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Implications of Climate Change for Water Resources Management

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INTRODUCTION

Adequate scientific evidence (for example, Intergovernmental Panel on Climate Change 2007) exists that confirms the global climate is changing. Three prominent visible signals of climate change are: (i) increase in global average temperature, (ii) change in regional precipitation patterns, and (iii) rise in sea levels. Projections based on climate models indicate that on a global scale, temperatures will keep rising over the next century, causing rise in sea levels and change in circulation patterns that affect precipitation. In terms of impacts affecting normal human life, the biggest impact will be on water—with respect to both water availability and extremes of floods and droughts. Although global scale projections indicate a possible increase in the mean precipitation over India, considerable spatial variation in the regional precipitation patterns will result in some regions within the country receiving lower rainfall in the future. The three prominent signals of climate change convert into signals of regional scale hydrologic change in terms of modifications in water availability, changes in agricultural water demand, hydrologic extremes of floods and droughts, changes in water quality, salinity intrusion in coastal aquifers, modification in groundwater recharge, and other related phenomena. Increase in atmospheric temperature, for example, is likely to have a direct impact on the runoff in snow-fed rivers and on the evaporative demands of crops and vegetation apart from the indirect impacts on all other phenomena of interest in hydrology and water resources management. Climate change, in conjunction with other changes occurring in the country such as rapid urbanization and industrial growth, has serious implications for policy and infrastructure growth in water and other related sectors.

To understand the regional implications of climate change on water policy and infrastructure, it is necessary to first obtain regional projections on temperature, precipitation, streamflow, and other relevant variables and then use these in the impact models to work out the specific impacts of the projections. Then, implications for infrastructure assets and their operations can be worked out. A common methodology for assessing the regional hydrologic impacts of climate change is to use climate projections provided by the General Circulation Models (GCMs) for specified greenhouse gas emission scenarios in conjunction with process-based hydrologic models (see Box 2.1) to generate the corresponding hydrologic projections. The scaling problem that arises because of the large spatial scales at which GCMs operate (compared to those required in most distributed hydrologic models), is commonly addressed by downscaling the GCM simulations to smaller scales at which impacts are needed. This commonly used procedure of impact assessment is burdened with a large amount of uncertainty due to the choice

Box 2.1
GCMs and Hydrologic Models

The GCMs also commonly known as Global Climate Models are the most credible tools available today for projecting the future climate. The GCMs operate on a global scale. They are computer-driven models used for weather forecasting, understanding climate, and projecting climate change. They use quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice. The most frequently used models in the study of climate change are the ones relating air temperature to emissions of carbon dioxide. These models predict an upward trend in the surface temperature, on a global scale. A GCM uses a large number of mathematical equations to describe physical, chemical, and biological processes such as wind, vapour movement, atmospheric circulation, ocean currents, and plant growth. A GCM relates the interactions among the various processes. For example, it relates how the wind patterns affect the transport of atmospheric moisture from one region to another, how ocean currents affect the amount of heat in the atmosphere, and how plant growth affects the amount of carbon dioxide in the atmosphere, and so on. The models help us to understand how climate works and how it is changing. A typical climate model projection used in the impact studies is that of global temperatures over the next century. The GCMs project an increasing trend in the global average temperature over the next century, with some estimates even showing an increase of more than 4^0C, with respect to the temperature during 1980–99 (for example, see IPCC 2007). Such projections of temperature and other climate variables provided by the GCMs are used to obtain projections of other variables of interest (but are not well simulated by the GCMs), such as precipitation and evapotranspiration, in the impact studies.

The Hydrologic Models simulate the hydrology much as the climate models simulate the climate. The hydrologic models are concerned with natural processes dealing with water such as the flow of water in a stream, evaporation and evapotranspiration, groundwater recharge, soil moisture, sediment transport, chemical transport, growth of microorganisms in water bodies etc. Hydrologic models operate at a river basin or a watershed scale. They play a significant role in understanding and addressing a range of problems dealing with water resources at these scales. These problems could be, for example, availability of water in a basin (its distribution with space and time), quality of water, inundation of land due to flood waters, consumptive use of water by vegetation and crops, extent of backing up of water due to the construction of a dam and other structures, sediment deposition and bank erosion, and so on. The inputs required by hydrologic models depend on the purpose for which the model is built. A river flow simulation model, for example, will need inputs such as precipitation, catchment characteristics such as the soil type, slope of the catchment, type of vegetation, type of land use, temperature, solar radiation, and groundwater contribution etc. The typical output from such a model will include the river flow at a location during a period (such as a day, a week, or a month) and evapotranspiration during the same period.

