TOOL KIT FOR INTEGRATED URBAN WATER MANAGEMENT

Volume 1: Tools

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Contents

Preface

The concept of integrated urban water management (IUWM), which is an extension of the concept of Integrated Water Resources Management for urban areas, is of recent origin. There are a few developed countries which actually practice IUWM in its entirety. In India, operationalizing of IUWM concepts is cities still in its early stage. In contrast to the traditional approaches to planning urban water systems which largely focus on planning and design of supply sources, water distribution, and sewerage collection and disposal infrastructure, IUWM takes several aspects of water management into consideration. They include demand side and supply side potentials of meeting the water requirements in urban areas, the cost effectiveness of various interventions, equity in access to water supplies, environmental sustainability of water resource systems and other sustaining logistical elements.

Planning urban water management interventions involves complex considerations of a wide range of physical, socio-economic, administrative, institutional and political characteristics influencing the performance of water systems in urban areas. Indian cities and towns display wide heterogeneity in these characteristics. Hence it was logical to discuss interventions for certain 'urban typologies' that exist in India, wherein each one represents a unique combination of features vis-à-vis these characteristics. Matching typologies with new technological choices and social and management institutions is vital in achieving integrated urban water management. This in turn calls for a "tool kit" for urban water management planning, which would embrace the technological alternatives and fitting institutions and instruments.

Arghyam Trust, Bangalore commissioned a study to prepare such a tool kit for the use of policy makers and managers involved in urban water management programmes. The Institute for Resource Analysis and Policy (IRAP) was entrusted with this task in August 2008. Preparation of the kit took 24 months of time for the researchers and included several rounds of discussion and deliberations with Arghyam staff for finalizing the research design and methodologies and 'urban typologies'.

The study involved exhaustive review of research undertaken all over the world on various aspects of urban water management by scholars and practitioners, including but not limited to urban hydrology, management of water supply infrastructure, water resources management, water quality management (WQM), groundwater management, technical and economic instruments for water demand management, technical and economic aspects of leakage reduction, environmental and economic aspects of wastewater treatment and reuse, storm water management, capacity building for IUWM and legal and regulatory frameworks. Primary data collection for 27 cities/towns and secondary data collection for 300 cities/towns was carried out, covering all the 16 delineated typologies. Suitable sets of IUWM interventions were identified for each typology based on the understanding of how the prevailing characteristics of these typologies influence the physical, economic, institutional, financial and environmental performance of urban water utilities. Continuous interaction of the client and researchers enriched the content of the tool kit and is now ready for the use.

These are five sets of tools detailed in the tool kit. The first set will provide analytical procedures for population and urban water demand projections under different socio- economic scenarios. These tools are useful in planning decisions. Next are environmental management tools, comprising tools for choosing urban water supply augmentation strategies, wastewater treatment technologies and methods, and storm water management practices. The third set of tools deal with capacity building and organizational change issues while the fourth set of relates to community interface. Finally the last set of tools pertains to issues in good governance, covering the practical suggestions for improving the key areas of urban water governance, and the legal and policy framework for affecting implementation of urban water management interventions. I sincerely hope these tools would come handy for not only water managers of urban local bodies, but also senior policy makers, scholars and practitioners concerned with water resources, particularly urban water.

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Major Concern

Growing urban water stress is one of the features of the water crisis being experienced by India today (Kumar, 2010; Mukherjee et al., 2010) The exponential growth in urban water demands owing to rising population, increasing per capita water demands for domestic uses, environmental sanitation, municipal & industrial uses, environmental management services, compounded by dwindling local sources of water and increasing inability of urban water utilities to improve the water supply infrastructure and undertake necessary institutional reforms have precipitated this crisis (Tecco, 2008). Reducing per capita supplies and reliability, huge water wastages, growing inequity in access to water and inefficient pricing of water across different classes are some of the problems. Growing deprivation of the urban poor to water for basic survival needs is a rude shock presented by the crisis (HDR, 2006).

The traditional civil engineering approach to managing water supplies had focused on increasing the capacity of existing sources, and exploiting new sources of water without much consideration to the sustainability of resource base, or environment or ecosystem (Coombes and Kuczera, 2002; Mitchell, 2004). Lack of focus on building institutional capabilities to regulate water use directly or indirectly is also visible with an over-emphasis on technological approaches (Vlachos and Braga, 2001). As a result, attempts to increase the supplies often results in increased consumption and greater pollution, while the gap between the rich and the poor continue to widen. This is compounded by the sectoral and segmented approach to managing water for urban areas (Brown, 2004; Vlachos and Braga, 2001). The overall outcome is that with growing size, urban areas are increasingly dependent on exogenous sources of water from far off regions (Mukherjee et al., 2010) that pose major technological, institutional and financial challenges to urban utilities.

Integrated water management as a concept and practice is gaining popularity among practitioners and policy makers in the water sector internationally and also within India (see refer to the technical report for IUWM definition). For achieving these goals, community participation, be it in planning urban water management interventions, or in the overall governance of urban water, or in providing some of the water & sanitation services or implementing best practices, is essential.

Need for IUWM and the Tools

The existing tools for planning of urban water systems largely focus on planning & design of water supply sources, water distribution and sewerage collection & disposal infrastructure. They are by and large generic. Integrated urban water management concept calls for identifying interventions that, while meeting the present and future water needs of urban areas, would also ensure hydrological integrity of the urban water cycle, which the existing tools fail to achieve. Augmenting supplies is an integral part of the utility' ability to meet the water needs of the present and future. The decision on which source to tap would require sound considerations of the supply potential and costs, and therefore would depend on hydrology, geo-hydrology, urban population size and density, topography and distance to sources. While the traditional approach to urban water management looked at conventional sources of water such as rivers, lakes, ponds and aquifers and did not care about the sustainability of resource base, sustainable urban water management requires that all water resources in urban areas including the storm water is tapped and used in an environmentally sustainable manner. The potential for the same would depend on the hydrological regime, the climate and the land use in the urban area.

Leakage in water supply lines need to be reduced wherever it makes physical and economic sense, meaning the amount of reduction in technical losses should be high and it should be cheaper than creating new source of water. Wastewater generated from urban areas needs to be treated to safe standard so as to reduce the demand for water for pollution assimilation environmental management services. The technologies for treatment of wastewater that offer physical efficacy and cost effectiveness need to be decided for the climate, topography and the socio-economic and institutional environment. The recycling and reuse potential for the treated wastewater need to be examined for the prevailing socio-economic and environmental conditions. But, equally important is its ability to reduce the demands for water needed for consumption. This would need technological devices, use of which would be encouraged only through economic instruments and institutional interventions.

Types of economic instruments, regulations and social institutions that are desirable for controlling water uses that give very low social and environmental returns and produce negative social welfare effects need to be designed keeping in mind the overall physical and socio-economic and institutional environment. The higher institutions in urban water sector need to be re-oriented or strengthened, and new institutions need to be created to ensure sustainable water allocation and use. The ability to do this is dependent on the overall socio-economic status of the urban area and the political will of the local government. At the lower level, the role of communities in urban water management needs to be enhanced for the conditions prevailing in the city or town. But, capacity building of urban water sector including these institutional innovations will be possible only if appropriate legal and policy framework exist. The policies for sustainable urban water management will be decided by the type of physical interventions, economic instruments, and institutional changes required. Since these would change from typology to typology, these policies also will have to be different for different typologies.

Hence, the task of development of tool kit on integrated urban water management planning started with the formulation of a series of research questions pertaining to technological alternatives, economic instruments, institutions and legal and policy framework. Furthermore, as it clear from the preceding section, that planning urban water management interventions involves complex considerations of a wide range of physical, socio-economic, administrative, institutional and political characteristics influencing the performance of water systems in urban areas. Hence it would be logical to discuss interventions for certain 'urban typologies' that exit in India, wherein each one represents a unique combination of features vis-à-vis these characteristics. Here, we have constructed 16 typologies for developing the IUWM tool kit, which allow us to consider physical factors such as hydrological regime, topography, geology and climate for choosing IUWM interventions for an urban area. Thus, each research question pertaining to urban water management interventions is answered for each typology.

Study: Approach, Methodology and Scope

Keeping in view the above questions, a two-year long research study was undertaken by IRAP. The larger question posed was: 'what are the key determinants of good performance of urban water systems from a physical, social, economic, financial, institutional and environmental point of view'? The research used the following methodology: 1] extensive review of international and national scientific literature on various aspects of urban water management, including engineering and social science research, and their synthesis; 2] analysis of secondary data available from various sources on a large number of urban utilities on various performance attributes; 3] case studies on best practices in urban water management; 4] analysis of data from primary survey in selected urban centres of India, which together represent all the 16 different typologies; and, 5] learnings from detailed research studies undertaken by Arghyam partners on various aspects of urban water management in Mulbagal town of Karnataka. The analysis of data from various primary and secondary sources and findings of research undertaken in Mulbagal were used to validate some of the dominant theories in urban water management. The research findings were synthesized to draw inferences on urban water management solutions for different typologies.

Subsequently, within each typology, we have considered the differences in socio-economic factors such as the "level of urbanization" and urban population density, and administrative aspects such as "size of the city", and degree of water scarcity" as planning variables to zero down on specific options that are socio-economically viable and politically feasible for each sub-typology within a broad typology of urban areas. The tool kit includes the tools that would help urban water managers to plan the strategic interventions that are required to make it possible to run urban water systems in an 'integrated' and sustainable manner.

Here, 'integration' means integration of the physical system affecting water availability (catchments, surface water, groundwater, storm water, wastewater outflows) so as to ensure hydrological system integrity; integration of the socio-economic systems affecting various water demands so as to manage inter-sectoral water allocation; integration of the technical systems that collect, treat and supply water for various uses, and collect and treat storm water and wastewater so as to ensure sustainable water supply[1]; integration of urban water management actions at various scales using the principle of subsidiarity in order to improve management capacity; and integration of institutions, policies and laws governing water supply and use in order to ensure that they do not work cross purposes. Besides this, IUWM would also mean cost effectiveness of the various interventions.

The tool kit will help the urban water planners to project the populations and water demands of a given urban area for future time periods; identify the key interventions for water management for a given urban area that would help maintain the balance between future water demands and potential future supplies; and also the social engineering and institutional interventions that are needed to affect the implementation of urban water management interventions. For this, the basic data on urban water system are to be made available. Such data include: past population; the percentage population living in bungalows; the category of urban area; the geographical area and the urban population density; the degree of urbanization and typology within which the town or city falls.

Tools: Content and Audience

The tool kit will help us evaluate many decision variables in urban water management planning. The first tool provides the analytical procedure for urban population projections under different socio-economic conditions, supported by data on human development index for various districts. The policy makers and those involved in overall urban planning decisions find the tool very useful. The second tool provides the methodology and analytical tool for estimating the per capita urban water demands, supported by data on per capita domestic water supply norms for different categories of towns/cities, and water intensity of different types of industries. The third tool suggests the types of water supply systems that are physically sustainable and socio-economically viable for each of the 16 different

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[1] Sustainability here refers to physical sustainability of water resource system, the technical system comprising water supply, sewerage system, wastewater treatment system and storm water management system; the social and economic sustainability of water supplies; sustainability of institutions engaged in urban water management; and environmental sustainability.

typologies, and the extent to which each one could be tapped to meet the water demands. The tool set also includes the analytical tool for estimating the total water supply benefits, and cost of producing & storing unit volume of water from roof catchments under different hydrological regimes, supported by data on rainfall & rainy days. This tool set will be useful for water supply engineers in urban local bodies, and NGOs working on urban water management issues.

The urban environmental management professionals will find the following set of tools useful. They include the tools which help: 1] choose the types of wastewater treatment system which is technically feasible and socially and economically viable, and ascertain the feasibility of diverting the treated wastewater for reuse for each of the 16 different typologies; 2] choose the types of storm water management interventions, and find out the manner in which they would augment the existing water supply sources for each typology; 3] test the economic and institutional viability of leakage reduction measures, and socio-economic viability of metering and volumetric pricing of water in a given urban area; 4] identify the factors influencing urban hydrology, and illustration of how the "surface water-groundwater interaction" and degree of natural treatment of wastewater", the key factors influencing urban hydrology, occur under different physical settings; 5] choose the key physical, chemical and biological parameters to be monitored for ascertaining water quality in each typology; and, 6] illustrate urban water planning using Water Evaluation and Planning (WEAP) system, and the procedure for setting up the database for running it. The WEAP model that derives its inputs from the IUWM tool kit and the outputs of detailed hydrological studies can analyze the extent to which various interventions need to be undertaken for managing urban water.

The third set of tools address sector capacity building and organizational change issues. Hence, senior bureaucrats in the dept. of urban affairs and dept. of water resources will find them useful. The first tool provides the techno-institutional models for water supply & sanitation for the urban poor and communities living in urban fringes. The next tool defines the key steps in capacity building of urban water sector, viz., institutional reform, organizational change and training for capacity building of human resources. The third tool lists the major practices for affecting institutional reforms, including the institutional design principles and criteria. The various models available for organizational strengthening of urban water utilities, with capitalize on the unique strengths and capabilities of community organizations and private sector agencies for provision of various services, are provided in the next tool. The next tool provides the models that are appropriate for private sector participation in urban water management under different socio-economic, political and institutional environments. The next tool provides the staffing norms for urban water utilities, to improve the effectiveness of the utilities in performing integrated urban water management functions, with an emphasis on how the norms could change with changing physical characteristics of utilities.

The fourth set of tools pertains to community interface in the implementation and management. It describes the key roles of communities in urban water management, viz., planning, governance, implementing best practices, and service provisions. The first tool shows which amongst these four roles could be effectively performed by communities under different conditions like urban slums, new settlements, old & consolidated settlements, and rich & progressive urban settlements. As regards training for capacity building, the tool lists different modules that are essential to provide a comprehensive understanding of IUWM practices and processes, and the different stakeholders (like the technical staff of the utility, the councilor, the community representatives, the political leaders) for whom each one of them is relevant. The next tool provides the type of regulatory mechanisms for water quantity and quality management, which are critical to institutional capacity building for WRM, for different types of towns and for different types of water users and polluters. The tool on finances suggests three major steps for strengthening the financial system of urban water utilities such as reducing UFW water combined with introducing '24X7 water supply', introducing tariff reforms; and improving the financial systems by increasing the market orientation. While it provides an analytical tool for working out the economics of '24X7 water supply' with UFW reduction, it also highlights under what situation this would be economically most viable.

Finally, the last set of tools relates to good governance and can best be used by heads of urban local bodies, and senior bureaucrats of dept. of urban affairs and dept. of water resources. The first tool provides a working definition of "urban water governance", lists the key practical measures for improving the key areas of governance, i.e., water supply, water & wastewater pricing, water infrastructure financing and provision of WATSAN services for the poor. The next tool lists four strategic legal interventions in the form of urban bylaws required to be introduced for ensuring sustainable urban water management such as urban land ceiling act, the building bylaws, legal framework for water metering, and water resources regulatory act. Further, the tool kit lists the nature of policies for sustainable UWM, the typologies for which they are relevant and the policy actions for each.

Limitations

The tool kit does not include tools for planning and operation of urban water supply system, sewerage systems etc., which are anyway available in the manuals used by water supply and public health engineers. A list of manuals available in the context of urban environmental management is given below. Also, it is not a design manual for various urban water management interventions. As the list indicates, there are design manuals for water distribution systems, storm water management systems, wastewater treatment systems and on-site sanitation systems. There are also manuals available on best practices for management of urban environment, such as that for water quality testing and water safety. There is also a manual available on capacity building of urban water utilities, and full cost recovery in water supply. But, here the role of the tool kit would be to help the urban water managers to decide on whether to go for a full cost recovery or not. In nutshell, the tool kit is useful to all involvement at management level and does not cover operational details. More importantly, for making best use of the tool kit to arrive at accurate management decisions, particularly the decisions on the scale at which various interventions need to be carried out i.e., for performing the 'scale analysis', detailed investigations would be required in urban areas. They could include: groundwater assessments, catchment studies, land-use studies, water infrastructure surveys and topographical surveys.

List of manuals

Sr. No	Name of Manuals	Agencies
1	Environment Management System ISO 14001, (Urban Local bodies and township) Manual	Clean Technology Initiative, USAID/ Development Alternatives
2	Environment Management System ISO 14001 (Waste water) manual	City of Gastonia Wastewater Treatment Division,
3	Storm Water Management manual	USEPA, SWITCH Department of Environmental Management, North Carolina University Atlanta regional Commission
4	Full Cost Recovery Model	Water & Sanitation Program, the World Bank
5	Disaster Management manual	Ministry of Home Affair, GOI

6	Land Use Manual	Texas Citizen Group
7	SCADA Manual	ILF consulting Engineers
8	O & M Manual for Sewerage system	CPHEEO, New Delhi
9	Water and Sanitation manuals	Yamuna Action Plan
10	Capacity Building for Utility management	UN-Habitat
12	Analysis of Wastewater for Use in Agriculture -A Laboratory Manual of Parasitological and Bacteriological Techniques	WHO, Geneva
13	Manual on O & M of Water Supply Systems, CPHEEO, MOUD, New Delhi 2005	Central public health and Environmental engineering organisation, Ministry of urban development, New Delhi 2005
14	Onsite Waste water Treatment Systems Manual, USEPA	USEPA
15	Quality and EMS, Manual	Draka Cableteq, USA
16	Water Quality Manuals	WHO, Geneva
17	Water Safety Plans (WSP) for Urban Piped Water Supplies in Developing Countries	Do
18	Wastewater Treatment Systems Design Manual	NAYADIC, Franklin
19	Wastewater Treatment Systems Augmenting Handbook Operation And Maintenance	Department of Defence, USA

Scope of Integrated Urban Water Management

Conventional urban water management considers water supply, wastewater and storm water as separate entities, planning, delivering and operating these services with little reference to one another. Current urban water systems harvest large volumes of water from remote catchments and groundwater sources, deliver potable water to all urban uses and subsequently collects generated wastewater. This wastewater is removed, taken to treatment plants usually located on the fringe of the city or town, then discharged to the surrounding environment. Only 9% of this wastewater is currently reused (Radcliff, 2003). Large volumes of storm water are also generated within urban areas due to the increased imperviousness of urban catchments. The majority of this storm water flows out of the urban area, with little management of its quality and even less of it being used. As a result, the adverse impact of conventional urban water management on the water balance of these areas is substantial (Mitchell *et al*., 1997; 2004).

In comparison, Integrated Urban Water Management takes a comprehensive approach to urban water services, viewing water supply, storm water and wastewater as components of an integrated physical system and recognizes that the physical system sits within an organizational framework and a broader natural landscape.

There are a broad range of tools which are employed within Integrated Urban Water Management, including, but not limited to water conservation and efficiency; water sensitive planning and design, including urban layout and landscaping; utilization of non-conventional water sources including roof runoff, storm water, grey water and wastewater; the application of fit-for-purpose principles; storm water and wastewater source control and pollution prevention; storm water flow and quality management; the use of mixtures of soft (ecological) and hard (infrastructure) technologies; and non-structural tools such as education, pricing incentives, regulations and restriction regimes.

Integrated Urban Water Management recognizes that the whole urban region, down to the site scale, needs to be considered, as urban water systems are complex and inter-related. Changes to a system will have downstream or upstream impacts that will affect cost, sustainability or opportunities. Therefore, proposed changes to a particular aspect of the urban water system must include a comprehensive view of the other items and consider the influence on them.

Integrated Urban Water Management Framework

There are five important considerations in urban water management: using various components of the urban water cycle viz., urban storm water, runoff from roof catchment, urban wastewater, and use of both good quality and poor quality water from surface and groundwater sources for sustainable water use; treating various components of the hydrological system as part of a single system for water resource assessments and planning, by capturing surface water-groundwater interactions, catchment-stream flow interactions, and quality as well as quantity aspects; water demand management, including inter-sectoral water allocation; cost effectiveness of the water management interventions; and use of subsidiarity principle in urban water governance and management (source: adapted from Mitchell, 2004). This would mean:

1. Using various sources of water (surface water, local groundwater, rainwater, storm water runoff) in an optimal manner for water supplies thereby reduced threat to the hydrological integrity of the water resource system, with "cost of production" of water remaining as another important consideration. Harnessing of storm water at the sites of generation reduces the chances of pollution of streams

2. Taking basin as the unit for water resource assessment and planning with catchments, groundwater and stream-flows as part of the same unit

3. Leakage is reduced to minimum (both technical and administrative) in the system and the economic target leakage is achieved, thereby revenue losses to the utility are reduced to minimum.

4. All individual connections are provided with water meters with readings taken regularly.

5. The water (supply & sewerage) infrastructure is adequate enough for the poorest communities to physically access water and dispose-off the wastewater.

6. Demand for water is managed at the end user level through efficient pricing, thereby reducing the need for augmenting the supplies with high financial & environmental costs; wastewater generation is reduced, thereby reducing the capacity of sewerage systems and wastewater treatment plants, with resultant infrastructure cost saving; increased concentration of sewage improves the energy recovery rate; storm water runoff generation is minimized thereby reducing the need for large storm water collection and disposal systems for flood control, and the chances of damage to the ecosystem health of natural water bodies.

7. The prices charged for water supply & sewerage services at the aggregate level reflect the long term marginal cost, which is referred to as marginal opportunity cost of production & supply. It would be the sum total of the cost of depletion of the resource, the cost of production and supply of water, and the environmental cost of degradation. The average prices fixed ensures full cost recovery.

8. The pricing is followed by institutional realignment to maximize social welfare.

9. Institutions are created for ensuring inter-sectoral water allocation and management, including management of water quality

10. Decentralized wastewater treatment systems wherever the geo-hydrology, climate and soils permit, and where land is available thereby reducing the need for large centralized systems

11. Wastewater from both industries and municipal uses is treated and reused or treated to effluent discharge standards and disposed off to the environment without causing negative consequence on it; or treated and put back into the water resource system on pure considerations of social and economic benefits and costs.

12. The agency has complete database of the water supply & sewerage connections in the town/city, with proper maps of the distribution and service lines.

13. The agency has adequate HR capacity for sustainable urban water management; has favourable governance systems, management structures, finances and administrative hierarchy to perform IUWM activities; appropriate legal and policy framework exist that facilitate institutional capability building to perform IUWM functions

14. The community's water use needs and priorities are taken care of. The quality standards of the supplied water match with the community's perceptions of good quality water.

15. Communities are able to do self assessment of the water demands before launching of new water supply projects so that the new systems become cost effective and the community's willingness to pay for the services also increase. Communities have the choice of tapping on multiple sources of water, on considerations of sustainability of water supplies, cost effectiveness, and environmental sustainability.

16. Forum exists for community to oversee the quality of execution of urban water systems and its operation and maintenance.

17. Institutional mechanisms for members of the urban communities to formally lodge complaints about poor performance of urban water system exist, and redressal mechanisms are adequate and transparent.

18. Urban communities are able to effectively participate in urban water management planning; investment decision making; urban water governance; provision of some of the urban water management services; and performing some of the best practices, through appropriate local institutions and in partnership with the urban local bodies.

19. Benchmarking of performance of urban water system is done. Community's views are incorporated while choosing the indicators for performance assessment and they actually participate in monitoring & evaluation of the work, and auditing.

Generic Framework for IUWM

The schematic diagram shown in Figure 1 has three important components. First is the water use system. The second is the water supply, storm water collection, and wastewater treatment system. The third is the water resource system, which includes water from desalination and imported water. These systems are interlinked. How much water is drawn from the water resource system depends on the demand for water in the water use system, and the network losses. The amount of wastewater generated demand on the water use.

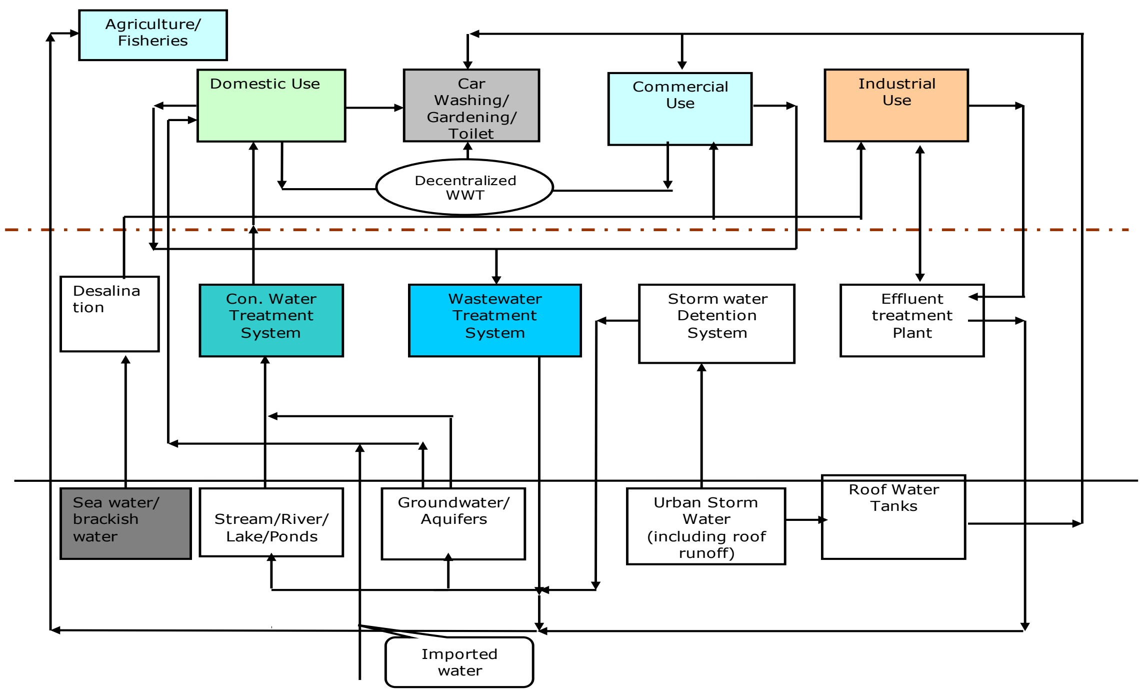
As indicated in the schematic diagram, treated water from the conventional water treatment system, which is of high quality, is used to meet the water demands for domestic purpose and municipal uses. Relatively poor quality water is used for gardening, vehicle washing and toilets. The wastewater generated is either treated locally or goes to a centralized treatment system. The treated water either joins the streams or groundwater or is available for reuse in agriculture. The storm water generated in the urban area including that from roof catchments is also collected, treated and can augment the water resources for use in urban areas.

As the box on the top right hand side indicate, the water use is a function of several complex physical, socio-economic and institutional and policy factors, viz., income level, water pricing structure and prices, supply restrictions, climate, seasons and culture, pollution tax and pollution control norms, subsidies for water conservation technologies, groundwater regulation and tax, presence of social institutions and organizations. The demand for water reduces with increase in price, and less elastic to price changes under hot and arid climates and also when income levels are high.

On the other hand, the wastewater, if treated and recycled or reused, can reduce the effective water supply requirement in the urban areas. For instance, the domestic wastewater can be treated and reused for gardening, car washing and toilets. If not treated, it can deteriorate the quality of water in the natural systems and ecosystem health. The nature of raw water treatment, water supply and wastewater treatment systems depend on water quality standards applicable to the urban area, climate, hydrology and quality of water available from the natural system, technologies available for wastewater treatment, financial health of the water utility, economics of various water and wastewater treatment options and land availability. To elaborate, when stringent water quality standards are strictly enforced by the enforcing agencies (say the Pollution Control Board), the incentive to set up wastewater treatment systems that treat water to very high standards would be high among the water users like the municipality and industries. Similarly, large-scale wastewater treatment systems cannot be employed in congested urban centres, with very high land value.

The availability of water from the water resource system for water supplies depends on hydrology, geo-hydrology of the basin, aquifer in which the region/basin, natural water quality, urban land use and land-cover, type of housing stocks and topography. In addition to the conventional sources of water (such as river, streams, lakes, ponds and groundwater), urban areas can augment their water supplies through rainwater harvesting. But, the amount depends on the rainfall (hydrology) and the total roof area and roof characteristics. The urban storm water, if collected treated in detention systems, can be used to augment the lakes, or aquifers.

