

CHAPTER 11

Operationalizing IWRM concepts at the basin level: From theory to practice

M. Dinesh Kumar^a, Charles Batchelor^b, A.J. James^c

^aInstitute for Resource Analysis and Policy, Hyderabad, Telangana, India

^bWater Resource Management Ltd., London, United Kingdom

^cEnvironmental & Natural Resource Economist, New Delhi, India

11.1 Introduction

Water of varying quality is demanded by multiple sectors and in varying quantities by multiple users within a catchment or a river basin. Allocating this water among various stakeholders involves tradeoff. Invariably, domestic and industrial sectors have the first call on the available water. These sectors largely contaminate more water than the amount they consume, unlike agricultural sectors where water is consumed in evapotranspiration or lost to saline aquifers. Therefore, the appropriate treatment of water used by domestic and industrial sectors will enable the reuse of water by another sector. Environmental flows, on the other hand, often improve the quality of water, and this water too may be used by another sector when needed (Kumar et al., 2017).

Water management has time and quality dimensions, in addition to quantity dimension. By incorporating all three dimensions while allocating water, conflict among sectors can be minimized. This would not necessarily eliminate difficult, but essential, tradeoffs between agricultural and environmental sectors. These tradeoffs will affect a catchment's hydrological processes and outcomes accordingly. As water scarcity looms large, the paradigm of water management should shift from fresh water for all uses and users to "timely supply of adequate amounts of water of acceptable quality" to each user. This will encourage water recycling within catchments, and the use of alternative water supplies for agriculture within catchments.

It is widely argued that integrated water resources management at the level of river basins, which gives due consideration to water demand management as well as supply augmentation, hydrological system integrity

(surface water–groundwater interactions, interconnection between catchment land use, runoff, and water quality), and meaningful community role in management decision making, is the most cost-effective, socially viable, and ecologically sound strategy for managing water, when freshwater resources are scarce, and there are multiple uses of water competing with each other (Jønych-Clausen, 2004; van der Zaag and Savenije, 2014).

The challenge is in operationalizing the concept of IWRM through appropriate coordinating institutions at the river basin level. As discussed by Biswas (2008, p. 12), “...operationally it has not been possible to identify a water management process at a macro- or meso-scale which can be planned and implemented in such a way that it becomes inherently integrated, however this may be defined, right from its initial planning stage and then to implementation and operational phases.” For river basins that are falling entirely within the provincial territories, this mammoth task is in the realm of the state water agencies, which have to create such coordination mechanisms. For interstate river basins such as Krishna, Cauvery, Godavari, and Mahanadi, it is in the realm of the Union government.

The basic concepts and principles of IWRM (such as economic efficiency, social equity, and ecological sustainability) are widely known and accepted (Jønych-Clausen, 2004; van der Zaag and Savenije, 2014). So are the key coordination mechanisms (UNESCO, 2008). But the fundamental question is in identifying and sequencing the various technical and institutional processes for getting them followed. In this regard, the real gray areas, which academics and researchers have not systematically worked on, are: (i) the nature of scientific/technical studies and inputs that would be required for planning IWRM in a basin context; (ii) the institutional model for implementing IWRM at the level of river basins, including the institutional design principles and institutional structure; and, (iii) the various institutional processes that need to be initiated for affecting implementation. Among all these, institutional design principles are of paramount importance, as poor institutional design would lead to institutional ineffectiveness.

In this chapter, an attempt is made to: (1) lay out the institutional design principles for setting up effective water management institutions; (2) discuss the overall institutional regime for implementing integrated water resources management actions at the state level and the institutional structure; and, (3) describe the key scientific and institutional processes that are necessary to operationalize them at the level of river basins. While doing this, we would also highlight some of the water management outcomes that are “integrated” in nature.

11.2 General plan of action for implementing IWRM

11.2.1 Institutional capability building for water management

11.2.1.1 *Design principles for setting up of new water management organizations*

In India, there are no separate agencies for water resources management covering planning, design, and implementation functions either at the union level or at the provincial level. At the union level, technical agencies such as Central Water Commission and Central Ground Water Board perform resource investigation and evaluation functions to quantify the amount of water available in river basins and underground formations, respectively.