In climate change impact studies, the projections provided by the GCMs are typically used as inputs to the hydrologic models to obtain the projections for the hydrologic variables of interest.

Source: Author's own.

of GCMs and emission scenarios, small samples of historical data against which the models are calibrated, downscaling methods used, and several other sources. Development of procedures and methodologies to address such uncertainties is an important current area of research. Vulnerability assessment, adaptation, and policy issues form the logical extensions to provide water resources managers and infrastructure developers with options for adaptive responses.

In this chapter, climate change issues specifically related to water availability and water quality are discussed, and an overview of implications for water resources management policies is provided. An accepted working definition of sustainability of water resources systems is given and some commonly used measures of sustainability are introduced. The procedure for climate change impact assessment is then explained. Recent studies carried out in India and elsewhere on impact assessment and development of adaptive policies, along with implications for urban water infrastructure are reviewed.

SUSTAINABLE WATER RESOURCES MANAGEMENT

Figure 2.1 shows a typical water resources system. A surface water reservoir created by a dam construction across a river serves the purpose of hydropower generation, irrigation, municipal and industrial water supply, and flood control, apart from other minor purposes such as recreation and navigation. The physical

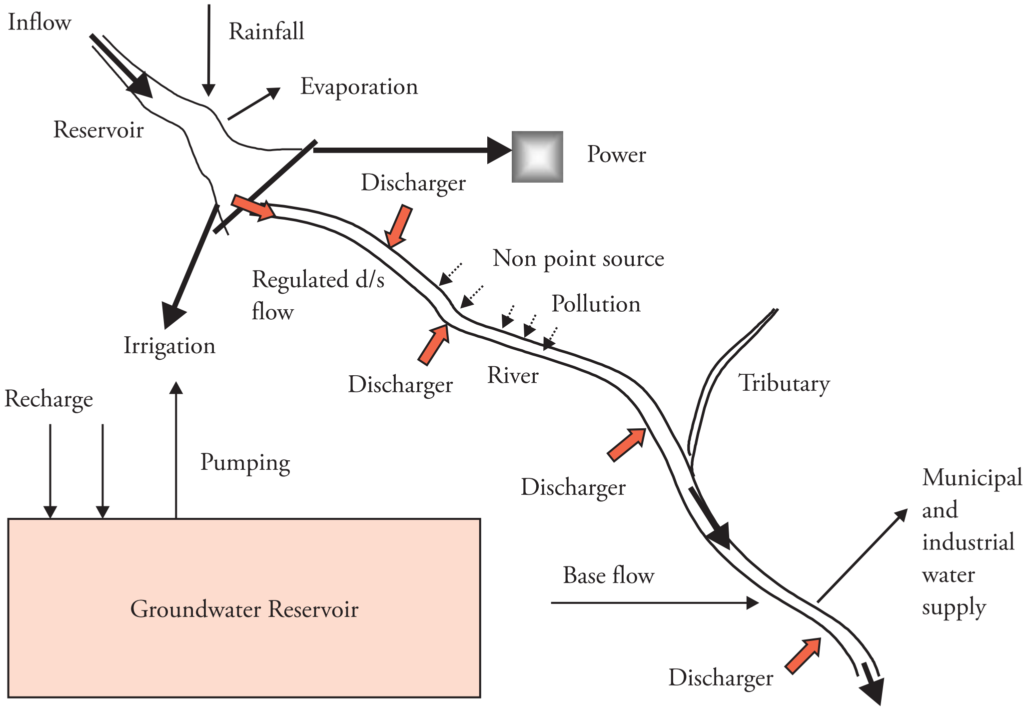

Figure 2.1 Water Resources System

Source: Author's own.

infrastructure associated with the reservoir includes the structure of the dam itself with its large structural and instrumental paraphernalia, such as the spillway gates, the canal and pipe networks with regulators, siphons, and cross drainage works etc. for supply of water for irrigation and municipal and industrial purposes, as well as penstocks, turbines, and other hardware in the power house for generation of power. The downstream structural components of a reservoir often consist of embankments for flood protection, pump houses and intake structures for lift irrigation schemes, and water supply systems for municipal and industrial supply. The surface water system is hydrologically complemented by the groundwater system. The structural components of groundwater usage typically consist of bore wells, tube wells, dug wells, and pumping systems. As may be seen from Figure 2.1, there is a continuous hydrologic interplay among the various components of the system. The inflow to the reservoir that actually determines the water available for use is governed by rainfall (or, broadly, precipitation) in the catchment area. The downstream flow in the river is governed by the release of water from the reservoir and the flow resulting from rainfall in the catchment downstream of the reservoir. The groundwater reservoir (aquifer, in a general sense) also contributes to the river flow through what is termed as the 'base flow'. Groundwater recharge takes place through rainfall and water used for irrigation, both from surface water and groundwater sources. The dischargers shown in Figure 2.1 are effluent dischargers. These may consist of industries and municipalities that use the assimilative capacity of the river to discharge wastes in conformity with the regulations stipulated by the pollution control boards. The non-point source of pollution of the river waters is mainly storm runoff that gathers pollutants (for example, pesticides and fertilizers) from agricultural lands on its way to the river. The water quality in the river, downstream of the reservoir, is thus governed by the release from the reservoir, the intermediate catchment flow, and the effluent discharges which constitute the point and non-point sources of pollution.