Figure 1: Generic Framework for Integrated Urban Water Management



Income Levels
Water pricing
Supply restrictions Culture
Pollution tax/Pollution Control norms
Subsidies for water conservation technologies
Groundwater regulation
Groundwater abstraction tax
Water availability
Social institutions/organizations

Water quality standards
Climate
Hydrology
Water quality
Technology availability for W/WW treatment
Finance
Economics
Land availability
Management Capacity

Hydrology
Geo-hydrology
Water quality
Land use & land cover
Type of housing stocks
Topography

Benefits of IUWM

According to a WHO report on cost benefit analysis of water and sanitation provisions (WHO, 2004) achieving the MDG target in water and sanitation, by using simple technologies, from a health point of view, would lead to a global average reduction of 10% of episodes of diarrhea. Choosing more advanced types of technologies such as provision of regulated in-house piped water would lead to massive overall health gains, but it is also the most expensive intervention. The burden of disease associated with lack of access to safe water supply, adequate sanitation and lack of hygiene is concentrated on children under five in developing countries. Accordingly, emphasis should be placed on interventions likely to yield an accelerated, affordable and sustainable health gain amongst this group. The analysis points to household water treatment and safe storage as one option of particular potential. This intervention results in high health improvements while incremental costs remain low compared to other types of interventions.

According to UN WWAP (2009), achieving the water and sanitation MDG target would definitely bring economic benefits, ranging from US$3 to US$34 per US$1 invested. Additional improvement of drinking-water quality, such as point-of use disinfection, in addition to access to improved water and sanitation would lead to a benefit ranging from US$5 to US$60 per US$1 invested. According to the SIWI (2005), 1.47 billion people stand to benefit if the MDG for sanitation is met. The economic benefits could be as high as USD 65 billion annually, with the greatest proportion of the benefits expected to accrue to the poorest regions in the world.

A compelling argument in support of further resource allocations to improving access to water and sanitation services is made when evaluating the health and the socio-economic benefits and the additional benefits of improving access to safe water supply and sanitation helps to support rational and informed decision-making, for resource allocation. Among the many possible and valid criteria, the ratio of economic costs and benefits of different intervention options is critically important. Also important in assessing costs versus benefits is that a ministry of health or water affairs would be unlikely to consider costs and benefits which have implications arising to other ministries, despite the importance of these costs and benefits (WHO, 2000). The implication of this is that when adopting one particular ministry perspective in evaluating cost effectiveness the true efficiency of many environmental health interventions is not measured, resulting in a cross-sectoral misallocation of resources (WHO, 2000).

Box 1: Overarching Practices under IUWM

- In high rainfall hilly and mountainous, roof top rainwater harvesting should be part of the mainstream water supply system, and subsidies should be available for poor people to adopt the system.

- In urban centres falling in low to medium rainfall areas, RWHS would be suitable for only large bungalows. But, provision of subsidies for the same should be subject to metering and volumetric pricing of supplies from the public utility. The level of subsidy should be equal to the unit cost of production of the amount of water that can be harnessed by the system.

- In order to encourage all bungalow dwellers to adopt RWHS in low and medium rainfall regions, it is important that incremental block rates for pricing of urban water are adopted. In this case, the pricing for levels of use higher than the basic needs should be fixed in such a way that it is higher than the unit cost of production of water through roof water tanks.

- In flood prone areas, flood management would be critical to achieving sustainable urban water supplies, and sanitation that ensure basic survival, community health and environmental management.

- In areas prone to water-logging (shallow water table areas), contamination of groundwater from leaching types toilet should be utmost concern.

- In high rainfall, mountainous areas, roof water would be an important resource and source for urban water supplies from the point of view of augmenting the water supplies and also making it cost effective.

- In low-lying cities that receive very high rainfall that cause flash floods, collection of roof runoff in tanks would help reduce the intensity of floods, thereby reducing the capacity requirements of storm water drainage systems.

- In semi arid and arid areas, the urban storm water can be detained in detention ponds instead of allowing it to be mixed with sewage and effluent; this can be used to recharge groundwater using the method of aquifer storage/recovery systems.

- In sub-humid and humid areas, urban storm water can be stored in decentralized detention ponds for sedimentation, and then discharged into natural drainage systems. This can reduce the capacity requirements of storm water drainage systems, and prevent urban floods.

- Wastewater treatment and reuse: land availability and land prices would be important considerations in choosing WWT technologies.

- Domestic wastewater has to be separated from industrial effluent to reduce the treatment costs. This would make treatments easy and feasible. Also, sewage has to be separated from storm water

- Decentralized treatment of the domestic wastewater and its reuse in the same localities would reduce the infrastructure and energy requirements for collection and disposal. It would also reduce the municipal water demand.

- Anaerobic treatment of wastewater would remove the organic matter and suspended solids; help generate energy from biogas (biogas); also, it is advantageous from the point of view of reuse of the treated water for irrigation and fish farming as the heavy metals would be removed. For aerobic treatment, very little land is needed, but energy intensive and generates a lot of sludge

- Growing duckweed is useful for removing the nutrients (nitrogen and phosphorous) and heavy metals from wastewater; the same biomass produced from the nutrient uptake can be used to grow fish in other ponds provided it does not contain heavy metal residues. This is suitable for sub-humid and humid environments.

- In urban areas with very few polluting units which follow similar processes and produce same type of effluents, stringently following pollution control norms would be a viable strategy.

- In urban areas with scattered populations (with low population density) and also in centres where population size is very large, a part of the wastewater (*grey* water) should be first treated in decentralized treatment systems, and only the remaining (*black* water) should only be taken to centralized systems.

- Decentralized sanitation systems (leach type, and septic tanks) can be encouraged only if groundwater table is deep, or is of poor quality and not used for human consumption.

- Effluent from septic tank from housing stocks and commercial establishments could be used in reed beds/constructed wetlands for further improvements in area where sewerage system connection is not available

- In small towns (towns and municipalities), since groundwater contribution to water supplies is high, the effort should be to augment the groundwater reserves, by levying prices (taxes) that cover resource cost, production cost and cost of environmental damage; and using it for recharge projects like SAT.

- In larger towns and cities, the users of private well water, who are not connected to the utility services, shall be levied charges that include only resource cost & environmental damage costs. At the same time, the "charges" for those connected to the utility, but still use private wells, should be kept at such levels that their total cost of water supply is comparable or higher than what the utility charges. The idea is to make the opportunity cost of deferring metering and payments to the utility high.

- Actions of RBOs should be coordinated with those of the urban water utilities, as either of their actions would affect each others' performance.

- River basin organization should carry out pollution treatment, and the utility has to pay the environmental cost component of the water charges to the RBO.

- The agency doing regulatory functions of Water Quality Management and the agency which carries out pollution control measures should be separate.

- The pricing of water and sewerage should reflect the increasing long-run marginal costs of water supply and its disposal, specifically addressing the costs of environmental damage in production and consumption, and the opportunity costs of depletion.

- The cost of using/depleting water would vary from region to region, but would be highest in the most water-scarce regions.

- Decision to do metering should be based on cost-benefit analysis. Water metering and volumetric pricing should receive priority in urban areas that have high percentage of UFW, and in areas where physical scarcity of water resources is of higher degree.

- To make urban water affordable to the poor, either subsidies should be paid by the government through the distribution of water coupons, or incremental block rates with very low rates for basic level of consumption could be introduced.

- Leakage prevention in the water supply system would be a major area for IUWM interventions, and must receive high priority in urban centres that have populations scattered over large geographical areas, and also those having undulating terrains which increase the leak.

Construction of Urban Typologies for India

The type of water management interventions, which are sustainable for an urban area, would depend on a wide range of physical, socio-economic, cultural and institutional factors. Physical factors such as the hydrological regime, the geological environment, climate and topography will have a great bearing on the water supply option, which is sustainable for an urban area from physical and economic points of view. For instance, hydrological opportunity for roof water harvesting purely depends on the magnitude of annual rainfall, and the cost per unit volume of the harvested water would depend on the pattern of rainfall. Similarly, the rainfall and topography would greatly influence the type of storm water drainage system which is required as it would influence the peak runoff from the urban storms, and the surface drainage possibilities. Geo-hydrology, rainfall and the climate together would greatly influence the degree of vulnerability of aquifers to pollution from on-site sanitation and effluent disposal. Therefore, they would also determine the potential of using land-based treatment processes for wastewater. In the same way, the climatic factors (temperature, sunshine and wind speed), and altitude would influence on the effectiveness of bio-chemical treatment processes.

Overall water situation (whether water is naturally scarce or abundant), which is determined by a range of physical factors, can influence not only the cost of production & supply of water, but also the viability of water metering & pricing. The ways in which these factors influence the various physical options for urban water management are illustrated in the tool descriptions for Tools 3-9.

On the socio-economic front, characteristic like the level of urbanization would have a great bearing not only on the feasibility of demand management options such as metering and volumetric pricing, but also on the economic viability of some of the wastewater treatment options. As regards the first, high level of urbanization would increase the social affordability of payment for water supply services. As regards the second, the price of land also would change with the level of urbanization, thereby affecting the viability of certain wastewater treatment options. Besides these, land availability, which is an inverse function of urban population density, is a crucial factor determining the type of wastewater treatment system viable for an urban area. The size of the urban area (whether big or small) will determine the viability of some of the water supply options, determined on the basis of some of the physical factors, for water supply for an area. Here again, the manner in which these factors influence the decisions on demand management options are illustrated in the tool descriptions for Tools 10-14.

But, India is a country with a lot of spatial heterogeneity in the physical, socio-economic and cultural conditions. Particularly, annual rainfalls, annual evaporation (determined by temperature, relative humidity and wind speed), geology, and topography vary spatially and these variations show a pattern. There are regions with high rainfall and humidity. Also, there are regions with extremely low rainfall and hyper-aridity. While the country has a total of 5,000 plus towns/cities, all sizes are found, starting from large metros, large cities and small towns. There are small towns which are highly urbanized. At the same time, there are large cities which have up to 50% population living in slums. Again, within that, the level of urbanization can change from town to town.

The urban administration can be Town Municipal Council, or Municipality or Municipal Corporation or Metros, which will have a great bearing on the technological option which can be opted for to supply water, and institutional models which need to be pursued. Now, there are a large number of permutations and combinations possible vis-à-vis the physical environment, socio-economic setting and the type of administration. It is difficult to develop a tool kit for each and every situation, which can be encountered. Therefore, it is important to identify the dominant typologies emerging from a combination of characteristics, be it physical, or socio-economic or administrative, and design tools for various components of integrated urban water management system for each one of them. A typology here is a geographical domain, which are similar vis-à-vis certain characteristics. For instance, places with low rainfall and high aridity cover large areas in the country, but those with low rainfall and high humidity is uncommon. Also, basalt formations are either in the plateau region or in the plains, but are not found in hilly terrain.

The tool kit is developed for dominant typologies that use physical characteristics, viz., rainfall, topography, geology and climate of the urban area. The reason is there is general spatial trend in most of these characteristics. While designing the tools, the unique situations vis-à-vis the socio-economic features and administrative types of the urban areas are incorporated separately within each typology, on a case to case basis, depending on whether that particular characteristic matters or not for the tool in question. The major reason for doing this is that no general spatial trend in many of the socio-economic characteristic is seen unlike in the case of physical characteristics. For instance, highly urbanized large cities are found throughout India, except in the north east. Cities with high and low population densities are found everywhere. In order to identify the dominant typologies, we have superimposed the India maps, each one showing the variations in one physical characteristic, on the map which shows different types of urban areas. Using the superimposition of the thematic layers, we have identified 16 dominant typologies. They are given in Table 1A.

Table 1A: Urban Typologies in India

Typology No	Common Characteristics of the Typology
1	Alluvial-Plain-Low Rainfall-High Evaporation **(A1-P1-H3-E3)**
2	Alluvial-Plain- Moderate High Rainfall -High Evaporation **(A1-P1-H5-E3)**
3	Extensive Alluvium-Plains-Moderate High Rainfall- Moderate Evaporation **(A1-P1-H5-E2)**
4	Extensive Alluvium-Plains-Very High Rainfall- Moderate Evaporation **(A1-P1-H7-E2)**
5	Alluvium/Sandstone-Plain-Moderate Rain-High Evaporation **(A2-P1-H4-E3)**
6	Sandstone-alluvial deposits-Plain-High rainfall-Moderate evaporation **(A2-P1-H6-E2)**
7	Sandstone-alluvial deposits-Hilly regions-High rainfall-Moderate evaporation **(A2-P3-H6-E2)**
8	Thar Desert **(A2-P4-H1-E3)**
9	Crystalline Rock-Plain- Moderate to High Rainfall -Moderate Evaporation **(A3-P1-H5-E2)**
10	Crystalline Rock -Plain-High Rainfall- Moderate Evaporation **(A3-P1-H6-E2)**
11	Crystalline Rocks-Plateau-Moderate Rainfall-High Evaporation **(A3-P2-H4-E3)**
12	Crystalline Rocks-Mountainous region-Very High Rainfall-Moderate Evaporation (**A3-P3-H7-E2**)
13	Basalt Rocks-Plateau-Low Rainfall-High Evaporation **(A4-P2-H3-E3)**
14	Basalt Rocks-Hills-Moderate High Rainfall-High Evaporation **(A4-P3-H5-E3)**
15	Coastal Alluvial-Plain-Very High Rainfall-Moderate Evaporation **(A5-P1-H7-E2)**
16	Coastal Alluvial- Plain -Low Rainfall-High Evaporation **(A5-P1-H3-E3)**

Naturally Water-Scarce and Naturally Water-Rich Regions

M. Falkenmark had developed an index named physical water scarcity index to assess the water scarcity of a region, which expressed water scarcity as a function of water resources and population. Going by M. Falkenmark, a region is physically water-scarce, if the total renewable water availability exceeds in that region exceeds 1,700 m^3 per capita per annum. The region can be called water-stressed, if the renewable water availability is below 1700 m^3 per capita per annum, but above 1000 m^3 per capita per annum. Further, a region would become "water-scarce" if the renewable water availability is in the range of 500 and 1000 m^3 per capita per annum, and "absolutely water-scarce" if renewable water availability falls below 500 m^3 per capita per annum. Here renewable water availability is sum of the total annual dependable runoff generated in the region and the annual replenishable groundwater. So far as India is concerned, these figures are available only for the country as a whole (Engelman and Le Roy, 1997), and just one of the states, i.e., the state of Gujarat for which the figures are available for the four regions, viz., south Gujarat, north Gujarat, Saurashtra and Kachchh (see, IRMA/UNICEF, 2001).

Obviously, it is extremely difficult to estimate the renewable water resources of different typologies, we have identified as they do not coincide with the boundaries used for assessing either surface water resources (basin and sub-basins) or groundwater resources (districts, watersheds and blocks/mandals). Therefore, we have used certain simple criteria, which use the four key factors affecting the natural water resource availability in a region, such as rainfall, geology, evaporation and topography, for deciding on whether a region is water-scarce or water-rich. Regions, with very high rainfall (and above) and low evaporation are treated as water-rich, irrespective of their geological settings. Regions with high rainfall (and above) and alluvial geology irrespective of the annual potential evaporation rates are treated as water-rich regions. Regions with low or moderate or moderate to high rainfall, but with high evaporation are treated as water-scarce regions irrespective of their geological settings. The classification of the sixteen different typologies on the basis of these criteria as "water-rich" and "water-scarce" is given in Table 1B.

A region, which is referred to as "water-rich" in the tool kit, is a "naturally water-rich region" as per our definition. Likewise, a region which is referred to as "water-scarce" is "naturally water-scarce". But, it is to be kept in mind that "natural water richness does not mean physically water-rich, i.e., the region's available water resources are currently able to meet the demands of the population, and that no water-scarcity or water stress is felt. It is quite possible that the renewable water resources are not harnessed or utilized to the extent determined by technical feasibility and economic viability. Nevertheless, as observed by Kumar and others in the context of India, naturally water-scarce regions are physically water-scarce regions (Kumar *et al.*, 2008), while vice versa cannot not always true. There are a few regions in India where not all the utilizable renewable water resources are tapped. These regions can still develop its water resources.

Table 1B: Water-scarce and Water-rich Typologies

Typology No.	Characteristics of Typology				Naturally Water Rich	Naturally Water Scarce
	Geology	*Topography*	*Rainfall*	*Evaporation*		
1	Alluvial	Plains	Low	High		***
2	Alluvial	Plains	Moderate High	High		***
3	Extensive Alluvium	Plains	Moderate High	Moderate		***
4	Extensive	Plains	Very High	Moderate	***	

	Alluvium					
5	Alluvium/ Sandstone	Plains	Moderate	High		***
6	Sandstone-alluvial deposits	Plains	High	Moderate	***	
7	Sandstone-alluvial deposits	Hills	High	Moderate	***	
8	Sandstone-alluvial deposits	Thar Desert	Extremely Low	High		***
9	Crystalline Rocks	Plains	Moderate High	Moderate		***
10	Crystalline Rocks	Plains	High	Moderate	***	
11	Crystalline Rocks	Plateau	Moderate	High		***
12	Crystalline Rocks	Mountainous	Very High	Moderate	***	
13	Basalt Rocks	Plateau	Low Rainfall	High		***
14	Basalt Rocks	Hills	Moderate High	High		***
15	Coastal Alluvial	Plains	Very High	Moderate	***	
16	Coastal Alluvial	Plains	Low	High		***

Rainfall Index

Extremely low:	100-200mm
Very low:	200-400mm
Low:	400-600mm
Moderate:	600-800mm
Moderate to high:	800-1200mm
High:	1200-1600mm
Very high:	Above 1600mm

Evaporation Index

Moderate:	1500-2500mm
High:	2500-3500mm

IUWM Framework for Different Urban Typologies

1) **Alluvial-Plain-Low Rainfall-High Evaporation** (A1-P1-H3-E3)

Water supply source: Groundwater pumping for small towns and municipalities; groundwater and imported surface water for corporations and metros; excess imported surface water to be used for recharge

Wastewater treatment: waste stabilization ponds (WSP) for small towns and municipalities and treated water to be used for irrigation purpose; SAT in river bed aquifers for large municipalities/corporations to be used for recharging the aquifers; decentralized WWT systems (reed bed; WSP etc.) for reuse in gardening; toilet and car washing; then centralized treatment for excess water using membrane (if water is imported) for reuse

Storm water management: collection and storage in detention ponds and discharge into streams for gravity recharging

2) **Alluvial-Plain- Moderate High Rainfall-High Evaporation** (A1-P1-H5-E3)

Water supply source: groundwater as source of water supply for small towns, municipalities (with % contribution from groundwater decreasing with population size); groundwater pumping by individual users in large municipalities to be restricted; and in metros to be based on permits; imported surface water in large corporations.

Wastewater treatment: waste stabilization ponds (WSP) for small towns and municipalities and treated water to be used for irrigation purpose; SAT in river bed aquifers for large municipalities/corporations to be used for recharging the aquifers; decentralized WWT systems (reed bed; WSP etc.) for reuse in gardening; toilet and car washing; then centralized treatment for excess water using membrane (if water is imported) for reuse; treated wastewater for irrigated agriculture in peri urban areas

Storm water management: storm water to be collected in detention ponds (local) and discharged into streams for gravity recharging

3 & 4) Extensive Alluvium-Plains-Moderate High to Very High Rainfall- Moderate Evaporation (A1-P1-H5/H7-E2):

Water supply source: river lifting and groundwater as source of water supply for small towns, municipalities (with % contribution from groundwater increasing with population size); Groundwater pumping by individual users in small towns and municipalities to be unrestricted; and in metros to be based on permits

Wastewater treatment: Centralized wastewater treatment using ASP; treated wastewater to ponds for nutrient removal using DWT; later on for fish production

Storm water management: storm water to be collected in detention ponds (local) and disposed off into rivers after cooling; in very high rainfall areas, rain gardens can be constructed for runoff reduction. In flood prone areas of both typologies, storm water from roof tops can be collected in roof water tanks and the excess can be released into the storm water drains.

5) Alluvium/Sandstone-Plain-Moderate Rain-High Evaporation (A2-P1-H4-E3)

Water supply source: groundwater for towns; groundwater + imported surface water for large municipalities and corporations

Wastewater treatment: decentralized waste treatment systems such as septic tanks; centralized WWT systems such as WSP; treated water to be used for irrigation

Storm water management:: collection, storage into detention ponds and discharge into streams after sedimentation & cooling

6) Sandstone-alluvial deposits-Plain-High Rainfall-Moderate Evaporation (A2-P1-H6-E2)

Water supply source: river water/tank/well-managed lake water for towns; river water + groundwater for large municipalities

Wastewater treatment: activated sludge process; treated water to be used for fisheries

Storm water management: Storm water collection and safe disposal in streams after pond detention

7) Sandstone-alluvial deposits -Hill-High Rainfall- Moderate Evaporation (A2-P3-H6-E2)

Water supply source: well-managed lake water +groundwater for the towns in the area

Wastewater treatment: activated sludge process; treated water to be used for fisheries, anaerobic treatment using waste stabilization pond

Storm water management: no special actions will be needed, except collection & conveyance of storm water through UGDs, as the surface drainage will be extremely good in the hills

8) Thar Desert (A2-P4-H1-E3)

Water supply source: well-managed local tank/pond as water source for small towns; imported surface water for large towns/cities (Jodhpur for instance)

Wastewater treatment: Decentralized treatment system for black water (septic tank) for scattered clusters; waste stabilization pond for domestic wastewater treatment; treated sewage to be diverted for irrigation; membrane technology for treatment and reuse in case of imported water

Storm water management: Storm water collection and storage in natural ponds/tanks after detention as aquifers are saline

9) Crystalline Rock-Plain-Moderate High rainfall-Moderate Evaporation (A3-P1-H5-E2)

Water supply source: well managed tanks/ponds for small towns; imported surface water from nearly or distant reservoirs for large cities

Wastewater treatment: activated sludge process, treated wastewater to be used for fish production

Storm water management: runoff reduction measures in large cities and towns with large built up area, and collection of excess runoff in detention ponds and then surface storage; just collection, detention and disposal of storm water in towns in small built up area

10) Crystalline Rock-Plain-High Rainfall- Moderate Evaporation (A3-P1-H6-E2)

Water supply source:: River/lake water for small towns/municipalities; river/lake water + groundwater for corporations; as water source; river/lake water + imported surface water in metros

Wastewater treatment: ASP for wastewater treatment; disposal into tanks/lakes of treated wastewater for fish production

Storm water management: to be collected in local detention tanks; and to be diverted into streams/tanks/lakes

11) & 13) Crystalline Rocks/Basalt-Plateau-Low to Moderate Rainfall-High Evaporation (A3/A4-P2-H4/H3-E3)

Water supply source: water from well-managed lakes/tanks for small towns; groundwater pumping & surface water from lake/tanks for small towns & municipalities; imported surface water for corporations, with small percentage of well water; and only imported surface water for metros (well managed lakes to be used for recreation; fisheries in urban centers).

Wastewater treatment: centralized WSP for WWT in small towns and municipalities and diversion for irrigation; decentralized treatment systems for domestic wastewater (reed bed technology; WSP) to be used back in gardening; car washing & toilet use in large cities; the excess wastewater to be taken to centralized WWT systems and disposal of treated water in lakes/tank

Storm water management: Runoff reduction measures other than RWHS & RG; excess storm water collection, detention ponds, and surface storage

12) Crystalline Rocks-Mountainous region-Very High Rainfall- Moderate Evaporation (A3-P3-H7-E2)

Water supply source: Roof water harvesting tanks + river lifting

Wastewater treatment: Centralized wastewater treatment for wastewater using Activated Sludge Process (as anaerobic systems won't work due to poor sunlight and low temperature). Nutrient removal from wastewater using duck weed in natural lakes; use of the treated wastewater for fisheries

Storm water management: collection and disposal into streams; no need for detention ponds

14) Basalt Rocks-Hills-Moderate High Rainfall-High Evaporation (A4-P3-H5-E3) (T, M)

Water supply source: Water from well-managed lakes/tanks for small towns with some amount of lifting; restricted use of the limited groundwater available in the rocky & hilly terrain

Wastewater treatment: waste Stabilization ponds, treated water to be used for irrigated agriculture

Storm water management: Collection and conveyance of storm water through UGDs, and drainage of water from the town will be through gravity

15) Coastal Alluvial-Plain-Very High Rainfall-Moderate Evaporation (A5-P1-H7-E2)

Water supply source: Water from tanks/ponds and river bed for small towns and municipalities; groundwater pumping + tank/ponds/river bed for corporations; and imported surface water for large metros; Roof water collection systems for scattered populations

Wastewater treatment: Activated sludge process; and disposal of treated wastewater into the ponds/tanks for fish production for towns, municipality & corporation. Membrane technology for higher level of treatment and reuse for domestic purpose in metros; sludge to be disposed off into the sea/ocean

Storm water management: Collection in detention ponds; and disposal in to streams after sedimentation and cooling; recharge into aquifers in cities with large built up area.

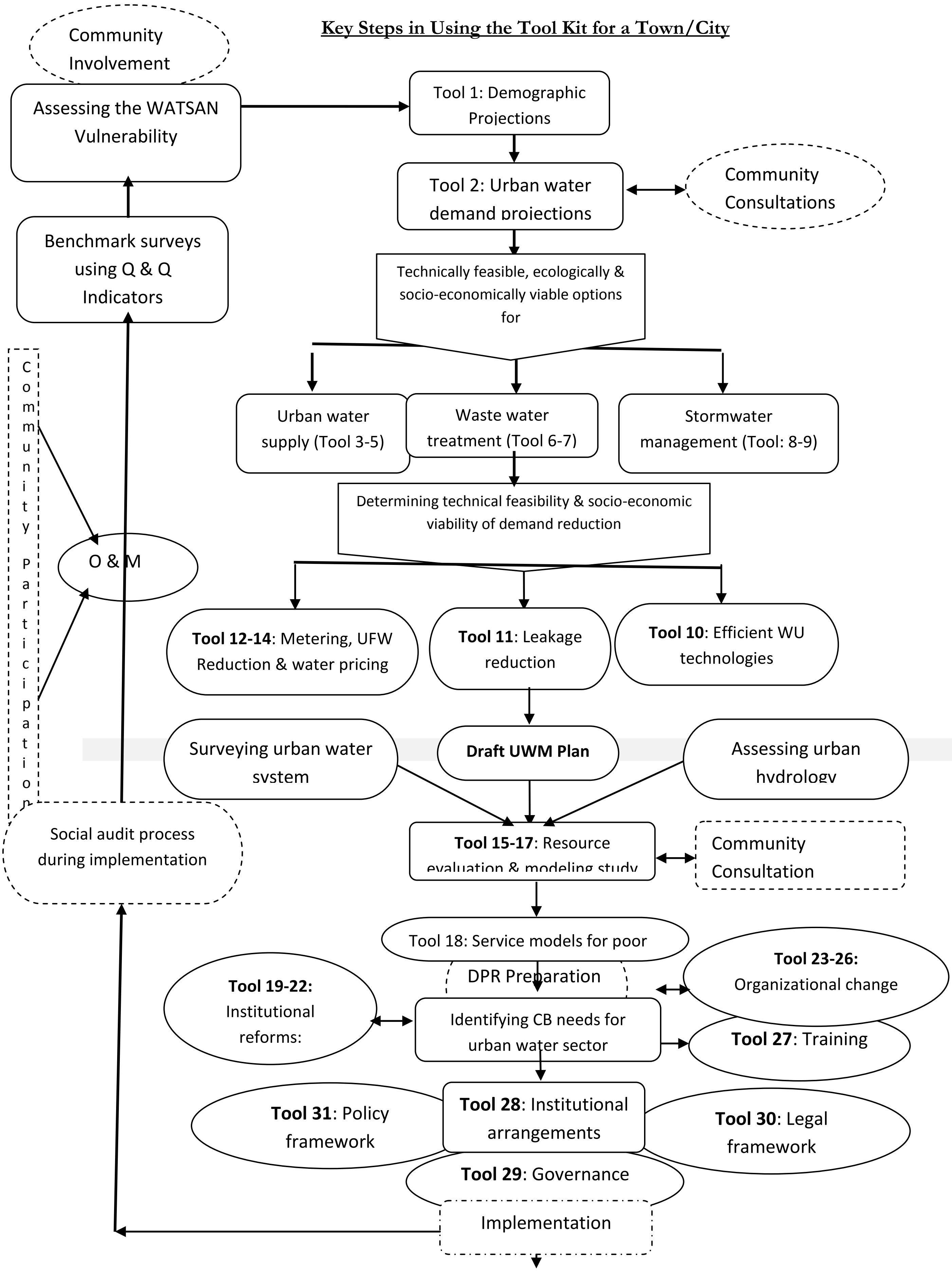
16) Coastal Alluvial -Plain-Low Rainfall-High Evaporation (A5-P1-H3-E3)

Water supply source: Surface water + groundwater for small towns; surface water +groundwater & desalination in municipalities and corporations; and imported surface water +desalination of saline groundwater or seawater in metros

Wastewater treatment: membrane technology for large cities (metros); and treated wastewater to be used for domestic water supplies other than drinking; SAT/waste stabilization pond for treatment of wastewater for small towns and municipalities; treated wastewater to be diverted for irrigation in the peri-urban areas

Storm water management: Rain garden for collection and simultaneous recharge of storm water for corporation and metros (with large built up area)

Key Steps in Using the Tool Kit for a Town/City



Demography, urban water demands

Water supply, wastewater treatment, storm water management

Urban water demand is a function of population and per capita water demand. The per capita demand (here we refer to the normative water demand) varies with income levels and climate. Rising income can lead to increased water demand as water needs for environmental services such as gardening, tree plantation, and environmental flows in rivers/streams increases (Rosegrant *et al*., 1999). Water demands are higher in hot and arid, and hot & humid climates as compared to cold & humid climates. The growth in per capita water demand is also a function of how the population is growing (WRI, 1995). The reason is this. Higher growth in urban population is likely to trigger growth in demand rate itself, which is owing to greater need for water for environmental sanitation. Larger cities would require greater amount of water for watering tree plantation etc. Hence, there are two sets of challenges in urban water demand projections: doing correct projections of future population growth rate; doing correct projections of per capita water demand.