Further, the same agency performs multiple functions. For instance, the water resources departments (erstwhile irrigation department) at the provincial level perform water resources evaluation and planning; undertake water resource development activities for surface water; and also do allocation of water to various sectors, including industries and drinking water supply. They are also responsible for flood control. Similarly, the state pollution control boards undertake water quality monitoring of aquatic resources (rivers, lakes, and groundwater), and are also responsible for enforcement of pollution control norms they set up. These create situations of conflict of interest and reduce their effectiveness (Kumar, 2006).

Since water is a state subject in India, setting up of organizations for carrying out the line functions in water resource management sector and nurturing them will be paramount to building institutional capabilities for water management at the state level. The line functions include water resource monitoring, water resource evaluation and planning, execution of water development and management schemes, water allocation, and water resources management. This apart, there is a need for an organization that can deal with the more complex issues. Some of them are deciding water allocation priorities across sectors, evolving criteria for allocation of water for different sectors in different regions, determining private/cooperative use rights, and fixing water tax and pollution tax.

The institutional design principles for IWRM, as formulated by Kumar (2006) and later on elaborated by Kumar (2016), are as follows: (1) the operational boundaries of the governance units created for effective management should match with the hydrological system boundaries; (2) clear distinction between water development and water resources management functions; (3) institutions responsible for water allocation or regulating water use have to be different from those providing water-related services—viz., irrigation

water supply and environmental management; (4) institutions responsible for water quality monitoring will be different from the ones managing water quality; (5) the institution responsible for investment in water quantity management and WRM should also be enforcing norm and regulations on water use; and, (6) the governance/management structure should be such that it integrates local water management interventions with larger basin management actions and promote involvement of user groups/communities in the governance and management.

11.2.1.2 State water development and management board

The State Water Development and Management Board will have the mandate of provide the overall governance of water resources in the State. To be set up through an act passed by the State Legislator. The Board is to be headed by a full-time Chairperson, who will be a highly respected “water engineer” or economist with a long career record with the State or Central Government. He/She will be directly appointed by a “Committee of State Legislatures” chaired by the Chief Minister. The candidate will be an official of cabinet rank. The Chairperson will have a 5-year tenure. The Board is not to be in the administrative control of any government department.

The Secretaries of all ministries dealing with water directly will automatically become its members, apart from senior professionals—environmental lawyers, academicians, water engineers, economists, and ecologists—social workers—who are to be nominated by the Governor. The nominated members will have a 3-year term.

The Chairperson can constitute a search committee to find and appoint the member-secretary, who will be the Director of the SWDMB Board. The Director and a group of senior professionals from hydrology, water technology, agricultural sciences, economics, management, and law will consist of the Board will constitute the executive wing of the Board, who will be guided by the Chairperson.

The Board will have the following objectives:

- Help the Government formulate State Water Policy and Water Law
- Review State Water Policy periodically
- Create appropriate organizational/institutional structures and mechanisms for governance of water resources for river basins and regions.
- Evolve criteria for allocation of water from river basins among various sectors of use along the guidelines of State Water Policy

- Evolve criteria for establishing private/cooperative property rights in water, including groundwater, canal water, and other surface water resources for different users in a particular sector.
- Evolve criteria for fixing water taxes for different sectors, viz., irrigation, drinking and domestic, industry and recreation, and pollution tax for different regions
- Evolve pricing structures for efficient use of water in irrigation, industry, and domestic use
- Represent the respective state governments in situations of interstate water disputes in the interstate water tribunals.

The operating funds for the SWDMB are to come from the State's annual budgetary allocations plus the annual service fee paid by the basin authorities/regional water councils.

11.2.1.3 Water resources monitoring and planning unit

Water resource monitoring and planning are important line functions in water management sector. However, this is a highly neglected area in India. While reliable scientific data are the crux of good water resource planning, they are often lacking. While data required for planning are generated through systematic monitoring, monitoring is also required to assess the impact of water management interventions on the socioeconomic system as well as the hydrologic system. There are several issues involved in water resource monitoring.

These issues point to the need for a separate institution to perform the line function of monitoring and planning. Since the same agency is carrying out planning and monitoring, the data requirements for realistic planning could be worked out, and accordingly monitoring system could be designed and implemented. It can be constituted as a scientific/technical wing of the State Water Development and Management Board. The unit should also co-opt specialists/experts from social science fields such as economics and sociology.

