and increasing. A combination of end-use efficiency, system efficiency, storage innovations (using different managed aquifer recharge options), and reuse strategies would reduce water demand.

4.4 Application of Natural Systems

Besides pipes and treatment plants, the natural capacities of soil and vegetation should be applied to absorb and treat water. Green infrastructure refers to techniques and systems that use the natural capacities of soil and vegetation to absorb and retain water, and to take-up, transform, or otherwise treat pollutants in water. These natural systems can be applied as secondary or tertiary treatment, allowing the removal of most of the bacteria, microorganism and the destruction of the organic matter. Such engineered natural systems include constructed wetlands, soil aquifer treatment and river/lake bank filtration, artificial recharge & recovery for treating drinking water.

The main features of natural systems is: *simplicity* - plants design, construction and operation are very simple; *cost-effectiveness* - plants require low building, labour, operation and maintenance costs (the only limiting factor is the availability and the cost of land to place the treatment plants); *efficiency* - natural systems plants are generally efficient at removing multiple contaminants in a single system; *reliability*: natural systems are very reliable even in extreme operating conditions and can are better able to absorb a variety of both hydraulic and contaminant shocks.

4.5 Innovative Sanitation

Increased sanitation for all will result in increased wastewater generation (that could impact the goal of 'Environmental Sustainability'). Centralized and highly sophisticated end-of-pipe technologies to absorb the huge volumes of wastes and effluents are not appropriate and sustainable for these conditions. In addition centralised urban wastewater management systems have several weak points, such as: removal of an important source of water out of the urban area; destruction of valuable nutrients; production of polluted municipal sludge etc (Vairavamoorthy, 2008). It is important to investigate pollution prevention-based approaches to wastewater handling in urban areas in which concentrated waste flows are separately collected and treated.

Ecosan systems offer new solutions to urban sanitation shifting the paradigms in wastewater treatment from an approach with centralised mixed systems to decentralised systems based on source control and separate treatment of concentrated and diluted household wastewater flows. Potential advantages compared to the 'central paradigm' are: avoiding environmental pollution, enabling the nutrient recovery for agricultural use and preserving water for groundwater recharge, irrigation and other purposes. Although several ecosan applications have been piloted in the past decade, the application to high-density city areas in developing countries should be studied.

5.0 THE 'SWITCH' PROJECT

SWITCH aims to develop scientific, technological and socio-economic solutions for the sustainable and effective management of water in the city of the future – 2050. SWITCH is an EU funded action research program being implemented and co-funded by a cross-disciplinary team of 32 partners from across the globe. The "consortium" is from the fields of academic, urban planning, water utility and consulting interests. This network of researchers and practitioners are working directly with stakeholders in ten cities around the globe. The overall goal behind this global consortium is to catalyse change towards more sustainable urban water management in the "City of the Future." This will be achieved by demonstrating research and sharing knowledge across a range of different geographical, climatic and socio-cultural settings, global adoption of more sustainable solutions can be accelerated.

SWITCH aims to develop innovations in the key areas described in Section 4:

- For example in relation to interventions over the entire urban water cycle; SWITCH programme will develop tools to analyse the interactions across the urban water cycle for a range of management and technological solutions. It will enable optimal urban water systems to be developed, driven by sustainability criteria, while recognising uncertainties associated with global change pressures.
- In relation to reconsideration of water use; SWITCH will develop innovations in the area of demand management and water reuse. These innovations will involve a combination of end-use efficiency, system efficiency, storage innovations (using different managed aquifer recharge options), and reuse strategies.
- In relation to Natural Systems: SWITCH will develop innovations in the area of natural systems for water/wastewater treatment and storm-water management. This includes: constructed wetlands, soil aquifer treatment, river bank filtration systems and sustainable urban drainage (SUDs).