Description of Tool 1:

Conceptual issues in urban population projections

There are conceptual issues in urban population projections owing to the mismatch between the city administrative boundary and the territory of the urban area. When the administrative boundaries of cities remain fixed for long periods of time, they are likely to misrepresent the actual growth of a city in both territorial and population terms. When administrative boundaries change with relative frequency, one can assume that they are reflecting the actual territorial expansion of the urban area linked to the functioning of the city, with habitations at urban levels of population density. Two metros where such expansions have happened in the very recent past are Bangalore and Ahmedabad. For a given city, if the population data are available for both "city proper" and metropolitan area, the second one should be preferred because they are expected to better represent the territory associated with the urban agglomeration than the data based on administrative boundaries.

For any given city, effort should be made to ensure that the time series data of population conforms to the same definition over time. Adjustments have to be made whenever necessary to achieve internal consistency. Often, the changes involved demand that the criterion for assessing the population of a city is changed. That is the case when data on a city in terms of the urban agglomeration are available for only one or two points in time and there is a longer and more consistent series of data on the population of the "city proper". In those circumstances, the data on the city proper, based on administrative boundaries, are used instead of those on the urban agglomeration since a sufficiently long time series based on the latter concept is normally not possible to reconstruct from the data available. When such reconstruction is possible, it is undertaken.

Underlying Premise

In order to derive equations for urban demographic projections, the following studies were mainly used. The first study pertains to the structural aspects of urbanization in India. The second study pertains to the impact of female enrollment in schools on fertility rate. The first study shows the following: 1] the large urban areas in India are experiencing rapid growth in population owing to constant migration from villages and smaller towns because of their link with national and international markets; 2] smaller ones are experiencing low growth rates owing to they being trapped in the local and regional economy, and, 3] in exception to what is found generally across the country, the smaller urban areas in socio-economically backward states of India, continue to attract rural populations owing to lack of infrastructure (electricity, roads and irrigation) in rural areas, and this is evident from the fact that more than half the population in such towns are engaged in agriculture (Kundu, 2006). The second study shows that alternative paths of future female enrollment in education will significantly influence the total fertility rates (Lutz and Scherbov, 2004)

Urban population projection functions for different categories of towns/cities

For small towns in socio-economically forward regions, the population of a given town after "n" years (θ) is estimated as:

P*(1+µ) ^n: .... (1)

Where, "µ" is the mean value of compounded annual growth rate in population estimated for 3 previous decades expressed in fraction; and P is the base population; "n" is the number of years for forecasting.

For large towns/cities and in small towns in regions which are socio-economically backward, the population of a given town after "n" years (θ) is estimated as:

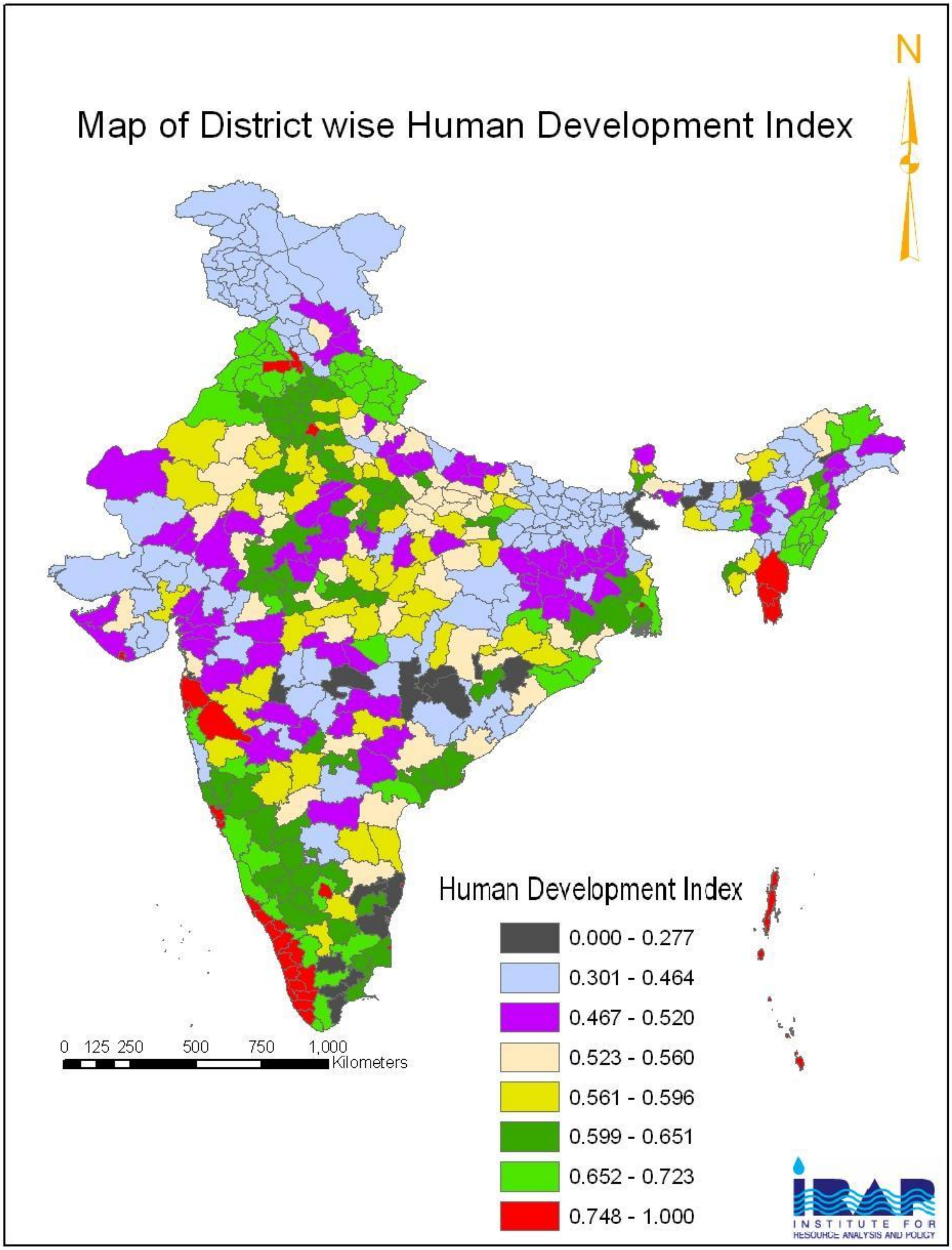
P (1+ [X+¥]) ^n: .... (2)

Where X is the compounded annual growth rate in population of the previous decade expressed in fractions; and ¥ is the average increment in the compounded annual growth rate in decadal populations in four decades, also expressed in fractions.

The Map provided below can be used to decide whether a particular city or town falls in a socio-economically backward or forward region. It gives the human development index figures.
As we have seen, the level of socio-economic development should be an important consideration for choosing the driver of population growth for any small town. The human development index can be a useful indicator of the level of socio-economic development of different regions as it captures the economic conditions, life expectancy and educational status, all three aspects of socio-economic advancement. Intuitively, it would also capture the female literacy, a factor, which has a bearing on future fertility rates, and population growth. This is because the regions of low female literacy also coincide with those which are socio-economically backward. The map showing the HDI values for different districts of India, based on 2001 data is given below. The districts that are having HDI values less than 0.50 are treated as "socio-economically backward", and those with HDI values exceeding 0.50 are treated as "socio-economically forward". Accordingly, equations are used for population projections.

Note: for more details refer section 5.1 in IUWM Technical Report

<u>Figure 4: District Wise Human Development Index</u>



Description of Tool 2:

Urban Water Demand Projections:

Estimating the Per Capita Water Demand:

The per capita urban water demand is a function of the per capita domestic water demands; the nature and size of industries located within urban areas which are dependent on urban water supplies for manufacturing; amount of water required for growing trees and maintaining urban environmental management services, including parks, fountains etc., which are public goods. The per capita domestic water demand is a function of: a] the per capita income levels, which influence the amount of water which dwellings use for various purposes like gardening, clothe and vehicle washing and other amenities; b] the climate; and c] price of water. But, there are practical issues in estimating the demand based on income owing to the difficulty in forecasting the income levels of different segments of the urban population, and the exact price of water. Therefore, we have considered a normative water demand, which is based on size of the city, and type of sewerage system. The value is constant for the entire population. Nevertheless, provision is made for meeting special demands such as gardening for bungalows.

However, this does not mean that the cities should keep provision for meeting all those needs of individual households and commercial establishments which are not essential. Whether the city/town should make provision for meeting these demands, depends on whether the resource is plenty or scarce. If the city is falling in a region which is water-scarce, there could be two sets of issues involved in provisioning water for meeting such needs. First: the financial and environmental costs of supplying large amount of water that would meet all requirements would be high; and 2] there are ethical issues involved in using water for meeting such needs in situations of scarcity, even when the consumers are made to pay the full cost of provision of water supply.

Per Capita Water Demand Projections

Since per capita water demand (normative) is a function of the population size itself, we have done population projections first. Since the provision of water for trees etc. is to be decided on the basis of city size, water demand projections are done for different categories of towns differently. Here, the environmental water demand is considered only for large towns (Class I) and metros.

Per capita water demand ψ (m^3/annum) for a town belonging to metros and Class I cities is estimated as:

$$\psi = \frac{(€ * \theta) + \partial\theta * \Delta + \nabla * \theta + \propto)}{\theta} \quad \text{.................................. (1)}$$

Where, € is the per capita water demand for domestic uses applicable to those categories of cities and is expressed in m^3 per annum (Table 3).

In estimating the per capita water demand, a "correction factor" can be applied on the per capita water supply "norm" for the particular city/town category to factor in the influence of climate on domestic water demand. This "correction factor" can be estimated from primary survey data by comparing the per capita use in cities/towns falling in different climates, but having adequate water supplies.

- Δ is the per capita water demand for gardening estimated from the survey data for bungalows (m^3/annum)

- $\partial\theta$ is the fraction of the urban households living in bungalows

- ∇ is the per capita environmental demand for water (m^3/capita/annum), and it can be estimated from the survey data (climate-wise) or on the basis of the norm

- $\propto$ is the industrial water demand estimated on the basis of industrial outputs generated within the town (Table 2).

Table 2: Water Use Rates for Unit Production for Different Industrial Production Units

Sr. No.	**Category of Industry**	**Water Requirement (m^3)/Ton**
1	Integrated Iron & Steel	22
2	Smelters	82.5
3	Petrochemicals and Refinery	17.0
4	Chemicals-Caustic Soda	5.5
5	Textile & Jute	20
6	Cement	4.5
7	Fertilizer	16.7
8	Leather Products	30
9	Rubber	6.6
10	Food Processing	6.8
11	Inorganic Chemicals	200
12	Sugar	2.2
13	Pharmaceuticals	25
14	Distillery (Req. Per 1000 litre)	22
15	Pesticides	6.5
16	Paper & Pulp	200
17	General Engineering	2.2
	Total	

Source: Report of the National Commission on Integrated Water Resources Development titled "Integrated Water Resources Development: A Plan for Action" (GOI, 1999).

Table 3: Normative Domestic Water Demand for Different Categories of Towns/Cities

Sr. No	City/Town Category	Per Capita Normative Water Demand for Domestic Use	Remarks
1	Metros (27 of them in India)	150	Presence of planned sewerage system
2	Non-metro cities	135	Do
3	Non metros without planned sewerage	70	Decentralized sewerage disposal system

While estimating the per capita urban water demand, we have not considered the water required by commercial establishments. The reason for this is that the main water demand by commercial establishments such as hotels, restaurants, shopping complexes etc. is originating that for human consumption (drinking, personal hygiene, cooking) which is already considered in the domestic demand of the urban population. One argument against this approach could be that the significant floating population which urban areas would normally have and which can create additional demand for human consumption, can get left out in the process. But, it is also important to keep in mind the fact that there would be large-scale and continuous movement of population from the city to rural areas and other cities on a daily basis, which would actually take away a portion of the water demand for human consumption. In nutshell, considering the demand by commercial utilities might lead to double counting of human demand for water.

Aggregate Urban Water Demand

The urban water demand function (λ) can be estimated as follows:

$$\lambda = (\theta) * \psi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, θ is the population of a town at a given point of time, and ψ is the per capita water demand in m^3/annum of that town.

Note: For more details refer section 5.2 in IUWM Technical report

Physical & technological options for urban water management

Those are physically feasible, socio-economically viable

Description of Tool 3:

Identifying technically feasible and cost effective options for urban water supply

In order to identify technically feasible and cost effective option for urban water supply in different urban typologies, the data available from 301 towns and cities across India on water supply and cost of production & supply were analyzed.

The findings emerging from these analyses, with regard to technical feasibility of water supply from a particular source, are as follows. *First*: in cities/towns and villages of states falling in hard rock areas viz., Andhra Pradesh, Karnataka and Tamil Nadu, the percentage contribution of groundwater to drinking water supply, in terms of number of households covered, is much smaller than that of surface water. Whereas in the villages and towns falling in the alluvial plains of Punjab, UP and Bihar, the groundwater contribution to the total drinking water supply, in terms of number of households covered, is much higher than that of surface water. *Second*: with passing of time, the water supply pattern changes from a single source to a combination of sources across regions. This is indicated by the increase in percentage of town populations covered by the combination of water supply sources among the group of cities falling in Class II category from 4.2 per cent in 1978-79 to 40.90 in 1999-00 (source: CPCB survey of 299 cities, 345 towns and 23 metros). With passing of time, and with increase in population, the water utility will have to tap more than one source, as the existing sources either become defunct or inadequate to maintain the supply levels. T*hird*: larger cities depend more on surface water resources that are exogenous (Mukherjee *et al*., 2010).

As regards the cost of production of water, it is found to be heavily dependent on the overall water endowment. The water abundant regions are the eastern Indo-Gangetic plains, covering most parts of Uttar Pradesh, the entire Bihar, and alluvial plains of West Bengal and Assam. These areas have high rainfall, very good aquifers, and perennial flows in streams and rivers, and large number of ponds and tanks. The water-scarce regions are those in peninsular India, underlain by hard rock aquifers with low to medium rainfall and high aridity; hilly areas receiving high rainfall; western India underlain by hard rocks, semi consolidated rocks and unconsolidated alluvium mostly with very low to low and medium rainfall; north western India, with low to medium rainfall, high aridity but underlain by alluvial aquifers. In parts of eastern and central India, characterized by hard rock formations, the groundwater is scarce, but surface water resources are abundant, with rivers, streams and tanks/ponds. In water-scarce regions, where physical sustainability of water supply source is poor, the cost of production of water is high. In contrast, the cost is very low in water-abundant regions, where the physical sustainability of water supply sources is good.

The reasons for high cost of production of water in water scarce regions are as follows. *First*: groundwater resources potential is very low in the hard rock areas of the south and western India (Chatterjee and Purohit, 2009; GOI, 2005). *Second*: they are heavily over-exploited in most parts of the south Indian peninsula, western India and most parts of alluvial north western India (GOI, 2005). Depletion of groundwater resulting in lowering of water levels, increase in cost of wells/bore wells, pumps and the reducing well yields increase the cost per unit of water pumped. *Third*: surface water resources are heavily over-appropriated in the basins of peninsular, western and north western India, barring the Godavari river basin in the South-east (Kumar et al., 2008a) Hence, water is not available in the downstream parts after the monsoon months. As a result, water has to be brought from distant places for meeting urban water needs. The degree of dependence on exogenous water increases with increasing size of the city (Mukherjee *et al*., 2010).

The cost of production and supply of water alone cannot be the consideration for choosing a particular source of water supply. How sustainably water supply can be provided is also an important consideration. In other words, a particular source of water supply might work out to be cheap, but might be able to meet only small fraction of the total water demand of a town or city. The examples are the tanks located in and around large cities of Andhra Pradesh and Karnataka. India. But, the second source, which has to supplement this first source, might work out to be prohibitively expenses. Hence, overall, the particular system might work out to be expensive.

Also, the possibility of arranging alternative sources becomes a consideration. A particular source might be very expensive. But, in situations where the possibility of arranging an alternative is absent, the costly systems will have to be resorted to.

Integrating the foregoing analyses, it could be reasonably argued that groundwater alone could be sustainable sources of the sole water supply in small towns in the water abundant regions of eastern Gangetic plains, after the local surface water sources are tapped. It could be the sole source of water supply in the alluvial Indo Gangetic plains, where surface water resources are limited. In very large cities, groundwater in conjunction with surface water from large reservoirs and lakes could be the sustainable sources of water supply. Whereas groundwater could be one of the many sources of water for meeting urban water needs in small towns in the water-scarce regions of the south. Exogenous surface water would become the major source of sustainable water supply in large cities of the south, which can be supplemented by local groundwater. It should be remembered here that a cost effective option for one typology will not be cost effective for another typology. The tool # 3 provides technically feasible and cost effective water supply options for towns and cities in 16 different typologies (Table 4).

Table 4: Water supply Options for different urban typologies

Typology	Water Supply Options					
	Lifting from local river	Groundwater abstraction	Local lake/pond/ tank	Surface water from reservoirs	Surface water import	RHWS/ Desalination
1		XXX			XXX	
2	XXX	XXX				
3	XXX	XXX				
4	XXX	XXX	XXX			
5		XXX	XXX	XXX		
6		XXX	XXX	XXX		
7	XXX					RWHS
8			XXX		XXX	XXX
9		XXX	XXX	XXX		XXX
10	XXX	XXX	XXX			
11		XXX	XXX		XXX	XXX
12	XXX					RWHS
13		XXX	XXX		XXX	
14	XXX		XXX	XXX		
15	XXX	XXX	XXX	XXX		
16				XXX		XXX

Note: XXX indicates that suitable options for different typologies.

For more analysis which forms the basis for choosing the water supply options for each one of the typologies, as provided in Table 3, please see section 7.1 in the technical report on integrated urban water management.

Description of Tool 4

Socio-economically and institutionally viable options for water supply

In the first step, we have listed the various water supply options physically feasible and economically viable for different typologies, as it is quite likely that in the same typology, more than one option would be viable from both fronts. The table provides a list of options for each typology, and does not mean that one can fully depend on one of these options. It only means that the particular option could also contribute to urban water supply provisions, or in other words, it does not integrate environmental sustainability considerations.

Whether this option could actually become viable for a given town can be decided on the basis of several criteria. They are: cost of supply; supply potential; scope for decentralization; and the O & M requirements. To elaborate: the contribution of a particular option to improving the overall water supply should be significant; as far as possible, the option should be one in which there is scope for decentralized management of the infrastructure and services; and 3] the system should be as simple as possible to enable O & M by the local staff of the utility. The manner in which these criteria will have to be used for selecting a sustainable water supply source for a town is shown in the Table 5.

The cost figures of water supply for some standard sources (groundwater based sources and surface water based sources) are provided for Class I and Class II cities under different typologies in Table 6 and Table 7, respectively. The unconventional sources such as RWHS and desalination systems are not included in this. They are provided separately in the subsequent sections. The reason for providing the cost figures typology-wise is that the cost of water supply is a function of the water resources endowment. The water endowment changes with typology. The reason typology takes into account the key physical parameters that determine the water resource endowment of a region such as rainfall, topography, geology/geo-hydrology and climate. The cost figures are based on 1999 prices and therefore have to be revised taking into account the average inflation rates for the time period elapsed.

The supply potential for aquifers in an urban area, or in other words the extent to which local groundwater resources can meet the urban water demand, can be worked out if the name of the district, which the city/town falls in, is known. The estimation procedure integrates the physical sustainability considerations, as it takes into account the annual renewable recharge of groundwater against the annual water demand. Likewise, the extent to which the local catchment yield can meet the urban water demand can be worked out if the name of the basin in which the city/town falls, is known. Table gives the average catchment yield of unit catchment area for 18 major river basins.

Table 5: **Socio-economically and institutionally viable options for water supply**

Note: the shaded box indicates that a particular criterion is important for the given category of town/city.

Criteria for choosing a technology option for water supply improvement	Overall physical condition w. r. to water availability and socio-economic status					
	Water-scarce			Water rich		
	City including metro	Small town		City including metro	Small town	
	Urbanized	Urbanized	Less urbanized	Urbanized	Urbanized	Less urbanized
Unit cost of production						
Supply Capacity						
Possibility for decentralization						
Need for O & M						

Note: Urbanized and less urbanized refer HD map

Table 6: Average cost of production per-cub-meter of water supply in Class-I cities

Typology	Average cost of production per cubic meter Class-I cities	
	Surface water	Ground water
1	3.79	2.03
2	1.37	0.87
3	0.96	0.87
4		0.46
5	3.67	-
6	1.73	2.67
7	1.72	-
8	4.95	-
9	2.00	3.50
10	0.74	1.67
11	2.25	1.06
12	2.78	0.85
13	2.24	2.07
14	1.74	-
15	-	0.81
16	-	2.93

Source: NIUA 1999

Table 7: Average cost of production per-cub-meter of water supply in Class-II cities

Typology	Average cost of production per cubic meter Class-II cities	
	Surface water	Ground water
1	-	2.06
2	1.34	1.19
3	1.21	1.03
4	2.03	2.10
5	1.53	4.58
6	2.37	1.36
7	-	-
8	0.72	10.12
9	1.86	1.79
10	2.08	
11	4.56	4.08
12	3.05	4.70
13	2.61	-
14	2.50	0.93
15	2.44	-
16	-	-

Source: authors' estimates based on NIUA (2005)

Note: the costs are for 1999 price levels, and therefore need to be adjusted for current prices, using the inflation rates

The extent to which the urban water demand in a town can be met by groundwater (***X***) (%) can be estimated by the mathematical formulation as:

$$X = \frac{\Delta * \mu}{\theta * \mathrm{p}} \qquad \text{..............................} \ (1)$$

Here,

- Δ is the groundwater richness in terms of m^3/per annum per sq. km
- $\emptyset$ is the population density of the urban area in no. of persons per sq. km
- p is the estimated per capita water demand in m^3 per capita per annum
- μ is the distribution (conveyance) efficiency in percentage.

The population density of the urban area can be obtained from the total geographical area and the total population.

Mathematical formulation for estimating the supply potential of local groundwater system

Groundwater richness of different districts

The groundwater richness of an area is defined as the average quantum of renewable groundwater resources available per unit area of the region in question, and was estimated by taking the ratio of the average district-wise renewable groundwater resources evaluated for a five year period by the central ground water board (CGWB), and the geographical area of the district. It is expressed in m^3/sq. km per annum. They are given for all the districts in India in Figure 3.

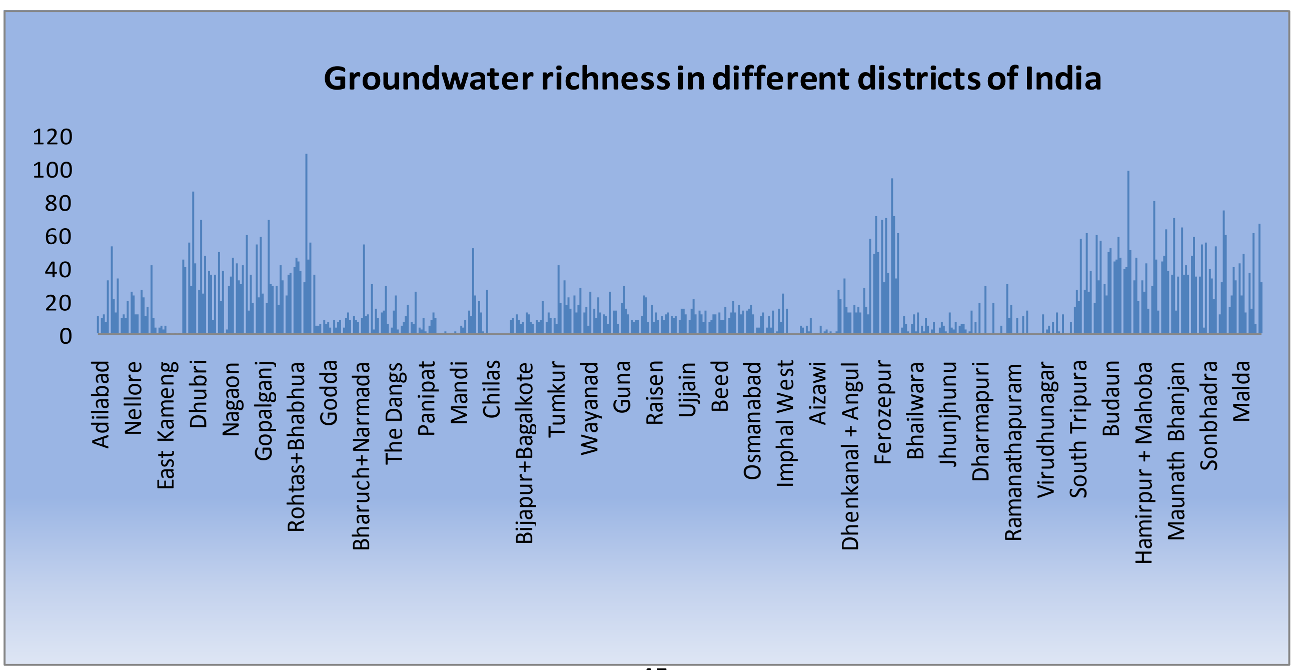


Figure 3: Groundwater richness of different districts of India

Mathematical formulation for estimating the supply potential of local surface water catchments

The annual utilizable yield of a catchment (in MCM per annum) having an area of A (sq. km) and average runoff rate r (m/annum) can be estimated as:

Annual utilizable yield of a catchment in MCM per annum

$$R = A * \mathrm{r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

The extent to which the urban water demand in a town can be met by local surface water (Y) (%) can be estimated by the mathematical formulation as:

$$Y = \frac{R^1 * \mu}{\mathrm{p} * \mathrm{P}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Here, R^1 is the uncommitted yield from the catchment obtained by subtracting the total committed flows from the total catchment yield R in MCM per annum; p is the estimated per capita water demand in m^3 per annum; μ is the efficiency of conveyance of water from source to the demand site; and P is the total urban population in million.

Catchment Yield

The estimates average catchment yield for 18 major river basins in India is given in Table 8. The amount of water from the catchment or basin already committed for other uses and appropriated through reservoirs and diversion systems, need to be factored out to estimate the uncommitted catchment. In many river basins, these committed flows are very high. Some examples are the Ganges, Sabarmati, Banas, Cauvery, Krishna, Pennar, the west flowing rivers north of Tapi in Saurashtra and Kachchh. On the other hand, a large share of the flows in Brahmaputra-Meghna river system in the north east, and Godavari in the south remain untapped. But, the actual utilizable surface runoff in a basin can vary widely from upper to lower catchment in the basin due to the large differences encountered in rainfall and reference evaporation (ET_0). In most of India' river basins, the rainfall is comparatively higher in the upper catchments, and ET_0 lower. Hence, the planners should make their own judgments while deciding the probable runoff rates, depending on the location of the catchment under consideration vis-à-vis the basin drainage area.