The unit can also evolve the criteria, decide upon, and observe the parameters for assessing the performance of other line agencies, which are engaged in implementing water development and management schemes. Some of them are basin yields, silt load of water in the reservoir and rate of siltation, quality of water in the rivers, streams, and aquifers, and the pollution load. Some others are per-capita water supplies for domestic uses, their quality and reliability,

duration of supply, irrigation intensities in terms of area irrigated, number of irrigation, rate of recovery of water charges, water utilization efficiencies, conveyance efficiencies, and economic outputs.

This means that the unit should collect the range of socioeconomic data apart from the hydrology-related data. The collection, compilation, and periodic publishing of such data will put pressure on the line agencies to perform better. For instance, publishing of data on irrigation performance and rate of recovery will put pressure on the farmer organizations and the irrigation bureaucracy to perform better.

An important task to be performed by the monitoring and planning unit will be to carry out resource evaluation, which can form the basis for detailed planning. It will undertake the resource evaluation for the major river basins of the state concerned and carry out prospective planning. The prospective planning will include the future demands of water in different basins and the potential future supplies and the ways to meet or manage the demands including interbasin transfer of water. The River Basin Organizations will have to obtain the data on basin's water availability and balance from the planning and monitoring unit.

The unit can collaborate with NGOs and other civil society organizations for collection and compilation of water resource-related data. This will help strengthen the capabilities of these civil society organizations in analyzing water management problems and issues and orient them about the state of affairs with regard to water management vis-à-vis the resource condition, access to and control over the resource by different sections of the communities. The government of Rajasthan has a state water resources planning department, which has similar mandate.

11.2.2 Allocation of tradable water use rights

In order to create incentive for efficient use, the water users should be confronted with opportunity cost of using water. To induce opportunity cost of using water from the natural system (rivers, lakes, surface reservoirs, and aquifers), establishment of tradable water use rights among the user groups and users is crucial (Howe et al., 1986; Rosegrant and Binswanger, 1994). Equity and sustainability are important considerations for establishing institutional regimes for water use. Hence, realistic assessment of total water resource availability, renewable freshwater, and economically accessible water resource in different regions/basins will be the cornerstone of establishing tradable property rights regimes. This is an extremely difficult task.

This task is to be performed by the planning and monitoring unit of SWDMB. In this section, we will discuss how the water use rights shall be operationalized for both surface water and groundwater resources.

As regards groundwater, in the deep alluvial areas, the total groundwater storage is many times more than the groundwater, which is accessible economically. The economically accessible groundwater is much more than the replenishable groundwater. Since sustainability considerations override economics, only the renewable portion of the water should be brought under the property rights regimes. But, there are certain practical considerations in evolving the criteria, which will differ for different regions (Kumar, 2006).

In alluvial areas, in view of the problem of excessive withdrawal (like in north Gujarat, central Punjab and western Rajasthan), the total volumetric use rights to be allocated every year should be much less than the renewable groundwater. This will help reverse the process of mining over a period of time. On the other hand, in certain canal command areas, due to the problem of underdevelopment of groundwater, the actual annual groundwater use rights could be much higher than the renewable groundwater till a good balance is achieved in the groundwater ecology of the region (Kumar, 2006).

In hard rock areas of India, the economically accessible groundwater will be less than the renewable groundwater resources as these regions have very little static groundwater. As groundwater is trapped in the fractures, fissures, and weathered zones, not all the recharge can be extracted using the available technologies. Another factor, which needs to be considered while establishing private property rights systems, is correlative right. In hard rock areas, well interference is a common phenomenon. When farmer pumps out water from his well for a long time, large draw down is created, which will bring down the water levels in the neighboring wells also. For an individual, the ability to access groundwater from the common pool, which he/she owns under the rights system, is related to the amount of water his/her neighbors are pumping out from the same pool. Therefore, the rights are correlative. Due to this phenomenon, the actual "abstraction quota" that can be permitted to any farmer and which does not deprive the neighbors of their rights will be much less (Kumar, 2006).

In order to internalize this phenomenon of well interference and make the rights "nonrelative" or exclusive, the communities can devise mechanisms.

The allocation of volumetric use rights in surface water should be determined primarily by two important considerations: the annual runoff, which is the renewable surface water (x), and the amount of water needed for ecosystem services (y). The amount of water for ecosystem services will depend

on the range of ecological parameters including the water requirements of riverine ecosystem, watersheds, the assimilating the pollution load in the river. The amount of water that can be allocated for various competitive uses annually therefore will be $(x) - (y)$.