5.1 SWITCH Research Process

The SWITCH research process is a combination of:

- *Learning Alliances* **–** SWITCH aims to link up a wide range of stakeholders at city level to interact productively and to create win-win solutions along the water chain. They consist of a series of structured platforms, at different institutional levels (national, river basin, city, community etc), designed to break down barriers to both horizontal and vertical information sharing. This will speed up the process of identification, adaptation, and uptake of new innovations.
- *Action Research* **-** SWITCH aims to carry out more demand-led, action-orientated research in cities with a view to achieving greater integration and wider impact through the Learning Alliances. Hence, SWITCH will address problems through innovation based upon involvement of users in local demonstrations (that are designed to show application of the new technologies in practical cases).
- *Multiple-way learning* – SWITCH aims to promote multiple-way learning, where European cities learn from each other and from developing countries, and vice versa. These multiple-

way learning pathways will be developed by linking experts on urban water from developed and developing countries, by pooling scientific, technological and financial resources from the partners and in the demonstration cities resulting in an integrated, multi-disciplinary research effort.

The three main components of the SWITCH research process described above, will lead to greater impact and more potential for taking innovations to scale through the development of locally appropriate innovations and ownership of the concepts and process. In addition, undertaking research at different institutional levels will both shorten the time between developing new knowledge and scaling it up; and, ensure that local solutions are nationally relevant and applicable. Also, by sharing the learning process among cities, replication of innovations will be accelerated.

5.2 SWITCH City Water

SWITCH will combine the above innovations into a framework, where future urban water strategies will be assessed against a range of uncertainties, with a view of developing robust, adaptable and sustainable solutions. The SWITCH programme will develop tools to analyse the interactions across the urban water cycle for a range of management and technological solutions. The tool being developed within SWITCH is called the City Water and has a number of component tools and models:

- *City Water Vision* **-** an interactive tool to assist stakeholders in exploring urban water issues and scenarios. It consists of several online questionnaires to help stakeholders identify and define urban water problems in their city.
- *City Water Balance* - A scoping model to show decision makers possible improved solutions for their urban water system. It will have the capability to take into account future global change pressures and explore various alternative water management strategies (e.g. direct grey water irrigation, stormwater re-use, wastewater recycling etc.).
- *City Water Drain* **–** assesses the performance of the existing urban drainage systems, their impacts on the receiving water, and how this performance would be affected by different strategic options and scenarios including climate change and increasing urban population. .
- *City Water Futures* **–** models the urban water system as a collection of autonomous decision-making entities called agents. The models simulate the simultaneous operations of the multiple agents in an attempt to re-create and predict the actions of complex strategies.
- *City Water Strategy* **-** a performance assessment tool coupled with a solution explorer and optimiser to develop strategies to cope with environmental, demographic and societal changes. It will develop sets of technical and non-technical options and find the optimal solution through multi-criteria analysis.
- *City Water System* - displays the urban water system through schematics of the components (e.g. treatment plants, energy resources, standards and policies, etc.) and their interrelations (e.g. influences between components, water / pollutant / energy fluxes, monetary or data flows). It will provide stakeholders in cities with an information system about their water system.
- *City Water Economics* - A model to explore the potential economic implications of future strategies on urban water management by analysing scenarios for cost recovery & economic drivers for change (financing, pricing and subsidies). Cost allocation and pricing schemes can be formulated for the entire range of water services provided.

6.0 CONCLUSIONS

There is an urgent need for planned action to manage water resources effectively. The problems in urban areas of developing countries are of particular concern as still large sections of the community are living without safe water supply and basic sanitation services. Providing adequate urban water and basic sanitation is likely to become more challenging in the near future due to several global change pressures.

To address the challenge of urban water management for the future, there is a need for a paradigm shift. The paradigm shift should include several actions such as: flexible and robust system design capable of adapting to new, different, or changing requirements and capable of coping with uncertainties; interventions over the entire urban water cycle; reconsideration of the way water is used (and reused); and greater application of natural systems for water and wastewater treatment.

It is anticipated that during the next few years, SWITCH will produce knowledge, technologies, models, techniques, institutional frameworks and improved management tools for sustainable urban water management for the city of the future. An important component of SWITCH is that it aims to bring together all stakeholders involved with, or who have interest in, urban water management. These multi-stakeholder learning alliances will guide and support SWITCH on the implementation of research and demonstration activities, by taking account of local problems and needs. Clearly, this will substantially contribute to a reduction in the vulnerability of cities and their capacity and preparedness to cope with global changes.

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