Structural measures for water resources development almost always involve a large number of conflicts with the surrounding environs. Such conflicts include, but are not limited to, those related to ecological damages due not only to submersion of forest areas rich in biodiversity but also due to irreversible alterations in habitat environs, displacements of large human populations, water quality, siltation, soil erosion, ability to meet future demands, structural and functional failures of the systems, and so on. In addition, uncertainty due to changes likely to occur in the future (such as climate change and land use pattern) poses the question of sustainability of water resources systems. Defining and measuring the sustainability of a water resources system is a major challenge. A working definition for sustainable water resources systems is given by Loucks (2000), which defines: 'Sustainable water resource systems as those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity'.

Three measures commonly used to examine the sustainability of a water resources system are: (i) reliability, which is a measure of the ability of the system to meet demands—both in terms of quantity and quality of water, (ii) resiliency, which is a measure of the ability of the system to recover from failure, once a failure occurs, and (iii) vulnerability, which is a measure of the loss or damage incurred because of a failure. The failure periods in a water resources system may be defined variously as, those periods in which the supply is less than the demand, or the quality of water is less than that expected, and so on. Resiliency indicates the time it takes to come out of a failure state. We would prefer systems with high reliability and high resiliency but with low vulnerability. These measures are determined by mathematical simulation of the water resources system (for example, Mujumdar and Vedula 1992) for specified operating policies of the system. All the three measures are directly impacted by climate change in as much as they depend on water availability, demands, and water quality among other criteria. In examining the sustainability of a water resources system, therefore, it is necessary to project availability of water, possible deterioration of water quality, and modifications in occurrence of floods and droughts under climate change scenarios.

PROJECTIONS OF WATER AVAILABILITY UNDER CLIMATE CHANGE SCENARIOS

Figure 2.2 describes the general procedure used to assess climate change impacts on water resources at the

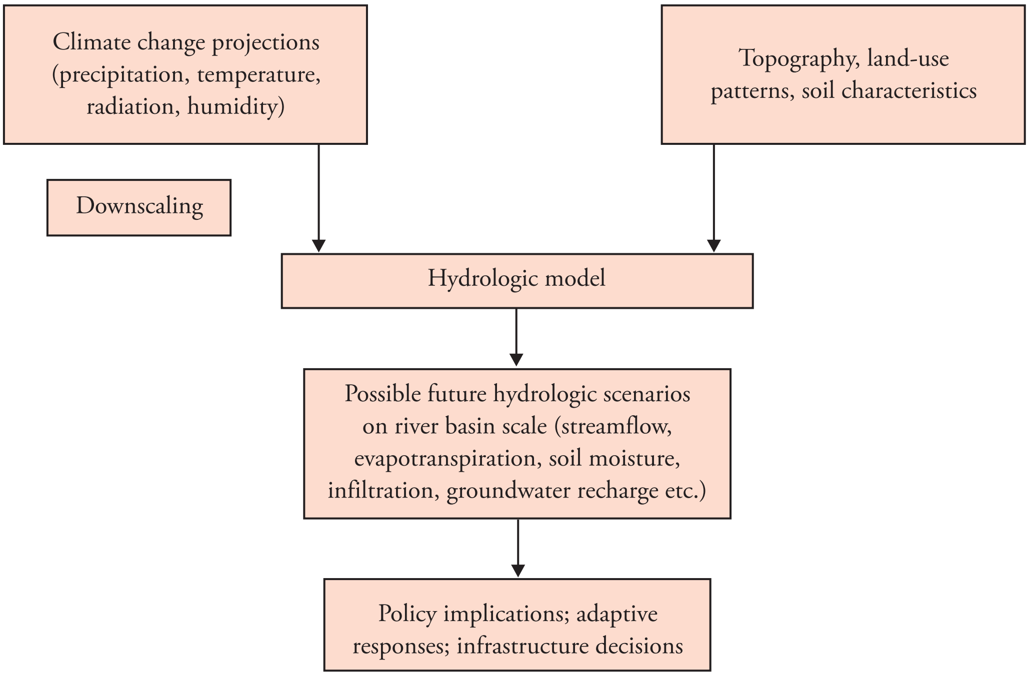

FIGURE 2.2 Block Diagram Showing the Procedure for Climate Change Impact Assessment