But for all practical purposes, the surface water (use) rights allocated to irrigation agency, drinking water supply agency, and industrial corporation in any region will be decided by the total volume of water that can be harnessed by the existing storage and diversion head works. While these considerations automatically factor in the ecological sustainability concerns of the water scarce regions, it will not be so for water-abundant regions. The import of surface water to such regions will have to be controlled to maintain ecological balance. Therefore, the rights to use canal water will have to be limited to encourage higher rate of withdrawal of groundwater.

Water rights systems exist in many developed and some developing countries, and in certain cases these rights are tradable (Rosegrant and Binswanger, 1994). For instance, in Australia, the water rights allocated to different users are tradable (Connell, 2011). For maintaining environmental flow in the river, which is a public good, surface water rights are purchased by the government from the market through trading. In Spain, the river basin organization allocates water rights for both surface water and groundwater among various users, including irrigation agencies, industries, and farmers (private irrigators). In the Middle Western United States, groundwater management districts exist in states such as Kansas and California, where water rights of individual appropriators of groundwater are allocated volumetrically and enforced.

11.2.2.1 Intersectoral allocation of rights

Once the quantum of resources to be brought under private property regimes is assessed for different basins and regions, the SWDMB is to evolve criteria for allocating water rights among different sectors of use and among different users and user groups within each sector. Hence, there are two major steps involved: allocation across sectors; and allocating rights within sectors among the users.

One important criterion for allocation of water use rights across different sectors could be the per-capita renewable freshwater availability in each of the four regions. In those regions where per-capita renewable fresh water is quite low, lion's share of the rights to use the available water will have to be allocated for basic survival needs (as defined by P. Gliick (1997)) and domestic food security.

Nevertheless, some allocation will have to be made to sustain the existing economic activities such as industries and recreational services and cash crop production. Nevertheless, the percentage allocation for these will be much less. The objective will have to be discouraging such economic activities in the regions that the water ecosystem cannot support in the long run. Therefore, the criteria for future allocation will also have to be based on the existing use patterns.

In regions, where per-capita renewable freshwater is high, larger share of the rights will be allocated to economic production purposes such as irrigation of cash crops, industries, and recreational purposes.

An important sector of water use, which will not come under the purview of markets, will be water for ecosystem services. The government will have to invest in procuring that much amount of water from the river basin organizations in larger public interest. Investing in procurement of water for ecosystem services will be of much higher priority in the water-scarce regions.

11.2.2.2 Intrasectoral allocation of rights among users/user groups

When rights are allocated across sectors, a major task for the SWDMB will be to allocate water use rights among individuals (private property rights) and user groups (cooperative property rights). According to the variation in criterion for allocation of available water across sectors, criterion for allocation within sectors will vary remarkably across regions. For instance, food security being the overriding concern in a water-scarce region, the allocation of water for agriculture in water-scarce region will be primarily based on considerations such as family size. The criterion such as “total cultivable land holding” will be only secondary. On the other hand, in water-abundant region, the criteria for allocation of water within agriculture sector will involve total cultivable holding as a primary criterion.

Similarly, in absolutely water-scarce regions, the criterion for allocation of water for domestic uses may involve only consideration such as “basic survival need” and “family size.” While in water-abundant regions, allocation may also involve considerations such as water for recreational services, water for gardening, etc. apart from “per capita water for domestic purpose” and “family size.” Here it is important to mention that water for basic survival (50 lpcd) is much less than the water requirements for drinking and domestic purposes.

Once the Board evolves appropriate criteria for allocation of rights, it becomes the responsibility of the respective River Basin Organization to

define and establish the rights of individuals, groups, and agencies. They are discussed in the respective sections on river basin organizations under the specific action plan.

11.2.3 Strengthening legal regimes

The State should have a comprehensive water law. The law should provide for:

- Recognition and enforcement of private/cooperative, tradable property rights in groundwater and canal water through appropriate institutional structures such as RBOs;
- Setting up of river basin organizations, State Water Development and Management Board, and Water Resources Monitoring and Planning Organization;
- Setting up of organizations for management of irrigation management up to the system level with appropriate legal status, including organization of water users;
- River Basin Organizations to have statutory powers to decide on the allocation of water across sectors; prices of water and sanction on certain uses of water; and,
- Involvement of multiuser stakeholder forums in governance and management of water

The State Water Development and Management Board shall be responsible for drafting the Water Law. The law should enable communities to protect and manage the water resources and for that purpose. It should allow them to frame and enforce rules and regulations locally regarding its use that are socially viable and hydrologically meaningful, within the existing institutional regimes, rather than trying to police. The agency should initiate institutional processes to activate public debate on the “draft document” and get maximum public and political opinion on the pros and cons of implementing the same. After receiving this, the draft bill could be considered for introduction in the assembly for making legislation. The Water Law should be widely publicized for community awareness and education. Every user of water should be aware of the law governing the use of water in the State, especially the provisions in the law for protection of private property rights and the penalties for actions that lead to violation of such rights.