Table 8: Annual Flow, Utilizable Surface Water and Average Runoff Rates

Sr. No	Name of the river basin	Catchment area in India (sq. km)	Average Annual Surface water potential (km^3)	Utilizable surface water resources (km^3)	Average Catchment Yield (m)
1	Indus	321289	73.31	46	0.143
2	Ganges	861452	525.02	250	0.290
	Brahmaputra-Meghna	236136	585.6	24	0.102
3	Godavari	312812	110.54	76.3	0.244
4	Krishna	258948	78.12	58	0.224

5	Cauvery	81155	21.36	19	0.234
6	Subarnarekha	29196	12.37	6.81	0.233
7	Brahmani and Baitarani	51822	28.48	18.3	0.353
8	Mahanadi	141589	66.88	49.99	0.353
9	Pennar	55213	6.32	6.86	0.124
10	Mahi	34842	11.02	3.1	0.089
11	Sabarmati	21674	3.81	1.93	0.089
12	Narmada	98796	45.64	34.5	0.349
13	Tapi	65145	14.88	14.5	0.223
14	WFR south of Tapi up to Tadri	55940	87.41	11.94	0.213
15	WFR south of Tadri up to Kanyakumari	56177	113.53	24.27	0.432
16	EFR between Mahanadi & Pennar	86643	22.52	13.11	0.151
17	EFR between Pennar & Kanyakumari	100139	16.46	16.73	0.167
18	WFR of Kachchh & Saurashtra including Luni	321851	15.1	14.98	0.047

Source: based on data provided in GOI, 1999: Table 3.6, for more details refer section 7.1 in IUWM Technical report

Description of Tool 05:

Determining the Hydrological Opportunity and Cost of RWHS

The hydrological opportunity for roof top rainwater harvesting is a function of the total amount of rainfall & snowfall; the roof catchment area; and the characteristics of the roof which determines the runoff coefficient (Kumar, 2004; Marsden Jacob Associates, 2007). This means, the amount of rainwater or water from snow melt that can be captured increases with increase in magnitude of rainfall, increase in roof area and increase in runoff coefficient of roof.

The cost per cubic metre of water would depend on the type of material used for construction of the tank, the type of geological formation that exists in the area in question and the actual storage capacity required to store the runoff generated. The actual storage capacity is the most complex part of the planning question. For a given storage capacity provided, the effective storage increases with the number of days of withdrawal during times of inflow. We have considered the total number of days of water withdrawal from tank during times of inflow to be equal to the total number of rainy days.

It is to be noted here that in India, the regions having low rainfall also experience the annual rainfall in very few rainy days (Kumar, 2004; Pisharoty, 1990). Hence, for regions having low rainfall, the roof water tank is assumed to function as a storage system for monsoon flows to be used later on in winter and summer, and not as a storage-cum-diversion system. As a result, in such cases, the effective storage would be same as the storage capacity provided. While the cost of the system depends on the storage capacity provided, the cost per unit volume of storage depends on the effective storage.

Mathematical simulations carried out for high rainfall regions (with rainfall magnitude ranging from 2000mm to 3000mm) using assumed values of roof catchment area, annual rainfall, annual rainy days and daily tank water withdrawal rates show that unit cost is lower for RWHS with larger roof catchments, while the total amount harvested would be higher. It also shows that the unit cost reduces drastically when the households increase the daily withdrawal in proportion to the greater inflows available from the larger catchments. It also shows that the unit cost reduces with increase in number of days of withdrawal, which was assumed to be a function of increase in number of rainy days, and therefore days of inflow into the tank.

The total amount of water that can be harvested (V) in m^3=

$$V = \propto * \Delta * \mu \text{ .... } \mathbf{(1)}$$

Here, $\propto$ is the roof area in m^2; Δ is the total annual rainfall in meters; and μ is the runoff coefficient for the type of roof that exists. The runoff coefficients for different types of roof are given in table below.

Table 9: Runoff Coefficient for Different Roof Types

Type of Roof	**Runoff Coefficient**
Galvanised Iron Sheet	0.90
Asbestos Sheet	0.80
Tiled Roof	0.75
Concrete Roof	0.70

The storage capacity required to storage a volume of as:

$$V_{tank} = \propto * \Delta * \mu - \delta * \cap \text{ ....} (2)$$

The unit cost of collection of water through RWHS $C_{roof-tank}$ (Rs/m^3) can be estimated as

$$C_{roof-tank} = \frac{1600\,\{\alpha * \Delta * \mu - \delta * \cap\}}{V} \text{ .... } (3)$$

Here, δ is the daily water demand in m^3 of a family/housing stock implementing RWHS; $\cap$ is the number of annual rainy days in the place under consideration. The empirical value of 1600 is taken as the cost of creating one cubic metre of underground storage system. However, this value can change depending on the local specific situation.

Note: For More details refer section 7.4 in IUWM Technical Report

Description of Tool 06:

Scope of Desalination

Desalination is a fast emerging water treatment technology around the world. This method of creating freshwater supplies is becoming cheaper in the wake of the drastic reduction in cost of membranes. There are many different technologies available for desalination: 1] reverse osmosis; 2] multi-stage flash distillation; and, 3] electrolysis. Reverse osmosis can be chosen for raw water having different levels of salinity, effectively from the point of view of cost. The membrane can be chosen in accordance with the concentration of salts in the raw water. Flash distillation is used for sea water. Electrolysis can be used for wide range of salinity.

In India, coastal areas of many regions which receive low to medium rainfalls and which are underlain by hard rock geology, except the coastal strip, experience absolute scarcity of water. Groundwater is the only source of water in these regions. Problems of water shortage are more severe in the cities/towns located in these regions. Desalination technology can be used to create freshwater supplies in these regions for basic survival needs such as drinking and cooking. The level of Total Dissolved Solids (TDS) in groundwater is higher than 5,000 ppm in these coastal belts, but does not exceed 10,000 ppm. Therefore, the process of Reverse Osmosis (RO) using membrane technology is most ideal for desalination in the area. When brackish water is not available in plenty, then seawater can be used for desalination. But, in addition to RO, flash distillation can also be tried in such situations.

The cost effectiveness of RO systems would depend on: [1] careful selection of plant size keeping in view the demand for water so as to make it run at full capacity; [2] proper selection of membrane keeping in view the salinity of raw water; [3] adequate investigation of quality of water to be treated; [4] uninterrupted supply of electric power; [5] use of non-corrosive material for construction of the plant; and, [6] use of trained staff for operation and maintenance (GOI, 1999). It is also important to note that the cost of production of water is lower for plants of larger size (authors' own analysis based on Shah et al., 1997) (Table 10), and also the cost comes down with lowering salinity of the raw water.

The cost of flash distillation depends on the source of thermal power used in distillation. In recent years, there has been increasing recognition of the scope for co-location of desalination plants with power plants has (El-Nashar, 2001; Hoffman and Zfati, 2003; Agashichev and El-Dahshan, 2003; Lokiec and Kronenberg, 2001). In fact, about 95% of the total potable water production capacity in the MENA countries is produced via cogeneration (Hoffman and Zfati, 2003). The choice of the type of power plant and desalination technology is an important one and is highly dependent on site-specific conditions and economic consideration (Hoffman and Zfati, 2003). In the coupling of steam-generating power plant and a thermal desalination plant, heat in the form of steam generated by the power plant is used as the source of heat for the co-located desalination plant (Al-Nashar, 2001; Hoffman and Zfati, 2003; Faibish and Ettouney, 2003). Experience shows that when multi-stage flash distillation is used in conjunction with power plants for co-generation of electricity & water, with the heat in the form of steam from power plants used for heating brine in the boilers, the cost of production of water comes down drastically. The experience in Israel shows a cost of US $ 0.50 per m^3 of treated water.

The economics of desalination, in terms of cost per cubic metre of treated water, for different types of technologies and for different levels of salinity are presented in Table 11. For one to consider these figures for working out the cost of desalination systems, two factors need to be kept in mind. First: the cost of membranes has been rapidly coming down over the years and therefore need to be factored in while looking at RO systems. Second: for all desalination systems, the cost figure need upward revisions to take into account the inflation, as the figures provided are quite old.

Capital Cost and O & M Cost of Desalination Plant by Installed Capacity using Reverse Osmosis

Table 10 provides the capital cost (of the plant) and 0 & M cost of RO based desalination systems of various sizes. The costs are based on 1997 prices and therefore need to be updated for inflation. But, also, the capital cost of RO systems had declined significantly over the past few years. Currently, it cost Rs. 2.5 lac for a plant having a capacity of 1 m^3 per hour. Proportionately, the capital cost for various plant sizes would come down.

Table 10: The Capital and O & M Cost of RO Plants of Different Capacity

Capacity of Desalination Plant (m^3 per Day)	Cost of Plant (Rs. In Lac)	Cost of O and M/ Year (Rs. in Lac)	Cost per m^3 of Water
10	6.0 to 10.0	1.0- 2.0	61.80-105.60
20	8.0-11.00	2.0- 2.6	50.30-65.20
30	9.0-14.20	2.6- 3.40	40.90-56.60
50	16.0-27.20	3.6- 6.0	38.10.61.70
100	20.0-41.30	7.0- 11.0	30.60-53.00

Source: Shah *et al*. 1997 and authors' own analysis

Economics of Desalination under Different Technologies

The cost per cubic metre of desalination depends also on the salinity of raw water, type of treatment used in addition to the size of the plant and utilization.

Table 11: Cost of Production of Water for Different Types of Desalination Systems

Sr. No	Type of raw water	Technology	Level of salinity	Cost of water Treatment (Rs/m^3)	Remarks
1	Seawater desalination	Reverse Osmosis	25,000 ppm+	30.0-105.0	The cost is a function of the plant size & potential utilization
2	Desalination of brackish groundwater	RO	5,000-6,000 ppm	27.0-30.0	Do
3	Desalination of seawater	Multi-stage Flash distillation	40,0000 and above	60.00	Freshwater recovery is 20%; the cost significantly reduces if coupled with power plant (thermal nuclear) to Rs. 25 per m^3 of water
4	Brackish water	Electro dialysis	< 5,000 ppm		

Source: based on Shah et al., (1997); IRMA/UNICEF (2001); Osman *et al.* (1999)

Description of Tool 07

Determining Technically Feasible Option for Wastewater Treatment

Wastewater treatment can be divided into four phases: 1] preliminary treatment; primary treatment; secondary treatment and tertiary treatment. The secondary treatment, which is the most important treatment process in urban wastewater, involves two main processes: nitrification and de-nitrification. The treatment for wastewater can be biological, or physical or chemical.

Nitrification is the process of conversion of food into ammonia and then into nitrates by a biological degradation process. Further conversion of nitrates into nitrogen requires both bacteria and some specialized chemical compounds like methanol. De-nitrification is a process involved in the treatment of wastewater. As wastewater is collected in a treatment facility, it contains high levels of ammonia. Through a bacterial degradation process this ammonia is converted into nitrate. If discharged into the environment, the nutrient-rich nitrate in sewage effluent can have a devastating effect on water ecosystems. De-nitrification refers to the process using a combination of chemical additives and bacterial degradation to convert nitrate (NO_3) into nitrogen gas (N_2) which is released to the atmosphere (Gijzen, 2001). Methanol activates anaerobic bacteria, which decomposes nitrates into nitrogen gas.

The two major conventional wastewater treatment systems available for urban areas which use biological processes using bacterial digestion are: aerobic treatment systems, and anaerobic treatment systems. Aerobic systems require oxygen to be supplied mechanically, whereas anaerobic systems would treat the wastewater through the use of anaerobic bacteria. There are several versions of these basic treatment systems available. The difference is in the degree of treatment. The septic tank, the anaerobic filter/baffled septic tank; and sludge up-flow anaerobic blanket, are all anaerobic treatment systems.

The aerobic treatment systems have several versions: the aerobic reactor using the activated sludge process; aerobic tanks; and facultative ponds. The aerobic reactors are energy-intensive systems, as oxygen has to be supplied mechanically for aeration (Parr *et al*., 2004). The less conventional treatment systems are constructed wetlands which treat wastewater outflows from septic tanks through filter media; and Soil Aquifer Treatment systems, which use natural filter medium of dry strata for removing BOD, nitrates, phosphates and bacteria; and waste stabilization systems which use both anaerobic and aerobic treatment ponds for removal of BOD, apart from bacteria.

The performance of wastewater treatment systems, that use biological processes, is a function of the climate, temperature, solar radiation, geo-hydrological environment and soil structure (source: based on Lawrence *et al*., 2001; Mara *et al*., 1997; Parr *et al*., 2004; Peña *et al*., 2002) for removing bio-chemicals; and soil moisture and temperature (Gerba *et al*., 1975) for removing micro organisms. The anaerobic systems perform well under hot climate in the presence of good sunshine, and with high BOD concentrations. Otherwise, their performance would decline. Aerobic treatment systems function well under cold climates. Under high temperature, more energy would be required for aeration, which would reduce the economic viability. Waste stabilization ponds work well under high temperature, with good sunshine and high winds. If temperature is low, the performance would go down unless the area of the pond is increased substantially to reduce the intake of BOD load. But, this would increase the cost.

SAT, that use both biological degradation and natural filtration and adsorption, requires deep sand bed for the wastewater to pass through before joining the groundwater system (SDC, 2000; Rose, 1999). Therefore, it is important to decide on the type of treatment systems based on these physical considerations of temperature, altitude, wind speed, sunshine and geo-hydrological environment. Table 12 provides the wastewater treatment technologies that are technically feasible for the 16 different typologies, which take into account these factors. Table 13 provides empirical values of degree of treatment possible with different types of decentralized wastewater treatment systems.

Table 12: Wastewater Treatment Options for Different Rainfall, Climates, Geo-hydrology and Topography

Typology No.	Type of waste water treatment technologies								
	Onsite sanitation	Waste Stabilization Ponds			Soil Aquifer Treatment	Constructed Wetlands	Septic Tank	Activated sludge process	Anaerobic Treatment
		Anaerobic ponds	Facultative ponds	Maturation ponds					
	Depth to GW table	Temperature and Land availability	Temperature and Land availability	Temperature and Land availability	Depth of GW table and soil texture	Soil texture and land availability	Depth of ground water and temperature	Land availability	Land availability and tempe rature
1		XXX	XXX	XXX	XXX		XXX		
2		XXX	XXX	XXX	XXX		XXX		
3						XXX		XXX	
4						XXX		XXX	
5		XXX	XXX	XXX					
6						XXX			
7						XXX			
8	XXX				XXX				
9		XXX	XXX	XXX					XXX
10								XXX	XXX
11		XXX	XXX	XXX					XXX
12	XXX							XXX	
13	XXX	XXX	XXX	XXX					XXX
14		XXX	XXX	XXX					
15						XXX	XXX	XXX	
16		XXX	XXX	XXX					XXX

Note: XXX indicates the suitable technologies for the typologies under consideration

Table 13: Degree of treatment possible with different wastewater treatment systems

Sr. No	Type of treatment system	Efficacy of Treatment (% BOD reduction)	Permanent area (m^2) required per m^3 of daily inflow	Suitability
1	Septic Tank/Imhoff Tank	25-50	0.5	ST is suitable for deep WT areas only IT suitable for up to $3m^3$/day of influent
2	Anaerobic filter/ Baffled Septic Tank	70-90	1.0	In AF, non-settleable and dissolved solids are removed by bringing them in contact with active bacteria A good filter provides a surface area of 90-300 m^2 per m^3 of reactor volume
3	Facultative aerobic pond	80-90	25.0	Land area required is large; but actual area also depends on the temperature
4	Anaerobic pond	75-90	4.0	Produces low quality, but less sludge; suitable for hot regions
5	Constructed wetlands	Do	30.0	To treat effluent from septic tanks
6	Waste Stabilization Pond	90	6.40-19.20	Sunlight and heat required. The area depends on the temperature

Sources: based on Peña *et al.* (2002); WHO (1989); GTZ Technical Information W8e

The required area, however, increases with the degree of pollution. In case of closed anaerobic systems, there may be no land requirements as they are usually constructed underground. In addition, the area for sludge drying beds will range between 0.1-10 m^2/m^3 of daily flow, depending on degree of pollution and de-sludging intervals.

In India wastewater is generally used as aquaculture stabilisation ponds and for irrigating crops. Although official estimates are not available Strauss and Blumenthal (1990) estimates the area under wastewater irrigation to be over 73000 ha. It occurs along rivers which flow through such rapidly growing cities as Delhi, Kolkata, Coimbatore, Hyderabad, Ahmedabad, Indore, Kanpur, Patna, Vadodara, Varanasi, Dharwad etc. Along the rivers, the water is diverted via weirs to canals and often to tanks and then channelled to the fields for irrigation. If such uses were included, a much higher figure than 73000 ha would be obtained as in Musi river, Hyderabad alone there are approximately 40500 ha irrigated with wastewater (van der Hoek, 2004).

Note: For more details, please refer section 8.1 in IUWM Technical report

Description of Tool 08:

Determining the socio-economic viability of the WWT options

As the first step in selecting the WWT technologies, we have identified the options that are physically feasible for a given typology on the basis of various considerations such as climate, topography. The physical feasibility is to be ascertained on the basis of the degree of reduction of pollutants in the wastewater. While some wastewater treatment technologies can be made physically feasible in any physical environment (vis-à-vis temperature, sunshine, wind speed etc.), making that system work would work out to be prohibitively expensive. Therefore, physical feasibility in a way means affordability. The different wastewater treatment systems which are physically feasible under different rainfall, climate, geo-hydrological and topographical conditions are given in Table 12. They were arrived at on the basis of extensive research on the performance of various WWT technologies available internationally and the knowledge available on the physical factors influencing the physical, chemical, and biological processes involved in WWT.

Then, decision on whether to choose it or not can be taken on a variety of considerations. Some of them are: 1] land area available for treatment 2] crop and fish production potential of wastewater (Gijzen, 2001); 4] degree of sophistication involved in the treatment system; 5] capital cost of the system; and 6] 0 & M cost. They are presented in a matrix form in Table 14. Though all the factors in a way lead to socio-economic viability of the technology, these factors have to be considered carefully. First: not all these factors might be important for a given town or city. For a city with physical shortage of land, the land area required for the treatment system would be important rather than the capital cost of the system. Second: each factor has different weightage, even if applicable to a particular situation. For example, the weightage of "0 & M requirement" as a factor to be considered in decision making in the case of a small less urbanized town, would be much higher in comparison to factors such as "potential of using treated wastewater for crop production" or for fish production".

The capital and O & M cost of three types of wastewater treatment systems viz., activated sludge process (ASP); TF; and Waste Stabilization Pond (WSP), along with the details of land area requirement per unit volume of wastewater to be treated are given in Table 15. These figures would help guide the decisions on the type of WWT systems to be chosen on the basis of the criteria presented in Table 14.

Economics of Wastewater Treatment

Assessing the economic value of the treated water is not easy. It depends on the kind of opportunities that exist in the urban/peri-urban situation for reuse of wastewater. There are four different types of possibilities: 1] there is a very high demand for the wastewater for irrigation, and currently untreated wastewater is used; 2] there is no demand for wastewater for irrigation, and hence will have to be disposed into streams; 3] there is no demand for wastewater for irrigation, but there is water demand for growing fish; and, 4] currently, untreated wastewater is not used for irrigation or fisheries due to high level of toxicity. In the first case, the cost of treating the wastewater should be less than the incremental benefits accrued from reduction in the health risks to the irrigators, and the environmental damage caused by degradation of the soil and groundwater quality. In the second and third case, the cost of the treatment system should be less than the benefits derived owing to reduction in the general environmental quality of the stream/river and improvements in aquatic life. In the fourth case, the cost of the treatment system should be less than the incremental economic outputs generated from crops irrigated with wastewater and the reduction in environmental risks associated with unsafe disposal of effluents into the streams.

Table 14: Socio-economic and institutional viability of the WWT options

Criteria for choosing a technology option for wastewater treatment	**Overall Socio-economic Condition**					
	Land-rich[1]			**Land-scarce**		
	City including metro	Small town		City including metro	Small town	
		Urbanized	Less urbanized		Urbanized	Less urbanized
Land area for treatment						
Crop production potential of WW						
Fish production potential of WW						
Degree of sophistication						
Capital cost of the system						
O & M requirement						

Note: shading indicates that the particular criterion is important for the typology in question

Table 15: Evaluation of Net worth Investment for 50 MLD capacity Sewage Treatment Plant

ITEM	**ASP**	**TF**	**WSP**
Assumed capacity (2025), MLD	50	50	50
Assumed Ultimate Demand (2040), MLD	67	67	67
Land Required in Ha/MLD	0.18	0.16	0.8
Cost of Land, Rs Lac/Ha	200	200	200
Capital Recovery Factor, CRF	0.12	0.12	0.12
Total Annual Cost (TAC) (lac Rs)	1022.94	604.1	124.88
Present Discounted Cost Factor, DR	8.06	8.06	8.06
Net Present Worth of Investment (lac Rs)	8156.28	4869.06	1006.55

Note: For more details refer section 8.1.15 in IUWM Technical Report

Description of Tool 09:

Technically Feasible Storm Water Management Practices

Concept of Integrated Stormwater Management

Integrated Urban Stormwater Management is a management concept that has evolved in the west over the last 20 to 30 years largely in response to the knowledge that the rapid conveyance of urban storm water led to the environmental degradation of receiving waterways (Wong and Eadie, 2000). It is more recently influenced by the idea that urban storm water could provide a valuable water resource. Overall, it is about enabling more sustainable management of urban storm water environments. It is attracting a lot of attention in places where storm water drainage network is separate from sewerage networks. Separating out the storm water from the wastewater is important on two counts: 1] it prevents the dilution of wastewater, thereby increasing the energy recovery efficiency in treatment processes; 2] it helps in preventing contamination of storm water, an important resource in water-scarce regions.

The potential benefits of integrated storm water management are: 1] flood reduction--minimizing peak storm water discharges from urban catchments; 2] pollution minimization--by preventing, collecting, and/ or managing pollution loads; 3] storm water retention--harvesting and beneficial reuse of rainwater and storm water runoff within or near the urban catchment; 4] urban landscape improvement--showing rather than hiding water by functionally incorporating storm water into urban streetscapes and green areas; and 5] reduction of drainage investments--innovative integration of storm water systems into the urban environment for reducing the cost of infrastructure.

These synergetic effects are difficult to achieve in storm water management in practical situations always. The reason being: there is very low incidence of cities which experience problems of frequent flooding problems facing physical shortage of water, and vice versa; 2] issues of pollution of water bodies are least likely in places which experience flooding. So, when flood control benefits of storm water management become high, the benefits of water conservation become low. When the economic benefits of creating new water sources are high like in mountainous area with high rainfall, the flood control and environmental management benefits are likely to be very low.

Storm Water Management Measures

Storm water management measures can be structural and non-structural. Non-structural storm water control measures include a wide range of actions that can reduce the volume of runoff and pollutants from a new development. Structural storm water control measures are designed to reduce the volume and pollutants of small storms by the capture and reuse of storm water, the infiltration of storm water into porous surfaces, and the evaporation of storm water (National Academy of Sciences, 2008).

The storm water management interventions for an urban area depends on the amount of storm water generated; its potential to create urban floods; the utility of the storm water in improving urban water management; and, the economic viability of using it as a source of municipal water supplies. Therefore, apart from rainfall, climate, soil characteristics and land-use (Dussaillant *et al.*, 2005), the storm water management interventions for an urban area have to take into account the overall water situation, the topography and geo-hydrological environment. Because of the influence of such physical variables on the effectiveness of storm water management interventions, the decisions have to be taken for each possible situation separately. Hence, we have followed the 16 urban typologies and their sub-categorization (based on land use) for identifying SWM interventions (Table 16). The design procedure for rain garden is also provided subsequently, and can be used for whichever typology it is relevant.

Table 16: Storm water management options for different towns/cities

Typology No	Types of Storm Water Management Interventions in		
	Large Cities with large built up area*	**Small towns with large built up area**	**Small towns with small built up area**
1	Storm water collection using UGDs, and pond recharge for recharge after detention	Storm water collection using UGDs, and pond recharge after detention	Storm water collection using UGDs, and pond recharge after detention storage
2	Storm water collection and pond recharge	Storm water collection, and pond recharge	Storm water collection and safe disposal in natural sink after pond detention
3	Storm water collection, and safe disposal in streams after pond detention	Storm water collection and safe disposal in streams after pond detention	Storm water collection and safe disposal in streams after pond detention
4	Rain Gardens; excess storm water collection and safe disposal in streams after pond detention	Rain Gardens; excess storm water collection and safe disposal in streams after pond detention	Storm water collection and safe disposal in streams after pond detention
5	Storm water collection, pond detention and recharge through ponds	Storm water collection, pond detention and recharge through ponds	Storm water collection, pond detention and recharge through ponds
6	No large cities	Storm water collection and safe disposal in streams after pond detention	Storm water collection and safe disposal in streams after detention
7	No special actions will be needed, except storm collection & conveyance of storm water through UGDs, as the surface drainage will be extremely good in the hills		
8	Storm water collection and storage in natural ponds/tanks after detention as aquifers are saline in the Thar desert		
9	Runoff reduction measures, excess storm water collection, detention ponds and storage on surface	Runoff reduction measures; excess storm water collection, detention ponds and surface storage in tanks	Storm water collection, detention ponds and surface storage
10	No large cities	Runoff reduction measures other than RWSTs; excess storm water collection, detention ponds and	Storm water collection, detention ponds and surface storage

		surface storage	
11	Runoff reduction measures other than RWHS & RG; excess storm water collection, detention ponds, and surface storage	Runoff reduction measures other than RWHS & RG; excess storm water collection, detention ponds, and surface storage	Storm water collection & conveyance using UGDs, detention ponds and surface storage
12	Roof rainwater collection tanks for domestic water supply; runoff from other built up area to be drained off naturally by virtue of the hilly topography		
13	Storm water to be collected and conveyed through UGDs, storage in detention ponds and storage in tanks	Storm water to be collected in UGDs, and stored in detention ponds and surface storage in tanks	Storm water to be collected in UGDs, and storage in detention ponds and surface storage in tanks
14	Collection and conveyance of storm water through UGDs, and drainage of water from the town will be through gravity		
15	Storm water collection & conveyance using UGDs, and disposal into ocean		
16	Storm water collection & conveyance using UGDs, and storage in garland canals for continuous recharge of coastal aquifers (for preventing intrusion of seawater)		

Note: For more details refer, section 7.3, in IUWM Technical Report

Design and Evaluation of Rain Garden

Dussaillant *et al.* (2005) developed a model for design and evaluation of rain gardens for different climatic conditions. The model uses the following parameters for estimating the water balance in the rain garden surface depression: 1] the rainfall; 2] the rainfall "run on", which is determined by the ratio of the impervious area to the pervious area; 3] soil infiltration rate; and, 4] the runoff, which is generated when the average depth of the ponding exceeds the maximum pond depth.

$$\frac{dh_s}{dt}A = Q_{run-on} + Q_{rain} - Q_{infiltration} - Q_{runoff}$$

The soil infiltration rate is estimated using the Green and Ampt Infiltration equation, on the basis of the depth of ponding at the time of infiltration, the difference in initial and saturated soil moisture storage ($\theta_{sat} - \theta_{ini}$) and the capillary intake of water (h_{wf}).

The equation is:

$$\frac{dF(t)}{dt} = \left(1 + {}^{B}/_{F(t)}\right)$$

Here F is the cumulative infiltration, and t is time.

B is estimated as:

$$B = \lfloor h_{wf} + h_s(t) \rfloor \lfloor \theta_{sat} - \theta_{ini} \rfloor$$

The soil is modelled as three homogeneous layers where the percolation between them is assumed to be only gravity driven. Then the drainage $d(t)$ from a top layer to the one below is approximated (Rawls et al., 1993; van Genuchten *et al.*, 1980) as:

The drainage between layers is estimated using

$$d(t) = K_{sat} * k^{1/2}(1 - (1 - k^{\frac{1}{m}})^m)^2$$

Here, $k = \frac{(\theta - \theta_{res})}{(\theta_{sat} - \theta_{res})}$**; and** $m = 1 - {}^{1}/_{n}$

K_{sat} is the saturated hydraulic conductivity of the soil which drains. The RECARGA model was benchmarked to the RECHARGE model (Dussaillant et al., 2005), with good results. Then it was used to model the impact on recharge of the same type of rain garden/bio-retention cell to three cities with differing climates: Madison, Wisconsin (humid); Santiago, Chile (semiarid Mediterranean); and Reno, Nevada (arid climate).

For the humid climate of Madison, modelling results show very high recharge rates in the rainy season, where a rain garden with an area of 10 to 20% of the contributing impervious area maximizes recharge. For the semiarid climate of Santiago, Chile, the optimum ratio was 10 to 20%, and for the arid climate of Reno, Nevada, USA, it was closer to 5%. Optimal values for garden to impervious area ratios would not present apparent problems for plant survival, as judged from simulation results.

The modelling shows that in arid climates, increasing the infiltration area will not help beyond a point in increasing the recharge through the rain garden. The reason for this is that the evapo-transpiration would become excessively high when the area increases whereas the inflow remains constant.