Source: Author's own.

river basin scale. Climate projections for pre-specified scenarios of greenhouse gas emissions in the atmosphere are obtained from the GCMs. The projections are next brought down to the spatial scales of interest. For example, if we are interested in precipitation at a sub-division scale, the projections on climate variables influencing precipitation, provided by the GCMs—which are at scales typically of the order of about 250 km by 250 km are 'downscaled' to sub-division scales and used for obtaining projections for future precipitation. These projections are used as inputs to run hydrologic models that are calibrated with historically observed hydrologic variables (for example, streamflow, evapo-transpiration, and soil moisture etc.). Other inputs used relate to land use patterns, soil type, and catchment characteristics etc., which are not likely to be influenced by climate change. This step of running the hydrologic models with future projected variables influenced by climate change produces projections of streamflow and other variables of interest, and provides an estimate of what the future streamflow is likely to be in comparison with the historical flows; thus quantifying the future water availability in the river basin, under climate change scenarios. The time windows used for such assessment are, typically, the years 2020s and 2040s. Such assessments should be used for long-term planning and infrastructural decisions.

Figure 2.3 shows the flow duration curves projected for the Mahanadi river in East-Central India, using several GCMs. The flow duration curves specify the flow that may be exceeded at a given level of probability, and are used in hydrologic designs of dams, culverts, bridges, and stormwater drainage networks etc. The dark blue curve in the figure is the flow duration curve with the historical data. Other curves show projected flow duration under climate change scenarios. The mid-level flows (for example, flows that are exceeded 40–70 per cent of the time) govern the performance of the system in

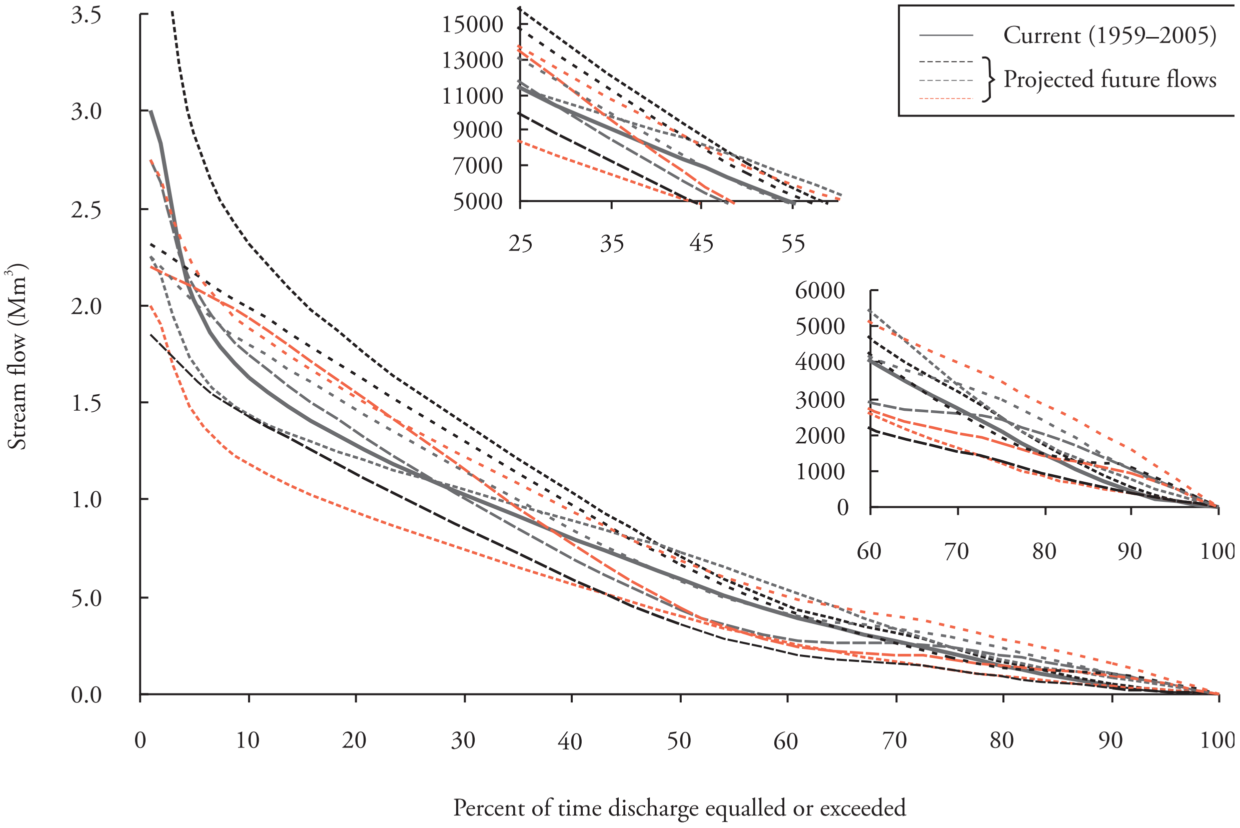

Figure 2.3 Flow Duration Curve for Mahanadi River at Hirakud (2045–65)