The State Water Development and Management Board can launch programs aimed at educating the public about the provisions of the Water Law.

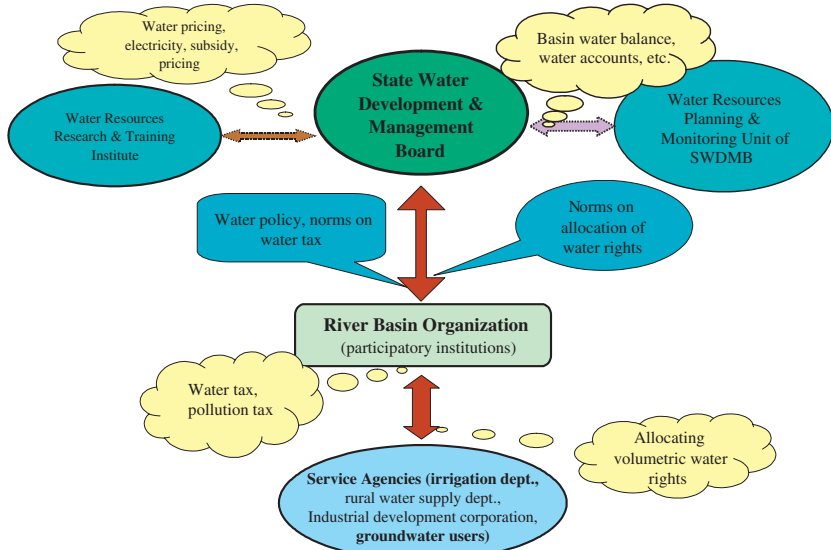


Fig. 11.1 Institutional regime at the state level for integrated water resources management.

The overall institutional regime for governance and management of water resources under the proposed paradigm is given in the flow diagram (Fig. 11.1).

11.3 Specific action plan for different regions

The action plans for addressing the water management challenges involve several steps. They are:

1. *Designation and Constitution of River basin Organizations:* the State Water Development and Management Board (SWDMB) shall designate river basin organizations. The first step will be to demarcate the exact boundaries of the basin vis-à-vis the administrative boundaries. The SWDMB shall then initiate constitution of Governing Councils for these basin organizations. It should have adequate representation from civil society organizations, and widely respected individuals and organizations concerned with/about water problems in the region. It should include the district dairy unions, credible NGOs working in the region, social reformers, naturalists, and champions of community development and environment. The Board can also initiate institutional processes to form *Stakeholder Forums*. The forum can work toward realizing the objective of effective, user-centered management of water in these basins. This shall comprise progressive farmers or representatives of farmer organizations, leading industrialists

from the region, representatives of grass root women's organizations who represent the interests and concerns of women water users in the basin. Besides these, it should have officials of various government agencies such as the irrigation department, forest department, GWSSB, and water supply wing of major municipal corporations as members.

The *Governing Councils* can then select the chief executive of the *Management Units* of the respective RBOs. The Chief Executive will subsequently set up a group of professionals to carry out the day-to-day management of the RBO under his/her supervision. The Chief Executive shall be a water resource professional with vast experience working on water management issues in the State. The management unit should consist of water technologists, hydrologists, geologist, economist, ecologists, and political scientists.

2. *Setting up of database of water users, socioeconomic profiles, and water accounts:*

Database on the physical and social aspects of water use is as much a prerequisite for management of river basins as the database on the physical aspects of water availability like the basin water balance. Developing this database will be the responsibility of the RBO. The specific database requirements for basin management would include the different types of users of water, their socioeconomic profiles, and the water accounts. The water accounts will show how much water is being diverted and consumptively used in different sectors. The basic socioeconomic data required for setting up the database are available with a number of organizations such as the revenue department, Industrial Commissionerate, Agricultural Directorates, and Animal Husbandry departments. Therefore, the task before the RBO will be in compiling these data at the level of river basin. Based on this database, water accounting can be carried out.