Wet detention ponds are storm water control structures providing both retention and treatment of contaminated storm water runoff.

For more details refer, Section 7.3.7 in IUWM Technical Report and also Storm water management manuals given in the list of Manuals

End use Conservation and leakage reduction

Description of Tool 10:

A. Water-less Toilets

Waterless toilets use no water for flushing and require only small amounts of water for cleaning. The most common types are pre-composting, composting and dehydration toilets, based on dehydration and composting processes. These toilet systems provide the ideal environment for pathogen destruction in human waste through dehydration and/or decomposition. What results from it is compost material. The available systems vary from simple toilets with temporarily storage of excreta to enhanced toilet systems with on-site treatment. The human waste is stored in watertight-sealed and well-ventilated containers and is converted in a compost-like material, which will be odour free. In some systems only a pre-composting process takes place in the sealed chamber of the toilet. In these cases the matter is transported for the finalization of the composting process to an adequate facility. Maintaining the right level of humidity is crucial for an appropriate dehydration and composting process. Therefore, dry toilet systems often provide facility for urine separation.

B. Low Volume Flush Toilets

Water-saving toilets require lower flush volume, as compared to common flush toilets. Some of these toilets are also available with separated drainage for urine to reduce the negative impacts on the receiving environment and to facilitate the reuse of the urine as a fertilizer. They can be differentiated in toilets with low volume cisterns (including vacuum toilets), dual-flush cisterns and cisterns with water-saving retrofit devices. Low-volume toilets typically use 6 litres of water per flush, but there are also toilets available which require only 4 litres or even only one litre per flush (source: Ultra Low Flush Toilets, a Massachusetts water authority publication, 2006). There are three types of low volume flush toilets: gravity tank toilets, flushometer toilets and vacuum toilets. The gravity tank toilets flush based on the gravity flow of water, flushometer toilets require a minimum water pressure for the flush. The transport of faeces in both systems is provided by gravity flow in sewer pipelines after flushing. Vacuum toilets require only a very small amount of water which is actually used as a slip additive. After flushing, the transport of faeces is provided by a vacuum created by a vacuum station connected to a collection tank at the end of the sewer pipeline.

C. Water-saving low head showers

Water-saving shower heads, or low-volume showerheads, improve water use efficiency compared with high-volume shower heads by mixing water with air, improving the spray patterns or by creating a narrower spray that simulates the feeling of much water with low-volume flows. A variety of spray and other design options are available for new low-volume showerheads. Retrofitting of conventional high-volume showerheads can be done with flow restrictors. Shower heads using flow control devices can be used to adjust the flow rates, independent of the water pressure. The function is generally based on a disc containing an elastic O-ring that is controlled by pressure. Under high pressure the O-ring flattens and reduces the water flow while it relaxes and allows higher flow under lower pressure. Additional water-saving devices, mainly applied in public buildings to avoid water losses, are metered-valve taps, delivering a preset amount of water before shutting automatically off. Self-closing spring-loaded taps feature a knob that automatically shuts off the water when the user releases the knob.

They are appropriate when the installed shower heads are meeting the comfort criteria of the user; or water has to be saved without changing behaviour pattern and without loss of comfort.

D. Pressure Reducers

Pressure reducers can be installed either at the supply point of a building or at certain points inside a building in case of larger or higher buildings. Pressure reducers are installed between pipeline joints to reduce the water pressure and to reduce the flow to taps and other fixtures. The technology is appropriate when Buildings are equipped with a centralized water supply; and the water pressure in the whole building or in building parts is high (above 3 kg/cm^2). Table 15 provides the conditions under which various efficient water use technologies and devices can be used in the urban housing context.

Note: This section draws heavily from UNEP, 2008:104-121

Table 17: Technological options for efficient water use in domestic sector and the socio-economic conditions

Type of technology	**Features**	**Conditions for which it is appropriate**	**Type of urban situations for which it is most suitable**			
			Poor urban neighbour-hoods	Rich urban neighbour-hoods	New settlement	Tall housing stocks
Waterless toilet	Cost ranges from Euro 8 to Euro 50 Waste has to be transported mechanically	When water shortage is acute; income is low; sewage disposal facility not available; area for use of faeces and urine are available	***		***	
Water-saving toilets	Three types: gravity type; flushometer type and vacuum type	System is connected to a treatment facility; pressurized water supply required for flushometer to work; water is metered & priced volumetrically		***		
Low head showers	Inexpensive; retrofitting is possible	When water has to be saved without loss of comfort; or without changing the behavioural patterns		***	***	
Pressure reducers	Easy to install; needed for every floor of the building	Used when the water supply is centralized and pressure is very high (> 3 bar)				***

Description of Tool 11:

Water auditing, and leakage detection and reduction

The purpose of water auditing done in urban water supply systems is to assess the amount of un-accounted for water, in the form of technical losses due to leakage in the pipelines and leaking taps, and the administrative losses due to thefts. Two different methods can be employed to assess this, depending on whether the connections are metered or not. But, it is to be kept in mind that while the first method helps find out un-accounted for water, the second one helps find out technical losses. Once the amount of un-accounted for water is assessed, the next step is to find out where the leakages really occurring. Several engineering methods can be employed to detect the exact location of the leakage in a pipeline network. The types of technology used and the method of leak detection are given in Table 18. The technology employed depends on the ground situation (see section titled: which technology is best for leakage detection? section 8.3.2 in IUWM Technical Report).

Economic Viability of Leakage Reduction Measures

Once leakage is detected, then based on the amount of leakage and the cost of engineering interventions for leakage reduction to be employed, the economic viability of leakage reduction measures need to be ascertained. The biggest issue in leakage reduction is that the cost of leakage reduction should be less than the cost of producing the water that is saved through leakage reduction. Economic viability therefore depends on the cost of leakage prevention measure. It is to be kept in mind here that while the cost of leakage reduction is a function of the degree of reduction in leakage, the unit cost is not constant. Low degree of reduction in the leakage could be achieved with minimum unit costs (Montgomery Watson, 2006), and for higher degrees of reduction in leakage, the unit cost would go up exponentially. Hence, what determines the cost of leakage reduction is the level to which the leakage is to be brought down, rather than the degree of reduction. Because of this, the unit cost of leakage reduction will be lower in situations where the current leakage is very high.

But, the unit cost of leakage prevention, corresponding to reduction of pipeline leakage to a certain level, would again be an inverse function of the area covered. This is because of the fact that when same volume of water is supplied to a small area, the amount of engineering infrastructure required to do leak proofing would be comparatively less (source: based on EPA, 2006: 9-10). Therefore, to determine the extent of cost saving through leakage reduction, the extent of leakage in pipeline network needs to be assessed.

Since the cost of production and supply of water is very high in water-scarce regions, leakage reduction measures would be economically viable there. The experiences the city of Bangalore in leakage reduction (Rs. 7.2/m^3) (Tsuchiya, 2004), where cost of leakage reduction and cost of production & supply of water (Rs. 10.12/m^3) (Source: ADB, 2007) are compared, also demonstrate this, even without considering the value of water, or the cost of depletion of water and environmental cost of its degradation. Therefore, the questions of whether to go for a leakage reduction measure or not would only apply to cities and towns which are falling in water-rich regions, where the cost of production & supply of water should be compared against the cost of leakage reduction. But, economic viability considerations alone cannot force urban water utilities to go for leakage reduction measures. The availability of trained personnel, who can undertake leakage detection surveys and execute engineering works for leakage reduction, is equally important. Small towns, especially those which are not urbanized, would find it difficult to manage trained staff for undertaking these activities.

Table 19 provides the various considerations for deciding on leakage reduction measures for urban areas falling in different typologies.

How to Do Water auditing?

Water audit can be done in two ways depending on the situation that exists. In case, the connections in a water district are metered, then audit become easy. The total amount of water used up at the end user level is volumetrically measured for a stipulated time period (say one week); and the total amount of inflow into the water system is monitored. The difference would give the total amount of water lost in conveyance--unaccounted for water.

In the second case, when connections are not metered, the water distribution system is divided into different zones, and flow is allowed into only one zone or district (with a trunk line length of 20-30 km) by turning off the valves in other distribution lines. Flow meters are installed at control points. Water flow into the district is measured over a 24-hour period, with measurements taken during night time and day time. The minimum flow rate during night time is compared against the average day-time flow rate to estimate the percentage un-accounted for water. Here, the assumption is that the minimum flow rate during night time is due to the leakage alone, when no one draws water from the tap.

Leakage Detection

Table 18: Equipment for leakage detection

Apparatus	**Method of Detection**
Electric leakage detector	Picks up leakage noise electrically on ground surface
Freezing method	This method keeps the water inside the pipe frozen with liquid air during repairs
Portable minimum flow meter	This flow meter is used at the minimum night flow measurement
Leakage Noise Correlators	This instrument locates the leakage by processing leakage noise picked up at two point on pipe
Underground radars	This radar radiates electro-magnetic wave to ground so as to search the underground condition
Time integral type leakage detector	Making use of the continuity of leakage noise, this instrument is able to check whether the leakage exists or not
Non-metal pipe locator	Making use of the transmission noise, this instrument can locate the non-metal pipe
Helium gas leakage detector for buried pipes	Detect leak points despite surrounding noises
Electro-magnetic leakage detector	Identifies a spot of leakage by detecting fluctuations of reflected electromagnetic waves in accordance with the movement of leaking water

Source: the Bureau of Water Works, Tokyo Metropolitan Government

Which Technology is best for Leakage Detection?

Leak noise correlators can be used to detect leaks in plastic pipes. Leak noise correlators are portable computer based devices with onboard data acquisition and analysis components. It works by measuring the vibration (vibration censors) or sound (hydrophones) signals at two points that bracket the location of the suspected leak. But, leak noise correlators are effective when the surveyors measured the actual sound propagation velocity in the pipe and used the correlators, with appropriate filer setting. Vibration censors were effective in detecting large leaks (20l/min). Hydrophones had to be used to detect small leaks (6l/min). But, the listening equipments were not effective unless listening censors or devices were used at access points that were close to leak sources. Noise correlators are more efficient and give more accurate results than the ordinary ground-based sound listening equipments. But, as Tokyo experience shows, leakage detection by acoustic methods became extremely difficult due to the increase of city noise, traffic density, and congestion of buried structures. In such cases, electro-magnetic detectors or tracer gases will have to be used.

Table 19: Leakage reduction measures in different types of cities under water-scarce and water-rich conditions

Criteria for Selecting a network for Leakage Reduction Programme	**Overall physical, socio-economic and political set up**					
	Water-scarce			**Water rich**		
	Cities including metro	Small towns		Cities including metro	Small town	
		Urbanized	Less urbanized		Urbanized	Less urbanized
Unit Cost of production						
Cost of leakage reduction						
Staff training						

Note: shaded area indicates that the particular criterion is not important for the typology in question; for more details refer section 8.3.2 in IUWM Technical Report

Economics of 24 X 7 Water Supply Scheme and UFW Reduction

Before we look at the merits of 24 X 7 water supply scheme, we would examine the effects of intermittent water supply. Indian cities and towns have intermittent water supply (ADB, 2007). In urban areas, as water becomes more and more scarce, utilities tend to resort to restricting the duration of water supply, on the assumption that it would result in reduced consumption. Contrary to this, studies show that increase in duration of water supply resulted in disproportionate reduction in average per capita water use (source: based on authors' own analysis using ADB, 2007 and NIUA, 2005)

In addition, it creates huge problems of inequity in access to water. Certain section of the population would be completely left out of the service. Amongst those who get water, by virtue of their position in the hydraulic system, the poor consumers will have the least ability in fetching water. The rich urban consumers would be able to manage their supply requirements by putting up large storage systems. This was found in a small town named Mulbagal in Karnataka where the per capita use consumption was found to be a direct function of the per capita intermediate storage capacity, and the same was a function of the household income. The inequity in access to water was also high. Further, the inequity was of slightly higher degree in wards, which had lower average per capita water storage.

Intermittent water supply comes with a cost. While it reduces the ability of the utility to raise the water tariff and charge the full cost, owing to poor quality supply, indirect cost to the consumers is very high. They actually incur a very high cost to "cope with" the poor quality water supply (source: David Foster, per. communication). As found by Misra and Chuan Eng (2007), the coping cost of poor quality water supply is often higher than the amount communities are willing to pay or sometimes close to affordable water bills.

Link between 24 X 7 and UFW Reduction

The pre-requisite for introducing 24 X 7 water supply scheme is to minimize the UFW. Metering would enable detection of illegal tapping of water, one part of the UFW. Metering would enable introduction of volumetric pricing, which will impact on the water consumption at the end use level also. The 24 x 7 water supply would reduce the need for providing intermediate storage systems also.

The benefits of reducing unaccounted for water are of three types. First: cost saving due to reduction in amount of non-revenue water supplied. This is the impact of metering, whereby the utility can find out how much water is loft in theft, thereby being able to detect the illegal connections. Second: the reduced wastage at the user level which is the impact of volumetric pricing of water. Third: the saving in the cost of provision of intermediate storage systems.

The third parameter can be estimated by taking the weighted average of the capacity of the storage facilities maintained by housing stocks belonging to different segments of the society. In case such storage facilities are not available, the opportunity cost of intermittent water supplies would be high as households will have to adjust their routine to match the water supply schedule. However, evaluating this cost is complex as they depend on the socio-economic profile of the household members. So, here we can consider the situation where family invests in intermediate storage systems.

They are captured in the equation (1) provided in the box, for estimating the cost saving from 24 X 7 water supply and UFW reduction. If we assume that the final UFW is the same, the cost saving would depend on what was the initial level of leakage in the system.

Mathematical formulation to estimate the economics of 24*7 water supplies, and UFW reduction

The cost saving in 24 X 7 water supply with UFW reduction can be mathematically expressed as:

$$C_{saving} = \frac{X[(A_1 - A_2) * C_{water-supply} + \emptyset * C_{storage}]}{(1 - A_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here:

A_1 and A_2 are the UFW in fractions, before and after the introduction of 24 X 7 water supply

$\emptyset$ is the total storage capacity available as a fraction of the total annual volume of water supplied by the utility; and

$C_{water-supply}$ is the cost of water supply (Rs/m^3)

$C_{storage}$ is the average cost of storing water per unit volume (Rs/m^3).

This can be estimated by taking the weighted average of the capacity (volume) of the storage facilities maintained by housing stocks belonging to different segments of the society.

When Would 24 X 7 Water Supply & UFW Reduction Be Economically Viable?

The economic dynamic of reducing UFW with metering improves with the extent of unaccounted for water in the system before rehabilitation and the cost of production & supply of water; the original volume of water supplied; and the cost of rehabilitation.

The unit cost of leakage reduction is not constant for different degrees of leakage reduction in a pipeline network. When applied across networks, it means that high degree of reduction in leakage could be affected with low unit costs, if existing leakages are high. The unit cost of rehabilitation would be an inverse function of the area covered. This is because of the fact that when same volume of water is supplied to a small area, the amount of engineering infrastructure required to do leak proofing, number of meters required to measure the supplies and the length of service lines would be less (source: based on EPA, 2006).

For the same size of population, the economics of 24 x 7 water supply (with UFW reduction) would be better under the following conditions: 1} the population density is very high, meaning the same amount of water would be supplied over a smaller area, reducing the cost of the infrastructure; 2] the cost of production & supply of unit volume of water is relatively high; 3] UFW before intervention is very high; and 4] quality of water supply prior to introduction of 24 x 7 is very poor in terms of reliability and duration.

Economic Instruments for demand reduction

Description of Tool 13:

Role of water pricing in urban water demand management

Pricing of urban water supplies serves two purposes: 1] recovering the cost of producing & supplying water; and 2] reducing the wastage of water, which helps in managing the demand (World Bank/GOI, 1998). As regards the second one, domestic water consumption can be varied substantially by small changes in usage methods. In household production process, opportunities for changes in input proportions in response to movements in relative prices exist. Moreover, part of demand, which is because of failure to fix leaking pipes, or to turn off taps after use, can be controlled by pricing. If the price of reflects the fact that it is plentiful and its delivery costs are very low, then "wasting" water is inefficient only if creates a significant external diseconomy.

An implication of price elasticity of water demand is that a mistake in pricing can have large consequences for water use. Prices that are too low create a demand to expand water delivery beyond the efficient point. Since urban water systems in India are primarily financed by general taxes or revenue from another utility, under-pricing water can be very expensive to society (Noll *et al.*, 2000).

There are issues with pricing water. The first one concerns what component of the cost should be included in water pricing. If water prices have to cover all costs and if costs are high due to inefficient or corrupt management, much economically warranted water usage can be cut off. Another problem concerns with the consumers not attributing enough value to the quality of water. If the effective demand for quality is too low because of above reasons, consumers may respond to higher prices for piped water by consuming too much low-quality water from alternative sources that are contaminated (Noll *et al.*, 2000).

Pricing to Reduce Usage Externalities

Research on the effects of improved water systems demonstrates that simply increasing the quality of water at the point of consumption will be effective in improving the health of the population, only if accompanied by good wastewater and sanitation policies (Esrey, 1996). But, even with perfect information, private incentives to install sewerage or wastewater treatment system are less than its social benefits (Noll *et al.*, 2000).

If either users or water utilities are not held accountable for the costs that they impose on others, they will overproduce pollution and use large amount of water for polluting purposes. The solution for this problem is to impose a tax that fully reflects the marginal cost of pollution on others (see Baumol and Oates, 1988, and Cropper and Oates, 1992). Taxes create a penalty for water pollution, and so provide a financial reason to invest in either sewers or water treatment facilities. These investments, in turn, will raise the price of water use, and so curtail consumption and the pollution that it creates. Users and water utilities will then have an incentive to cut back on polluting uses of water, and to treat waste water to remove pollutants, until the marginal cost of abatement equals the marginal cost of pollution.

If instead of using taxes the government issues regulations that require these investments, the utility has a financial incentive to delay taking actions and to undertake the minimum actions that are consistent with the law. The decision about the level of tax to impose is subject to distortions in the political process. This may cause the government to demand too much rather than too little abatement. In addition, political distortions also may misallocate the burdens of pollution and pollution abatement for the same reason that they can distort the price structure (Noll *et al.*, 2000).

The norms for pricing urban water supplies are discussed in this section. Table 18 helps us test the viability of metering and pricing of urban water supplies.

Norms for pricing of urban water supplies

The importance of using volumetric pricing for water supplies and pollution tax for wastewater generated as instruments for reducing the demand for water for consumption and pollution assimilation, respectively, is well understood. But, it is difficult to meter both supplies and wastewater in domestic sector. Therefore, a water supply pricing norm that takes into account the negative environmental effects of water supply, i.e., pollution would address both the issues.

The norm for fixing prices can be based on certain sound principles and objectives. Financial cost recovery is an interim objective in urban water pricing. In the long run, the objective of pricing should be such that it reflects the increasing long-run marginal costs of water supply and its disposal, specifically addressing the costs of environmental damage in production and consumption, and the opportunity costs of depletion. This is referred to as marginal opportunity cost of production (MOCP). The MOCP has inbuilt economic efficiency and financial cost recovery considerations.

This can be defined as: MOCP = MDC + MEC =MUC

MDC =Marginal Direct Cost (of the resources needed to supply water & provide the sewerage treatment facility)

MEC = Marginal External (Environmental & Social) Cost due to the negative impacts on environment and society owing to reservoirs, ecological damage, pollution from sewage etc.

MUC = Cost of using/depleting the resource

Source: World Bank, 2007

The cost of using/depleting water would vary from region to region, but would be highest in the most water-scarce regions (Source: based on Kumar *et al.*, 2008b; World Bank, 2007). This would, however, be determined by the alternatives uses of water that exist in the region under consideration. Not only the cost of depletion but also the marginal direct cost of production (MDC) of water also could vary significantly from region to region.

Metering is required for introducing volumetric block rates. But, metering decisions must be subjected to cost-benefit analysis and introduced on a case-by-case basis. The case for metering will become strong as both incomes, and water supply and disposal costs increase. The reason is that the cost saving and economic/social benefits from reduction of wastage and effluent load would increase at higher costs of production of water. Also, the feasibility of introducing meters and volumetric pricing would increase with increase in income, as affordability would be higher at higher incomes.

The marginal opportunity cost pricing could be used for deciding prices for uses far in excess of the basic needs within domestic sector, and commercial and industrial sectors. Such prices would be far higher than those fixed for achieving financial cost recovery. But, the community may not be willing to pay the marginal opportunity cost of production of water (MOCP) due to problems of affordability. So, the norms for price fixing can be arrived at by integrating the concerns of affordability and equity with economic efficiency and full cost recovery considerations. In the case of low income groups needing water to meet low levels of demand, a lower tariff could be used for domestic water supplies. In sum, the decision on whether to do metering and volumetric pricing of water supplies in a particular urban area should integrate several considerations. They are: unit cost of production & supply of water; percentage UFW; volume of water supplied; affordability and political will (see Table 20).

Table 20: Economic viability & political feasibility of metering & volumetric pricing of water supplies in different types of urban areas in water-scarce & water-rich conditions

Criteria for Selecting a Utility for Metering & Volumetric Pricing	Overall physical, socio-economic and political set up					
	Water-scarce			Water rich		
	City including metro	Small town		City including metro	Small town	
	Urbanized	Urbanized	Less urbanized	Urbanized	Urbanized	Less urbanized
Unit cost of production						
% of UFW						
Volume of water supplied						
Affordability						
Political will						

Note: The shaded portion indicates that the criteria for metering are not relevant for these typologies.

It is good to start metering individual domestic users, and commercial and industrial users. In cities where majority of the population live in apartments, pricing bulk users would be the only option for charging for domestic water supplies. But, this would call for creating new institutional mechanisms at the level of the user group. Given the politically infeasible nature of tariff rise, a gradual approach to price reform would always be desirable (World Bank, 2007). Public hearings, consumer education, and transparency are necessary to overcome resistance to price reform, especially when the quality of the existing service is poor. Often the consumers are not informed about the various components of the charges the utility levy; the actual cost of the services provided, and the level of subsidies given; and how they have been arrived at.

Note: for more details refer section 6.3-6.4 in IUWM Technical report

Description of Tool 14:

Estimating the elasticity of urban water demand

Changing price of water can influence the consumption levels. But, how it influences would also depend on the household income; the manner in which price change affects the overall financial burden on the consumers; and the climatic conditions which determine the physiological water needs (based on Hoffman *et al.*, 2006; Olmstead *et al.*, 2007; Renwick *et al.,* 1998).

Field based research was carried out in three metropolis of South Africa to estimate the price elasticity of urban water demand for domestic purposes, covering high income, middle income and low income groups. The cities are: Cape Town; Tshwane; and Ethekwini. The results showed that price elasticity of water demand is a function of household income (source: Payment Strategies and Price Elasticity of Demand for Water for Different Income Groups in Three Selected Urban Areas, March 2004**,** Report No 1296/1/04).

Olmstead *et al.* (2007) estimated the price elasticity of water demand with household-level data, structurally modeling the piecewise-linear budget constraints imposed by increasing block pricing. They developed a mathematical expression for the unconditional price elasticity of demand under increasing block prices and compared conditional and unconditional elasticities analytically and empirically. The study, which involved 1082 households from 11 urban areas in the US and Canada served by 16 public utilities, found that the price elasticity of water demand was higher under increasing block prices (IBP), than under uniform (marginal) price. The demand elasticity was 0.59 under IBP, against 0.32 under UP.

Renwick and others (1998) formulated an econometric model to assess the potential of price policy as a residential water resource management tool in California. This econometric model explicitly incorporates alternative demand side management (DSM) policy instruments, endogenous block pricing schedules, and a Fourier series to separately capture the effects of seasonality and climate on residential demand. The analysis relied on agency-level cross-section time series data for eight water agencies in California representing approximately 7.1 million people or 24% of the total population.

The estimation results suggest that price is a moderately effective instrument in reducing residential demand within the observed range of prices. The coefficient on the marginal price of water is, as expected, negative and statistically significant. The estimated own-price elasticity of demand equals -.16, implying a 10 per cent increase in price will reduce the aggregate quantity demanded by 1.6 percent. Isolating seasonal own-price elasticity indicated that the own-price elasticity of demand for the summer months (June - August) equals -0.20. The estimated own-price elasticity is only valid within the region of observed marginal prices which ranged from $.47 to $ 4.25.

A study by Hoffman et al. (2006) to estimate the price & income elasticity of urban water demand in Brisbane, Australia showed that the short-run price elasticity of demand across all households is -0.507, while the long-run price elasticity of demand is -1.167. The income elasticity of demand of 0.235 suggests that a ten percent increase in income is associated with a 2.35 percent increase in the quantity of water demanded.

Cairncross & Kinnear (1992) used the date from a survey of the quantities of water purchased from vendors in the squatter areas of Khartoum, Sudan to assess the effect of water price and household income on domestic water consumption. The study used observation and interview. In spite of the substantially higher charges (56% of income against 17% in Meiyo), water consumption in Karton Kassala was as high as that in Meiyo. Household water consumption against income and expenditure on water consumption showed no price elasticity or income elasticity. One reason for this is that a low-income household's consumer surplus for domestic water is very high.

Price and Income Elasticity of Urban Water Demand

The price elasticity of urban water demand is a function of climate, income and pricing structure. Higher the prices, lower would be the consumption, if income and climate remain the same. However, the income elasticity of urban water demand also depends on how critical is water supply to sustaining the households income. If the consumer surplus from use of water is very high, in relation to the total household income, higher price may not lead to lower consumption. Higher the temperature and aridity, lower would be the price elasticity of water demand. Higher the income levels, lower would be the price elasticity of water demand, under similar climates. The results from a study undertaken in three cities of South Africa on the price & income elasticity of water demand are furnished in Table 21.

Table 21: Price & Income Elasticity of Water Demand in three Cities of South Africa

Income Groups	Total price Elasticity of Demand	Range of Values Falling within 95% Confidence Level
Low Income Groups		
Tshwane	-0.365*	-0.227, -0.502
Cape Town	-0.110	-0.048, -0.290
Ethekwini	-0.130	-0.038, -0.195
Mid Income Groups		
Tshwane	-0.167*	-0.022, -0.191
Cape Town	-0.101	-0.025, -0.177
Ethekwini	-0.134	-0.012, -0.161
High Income groups		
Tshwane	-0.116*	-0.039, -0.220
Cape Town	-0.087	-0.048, -0.223
Ethekwini	-0.137	-0.050, -0.225

Note: * = Statistically significant difference (on a 5% level) in price elasticity between low, middle, and high income.
Source: Payment Strategies and Price Elasticity of Demand for Water for Different Income Groups in Three Selected Urban Areas, March 2004**,** Report No 1296/1/04).

For more details refer section 6.2 in IUWM Technical report

Description of Tool 15

Resource evaluation and planning of urban water management actions

The tools described earlier would help the urban water management professionals to do some quick assessment of the water-supply & demand situation. But detailed analysis of the potential future water supplies against the demands and the resource condition emerging out of it would need detailed evaluation of the urban hydrology in qualitative and quantitative aspects.