Source: Raje and Mujumdar (2010).

terms of the water supply for irrigation and hydropower generation. With many projections indicating a likely decrease in the mid-level flows (see insets in Figure 2.3) it is important that the water use polices are designed to take care of the likely deficit in the coming decades. This projected decrease in streamflow is because of the likely decrease in precipitation in the region. However, as seen from the figure, the direction of change in the streamflow projected by different models may be different; that is, some models project an increase while others project a decrease in the streamflow. Addressing such uncertainties to provide policy makers with options of adaptive responses is a challenging task. Raje and Mujumdar (2010) provide examples of adaptive reservoir operating policies for hydropower generation. They use the flow duration curves shown in Figure 2.3 and develop reservoir operating policies for the Hirakud reservoir to best maintain the reliability of hydropower generation at the current level, considering trade-offs between hydropower, irrigation, and flood control. This work is still at the research stage and needs to mature to a level where it may be transferred for actual implementation, because of the large uncertainties involved in assessment of the climate change impacts. However, it is clear that water management policies need to be adjusted to take into account the possible decreases in inflow to the Hirakud reservoir.

CLIMATE CHANGE IMPACTS ON RIVER WATER QUALITY

Figure 2.4 shows an example of impact of climate change on river water quality. This example relates to the case study of the Tunga-Bhadra river in Karnataka, discussed by Rehana and Mujumdar (2011). Historical data analysis shows evidence of decrease in the streamflow over the last few years in the river, along with an increase in the temperature in the region. The checkpoints referred to in the figure are locations along the stream at which the river water quality is measured or estimated. Hypothetical climate change scenarios are used to construct the graphs. The water quality (which, in this case is measured by dissolved oxygen [DO] concentration) at a location in a stream is primarily affected by the upstream activities in terms of pollutant discharge, streamflow and air and water temperatures. Given the same level of effluent discharge