3. *Water resource mapping:* the RBO shall take up the exercise of complete mapping of the water resources in the basin. This will form the basis for basin planning. This exercise should include mapping of drainage patterns, determining surface flows, demarcation of aquifers, their recharge and discharge areas, mapping groundwater levels and quality, evaluation of recharge, and abstraction. The RBO can obtain the necessary data from the water resource monitoring and planning unit of SWDMB.

4. *Mapping of the existing water harvesting/storage/abstraction structures:* data on the existing water harvesting, storage, and abstraction structures can be obtained from water resources department, groundwater/minor irrigation department, rural development department/watershed

development agency and state remote-sensing application centers (SAC). The water resources department can provide data on all minor, medium, and major irrigation schemes. The groundwater/minor irrigation department can provide data on their irrigation tube wells. The Agricultural Directorate can provide data on private wells. The SAC can provide data on land use pattern.

5. *Mapping of areas and villages affected by serious water quality problems:* excessively high levels of fluoride in groundwater are a menace in many regions of India—Gujarat, Rajasthan, Haryana, Telangana, Karnataka, and Chhattisgarh are some of them (GOI, 2010). Therefore, one of the basin management objectives will be to reduce the fluoride content in groundwater to permissible levels. The RBO has to take up complete mapping of the fluoride-affected areas. The State Water Supply and Sewerage Boards or Public Health Engineering Departments can act as the nodal agency to set up this database. It can carry out detailed investigations on the extent of impact of fluorides on human and animal life. The purpose is to get a comprehensive understanding of not only the degree of fluoride contamination of groundwater, but also the extent of physiological and biological and toxicological impact on the fluorotic individuals.
6. *Mapping of the existing rural economic institutions:* a large number of grass root organizations are required to implement the local water management interventions planned for the basin. Local institution development is a painstaking process, and needs investments in terms of human resources, time, and money. Where local institutions are active, they can be motivated to play an important role in local water management. This is subject to the condition that they have large stake in water management.
7. *Evolving basin management objectives and development of basin plans:* analysis of water balance, water accounts, and the needs and interests of the stakeholders can form a sound basis for evolving basin management objectives. Based on the management objectives, a basin plan can be developed. Water balance studies have to be taken up for this as well. The plan should indicate different physical interventions that are possible in the basin, and the extent to which they could contribute to augmenting water supplies. For instance, it should indicate the potential for watershed management, wastewater treatment systems, local water harvesting, large-scale artificial recharging and conjunctive

management options, and their potential impacts. It should also indicate the technological interventions for managing the demand for water in different water use sectors. The basin management plans are not blue prints for direct action but will throw indications on the directions for developing more realistic local management plans that can be taken up for implementation, and their potential impacts on the overall water supply and demand balance.

There are several good examples of development of basin management plans from Australia, Spain, and France. In the case of Murray Darling basin in Australia, the basin management plan is a statutory document, which the basin states will have to comply by while undertaking land and water management interventions in the respective jurisdictions (Connell, 2011). In Spain river basin, authorities exist for all the major basins of the country, known as *Confederacion Hydrographica Del* (the Basin name) and they carry out hydrological planning for the respective basins (source: “The Jucar River Basin District,” prepared by Ministry of Agriculture and Fisheries, Govt. of Spain).

8. *Setting up of subbasin organizations*: many of the river basins in India that are falling entirely within the country’s territory are too large—to name a few, Cauvery, Godavari, Krishna, and Narmada. They cut across different agroecological subzones. Apart from the variations in soils and climate, there are remarkable variations in geology, hydrology, vegetation, and overall water availability situation. Hence, it is difficult to work out detailed local management plans from the basin plan at least in the case of these two basins. Keeping in mind the broader basin management objective, specific subbasin planning has to be carried out. Sub-Basin Organizations (SBOs) have to be created for this purpose. Constitution of the SBO will be the mandate of the RBO.
9. *Preparation of specific management plans for subbasins*: the objective will be to match the demand and supplies, and arrest groundwater depletion. This will be the responsibility of the SBO. The following analysis would be carried out to arrive at subbasin plans.
 - The scale and potential impact of watershed management interventions and local water harvesting structures in the upper catchment areas and plains, respectively, on water balance.
 - Identification of villages and watersheds.
 - The scale and potential impacts of conjunctive management activities such as recharging of deep aquifers using the excess runoff diverted from the river, and their potential impacts on groundwater hydrology.