Constructing the *potential water balance* of the urban area is crucial to assessing the water availability. The next step is to analyze and compare the actual water use hydrology: residential and industrial water use, the discharge of wastewater and storm water run-off. A comparison of the water use hydrology with the water balance may result in a better understanding of the problems and opportunities for storage and augmentation in the long run

Data on Water Availability

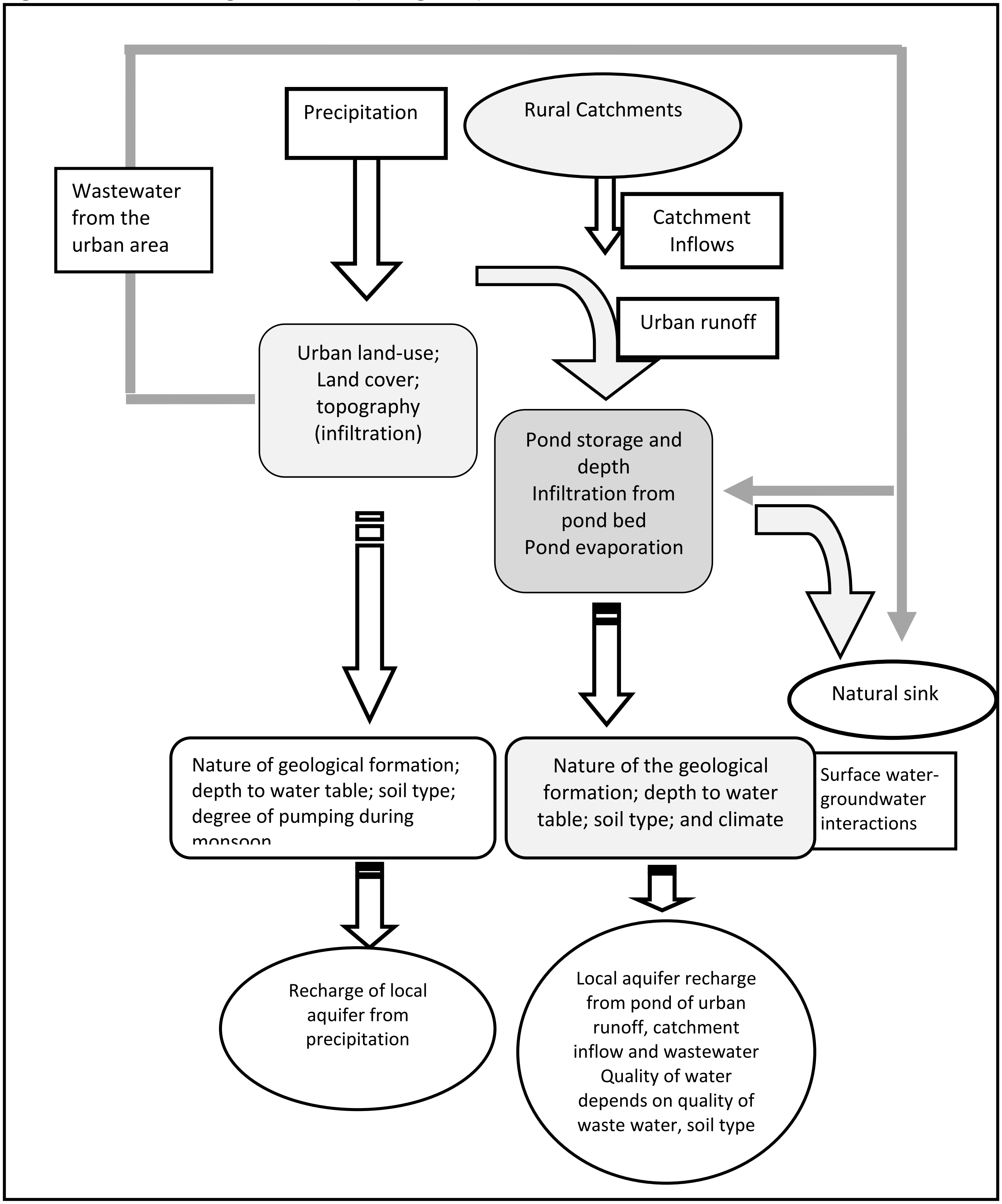
Urban hydrology is very complex with runoff from natural catchments; runoff from artificial catchments; groundwater; and wastewater outflows. They also interact among each other. The storm water flows can contribute to the stream flows into rivers, lakes and ponds. The amount of storm water generated is a function of the rainfall characteristics and the land use. Changes in land use can increase the storm water flows, and potentially threaten the ecosystems by increasing the sediment load, and water temperature etc. A typical flow diagram for analyzing the urban water cycle is shown in Figure 3.

The data needed for analyzing urban water resource availability are: 1] catchment characteristics for estimating the rainfall-runoff relationships; 2] the annual rainfalls for several years, particularly for locations that are falling in low to medium rainfall regions to arrive at the stream flows in different years; 3] the location of various water bodies, their storage features and pond infiltration rates; 4] the depth to water table and the pre and post monsoon fluctuations; 5] the land use and land cover of the urban area, including the roof area and characteristics, to estimate the storm water generation potential; 6] the urban drainage pattern; 7] the outflows of wastewater, and the rate of wastewater generation, the quality of wastewater and level of assimilation due to mixing up with streams and water bodies; 8] infiltration rates from water bodies; 8] the geo-hydrological parameters.

Of these, "surface water-groundwater interactions" and "wastewater return flows" are the two critical components which affect both water quality and quantity in the urban area, but are least known. There are certain physical factors which influence the surface water-groundwater interactions significantly in urban environments, viz., formation characteristics, and geo-hydrological environment (Ahmad *et al*., 2004). Taking these factors and the nature of their influence into consideration, certain typologies are constructed for analyzing the possible groundwater surface water interactions. The possible groundwater-surface water interactions under each typology for two scenarios, i.e., "pumping during times of recharge" and "non-pumping during times of recharge", are presented in Table 22. Similarly, the range of factors, which influence treatment of wastewater reaching underground, namely, water table condition, soil type and climate (source: based on Laurence *et al*., 2001; Gerba *et al*., 1975; Parr *et al*., 2004; Rose, 1999), are identified and typologies constructed. The degree of treatment of wastewater possible under different typologies is presented in Table 23**.**

These tools essentially help in knowing whether this particular component of urban hydrology is important for a particular town or city that represents a unique typology. For instance, it would tell us whether surface water-groundwater interaction is important for the city, which is underlain by alluvial formation and deep water table conditions, and hence whether a detailed study would be needed or not.

Figure 4: Schematic Diagram of the Hydrological System in an Urban Area



The above diagram helps us identify the vital components of urban hydrological system for any given urban area; the key hydrological parameters that are important for the area. Table 22 provides enough leads on how these variables can influence the urban hydrological system and water availability for different geological formations under different geo-hydrological setting.

Table 22: Type of groundwater-surface water interactions under the typologies those are possible in India

Type of Formation/ Geo-hydrology	**Deep water table conditions**	**Shallow water table condition**		**Coastal Areas**	
		No pumping	**Round the year pumping**	**No pumping**	**Pumping**
Consolidated	Weak surface water-groundwater link	Recharge limited to the short period of monsoon and stops after steep rise in WT	Recharge is continuous throughout the year[2]	Groundwater outflow to sea to maintain hydrostatic balance	Maintain the groundwater balance and check movement of seawater. Intrusion will be faster with increase in porosity, and presence of caverns
Semi consolidated--sandstone, limestone	Weak surface water-groundwater link	Continuous recharge during the whole year	Do	Do	
Unconsolidated	No recharge; [1]	Continuous recharge during the whole year	Do	Do	

Table 23: Degree of treatment possible for municipal wastewater under different typologies

Water Table Condition	Heavy soils, humid to sub-humid climate	Heavy soils, arid to semi arid climate	Light soils, arid to semi arid climate	Light soils; humid to sub-humid climate	Hard rock geology; with fissures and cracks exposed to the surface
Deep water table	Does not exist	High degree of treatment (biochemical & bacteriological)	High degree of treatment		Low level of bio-chemical purification; no bacteria & virus removal
Shallow Water Table	Reasonable level of bio-chemical treatment; poor bacteriological purification	Reasonable level of bio-chemical and bacteriological purification	Low level of bio-chemical treatment; low level of bacteriological purification	Low level of bio-chemical treatment; no bacteria and virus removal	
Outcrop areas of deep aquifer	Low level of bio-chemical treatment; no bacteria & virus removal	Low level of bio-chemical treatment; reasonable level of bacteria and virus removal	Very low level of bio-chemical treatment; poor removal of bacteria & virus	Very low level of bio-chemical treatment; no bacteria removal	Not applicable

Note: Heavy soils are those with high clay content. Light soils have poor clay content. Bio-chemical treatment here refers to reduction in BOD and COD. Arid to semi arid climate ensure hot and dry conditions, whereas cold and humid to sub-humid conditions ensures cold & moist conditions.
For more details refer section 9.1.1 in IUWM Technical Report

Description of Tool 16:

Generating Data on Water Quality

In urban water management, water quality monitoring (WQM) is of paramount importance in order to make sure that: people in the urban areas get water of adequate quality; and also the quality of the natural sink into which the wastewater is disposed, is not adversely affected to cause undesirable effects on the water ecosystem and the uses that they cater to.

Water quality monitoring is an expensive affair (Biswas, 1996). It is impossible to monitor groundwater in all the towns and cities for all water quality parameters given the magnitude of work and the resources needed. Therefore, it is important to identify: the pockets which are most vulnerable to groundwater pollution; the pockets that have polluting industries; and pockets having low ecosystem carrying capacity. This will help in economizing WQM.

There are important conclusions emerging from the analysis with regard to factors influencing the decision on parameters for monitoring and network density. They are: 1] pollution vulnerability should be an important consideration in deciding on the density of monitoring network in a region; 2] following the same set of parameters for pollution monitoring won't make much sense, and instead the type of parameters should be decided by the history of groundwater quality problems, and the nature of polluting sources (based on Kumar and Shah, 2004); and 3] for the same level of pollution load, the degree of pollution of water body would be an inverse function of the ecosystem carrying capacity. This also means that following a uniform standard for effluent discharge will not be effective in controlling pollution, and the standard should be set by the ecosystem carrying capacity (Rajaram and Das, 2008).

The tools provided in this section concern: 1] the tool for assessing the degree of vulnerability of aquifer to groundwater pollution in different typologies; and, 2] the tools for deciding on the types of water quality parameters to be monitored in each typology, with due consideration to presence or absence of industries and ecosystem carrying capacity, and degree of aquifer pollution vulnerability. The aquifer pollution vulnerability assessment is based on the findings emerging from review of past research that degree of contamination of aquifers to pollution is a function of the rainfall, the soil characteristics (CPHEEO/WHO, 2005; Gerba *et al*., 1975; Rose, 1999) and the geo-hydrological environment. The tool to decide on the parameters to be tested for groundwater quality is prepared on the basis of an extensive review of natural groundwater quality problems across Indian states undertaken by Kumar and Shah, (2004). The first tool (for assessing the degree of vulnerability of groundwater to pollution) is given in Table 24, and the second (for deciding on the water quality parameters for testing) is given in Table 25.

Table 24: Degree of vulnerability of aquifers to groundwater pollution

Type of aquifer/Soils, rainfall	Hard rock strata; low to medium rainfall	Hard rock strata; high rainfall	Heavy alluvial soils, low to medium rainfall	Heavy alluvial soils; high rainfall	Light alluvial soils; low to medium rainfall	Light alluvial soil; high rainfall
Unconfined aquifers with shallow WT	Medium vulnerability	High vulnerability	High vulnerability	Very high vulnerability	Very high vulnerability	Highest degree of vulnerability
Unconfined aquifer with deep WT	Low vulnerability	Does not exist	Very low vulnerability	Does not exist	Low vulnerability	Does not exist
Confined aquifer	Does not exist	Does not exist	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable
Outcrop area of confined aquifers	Do	Does not exist	High vulnerability	Very high vulnerability	Very high vulnerability	Highest degree of vulnerability

Note: In India, confined aquifers are found only in alluvial basins. As a result, there are no outcrop areas encountered in hard rock aquifers. The hard rock aquifers include basalt and crystalline rocks.

Table 25: Essential Water Quality Parameters to be monitored in Different Urban Typologies

Typology No	Water Quality Parameters		
	Large industrial cities	Small industrial towns	Small non-industrial towns
1.	Fluorides, TDS, heavy metals	Fluoride, TDS, heavy metals	Fluoride, TDS
2.	Nitrate, TDS, Heavy metals	Nitrates, TDS, Heavy metals	Nitrate, TDS
3.	Arsenic, Fluoride, Nitrate, BOD, pH, Iron, heavy metals	Arsenic, Fluoride, Nitrate, BOD, pH, Iron, heavy metals	Arsenic, Nitrate, BOD, pH, Iron
4.	TDS, BOD, Arsenic, Nitrates, Iron, heavy metals	TDS, BOD, Arsenic, Iron, Nitrate, Heavy metals	TDS, BOD, Arsenic, Iron, Nitrate
5.	TDS, Fluoride, Iron	TDS, Fluoride, Iron	TDS, Fluoride, Iron
6.	BOD, Nitrate, Iron	BOD, Nitrate, Iron	BOD, Nitrate
7.			
8.	TDS, pH, Fluoride	TDS, pH, Fluoride	TDS, pH, Fluoride
9.	TDS, Fluoride, pH, Heavy metals,	TDS, Fluoride, pH, Heavy metals	TDS, Fluoride, pH
10.	BOD, Nitrates, Heavy metals	BOD, Nitrates, Heavy metals	BOD, Nitrates
11.	TDS, Fluorides, Heavy metals	TDS, Fluoride, Heavy metals	TDS, Fluorides
12.	Iron	Iron	Iron
13.	Heavy metals, TDS, Fluorides	Heavy metals, TDS, Fluorides	TDS, Fluorides
14.	Fluoride, TDS	Fluoride, TDS	Fluoride, TDS
15	Nitrate, BOD, pH, heavy metals	Nitrates, BOD, pH, Heavy metals	Nitrate, BOD, pH
16	TDS, Chloride, pH, Heavy metals	TDS, Chloride, pH, Heavy metals	TDS, Chloride, pH

Note: The inherent chemicals found in groundwater are: fluorides, nitrates, nitrites, chlorides and arsenic, for more details refer section 9.1.2 in IUWM Technical Report

Description of Tool 17:

WEAP simulation of urban water system

For generating comprehensive knowledge about the benefits and dis-benefits of the many tools and systems which fall within the ambit of integrated urban water management, many knowledge gaps need to be filled in. The following comments about knowledge gaps and research needs relates to the *integration* aspect of IUWM rather than its constituent components.

Knowledge gap about infrastructure cost saving

At the present time, water authorities are not sufficiently confident of the long-term changes in system performance and operation and maintenance costs resulting from the operationalising of IUWM concepts. One such concept will be integrated operation of local groundwater system, lakes and tanks and a distant large reservoir for supplying water to an urban area. The normal tendency of the urban utilities is to tap only one source, if it is capable to meeting all the demand, instead tapping multiple sources. According to Coombes and Kuczera (2002), infrastructure cost savings will only be realized if water authorities downsize or defer augmentation of centralized infrastructure to account for lower system burden achieved by implementing IUWM approaches.

One reason is that the experiences of other utilities such as energy have not been encouraging. Also, the utility managers do not want to diverge very far from the least-risky traditional planning practices. They are conscious of the difficulties in bringing about changes in existing technical system configuration. Further research into the changes in system behaviour, and therefore, the changes in design, and operation and maintenance requirements, is lacking.

Knowledge Gaps about Outcomes & Impacts of Experiments

A major knowledge gap is how best to integrate cutting-edge technologies into existing infrastructure systems. Little work has occurred in the area of "retrofitting" existing systems that tap the potential of more strategically focused retrofit and/or replacement programmes, collectively considering allotment, street scale and regional infrastructure. This requires greater attention in the coming years. Further, the efficacy of non-structural techniques for storm water management etc. is not well understood. Research into the acceptability of measures such as "source control" and "prevention at source", particularly those that require behavioural change of individuals is also required. The impact analysis of policies pertaining to urban densities should go beyond transport, energy, housing and employment to include impacts on water systems, to provide a holistic approach to urban planning and sustainable development.

Extending IUWM Concept into Urban Planning

According to Niemczynowicz (1999): "New integrated system solutions based on sustainability criteria must be introduced already at the level of long-term regional physical planning to guide all subsequent detailed planning and implementation. Such solutions should be put into practice in the construction of urban areas and their infrastructure." Mouritz (2000) also discussed the need for policy and planning frameworks and the opportunities within the planning hierarchy.

There is significant scope to extend the concept of IUWM into the arena of integrated urban planning. For instance, with vertical growth, cities will be able to provide water supplies with lesser manpower and lesser cost; sewerage system at lesser cost; and cities with well laid out streets with sufficient clear space will be able to provide efficient solid waste disposal; cities with smaller geographical area and with higher population density will be able to implement leakage reduction measures cost effectively (source: based on authors' own analysis of NIUA, 2005).

With new interventions, we need to make sure that we are not just shifting the environmental, social and economic dis-benefits of urban water servicing in either time or space, by simply shifting them to a new location, or by moving from immediate negative impact to a slow building but long-term impact. There is a need for a commonly agreed, robust, assessment tool that could be used to evaluate the merits of proposed alternative water servicing options on environmental, social and economic criteria, considering short, medium and longer term time horizons.

WEAP Model for Analyzing the Impacts of System-wide Water Management Interventions

Water Evaluation and Planning (WEAP) system, a model developed by Stockholm Environment Institute, Boston, is one of the tools for planning urban water management. It can simulate any urban water management system, like it is used to simulate water management systems of river basins. Based on several inputs pertaining to urban water demands and supplies and various interventions for changing them (such as water import, water harvesting & recharging, storm water management, water conservation technologies, water pricing, leakage reduction etc.) the model can construct future water supply & demand balances, which include "business as usual scenarios" and scenarios with newly introduced interventions. The WEAP model in any town/city can be configured depending on the scale at which output are required, whether at the aggregate level for the town or for the zone or ward level.

The model can simulate the interactions of various components of physical systems affecting water availability (groundwater, surface water, catchments including both built up and natural) and also the interactions of various socio-economic and ecological systems affecting urban water demands (domestic consumers, agricultural users of municipal wastewater, manufacturing; and riverine ecosystems). Therefore, it can incorporate the likely effect of any changes occurring in one component of either physical or socio-economic system on the other. It can also simulate the interaction between the supply source and the demand sites in the form of conveyance of water and losses, and potential interaction between demand site and supply sources in the form of return flows. While deciding on the management interventions and their scale, various social, economic and environmental criteria can be used.

The inputs required for running the WEAP model in different typologies are given in Table 26.

Table 26: WEAP simulation of urban water system for different urban typologies

Sr. No	**Nature of Urban Water Management Planning**	**Typologies for which it is applicable**	**Other characteristics**
A	**WEAP modeling inputs**		
1	Current population figures ward-wise	All typologies, except coastal ones	
2	Population projection data	Do	
3	Per capita domestic water use rates for each ward; and per capita water demand for different time horizons	Do	
4	Annual municipal water use other than domestic	Do	
5	Irrigated area within the municipal limits,	All water-scarce	Not important for

	with the break-up of area under different crops; also the average depth of irrigation provided to the crops	typologies	metros with population more than a million
6	Physical, chemical and bacteriological quality of the municipal waste water		
7	The points of disposal of the municipal wastewater and the approximate volumes:	All typologies	All towns/cities with centralized sewage collection system
8	Type of treatment viable for the area and the physical efficacy of the system	Do	Do
9	% households having decentralized sanitation system and the total amount of wastewater generated per day	Do	Humid, sub-humid regions with shallow WT
10	Sustainable groundwater yield	All typologies with hard-rocks & sandstone-alluvium+ all coastal typologies	
11	Urban drainage studies to examine changes in drainage pattern	All typologies except hilly & mountainous areas	
12	Total area of different catchments which form the source of water for tanks/lakes	Hard rock peninsular, central & eastern India which have tanks	
13	The annual rainfall figures for 30 years	All typologies	Rainfall intensity also (flood-prone area)
14	Rainfall-runoff relationships	All typologies, except the one with rainfall more than 1,800 mm	
15	Infiltration rates for lakes/other surface water bodies; daily evaporation rates	Hard rock peninsular & central India, eastern India	
16	Total number of groundwater abstraction structures owned by municipality and individuals	All typologies	
17	Average groundwater utilization capacity of the wells	All typologies	Actual well yields and number of hours of running important for hard rock areas
B	**Survey of water supply & sewerage infrastructure**		
1	Mapping of the water distribution and sewerage networks	All typologies	
2	Leakage detection survey	Networks older than 30	

		years	
C	**Hydraulic Modeling**		
1	Measurement of pressure losses at key control points	Old networks	Towns/cities spread in large geographical area
2	Estimation of roughness coefficient of pipes	Do	
3	Detection of points of excessive leakage-water tapping	Do	Plus large cities; cities with low % connections
4	Water auditing	Do	Also in large networks where population density is low
5	Identification of stretches for remodeling, redesign etc.	Old networks	

Based on the outputs generated from WEAP model, the various inputs considered for planning urban water management can be reviewed. For instance, if the gap between future supplies and demand for water is going to be wide for the "business as usual scenario", then the variables such as per capita water supply requirement can be re-visited. Also, the outputs can provide leads on which parameter is critical to changing urban water balance. Based on this lead, detailed studies can be initiated. For instance, if leakage reduction measure is found to impact on the future water balance of a city significantly, then detailed studies can be carried out to find out the actual costs, and subsequently, the same can be used in the model to get more refined results of water balance. F**or** more details refer section 9.4 of the technical report on integrated urban water management.

Description of Tool 18

Techno-institutional model for water supply & sanitation for the poor

Many constraints have hindered the efforts of the various institutions to provide adequate water supply and sanitation. They include: firstly, institutional inadequacy and insufficiency of conventional approaches which hindered participation of stakeholders and informal institutions in infrastructure provision and management (Stren, 1989; Fekade, 1997; UNCHS, 1996; Arrossi *et al*., 1994; Kyessi, 2002). Secondly: supply-driven infrastructure provision sticking to rigid planning/ design standards and regulations thus failing to bridge the growing gap in services especially for low-income communities. Similarly, trying to provide access of the urban poor to a centralized sewerage system would be difficult as the poor communities live in low lying areas or river beds which are often drainage outlets of urban storm water. Also, the fact that many low income communities live in illegal settlements automatically deny them rights to infrastructure provisions such as piped water supply, drainage or sewerage connection, as they lack proper entitlements.

Thirdly, high cost of conventional systems that did not recognize progressive improvement of infrastructure (Choguill, 1996, 1999). The progressive improvement model may seem to favour the majority of households in developing countries that has less than US$500 per year (Aligula, 1999) and spends more than 50 per cent of that on food (Kironde, 1999; Kyessi, 2002). The approach for water & sanitation hence has to be demand driven, flexible vis-à-vis infrastructure provisions, with dependence on informal institutions. Two glaring examples of demand-driven approach to building water & sanitation infrastructure, which is based on gradual improvement model is available in *Daar e Salam*. The technical, natural, human and financial resources were mobilized from the neighbouring local government bodies, donors, civil society members, private individuals and politicians. Three types of models exist for water supply: 1) privately managed and operated water system; 2) community-based water management system; and, 3) household water management system. This might be essential to meet the needs of people belonging to different income groups (Anzerona et al., 1998).

Table 27: Water supply for urban fringes: gradual improvement model

Time horizon stages	Step by step technological change			Remarks
	Stage I	Stage II	Stage III	
Type	Traditional well	▪ Shallow hand pump	Motor pump and raised tank with stand pipe and with distribution network	Technical support from the municipality/ corporation needed for design of the well, pump set, storage and distribution system
Scale	Small and open; use bucket to scoop water	▪ Medium scale (sufficient for 40-50 families)	Large scale up to 4-5,00 cubic metres (sufficient for up to 1,000 families	Large and consolidated slums, with many adults having voting rights; ration cards
Operation and maintenance	Household member	▪ Household members ▪ Hired attendant	▪ Household members ▪ Hired pump operator	When the scale increases, community members won't be able to provide O & M
Quality of water	Biologically contaminated		Chemical quality may not be assured; but chances of biological contamination are less	Periodic water quality testing might become necessary

Table 28: Water supply for slums: gradual improvement model

Time horizon stages	Step by step technological change				Remarks
	Stage I	Stage II	Stage III	Stage IV	
Type	Stand posts	▪ Surface Storage Tank with several taps	▪ Storage & pumping system with distribution pipes to each house ▪ Obtaining land tenure is crucial	▪ Individual households connected to the municipal sewerage system ▪ Obtaining land tenure is crucial	Technical support fro design of storage connection The real owner is wil to the slum dweller without
Scale	Cover a few households in small slums	▪ Medium scale (sufficient for 40-50 families)	Large scale up to 4-5,00 cubic metres (sufficient for up to 1,000 families	Large slum with 4-500 households; per capita water use comes up to the "norm"	Stage III & IV for many adults having v
Operation & maintenance	No special O & M work	▪ Slum Committee responsible for protection of taps, and ensure distribution of water	▪ Slum committee to take O & M decisions; recover water charges ▪ Hired pump operator for routine operation ▪ Plumper hired locally for repairs	▪ Slum committee to take O & M decisions; recover water charges; collect connection charges for sewer; ▪ Hired pump operator for routine operation ▪ Plumper hired locally for repairs	When the scale incre able to provide O &

Note: For more details refer section 11.1 in IUWM Technical report

Social and institutional aspects of urban water management

Capacity Building for IUWM

Capacity building in the water sector is a new concept that starts from three premises (Alaerts and Hartvelt, 1996): 1] water is a finite resource, for which numerous users compete, most notably the waste dischargers (who lower the usefulness of the water); 2] water is essential for a healthy economy as well as for the environment and, therefore, it is a resource that should be managed in a sustainable way; 3] institutional rather than technical factors cause weakness in the sector.

Capacity building efforts have been typically implemented as training and education programs based on the idea that equipping individuals with new knowledge, skills and professional competencies will enable them to successfully operationalise sustainable practices (Wakely, 1997). However, the organizational and broader institutional context presents as great an impediment to the sustainable management of urban places as the inability of professionals, technicians and ordinary people to operationalise sustainable development (Wakely, 1997; Brown, 2003). Therefore, local government capacity for IUWM is dependent on not only having sufficiently developed human resource capacity but also sufficient capacity within organizational and directive contexts (Wakely, 1997, UNDP, 1998; Peltenburg *et al.*, 2000). The various dimensions of capacity building are presented in Table 29.

Table 29: Dimensions of Capacity Building

Capacity Building	Description	Interventions
Human resource development	Equipping individuals with the understanding, skills and access to information, knowledge and training that enables them to perform effectively	Recruitment, training
Organizational change	Elaboration of management structures, processes and procedures, not only within organizations but also the management of relationships between the different organizations and sectors (public, private and community).	Changing institutional structure; reporting systems; financial powers; funding
Institutional reforms[1]	Making legal and regulatory changes to enable organizations, institutions and agencies at all levels and in all sectors to enhance their capacities.	Water pricing & water distribution policies, laws on protection of water sources, development of new institutions, prevention of water theft etc.

Source: Brown, 2004

The instruments for capacity building (Tool 19), which can be adopted in the urban water context, by external agencies, are listed in Box 1. The institutional design principles and practices, for urban water management and the institutional design criteria (Tool 20 & 21) are described in Box 2 and 3, respectively. This is based on extensive review of the design principles for sustainable water management, and best practices worldwide (Frederiksen, 1998; Misra and Chuan Eng, 2007). The institutional regime, which emerges as the final outcome of the suggested application of the principles and practices, and the design criteria process (Tool 22), in the urban water sector is presented in Figure 4.

Description of Tool 19

Instruments for Capacity Building

The instruments, which can be used to build institutional capacities of urban water sector, comprising urban local bodies, the state urban affairs departments and central urban development ministry, are as follows:

1) **Technical assistance for sector analysis and programme development**: water sector assessments, which comprehensively analyze the national and state water sectors and suggest priority action plans, need to be undertaken by interdisciplinary teams.

2) **Technical assistance for institutional change**: The expertise for this will differ depending on the institution that is under consideration and it may relate to policy, micro or macro-economic structures, management systems, and administrative arrangements. This can come from multi-lateral agencies such as the World Bank, Asian Development Bank and UNDP, and nationally and international experts on institutions.

3) **Training for change at different levels,** including decision-makers, senior staff and engineers with managerial assignments, junior staff and engineers with primarily executive tasks, technicians and operators, and other stakeholders.

4) **Education of prospective experts who will play a role in the sector**: The water pollution control sub-sector is so complex and develops so fast that in most developing countries not more than 10 per cent of the required technical expertise (as university graduates) is available. Many graduates are inadequately prepared for the tasks in their country (Alaerts, 1991). This encompasses physical and technological sciences, financial and human resource management and behavioural sciences.

Description of Tool 20:

Box 2: Institutional design Principles and Practices in Urban Water Sector

Separating out water resource management functions from water supply functions: The biggest intervention in institutional reform is the one by which the utility to confront the opportunity cost of using water, including pollution. For this, the urban water utilities have to be financially autonomous institutions, where they have to manage their affairs without interference and support from the government. Hence, corporatization of the utility becomes a pre-requisite. Also, the functions of water resources management and water-related services will have to be looked after by separate agencies. Thus, the agency concerned which allocates the resources will have to be different from the agency which uses water.

If the utility is autonomous and has to purchase water in bulk from the open market, it will have strong motivation to recover the cost of supplying water. Also, the utility would be under pressure to: reduce the dependence on purchased water by tapping the non-conventional sources such as desalination systems; and reduce the negative effects on environment caused by storm water disposal thereby increasing profitability.