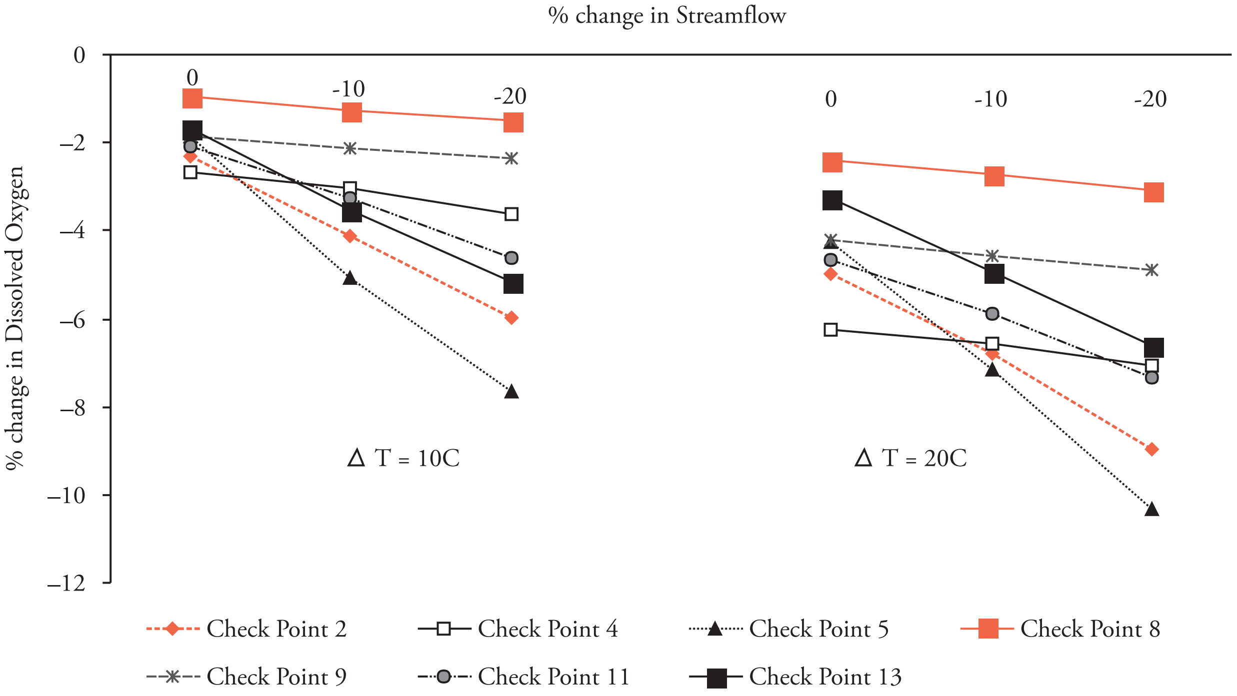

FIGURE 2.4 River Water Quality in Response to Climate Change

Source: Rehana and Mujumdar (2011).

upstream of a location, the lower the streamflow, the lower will be the DO level at that location, because of lower dilution effects. Similarly, higher temperature, in general, implies a lower water quality in terms of DO concentration. The hypothetical scenarios presented in Figure 2.4 are combinations of: (i) 1^0 and 2^0 rise in air temperature, and (ii) 10 per cent and 20 per cent reduction in streamflows. The graphs on the left show the response of water quality for a 1^0 rise in temperature; points along the given line correspond to different levels of reduction in streamflow (0 per cent, 10 per cent, and 20 per cent). Similarly, the graphs on the right show the response of water quality for a 2^0 rise in air temperature. A line corresponds to a particular checkpoint, as given in the legend. These results were obtained by simulating the water quality in the stream, taking into account the non-point and point source pollution due to industrial and municipal effluents at various locations along the stream (for details of the case study and the methodology used see Rehana and Mujumdar 2011). The results from the study suggest that all the hypothetical climate change scenarios would cause impairment in water quality. It was found that there is a significant decrease in DO levels due to the impact of climate change on temperature and flows, even when discharges were at the safe permissible levels set by pollution control agencies (PCAs). The need to improve PCA standards and develop adaptation policies for dischargers to take climate change into account is examined through a fuzzy waste load allocation model developed earlier. Such studies are useful tools for revising the standards for effluent discharges in the streams. The pollution control standards may be designed to take cognizance of the extreme projected situations, or, given the uncertainties, may be designed on the basis of the intermediate scenarios.

Implications of Climate Change on Urban Water Infrastructure

Climate change presents a significant challenge to the urban water management agencies. The urban water infrastructure, consisting of water supply systems and sewage networks, stormwater drainage systems, pumping systems, detention tanks, groundwater pumping, and recycling of wastewater, is vulnerable to stresses caused by climate change. Most cities in India depend on surface water sources for municipal water supply, although locally a large number of city residents rely also on groundwater. The first level of impact of climate change on urban water supply is through the depletion of surface and groundwater sources, because of reduction in streamflows and reduction in recharge due to rainfall. An indirect effect of climate change is an increase in water demand, because of rise in temperatures, for the same given population. Increasing intensities of rainfall along with unplanned development of cities exacerbate the already critical problem of urban flooding. It is essential that the water administrators as well as companies in charge of municipal and industrial water supply and stormwater drainage account for climate change impacts in planning for infrastructure investments. The science of developing adaptive policies to offset climate change impacts is, however, still young across the world and issues related to infrastructure adaptation have begun to be addressed only recently. In the Indian context no comprehensive study is yet available on implications of climate change on urban infrastructure.

Brugge and Graaf (2010) and Graaf and Brugge (2010) recently investigated how urban water management organizations in Rotterdam, Netherlands, developed climate change adaptation strategies that are sensitive to water issues. A key factor in the strategies was the recognition that additional water retention in urban areas could only be realized if this aspect was taken in the urban renewal programme. Their study indicated that the Rotterdam management organizations realized a successful water policy innovation, but that institutional mechanisms necessary for implementation of this innovation are still missing. Jollands et al. (2007) report a study of the impact of climate change on infrastructure services in Hamilton city, New Zealand and conclude that many of Hamilton's infrastructure systems demonstrated greater responsiveness to population changes than to climate change. The Hamilton city case study considered by them is the first of a series of case studies (to be) taken up by Climate's Long-term Impact on New Zealand Infrastructure (CLINZI). Such large projects that address all aspects of urban infrastructure services with climate change as an important component are needed in the Indian context. Semadeni-Davies et al. (2008) assess the potential impacts of climate change and continued urbanization on waste and stormwater flows in Helseingborg, Sweden with present conditions and projections provided by two climate change scenarios and three progressive urbanization storylines. They report that city growth and projected increase in precipitation are set to worsen the current drainage problem in the city.