- The scale and potential of demand management interventions: change in water use technology, change in cropping patterns, efficient conveyance system, wastewater treatment and reuse systems, etc., and target the regions/localities for their adoption.

Scientific water balance studies are required for evaluation and planning of water management interventions. The studies should assess the catchments for estimating the availability of surface runoff, base flows, and groundwater using hydrological (simulation) models for various rainfall conditions and compare the water availability against the estimated future water demands from various sectors. The studies should then also consider various water management scenarios for the subbasin; evaluate the impacts of the key interventions planned under those scenarios to improve the water balance of the subbasin; and analyze their overall impact on the water resource condition—stream flow regimes, quality of the runoff water, groundwater recharge, and changes in groundwater levels. The models should be such that they capture the groundwater-surface interactions adequately. The specific management plans for the subbasins will aggregate to constitute the basin management plan.

- 10.** *Determining sustainable levels of groundwater abstraction in the basin:* simulation models of groundwater for the entire basin need to be developed. Such models are available in the market. They can simulate the natural recharge and artificial recharge conditions under different rainfall regimes and different groundwater abstraction and surface water diversion scenarios under the basin management plan. The groundwater-level trends could be analyzed for different degrees of abstraction. The abstraction levels suggested by the scenario, which creates permissible draw down, can be adopted as the sustainable level of abstraction for a given rainfall regime. However, the permissible annual draw down for the basin will be decided by the overall basin management objective. If the basin management objective is to raise the groundwater levels over a period of time, then the permissible draw down will be negative and accordingly, the sustainable abstraction figures will come down significantly.
- 11.** *Technical assistance from scientific institutions to RBOs:* since the RBOs will have to focus on governance and management issues in water, they cannot develop into full-fledged scientific institutions. But scientific skills are required for carrying out detailed resource mapping, periodic water balance studies, water accounting, and basin planning. These skills will not be available with the RBO. The RBO, therefore, will have to

enter into technical collaboration from scientific agencies such as the Central Ground Water Board, Space Application Centre, and the newly promoted Water Resources Research and Training Institute. The areas for technical collaboration are:

- Delineating different aquifers spatially—horizontally and vertically
- Identifying areas suitable for artificial recharge in shallow and deep aquifers.
- Designing conjunctive management systems and artificial recharge structures

For perspective planning of river basins, the RBO can seek inputs from the water resource monitoring and planning unit of SWDMB.

12. *Identification of agencies for local institutional development:* appropriate institutional arrangement for implementing the management actions is as important as developing a good management plan. The RBO and the SBOs will have to identify agencies for putting in place appropriate institutional arrangements at the local level for microplanning and their implementation. These agencies will have two primary roles. (i) Local institutional development, and (ii) integrating them with the RBOs. This apart, the agencies will also have to help the local institutions so formed in preparing their management plans. However, in areas where grass root institutions already exist, the effort will have to be only in motivating them and developing and channelizing their potential.
13. *Promotion effective local watershed management institutions:* in areas where local institutional capacities do not exist, the agencies can focus on the following: (i) Creating awareness on the need for water conservation and management, and (ii) Social Organization, (iii) Developing the technical and organizational capabilities for water management. There are three distinct typologies for local water management institutions, depending on the overall focus.

First: in the upper catchment areas of the subbasins or large watersheds, as the interventions will be watershed based, watershed management committees can be set up. Watershed boundaries can form the basis for constituting such organizations. If a particular watershed falls within a village boundary, the watershed management committees shall be formed at the village level. The Committees shall involve all water users within the village administrative boundary. If the watershed boundary extends beyond the village administrative boundaries, then users from more than one village have to be included in the watershed management committee.

In the plains, where local harvesting activities such as construction of percolation tanks, and other decentralized recharge systems are to be carried out, water management committees shall be promoted. They can be formed at the level of a village. In situations where boundaries of the water systems like tanks and ponds extend beyond village boundary, water management institution should include all users from the villages concerned.

Finally, in the lower plains, where no supply management interventions are possible, water users' associations shall be promoted. Next step will be developing the technical and managerial skills of the newly formed organizations. The technical skill development shall include water management activities, water harvesting, artificial recharge, construction and postconstruction management such as desilting and catchment protection.

In areas where community-based, local institutions are present, they can be motivated. Once these local institutions are fully developed, they need to be integrated with the higher institutions in the hierarchy.