On the other hand, the presence of formal water markets would force the basin authority, which is trading in bulk water, to manage the resources efficiently and sustainably (Sibly and Tooth, 2007). Here in this case, the utility will have to obtain water rights in volumetric terms from the RBO and also pay for every unit of pollution load it generates. The utility would recover the resource cost, and the cost of environmental degradation from the consumers in addition to the cost of building and managing the water supply & sewerage infrastructure in addition to the above ones.

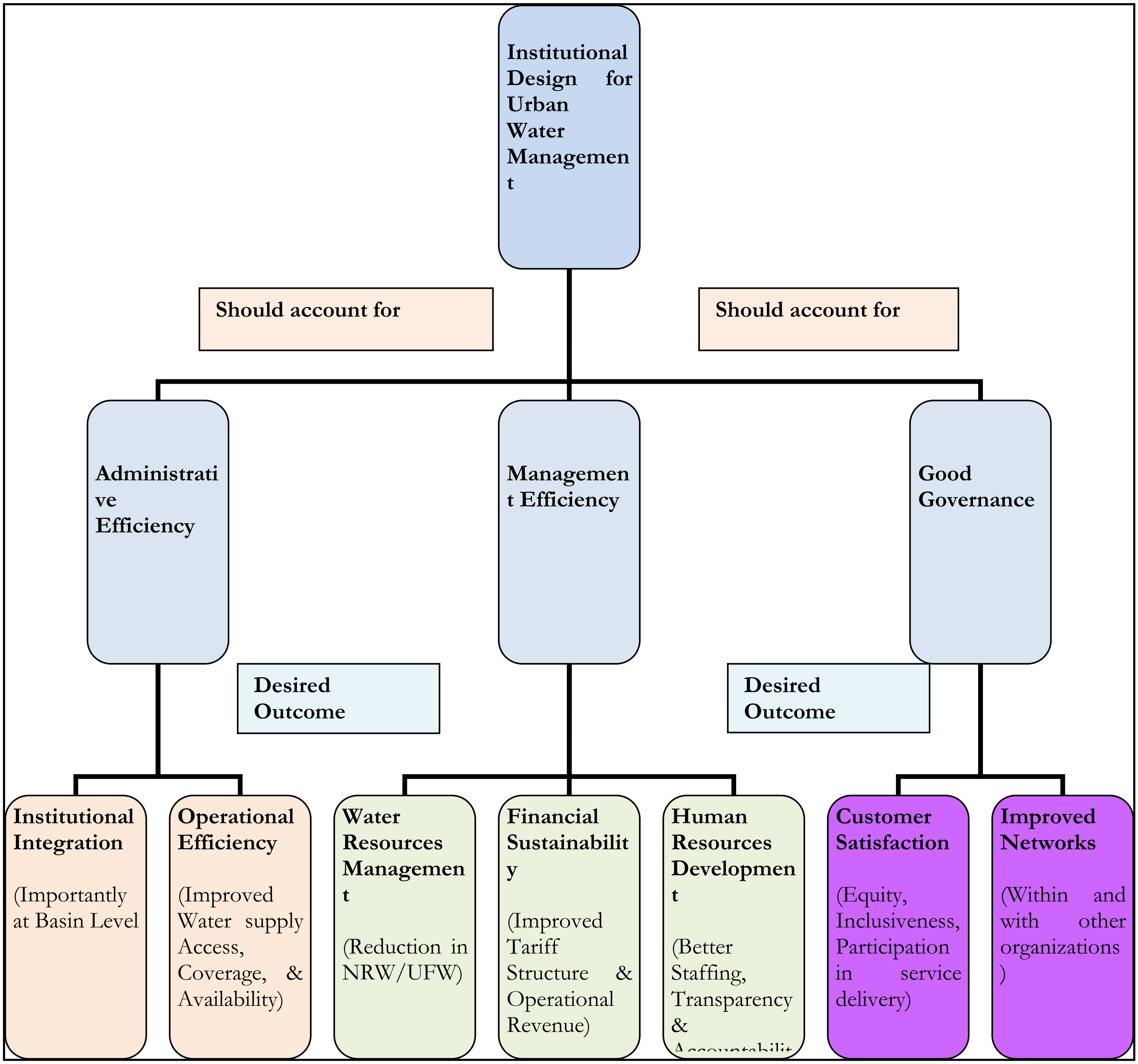
Create an independent water pricing regulatory authority: The authority can decide the pricing norms and tariff levels in consultation with the primary stakeholders based on periodic review of the operating costs and efficiency figures provided by the utility. This essentially means that the utility will not be in a position to raise the water tariff on account of high operating costs. It will have to first raise the operating efficiency by reducing the non-revenue water, improving the staff efficiency and efficiency of the machinery and infrastructure. This will force the agency to be much more transparent in business.

Separating out water quality regulation functions from pollution control measures: The basin-wide regulation of water quality can lie with the River Basin Organization. Different models are available (Chéret, 1993). The Pollution Control Board can do water quality monitoring and RBO can undertake pollution control measures. The institutional design principle to be followed is that the agency doing regulatory functions of Water Quality Management and the agency which carries out pollution control measures should be separate (Frederiksen, 1998).

Stakeholder involvement in urban water governance: stakeholder participation should be encouraged in urban water governance, by creating a separate forum for their involvement to improve the overall governance. Such a forum can essentially: 1] provide periodic feedback on the norms for fixing the charges for water supply & sewerage connection, and provision of water subsidies to disadvantaged sections; 2] decide on the norms for water supply, supply schedules (24 X 7 or intermittent) and any restrictions needed in water supply during droughts; 4] decide on the criteria for provision of subsidies for adoption of water-efficient technologies by the urban consumers; and 5] decide on the penalty for illegal connections.

Description of Tool 21:

Box 3: Institutional Design Criteria for Urban Water Management



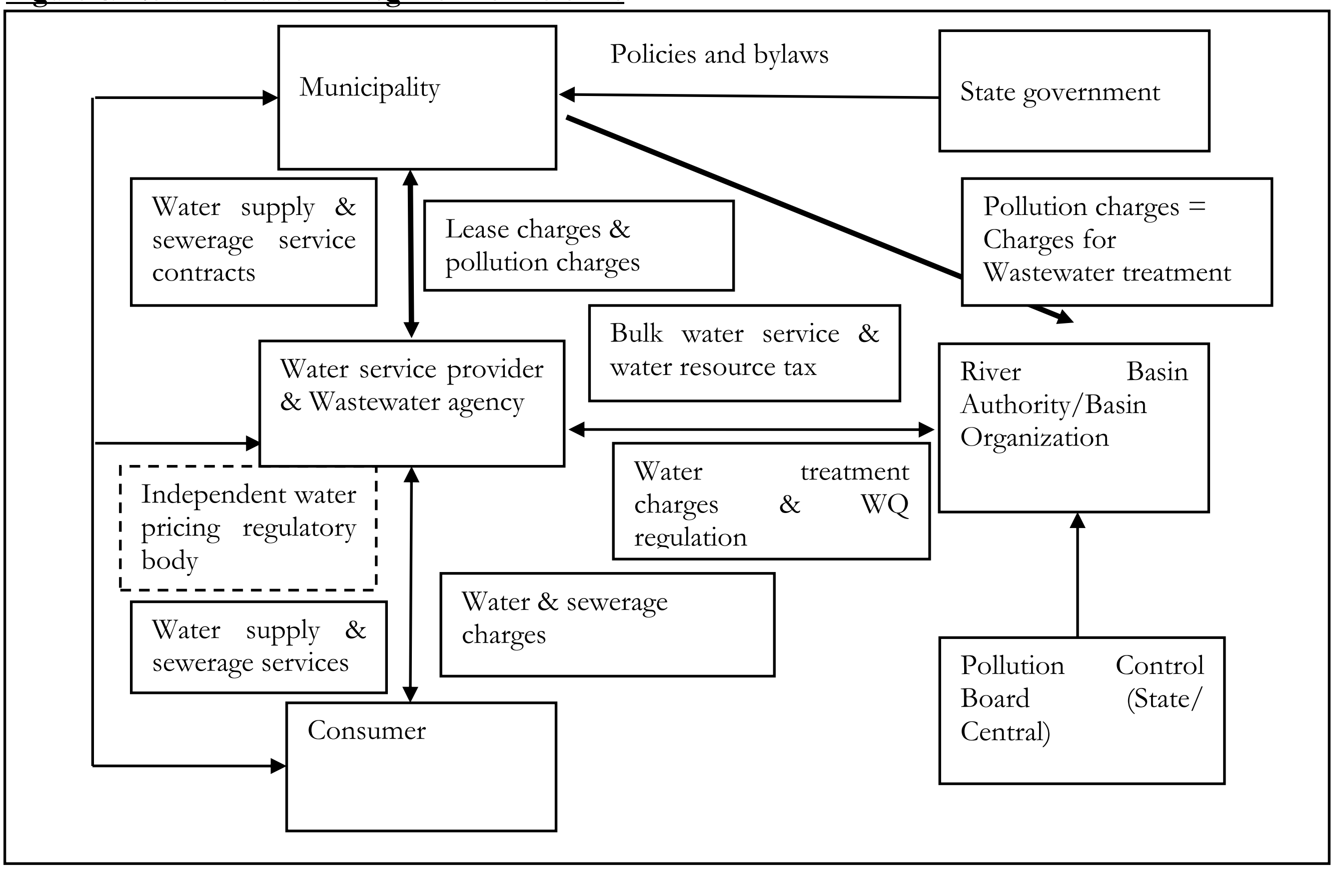
For more details refer section 10.4.1 in IUWM Technical report

Description of Tool 22:

Institutional Regime for Integrated Urban Water Management

The various agencies which would be involved in urban water management sector, their roles and responsibilities and the interactions amongst them and also with the primary stakeholders are shown in Diagram. The water abstraction and allocation rules, norms for effluent discharge and the fiscal instruments for controlling inefficient use and pollution such as volumetric water charges, sewerage charges and pollution tax are the organizing features of this institutional regime. The dynamics of interaction between various institutions envisaged under the new institutional regime are 10.4.2 of the technical report on integrated urban water management.

Figure 4: New Institutional Regime after Reforms



Description of Tool 23:

Organization Set Up for IUWM under Different Conditions

One of the routes to organizational strengthening of water utilities or ULBs for improved urban water management is by involving various stakeholders in performing different functions--from capital works, to operation and maintenance, financial and human resource management to monitoring of water supplies and quality--depending on the unique skills they bring in, rather than performing all functions related to running urban water system themselves. These stakeholders could be private sector agencies, community groups, small-scale service providers or public agencies such as the Pollution Control Board. Depending on the nature of urban local body, the strengths could vary. Hence, the functions which can be effectively performed by the utility or the ULB can also change. So are the functions which need to be performed by other stakeholders.

Based on the review of international and local experience with different models of urban water management including private sector participation in capital works, private sector involvement in O & M, involvement of small-scale service providers in 0 & M related tasks, and involvement of communities living in the fringes in the provision of water supply & sanitation services, under varying situations of urban administration, and taking into account the general situation prevailing in urban areas with regard to political stability, government power, the alternative organizational models for urban water management are worked out.

The important research studies which have been used to work out the organizational set up are: Perald (2003); Biswas and Tortajada, 2003). First: according to Biswas and Tortajada (2003) from the Third World centre for Water Management, carried out in several countries, primary institutional model, which is likely to come up in future, is very significant improvement in the current performances of the public sector institutions. Further, the private sector will play an important role within this new institutional paradigm, but not as the managers of large concessions, but as providers of specific services like meter-reading, billing, bill collection, leak detection and repair, vehicle management, construction of desalination plants on a BOT basis, etc. Secondly: going by the experience, private sector participation in urban water supply is likely to come up if country is politically stable and governments are powerful (Perard, 2006).

Table 30 provides the organizational set for urban water management with the suggested role for community organization, private agencies, and small scale service providers for performing roles such as building capital work, undertaking operation & maintenance, doing financial and human resource management and overall monitoring of water supply, under different urban administrative set ups.

Table 30: Organizational Set up for Urban Water Management in Different Types of Towns

Nature of Works / *Type of Urban Centre*	Slums/Small Urban Settlements	Small Towns	Large Cities	Metropolis
Capital Works	Urban Local Bodies(ULBs)	State Level Agency* or Urban Local Body or Small Autonomous Utility (SAU) or Private Sector	Urban Local Body, or Private Sector	Specialist Metropolitan Authorities (SMA), or Private Sector
Operation and Maintenance Works	Small Scale Service Provider, Community Involvement	State Level Agency, or Urban Local Body or SAU, or Private Sector	Same as above: private sector involvement in service provision in the case of ULB	Same as above; private sector involvement in the case of earlier set up**
Ownership of the System	Either with community or Urban Local Bodies(ULBs)	State Level Agency or Urban Local Body or SAU	State Level Agencies	SMA
Financial & Human Resources Management	Community with hired professional management staff	Do	Urban Local Bodies (ULBs), Private Sector	Same as above
Monitoring	If done, by Community with help from local water resource department or pollution control board	By the community with help from Urban Local Body (ULBs) or local water resource department or pollution control board	Urban Local Bodies (ULBs), Water departments	Same as above

* Public Health Engineering Department or State Level Water Supply and Sewerage Board

** Private sector involvement is to be governed by the following considerations.

Description of Tool 24:

Criteria for Selection of Private Sector Participation (PSP) Models for Integrated Urban Water Management (IUWM)

Review of international experience with PPP shows that BOT would work when the political system is by and large non-corrupt; governments/ bureaucracy functions; but the urban local body lacks enough technical and managerial skills and financial resources. Obviously, BOT contracts and "concessions" are necessary when a new water supply system is to be built and not when a functioning system already exists (Biswas and Tortajada, 2003). Whereas in the case of large urban local bodies, wherein the technical and managerial skills are present, but administrative/institutional capabilities for direct contact with the communities are absent, private sector participation can be sought for provision of basic services. They can include: detection of illegal connections; installation of meters, taking meter readings, billing and collection of water charges. One important issue with meter reading is the high corruption and false readings. Going by Braadbaart *et al.* (1998), the fact that secondary cities are too large for user management of the kind found in small towns and rural areas, and that they are too small and too numerous to be privatized is compelling reason for PPP in such cities.

In situations where the upkeep of the system is poor or the agency is lacking committed human resources to run and maintain the system, an O & M contract could be made to a private agency. Here, the payment is normally fixed. In order to create incentive among the private agencies to save water, the payment could be linked to the number of water supply connections being serviced. Such contracts are made in such instances where the private agency does not have to make major capital investments for sourcing water, or building the basic distribution infrastructure etc.

Where major investments are to be made, and the government has the capacity to make those investments, lease agreement is a good proposition. Here, the use of private agency should be to get highly skilled manpower for specialized services such as design and operation of sophisticated wastewater treatment systems, desalination systems etc. In other instances, the improvements in institutional arrangements for the public utility need to be tried out. This could be for tapping financial resources; adopting pricing policies.

Overall, the decision to privatize urban water supply should involve the following consideration: political stability and power of the government; effectiveness of overall governance; the overall financial condition; the ability to raise finances from external sources; infrastructure conditions; and the institutional capability in terms of policies & legal framework and administrative capabilities (Source: based on Braadbaart *et al.* (1998) Biswas and Tortajada, 2003; IWE Cranfield PPP database, Franceys, 1992; Perald, 2006). Accordingly, the favourable urban conditions for trying out different PPP models are presented in Figure 5. They are six PPP models considered for this, viz., divestment, BOT, concession, lease, management contract and service contract.

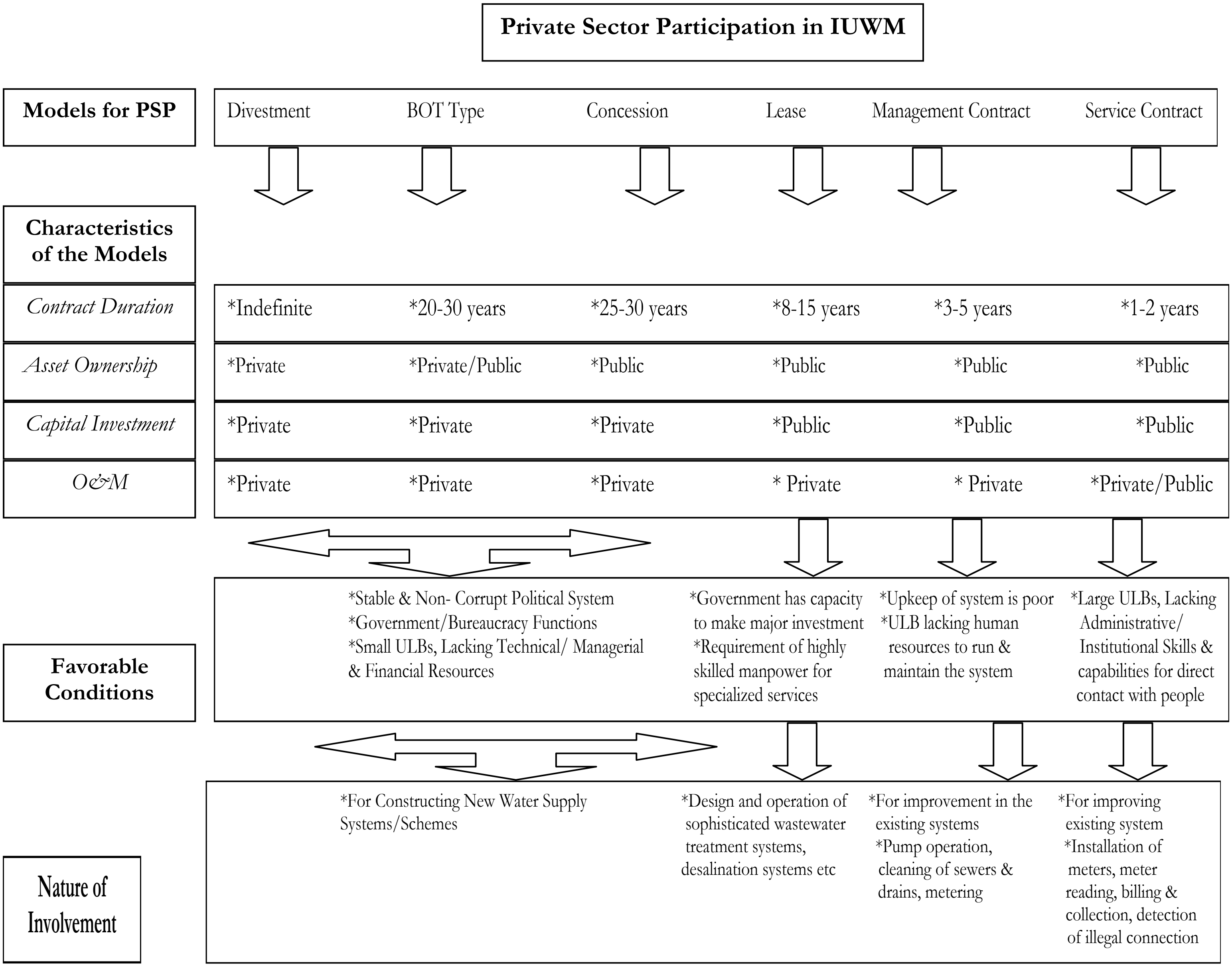


Figure 5: Private Sector Participation Possibilities in Different Urban

For more details, refer section 11.1 of IUWM Technical Report

Description of Tool 25:

Appropriate staffing of urban water utilities

Appropriate staffing is crucial for strengthening urban water utilities. Now, two utilities offering the same level of water supply, wastewater and solid waste management services may be requiring different levels of staffing. This is because there are many physical and socio-economic factors influencing the staff efficiency. Hence, a staffing norm based on simple criteria of the size of population to be catered will be improper. Hence, the various factors that influences the physical, management and economic performance of the utility need to be identified.

Factors Influencing Management Performance

The managerial performance of the urban water utility in terms of provision of water supply, sewerage collection and treatment, solid waste disposal etc is a function of the institutional regimes, especially the incentive structures; and training and skill development etc. But, it is also a function of the characteristics of the urban area, which is influenced by the way they are planned. Number of staff per '000 connections and number of staff per '000 people are indicators of management performance. Our analysis using data from 301 towns/cities shows that cities with high population density would be able to manage their water supply affairs with lesser number of staff. At the same time, they will be at a lesser advantage when it comes to managing solid waste collection and disposal.

Factors Influencing Institutional Performance

Number of connections per unit size of the population is a good indicator of institutional performance of urban water utility (Arghyam/IRAP, 2009). Analysis with number of staff per thousand population and number of connections per '000 population shows that larger the staff size, higher the institutional performance, expressed in terms of number of connections per thousand persons. With the same staff strength, cities with higher population density will be able to provide water supplies to a larger number of people.

Factors Influencing Physical Performance

Increase in area coverage reduces the physical performance. This validates a well-known theory in water supply engineering, and is perhaps due to greater length of the distribution lines per unit volume of water transported and the greater pressure to be maintained in the waterline due to higher pressure losses. Both length and pressure increases the technical losses in water supply pipelines. Our analysis using data on average percentage of accounted for water (AFW) for cities with different geographical areas shows that with increase in geographical area, the % AFW increases.

Staffing Norms for Urban Water Utilities

A method to work out the norms for staffing of water utilities is to look at the norms of those which are performing well. Therefore, we compared the staffing of utilities, which have differential performance, but not markedly different in their physical attributes. Metros were used as a benchmark for comparing performance as they show the best performance. The following attributes are considered for performance. 1. Water supply coverage. 2. Demand coverage. 3. Sanitation coverage. 4. Wastewater treatment. First of all, the water supply coverage is highest for metros, whereas the supply gap is lowest. Rate of solid waste collection is also highest for them. Sanitation coverage is highest for metros both in terms of population covered and the proportion of the geographical area covered. Further analysis also showed that higher the staff strength, higher the number of connections for that population.

Table 31: Staffing norms for urban water utility

Sr. No	Staff Category	No. of Persons for '000 population (current)	Most desirable	Suggested amendments in norms
1	Water Supply & Sewerage	0.73	1.00	Can be 10% less if urban population density is very high
2	Wastewater Treatment	NA	0.50	
3	Solid Waste Collection & Management	2.3	2.50	Can be 10% more if the urban population density is very high

Source: based on authors' analysis

The staffing norms for urban water utilities is worked out on the basis of the following important inferences drawn from analysis: 1] raising the performance of the utilities of smaller towns from the present levels to that of the metros would require bringing parity in staffing and improving the staff composition; and 2] further improvement in performance of the utilities in certain areas like wastewater treatment would require higher staff strength. The tool on staffing (Table 31) provides empirical norms for staffing difference services such as water supply & sewerage, wastewater treatment and solid waste collection & management, and indicates how these norms should be changed under different physical conditions.

There are three major steps, which will have significant implications for improving the staff efficiency in managing urban water supplies. They are: 1] implementation of SCADA (Talati and Kumar, 2005; Wachasundar, 2007); and 2] computerized billing; and 3] automation of metering. Supervisory Control and Data Acquisition System is meant for operational control of the system for optimum performance and better efficiency (Newquist, 2000). It is done by logging and transferring of data relating to reservoir levels, pump discharge, pump efficiency, water pressure, water quality etc. to a master control facility (Talati and Kumar, 2005). By this, the utility can save the staff time required for physical supervision and monitoring of performance of reservoirs and gate operations, and coordination amongst multiple locations (Newquist, 2000). Also, use of sensors in SCADA can be used for continuous monitoring of quality of water in the distribution system. It could also monitor pressure development in the pipes, thereby guiding valve operations and averting the danger of pipe bursts (per. Communication, Tippesamy, February, 2010).

The details of the detailed methodology used for arriving at the norms for staffing of utilities are provided in 10.5.3 of the technical report.

Description of Tool 26:

Community Participation in Urban Water Management

Community participation in the context of urban water management is a complex theme, and has many dimensions. It can be at different degrees in different contexts. The involvement of community in urban water management could cut across various spheres viz., 1] planning of water supply & sewerage systems (mainly having an influence in the selection of the type & nature of technical systems for water supply, sewerage disposal, wastewater treatment supply, water supply schedules); 2] Delivering certain services, which are parts of urban water management activities; 3] Overall governance of urban water as civil society --including making of the rules for fixing the price of water, introduction of supply water restrictions, deciding on investment/funding priorities, provision of budget for public auditing; and 4] implementing best practices.

Nature and Degree of Community Participation

The upper boundaries of involvement for a local community institution in urban water management activities would be defined by its operational jurisdiction, the level at which the scheme operates and the physical characteristics of the scheme. For participation to be meaningful, it would be advisable that the next layer of community institutions is created at the level of the hydraulic infrastructure. This will help internalize some of the externalities in local management induced by conflicting management decisions taken by different local communities.

The physical characteristics of the scheme, to a great extent, can define the level of involvement. For simple local schemes, it would be easier for the "ward committee" to even plan and manage. The same will not be true for a scheme which involves long distance water transport through pipeline involving heavy pumping machinery, and leak detection equipments.

For a given community, the desirable level of participation is determined by its own perceptions of "participation", and the ability to participate. This is in addition to "physical system characteristics", which would influence the level of participation to a great extent. The community's perceptions of and ability to participate would change according to their level of knowledge and exposure and capability to mobilize resources. The capability can be social, economic and human resource-related.

But, the willingness of the community to participate would change according to the priorities of the communities. In a highly cosmopolitan community, the ability to participate in planning and management decision making relating to urban water systems and to mobilize resources for the same might be high. So a higher level of participation is desirable in this case. But, the community may not have the time to commit for achieving this, as the opportunity cost of non-participation might not be significant. Against this, in the case of slum dwellers, the knowledge, skills and resource mobilizing capability will be much less. But, the community might have more time to spare as the opportunity cost of non-participation would be high. Hence, the most desirable level of participation might be low in the form of their involvement in repair and maintenance. But, it would be achievable.

The other factors that determine the degree of participation include: a] homogeneity of the group/community (communities from the same clan, religion, caste, creed etc. are likely to participate more and better than a heterogeneous society); b] incentive (whether financial, natural or human asset gains, e.g. capacity building) which community see/perceive in case of participation; and c] effective leadership. Here it is important to remember that the incentive structure can influence the opportunity costs of non-participation and therefore the willingness to participate. Figure 6 provides the suitability conditions for different spheres of involvement of communities in urban water management; the forms of user participation; the characteristics of participation; the processes involved and the benefits.

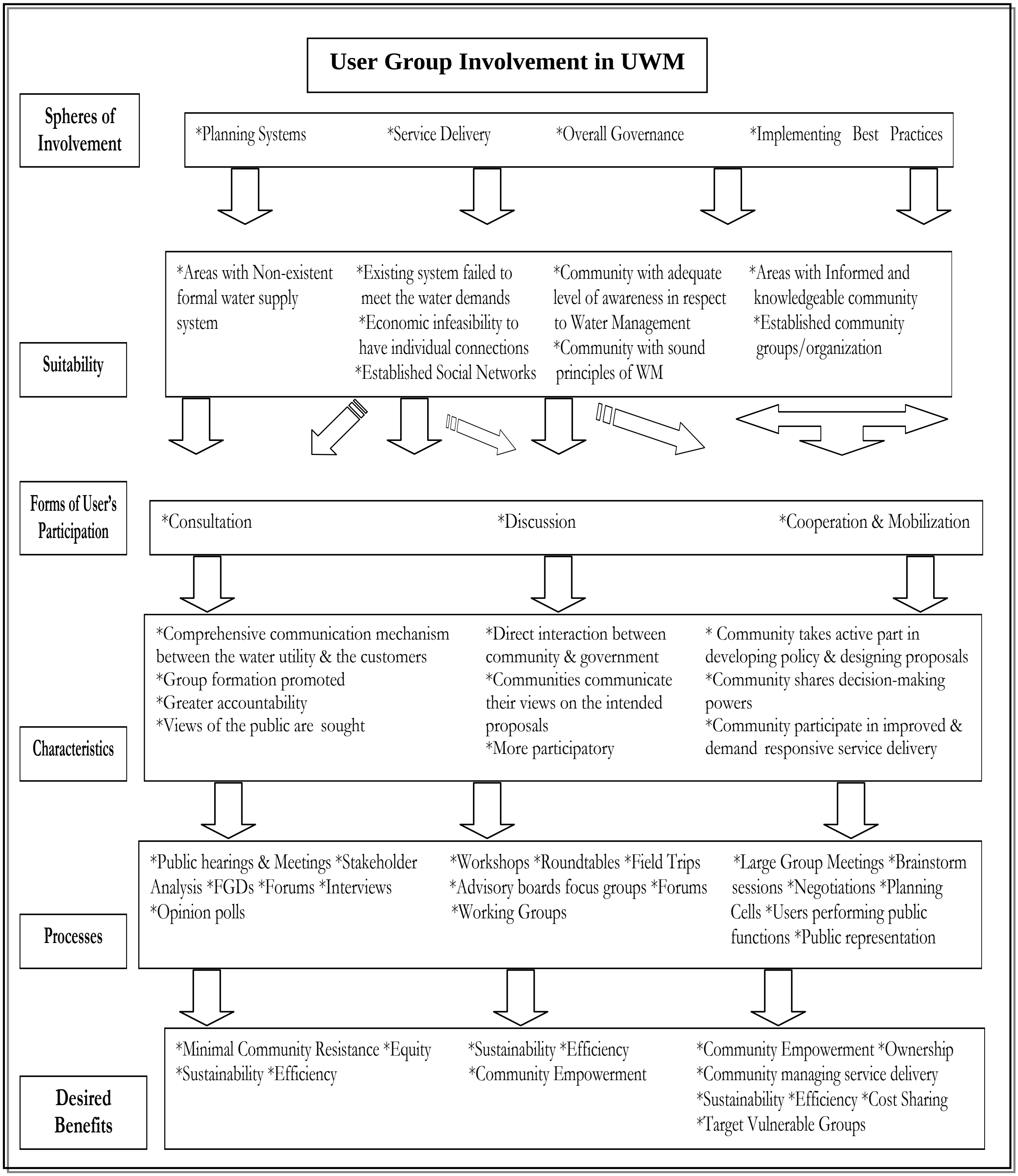


Figure 6: Suitability Conditions for Different Spheres of User Group Involvement in Urban Water management

Note: For more details refer Section 10.5.1 in IUWM Technical Report

Description of Tool 27:

Training for Capacity Building

Most urban water utilities in India today perform very limited functions. In the case of small towns, the job is mostly limited to supplying treated or partially treated or untreated water to the urban consumers, with the orientation mostly on conventional systems. But, there are many non-conventional water supply systems, which can provide future water supplies in many cities and towns such as rainwater collection tanks, and desalination systems. The conditions under which they are feasible, the opportunities they offer and their economic aspects need to be understood by the professionals.