Infrastructure to manage/mitigate urban flooding consists of storm water drains, pumping systems, and detention/retention tanks. Hydrologic designs of these components are based on the design intensities of rainfall, which are obtained from the intensity-duration-frequency (IDF) relationships for a given location. The IDF relationships are derived with the historical, observed rainfall, generally using an extreme value distribution for maximum rainfall intensity. It is expected that climate change will alter the frequency of occurrence of extreme rainfall events and we are likely to experience more frequent high intensity rainfall in cities. To account for climate change effects in hydrologic designs for urban flooding, it has now become necessary to examine the possible change in IDF relationships in the future and to use revised intensities of rainfall, both for checking adequacy of the existing systems and for making new designs. Changes in rainfall intensity have two consequences for drainage infrastructure design: (i) the flow for which a structure is designed is no longer constant over time, and (ii) the level of service provided by drainage infrastructure will also gradually decrease over time, as storm sewers will flood more frequently (Arisz and Burrell 2006). Bruce (2002) suggests that the costs of expanding drainage capacities must be weighed against the projected costs of more frequent flooding, with return periods of severe rainfall events projected to be cut in half. Watt et al. (2003) recommend designing drainage infrastructure based on modelling a design storm determined using available climatic records and then increasing the magnitude of the design storm by 15 per cent to accommodate the effects of climate change. This is equivalent to recommending that infrastructure should be designed and built with hydraulic capacities appropriate for the end of its service life rather than hydraulic capacities appropriate for present-day requirements, but at costs that have to be incurred before the increased hydraulic capacity is fully needed. However, the oversized infrastructure would provide greater capacity to handle extreme flood flows, whether or not such flood events are associated with climatic change. Kirshen et al. (2008) analyse the interdependencies of the impacts of climate change and adaptation strategies upon infrastructure systems in the Metro Boston urban area in north-eastern USA. They find that taking anticipatory actions well before 2050 results in less total adaptation and impact costs to the region than taking no actions.

Mailhot et al. (2007) assess a possible change in the IDF relationship for Southern Quebec, Canada. They conclude that the return periods of events of 2-hour and 6-hour durations will likely halve in future climate. That is, the average no. of years between the occurrence of rainfall intensities corresponding to 2-hour (and 6-hour) duration will be halved, implying more frequent occurrences of these events. They suggest that annual extreme rainfall events may result from more convective (and thus more localized) weather systems in Quebec. There are no such studies available for Indian cities at present. The author's team is now working on developing IDF relationships for Bengaluru city, accounting for climate change effects.

This brief review suggests that the design and operation of urban water infrastructure needs to take into account the climate change impacts, while planning for future. Action now as adaptation to climate change is likely to save costs compared to non-action. The recently released National Guidelines for Urban flooding (National Disaster Management Authority [NDMA] 2010) list out several issues in urban flooding in India, and refer to the recent flooding in Hyderabad in 2000, Ahmedabad in 2001, Delhi in 2000 and 2003, Chennai in 2004, Mumbai in 2005, Surat in 2006, Kolkata in 2007, and Guwahati and Delhi in 2010. Poor land use planning with old and aging stormwater drainage infrastructure of grossly inadequate carrying capacity along with increased intensities of rainfall are the main causes for the frequent urban flooding witnessed in India in recent years. Corrective actions must account for the possible increases in rainfall intensities in the years to come, due to climate change.

Adaptation to Climate Change: Policy Issues

Climate change is expected to produce water stresses in several parts of the country. The water management policies—both at the large river basin scales and at the local administrative levels—must account for uncertainties due to climate change, and, include the worst possible scenarios projected by climate models in their plans. In England, the water companies have recently released their draft Water Resources Management plans that set out how each company intends to maintain a balance between supply and demand over the next 25 years. Chaltron and Arnell (2011), who have reviewed these plans, state that whilst the magnitude of climate change appears to justify its explicit consideration, it is rare that adaptation options are planned solely in response to climate change but as a suite of options to provide a resilient supply to a range of pressures, such as the pressures on supply-demand balance, which occur even without climate change.