In most cities, wastewater is not treated at all. Similar is the situation vis-à-vis storm water generated in urban areas. Neither there is adequate system for storm drainage and disposal. In many towns, the storm water from most parts of the town/city is collected by the sewers.

Planning, designing, building and operating wastewater treatment and reuse systems would also require good understanding of the theories in bio-chemical engineering, biology, environmental engineering and environmental economics, which are used in the design of wastewater treatment and reuse systems. It also would require familiarization with various wastewater treatment technologies now available, as these technologies are not in use in any of the urban areas in India. Providing for integrated storm water management would require sound understanding of the very concept of sustainable storm water management. All these would require training.

Over and above, the various emerging concepts in urban water management such as demand management, community participation in urban water management etc., which are part of urban water cycle management, and the technical and economic tools for achieving them need to be understood at various levels such as the bureaucrats in the municipality/ corporations, the technical staff handling urban water systems within the municipality/corporation, the representatives of the people.

But, the types of training which the primary stakeholders require for building their capacities to participate in urban water management would be different from those which the utility officials require for implementing them. Generally, the officials of the utility would be concerned with different aspects of various technical, institutional and policy interventions. Again, there are too many topics to be covered. It is impossible to cover them in one module, given the practical issues involved in attending long duration trainings for the participants, and the need for some time duration between one training event and another event to facilitate good learning. Therefore, it is important to split the training programme into several modules on the basis of the themes and their utility for the stakeholders.

The idea is that themes, which are relevant for certain stakeholders only, can be appropriately targeted. Tool 29 provides the list of different training modules, the topics which can be included under each module, and the target groups. Table 32 suggests the types of IUWM training modules relevant for different stakeholders under different typologies.

Table 32: Listing of Capacity Building Training Programmes at various levels and Module Contents

Module No and Theme	Topics	Participants
Module 1 One Day Orientation programme-Town Level	1. Importance of water security & environmental sanitation 2. IUWM and its scope for the town 3. Need for participatory approaches	TMC (ULB) Ward Councilors, Political leaders, WATSAN Officials, SHG reps, Private water vendors and operators, Local NGOs, implementing agencies of IUWM etc.
Module 2 Project Launching Workshop (Integrated Urban Water Management)	1. Introduction to IUWM 2. Economics of investments in IUWM 3. IUWM Principles & Practices 4. IUWM framework and the key elements	TMC (ULB) Ward Councilors, Political leaders, WATSAN Officials, SHG reps, Private water vendors and operators, Local NGOs, implementing agencies
Module 3 Understanding existing urban water systems	1. Survey of urban water infrastructure 2. Use of decision support systems (GIS) for water distribution planning; water supply system design 3. Use of expert systems for analyzing the resource dynamics, hydraulic efficiency estimation, and leakage detection	TMC (ULB) key officials, WATSAN Officials, Ground water department, river basin agency (if any)
Module 4 Community involvement and Participation	1. Level of community involvement in water & sanitation activities 2. Role of community in IUWM 3. Legal rights/regularities of CBOs in IUWM	Representatives from community, TMC governing body members
Module 5 Urban water cycle management	1. Water resource management (river, ponds, lakes, aquifer) 2. Water supply management 3. Water demand management 4. Analysis of urban hydrology (roof water catchments, storm water flows) 5. Efficient water use in urban areas & technologies 6. Water treatment & reuse potential 7. Water vending 8. Packaged drinking water & and its SWORT analysis	TMC (ULB) key officials, WATSAN Officials, GWD, CBO reps, Land use board, Pollution control board, IUWM implementing agencies etc.
Module 6 (2 parts) 1) Waste water 2) Solid waste	1. Generation of waste water 2. Treatment of wastewater 3. Reuse of wastewater (potential & threats) 1. Solid waste management and recycling	Sewerage board, SWM agencies, Publics,

Module 7 Sustainable Storm Water Management	1. Accounting of storm water 2. Using storm water for town needs: water quality aspects 3. Storm water management and reuse options	TMC (ULB) key officials, WATSAN Officials, CBO reps, Private water vendors and operators, implementing agencies.etc
Module 8 Eco-sanitation and industrial waste management	1. Adoption of eco friendly toilets /sanitation facilities to reduce water consumption and contamination 2. Newer techniques to control industrial wastes	TMC (ULB) key officials, WATSAN Officials, CBO reps, industrial entrepreneurs and related officials from departments, pollution control board, health departments
Module 9 Institutional change	1. Existing organizational set up, and governance systems 2. Institutional capacity building in UW Sector 3. Instruments for capacity building 4. Institutional reforms 5. Public-private partnership and relevant models 6. Community participation in UWM, and the roles	TMC (ULB) Ward Councilors, Political leaders, WATSAN Officials, CBO/SHG reps.
Module 10 Water Pricing & Water demand management	1. Price elasticity of urban water demand 2. Economic principles in pricing urban water 3. Metering of water supplies 4. Technical issues in metering	TMC Governing members, WATSAN officials, CBOs
Module 11 Setting up of MIS	1. Generating data on urban water systems & supply 2. Setting up database on GIS platform 3. Generating management information systems	WATSAN Officials, GWD,TMC (ULB) key officials, department officials from irrigation, Urban planning,
Module 12 Operation & Maintenance of Water supply and sewerage systems	1. Role of service providers for O & M of urban water systems 2. Preparation of contracts 3. Contract laws and their provisions relevant for water supply and related services	TMC(ULB) Ward Councilors, , WATSAN Officials, implementing agencies of IUWM, private service providers etc.
Module 13 Rain Water Harvesting	1. Urban bylaws for promotion of RWH tanks 2. Use of rainwater for meeting urban water needs: quality aspects 3. Design of rainwater collection systems	Key experts from various Departments and agencies related to environment, Agriculture, WATSAN, Urban development, Social development etc. TMC (ULB) Ward Councilors, CBO/SHG reps, Local NGOs
Module 14 Ground water recharge	1. Role of groundwater in urban water management 2. Key characteristics of groundwater in urban areas 3. Groundwater management 4. Artificial groundwater recharge: sources, and techniques	Key experts from various Departments and agencies related to environment, Department officials from Irrigation, Agriculture, WATSAN, Urban development, Social development etc. TMC (ULB) Ward Councilors, , WATSAN Officials,

		CBO/SHG reps, farmer's associations, Local NGOs, land use board
Module 15 Financial Management	1. Tools for improving the finance of water utilities (pricing, mobilizing funds) 2. Improving revenue collection systems 3. Online payment of water charges, and grievance systems	TMC (ULB) key officials, IUWM implementing agencies etc.
Module 16 Risk management	1. Prevention, mitigation and preparedness for water &climate related disasters 2. Extension of WATSAN facilities according to the growth of population& migration	Disaster management units, TMC &WATSAN officials, Urban planning department

Description of Tool 28

Institutional arrangement for urban water management

Institutional arrangement in water management can be defined as a combination of: 1) legislation and regulations; 2) policies and guidelines; 3) administrative structures; 4) economic and financial arrangements; 5) political structures and processes; 6) historical and traditional customs and values; and, 7) key participants or actors (Mitchell, 1990).

Improved IUWM will require engagement with a complex array of administrative, political, institutional, social, economic challenges in cities. There is a need, therefore to stimulate changes in policy and practice in urban water management within institutions, other levels of government and civil society. The new paradigm is likely to require: changes in holistic environmental thinking; changes in institutional structures and frameworks; change in use of means and resources; changes in managerial methodologies and approaches & changes in approaches to financial planning and management to include explicit attention to pro-poor and gender-specific strategies. Edwards (1988) has developed manual that provides practical and immediately useful information about developing and managing institutional change projects in the water supply and sanitation sector. He points out that institutional development projects should "*focus on the development of comprehensive organizational systems and the people within the system which make them work*."

Institutional Integration

Planning and management of water resources involve complex considerations of the physical systems affecting water availability, and the socio-economic systems affecting water use (Kassem, 1996). In order to integrate these complex aspects related to water resources management, comprehensive and complex systems such as river basins should be the unit for governance of water resources and not local systems (Klomp *et al.*, 1996; El-Ashray, 1991). Therefore, there is a need for building institutions at the level of river basins that are capable of balancing the current and future demands with the supplies, without threatening the hydrological and ecological integrity of the basin. The functions of various institutions engaged in different aspects of water development and management in the basin will have to be integrated at the basin level to manage the entire water system comprising water resource system and water supply and use system in a comprehensive manner.

A single agency, here an RBO, is required to carry out water resource management functions at the level of river basins. Since water resource management needs at the local level widely varies across the basin, a range of micro-level actions will be needed. Hence, a decentralized institutional format would be required for the RBO. Apart from carrying out WRM activities, the RBO can be vested with the powers for allocation of rights to various sectors of use including the urban water utility. In this process, they become the coordinating institution for various line agencies dealing with water related services for different sectors of use, and can integrate their activities at the level of river basin (Kumar, 2006). In this set up, the service agencies will have to obtain the volumetric water use rights from the RBO (please see New Institutional Regime for Urban Water Management after Reforms: Tool 19).

In tool 19, we have discussed the larger institutional reform in urban water sector, in which the relationship with external agencies such as the state, RBO, state pollution control board etc., are discussed. The process of organizational change through various modes of pubic private participation and user involvement in urban water management, and adequate staffing of utility can be identified from Tool 20. The training needs for capacity building of various stakeholders were can be identified from Tool 21. The ways to improve the finance of utilities such as water pricing and UFW reduction can be found in Tool 13. Therefore, we would only discuss the regulatory approaches in this tool.

Regulatory Framework for Water Resource Management

Regulation is an integral part of the institutional arrangement for water resource management (Mitchell, 1990; Frederiksen, 1998). This can comprise of regulations of water resources in terms of quantity and water-related services through acts and laws; establishing regulatory framework for effluent disposal that take into ecosystem carrying capacity; setting up of regulatory frameworks by local communities; and use of economic instruments of coasian bargaining, enforcement of effluent discharge norms for SMEs and declaration of critical zones of heavy damage.

Regulation of Water Resources and Services

There should be acts that provide the regulatory framework for water resources and water related services. South Africa has the National Water Act (1998), and National Water Services Act (1997), two laws that directly relate to water. The WSA provides the regulatory framework for the provision of water services by local authorities, under the overall authority of the Minister. The NWA mandates the Department to ensure that all activities relating to water resources management, by whomever they are undertaken is in accordance with the requirements of the Act.

The catchment/basin management authorities can use the information about water development plans for towns and cities falling within its drainage area for the determination of allocations to these towns and cities. The requirement of water as per the water development plan must be reflected in the catchment management strategy of the authority concerned. The urban water utility, on the other hand, should refer to the relevant catchment management strategy for information about the availability of water to support proposed water services targets; water quality requirements for the wastewater that is to be returned to the water resource after use; and the riparian rights of the downstream water users. Hence, the Acts should provide for administrative/ institutional mechanisms for better coordination between resource management agency and agencies that provide water-related services.

Regulatory Framework for Effluent Disposal

The regulatory framework has to be location-specific, guided by the ecosystem carrying capacity, rather than uniform standard for discharge of effluents (Rajaram and Das, 2008). The important aspect of regulation of effluent discharges will be best accomplished with the help of local bodies, as management of ecosystems has to be at the local ecosystem level only--where the dynamic nature of impact of effluents can be appreciated only by those who are affected by it on a daily basis--and cannot be centralized.

The key aspect of protecting environmental resources is the assignment of property rights to facilitate its protection from industrial externality. The first step is to work out the ecosystem specific standards for effluent discharge. We argue that the surface water endowment in a region and the type of aquatic life could be a strong indicator for ecosystem carrying capacity and deciding the effluent discharge norms vis-à-vis water quality. As a general principle, in surface water abundant areas with perennial streams and rivers, the norm could be less stringent.

Community Regulation of Water Quality through Monitoring

Any regulatory programme will be successful only through effective monitoring. But, with the current density of WQM sites maintained by the CPCB, effective monitoring and regulation is a distant possibility. Hence, the local council of the areas affected by these effluent discharges can be empowered to collect samples randomly at a frequency based on the toxicity of effluents. These samples shall be sent for analysis preferably to a district level accredited laboratory or public funded academic/research institutions. The local SPCB can provide a supporting technical role to this. The impact of information availability in the hands of local community will be a key factor in cost effective pollution regulation. The main advantage in involving the local people is that a major portion of manpower cost can be saved, since they will volunteer to safeguard their own survival.

Slowly, the local councils can be aided to upgrade their programmes to address domestic sewage treatment, non-point sources of pollution and finally total environmental management for sustainable development. The emphasis should be to utilize existing institutions (academic/research) in every taluka (subdivision of a district) and district.

Other Important Steps for Comprehensive Regulation

Regulation of large industries through economic instruments: For a large industry operating in a rural setting, the economic instrument of coasian bargaining is an effective option. The industry can negotiate with a local council for its discharges and compensations to arrive at a consensus. The agencies like SPCB/MoEF can provide technical assistance to the local council in protecting their interests and to aid the industry in integrated pollution prevention control (IPPC) efforts. However, such approaches should be resorted to only if pollution control is technically feasible or economically viable.

Regulation of small and medium enterprises (SMEs): The first requirement is to locate them in clusters/industrial estates based on industrial symbiosis and carrying capacity. But, control of these will remain a major socio-economic challenge. The only way out in industrial estates is to channel the effluent of SMEs to a CETP, and also to ensure that it functions efficiently. This can be made possible through efficient monitoring, and heavy penalties have to be imposed to compensate the victims.

Declaration of critical zones: Areas of heavy damage around industries, where remediation is not possible in the short-term, should be declared as pollution hotspots/critical zones and the affected population must be resettled/ rehabilitated. Where resettlement is not possible, legislation should be framed which will hold the industries responsible to provide livelihood allowance, medical facilities, health insurance and license fees for local resources.

Synthesizing the above analysis, the nature of regulations for water management has to be location specific, depending on the type of urban area (small or large), the type and sources of water use (whether surface water or local groundwater), the nature of pollution (whether many small polluters, or a few large polluters, etc. The instruments for regulation and the agency for monitoring water use and pollution would also change according to the situation. The regulatory frameworks for WRM in the urban areas for the most common situations are summarized in Table 33.

Table 33: Regulatory Framework for Water Resource Management

Type of Water User/ Polluter	Regulation by	Nature of regulation	Instrument for Water Quantity/Quality Management	Vol. Allocation/ Water Quality Monitoring by	Water Metering/ Water Quality Testing
Water Quantity Management					
Water utility using surface water for municipal supplies	River Basin Organization (RBO)	Evolving broad WRM plans for the basin, and defining water rights for different sectors	Volumetric, basin-wide allocation; enforcement of water rights; and levying water tax from the utility	RBO	Metering of water withdrawal by the utility
Urban water utility using local groundwater	RBO	Do	Do	RBO	Do
Groundwater pumping by individual urban consumers*	No regulation		Groundwater tax (based on wells kept at a very low level		No metering of withdrawals, but only the no. of wells
Water Quality Management					
Large cities located within large river basins	RBO	Setting norms on effluent quality	Pollution charges; payment for WWT to the service provider; and performance monitoring	State Pollution Control Board (SPCB)	SPCB
Small towns located within large basins	Do	Setting norms on effluent quality	Pollution charges and payment for WWT system; and performance monitoring by community	By community with technical support from SPCB	Accredited district level agencies of the state government or academic institutions
Small towns located outside large basins	Local community	Setting norms on effluent disposal based on knowledge of the local eco-	Use of environmental protection laws, with technical support of SPCB	By community with technical support from SPCB	Do

		system			
Regulation of large industries	RBO	Setting norms on effluent quality, including that for quality of different types of pollutants	Direct regulation and technical assistance	Pollution control board	Pollution control board
Large number of small industries	RBO	Placing them all in one locality and levying pollution tax	Investment in CEPTs	Pollution control board	State Pollution Control Board
Declaration of critical zones	RBO	IPPC* with 5-10 year binding targets	Resettlement, or livelihood allowance + medical allowance		

*IPPC is integrated pollution prevention and control

Governance, Policies and Legal Framework

Description of Tool 29:

Practices for improving urban water governance

Governance refers to the art of rule making. Water governance refers to the range of political, legal, social, economic and administrative systems that are in place for effective management of water resources and their service delivery at different levels of society. Governance translates into political systems, laws, regulations, institutions, financial mechanisms and civil society development and consumer rights (GWP, 2003). Good water governance essentially leads to sound practice of making rules relating to water resource evaluation, water resource planning, water development, and water management (Hunter Districts Water Board, 1982; Page and Bekker, 2005).

Four Important Areas of Urban Water Governance

The four areas of urban water governance, improvements in which can bring about, major improvements in the performance of urban water systems, are: water and wastewater pricing; urban water infrastructure financing; and water supply.

Governance of water supply refers to making rules regarding the per capita supply levels, the supply schedules, the quality of water to be supplied, provision of new connections; the desirable level of consumer awareness about water supply, redressal of complaints and the "beneficial uses". Governance of water & wastewater pricing refers to making rules relating to fixing prices of urban water supplies and sewage, which would touch upon matters such as: the norm for fixing prices; who should fix the prices; who should administer the prices; and who should have a say in fixing pricing norms; and nature of subsidies for the poor. Governance of water infrastructure financing refers to setting rules & norms regarding: setting priorities on the type of infrastructure to be supported in water sector; preparing the DPRs and cost estimates; who should give the financial approval; release of funds for building infrastructure; and infrastructure building performance review process.

Challenges in Achieving Good Governance

Good governance of urban water supplies means that the rules and norms regarding water supply are most user oriented; and are also known to the urban water users. This means that for good governance of water supply, the norms regarding per capita supply levels and quality of water should be worked out on the basis of the climatic conditions and the socio-economic status of the dwellers, keeping in mind the highest quantum that users are willing to buy at the prices that exist.

The challenge in improving governance of urban water pricing is to make sure that the estimates of cost of water supply provision, cost of depletion of the resource and the cost of resource degradation are authentic. When private agencies are involved in water supply provision under PPP or otherwise, it is necessary that the above-mentioned estimates undergo full scrutiny by an independent regulatory authority in order to make sure that the consumer interests are protected.

The key challenges in improving water infrastructure financing include: prioritizing investments in urban infrastructure that give due considerations to physical sustainability and economic considerations; making ULBs in water scarce regions to invest in water efficiency plans, and green infrastructure; and linking release of funds to outcomes rather than outputs; and making review technical and financial proposals for urban infrastructure projects independent.

Based on our understanding of the universally accepted criteria for good governance, and supported by the review of international literature on best governance practices and study of limited experiences from Indian towns, we have listed certain governance practices that have the potential to improve urban water management. They fall under six categories, viz., institutions for urban water management; urban water & wastewater pricing; water infrastructure financing; water supply; pro poor governance of water and pro poor sanitation. They are summarized in Table 34.

Table 34: Urban Water Governance Practices

Criteria for Good Governance	Key Performance Area	Practices
Accountability, transparency, predictability, participation	Institutions for Urban Water Management	1.Enabling Act for private sector and community participation in urban water management functions 2. The roles for both communities and private sector to be determined using sound principles in institutional design, management
	Urban water & waste water pricing	1. An independent regulatory authority approves the charges, and the manner in which the various cost components" are worked out. 2. Sound economic principles are used for fixing water prices 3. The norms used for fixing prices and working out the water bills are known to the consumers. 4. The actual efficiency levels obtained by the utility is maintained at desirable levels, and also known to the independent regulatory body and the consumers. 5. Income related measures are used to target the subsidies for the poor. 6. Good redressal mechanism exists for the consumers to complain about the tariff and the changes.

	Water Infrastructure Financing	1. Prioritizing investments for water infrastructure based on sound analysis of water resources. 2. Creating special funds in state & central governments to assist municipalities in implementing green infrastructure projects. **3.** Develop Water Efficiency Fund to support municipalities in the design and implementation of water efficiency programmes. 4. Water efficiency plans and programmes to be made an integral part of the urban water infrastructure project. 5. Implement a *Water Efficiency Act* that sets mandatory water efficiency standards for appliances and phases out outdated technologies. 6. Linking fund release to outcomes rather than outputs. 7. Creating independent authority to review technical & financial proposals to review the technical proposals and budgets.
	Urban water supply	1. The norms regarding per capita supply and quality of water to be worked out on the basis of the climate and the socio-economic status of the dwellers, keeping in mind the highest economic demand. 2. Scientific studies for demand estimation for different income segments and for the given climate to be made mandatory for fixing norms of water supply. 3. The norms relating to connection charges and "maximum waiting time" for different zones, the procedure for application and the eligibility criteria to be made public. 4. Supply schedules to be worked out on the basis of proper scientific assessment of the schedules that are convenient, and are known to them in advance. 5. Clear cut timeframe to be fixed by the water utility in consultation with the technical department for complaint redressal, and this should be known to the consumers. 6. Users to know the quality of water being supplied

		7. The utility to have clear-cut rules regarding the type of information on water quality to be shared with the public, the frequency, and platforms used for sharing. 8. The criteria used for defining certain water uses as "non-beneficial" should be revealed to the public, and if penalties exist for such uses that also should be known to the water users through public awareness campaigns.
	Pro-poor governance of Urban water	1. Recognizing on-line complaints as legitimate 2. Consumers to have a say in fixing priorities regarding the beneficial water uses and non-beneficial water uses. 3. Affordability to be made an important criterion for fixing water tariffs and deciding connection charges 4. Holding engineers accountable, if they fail to respond to complaints 5. Convening monthly meetings to give city residents the chance to talk with engineers: institutional processes.
	Improving Sanitation for Urban Slums	1.The official sanctioning of urban infrastructure projects to be subject to provision of WATSAN services for the construction workers 2. Starting of any construction to be subject to certification by the concerned authority of completion of such works.

Tool 30: Legal Framework for Integrated Urban Water Management

Urban Bylaws for Sustainable Urban Water Management

Urban Land Ceiling Act: The aim of the proposed urban land ceiling law should be to prevent unscrupulous lateral growth of urban areas, particularly in cities/towns which have very low population density. This can be achieved by providing for imposition of differential taxes on new developments and old developments by the urban local body. The building tax for new developments could be kept at a much higher level than that for old ones. The license for housing stocks and other developments in new areas should be subject to them managing their own water supply, wastewater treatment and storm water drainage systems.

Building Bylaws: In very high rainfall plains as well as hilly areas, the building bylaws should provide for provision of separate rainwater storage tanks by new constructions. Only those new constructions which have underground storage tanks, with capacity proportionate to the size of the roof, should be given license to construct. The completion certificate shall be issued by the competent authority only after site verification to see whether the proposed construction is built as per the plan approved by the urban local body. Disincentive could be created for old constructions, which are not complying by the new building bylaws, in the form of additional taxes.

In high rainfall areas and those prone to floods, the new constructions should provide for rain gardens, in proportion to the total built up area.

Legal Framework for Metering System: In order to make metering and pricing of water supplies efficient and smooth, the legal framework should provide for: 1] protection of consumers against false metering and charging false bills; 2] penalizing of consumers who tamper with meters to protect the utility interests; 3] consumer right to ask for timely replacement of malfunctioning meters; 4] creation of special testing labs for proper functioning of meters; and, 5] protection of meter readers from physical assault by errant consumers.

Water Resource Regulatory Act: Researchers for long have argued that for sustainable water resource management, the agency responsible for water allocation should not be same as the agency using the water (Frederiksen, 1998; Kumar, 2006). Separating out the water resource management functions from water service functions would create conditions under which the utility (the water supply agency) would be confronted with opportunity cost of using the water. The Water Resources Regulatory Act, being proposed here, is to provide for establishment of tradable water rights and creation of RBOs as legitimate organizations for fixing and allocating water rights, and its enforcement, and regulation of water quality. Currently, only one state in India, i.e., Maharashtra had a Water Resources Regulatory Act of 2005, and this Act had provided for the establishment of a Water Resources Regulatory Authority. There are legal provisions under this Act, for setting up of river basin organizations (RBOs).

As per the Maharashtra Water Resources Regulatory Authority Act (2005), River Basin Agencies issue bulk water entitlements based on the category of use (irrigation water supply, rural water supply, municipal water supply or industrial water supply) and subject to the priority assigned to such use under State Water Policy (MWRRAA, 2005). Further, it was stipulated that the existing Irrigation Development Corporations should function as River Basin Agencies. But currently, IDCs are only responsible for survey, planning, design, construction and management of Major, Medium and Minor Irrigation Projects, and irrigation water services. Hence, the new arrangement is likely to protect the entrenched interests of irrigation Corporations to over-allocate water for the sector it is concerned with, which is against the principle of sustainable water resources management in the river basin.

Tool 31: Policy Framework for Urban Water Management

Table 35: Policy Framework for Urban Water Management

Sr. No	Type of Policies	Typologies	Policy Actions
1	Policies to encourage runoff reduction	Very high rainfall, plain areas, including those prone to floods	Taxes for housing stocks without RWHS, and tax benefits for those having it
2	Policies to encourage water conservation at end user level	Water-scarce cities/towns, and large cities	Water metering & volumetric pricing
3	Policies to reduce unaccounted for water	Water-scarce towns, and all large cities	Water metering & pricing
4	Policies to discourage water consumption for low valued uses (gardening, swimming pool)	Water-scarce towns, and large cities	Incremental block rates
5	Policies to encourage excessive consumption	Water-rich areas, but with WS infrastructure having excessive capacity	Declining volumetric prices with increasing use or fixed charge
6	Policies to encourage waste water reduction	Cities with very high land prices; cities where high concentration BOD is needed for energy recovery	Volumetric sewerage charges
7	Policies to reduce toxic waste reduction at the manufacturer level	Areas where industrial units are heterogeneous	Stringent pollution control norms
8	Policies to discourage horizontal city expansion	Cities with very low density, and with water scarcity	Implementation of Urban Land Ceiling Act
9	Policies to encourage groundwater use	Cities falling in groundwater abundant areas	Subsidized electricity for domestic & municipal pumping of groundwater
10	Policies to discourage groundwater withdrawal for municipal uses	Cities where groundwater depletion is causing environmental degradation	Groundwater abstraction tax to be kept higher than the unit price of supplied water
11	Pro poor policies for water supply	Water-scarce towns and large cities	Subsidized tap water supply connection charges
12	Pro-poor environmental centralized sanitation services	Areas **vulnerable** to groundwater pollution*, particularly those in the urban fringes	Subsidized connection charges for centralized sewerage system for poor families,
13	Pro-poor decentralized sanitation services	Areas "**least vulnerable to groundwater pollution**" + other areas in urban fringes	Subsidies for toilet with septic tank construction

Note: Vulnerable, highly vulnerable and very highly vulnerable, for more details refer section 17.1 in IUWM Technical report

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