In India, water is primarily governed by the government. There is increasing acknowledgment by the government of the importance of climate change issues in water resources management in the country. The National Water Mission proposed in the National Action Plan on Climate Change listing out the following priority actions: focus on ensuring integrated water resources management to conserve water; minimizing wastage and ensuring equitable distribution across and within states; developing a framework to optimize water use in line with provisions of the National Water Policy; recycling of wastewater to meet a large part of water needs in urban areas; adoption of new and appropriate technologies such as low temperature; desalination for coastal cities; basin level management strategies in consultation with states; enhanced storage; rain water harvesting; equitable and efficient management structures; and optimizing efficiency of existing irrigation systems (rehabilitation, expansion along with increase in storage capacity, incentives for water neutral or water-positive technologies, re-charging of underground water sources, adoption of efficient large-scale irrigation programmes). These constitute a comprehensive list of actions planned. The challenge is to implement the actions at the local level. Vulnerabilities of local communities to water stresses caused, among other factors, by climate change, need to be assessed. An example of the vulnerability assessment is provided by Kelkar et al. (2008). They present a participatory approach to investigate vulnerability and adaptive capacity to climate variability and water stress in the Lakhwar watershed in Uttarakhand. Modelling results were shared by them with the communities in two villages to stimulate discussions on possible future changes and adaptive interventions. Similar studies are needed in other vulnerable regions, with a specific focus on rural areas to put adaptive responses in place. To institutionalize the assessment of vulnerability, a bottom–up rather than a top–down approach may be necessary, where the village *panchayats* are empowered with information and knowledge tools (such as, for example, Geographic Information Systems with relevant databases and inbuilt climate change projections), to provide information to the district administration set ups and further to the state level and so on. Given the current level of technology and the economic capability in the country, this is a very achievable goal.

The following issues and actions are of importance in evolving climate-resistant water management policies at local administrative levels:

- Heterogeneities in space and time are significantly important in the national context, with respect to water. Most parts of the country receive precipitation in the form of rainfall over a period of about four months; the spatial distribution of the rainfall is also highly non-uniform. Any larger level policy intervention must take such heterogeneities into account.
- Rapid urbanization will continue for the next three to four decades. Many towns and cities will struggle to meet water demands even for domestic purposes unless specific policy and administrative mechanisms are put in place. Climate change is only likely to increase such stresses. In this context, wastewater recycling and desalination technologies gain importance. Diversion of flood waters for groundwater recharge must also be practised by the municipal corporations. Legal regulation of groundwater use will soon be a necessity.
- The current level of hydropower generation in the country is quite low compared to the potential. Being a clean form of energy (in terms of carbon emission), hydropower is proposed to be increased from the current level of 7 million tons of oil equivalent (mtoes) to 43 mtoes in the National Action Plan for Climate Change. Such actions require prioritization in the National Water Policy.
- Even with a stabilized urban population by around 2040s, a considerable fraction of the rural population will still depend on agriculture, as a means of

> livelihood. Unlike in most developed countries, agriculture in India (and other similar countries) is characterized by small farmers (farmers with small land holdings, typically less than 2 hectares) most of whom depend on rainfall for agriculture. For food security and long-term sustainability of agriculture—and ensuring enhanced quality of rural life—irrigated agriculture needs to be given importance, with technologies and non-structural measures put in place to increase efficiency of water use. Alternatively, decentralized irrigation systems including watershed development, rainwater harvesting, development of village tanks and water bodies, need to be encouraged as an insurance against the uncertainties due to climate change.

The challenge is to bring in institutional reforms and collaborations to achieve these. There are far too many institutions dealing with various aspects of water, as related to climate change: the India Meteorological Department (IMD) that is primarily the custodian of all meteorological data, the CWC, in charge of the hydrologic data, apart from being an approving authority for major water resources projects, the state water departments, government and private hydropower corporations, state and Central PCAs, agricultural departments, irrigation departments, city development agencies, municipal bodies, the private water industry, and so on. Bringing them together to evolve integrated adaptive responses to climate change is necessary.

CONCLUSION

Climate change is expected to cause water stresses in several regions of the country, and is likely to exacerbate the already critical water situation in most river basins. While the climate change projections derived from climate models are useful at large regional scales, the impacts need to be assessed at local scales. The water management agencies and policy makers must use projections provided by climate models in assessing local impacts to take into account the uncertainties, while planning for the future.

The following specific adaptation options are relevant in the water sector, to combat the adverse effects of climate change: (i) demand management to suit the supply, by choosing appropriate cropping patterns and technologies to reduce water consumption in industry; (ii) increasing efficiency of water usage, particularly in the irrigation sector where the current efficiencies are very low; (iii) structural measures of increasing reservoir storage; (iv) non-structural measures of developing and operationalizing adaptive reservoir operating rule curves, taking into account the likely mismatch between supply and demand; (v) out-of-the-box solutions to use the flood waters as a resource, say through diverting flood waters to potential groundwater recharge zones; (vi) large scale recycling of wastewater; and (vii) desalination of sea water to meet the municipal needs.

In addition, the standards of effluent discharge into streams and water bodies may need to account for climate change effects, and where necessary must be revised. The hydrologic designs dealing with floods (for example, stormwater drains, flood embankments etc.) should take into consideration the likely changes in the frequency of floods of a given magnitude. These actions will necessitate significant interventions in the institutional mechanisms.

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