The PIAs shall be engaged in educating the local water management institutions about the new property rights/management regimes that the users are to be brought under. They will also educate the users about the enabling laws that are newly introduced for protection of private/cooperative property rights.

The local management institutions should be legal entities as transfer of funds is required. They can be registered as cooperative societies.

14. *Promotion of electricity users' cooperatives:* the state electricity utilities can facilitate formation of Electricity Users' Cooperatives (EUCs). In areas, where electricity is not consumed in the farm sector, or the consumption is negligible, such cooperatives are not required. The SEBs can go for bulk supply of electricity to the EUCs in these areas but have to supply meters to them. The EUCs will have to install meters in each well owner's pump. The SEBs will sell electricity to the EUCs. They will meter it at the transformer kept for each cluster. The EUCs will have to pay for the consumption as per the meter reading at the transformer level. It will be the responsibility of the EUCs to monitor the consumption of every individual user and recover the charges. The information on electricity consumption will be a critical input for the local water management organization for monitoring groundwater use and understand as to what extent they are able to enforce property rights locally.
15. *Promotion of WUAs for irrigation management:* Though water users associations are promoted under the participatory irrigation management program, they have so far made only negligible impacts on the ways

in which irrigation systems are managed. There are three reasons for this.

First: the number of farmer organizations so far created is very low due to the low level of priority irrigation management enjoys within the department. Second: the involvement of WUAs in irrigation management is limited to the outlet and below due to which the farmers have little control over the water. Lack of assurance from the irrigation department to the farmers on either meeting the minimum requirements, or otherwise adequately compensating for the losses arising out of nonprovision of irrigation water is the third, but the most important reason.

There is a need for setting up a separate wing within the irrigation department to implement the irrigation management transfer. This can be called a Farmer Management Support Cell along the lines of the Water and Sanitation Management Organization (WASMO) of Gujarat and Water Supply and Sanitation Organization (WSSO) of Maharashtra. This FMSC has to have good social, managerial orientation as well as the ability to appreciate technology-related issues. The FMSC has to run as a project of the irrigation department. Such a flexible institutional framework can provide the much-needed flexibility in administration.

The FMSC can comprise mainly professional with background in rural management, social work, and social and political sciences and can be headed by a professional in the rank of Chief Engineer. The mandate of the FMSC is to enable formation of water users' associations, and build their technical, organizational, and managerial capabilities for managing irrigation. For this, it can take up the following activities:

- Publicity campaigns on irrigation management and turnover policy through its field offices;
 - Regular meetings with progressive farmers and NGO representatives on irrigation management; and,
 - Identification of NGOs/voluntary organizations for social mobilization
- NGOs and other voluntary organizations so identified will then be responsible for setting up appropriate forms of organization of farmers in the commands of the schemes. The FMSC can organize "training of trainers" for the staff of the NGOs and other civil society organizations, which are engaged in promoting the WUAs. The topics for training should include management of irrigation systems, irrigation water management, concepts of farmer management of irrigation, and roles and responsibilities of farmer organizations in irrigation management at various levels in the irrigation system.

An alternative will be to use the social mobilizing skills of the dairy unions. In such a case, promoting of water users' associations at the primary, secondary, and tertiary levels will be the responsibility of the union.

The NGOs can promote water users' associations comprising farmers who own land under each outlet as the Tertiary Committees. They can then set up a federation of such Tertiary Committees at the minor level, by drawing two representatives from each Tertiary Committee. This can be called a VSA Committee. In order for promoting WUAs, the NGOs can take up the following activities. 1. Social mobilizing, and 2. Training on technical and organizational aspects of irrigation management for capacity building. The training requirements for various levels in the organizational hierarchy of farmers will be different.

In states like Gujarat, the district dairy unions might be appropriate for managing the system at the level of distributary and could be equipped to manage 4–5 distributaries commanding a total irrigated area of 40–50,000 ha. The district unions can motivate the village dairy cooperatives to take over the management of minors. The village dairy cooperatives can organize the farmers under each outlet and set up the Tertiary Committees (TC). Since the district dairy unions already have attained social mobilizing skills, it will be easy to prepare them for local institutional development.

This is one component of the irrigation modernization. The next step is technological innovation and is discussed in the following paragraph.

16. *Technological Innovations as part of modernization:* The modernized scheme should have robust hydraulic designs to facilitate automatic control and measurement of flow rates and/or water levels at various control points along the hydraulic system. The control points at various levels in the hydraulic systems also correspond to the interface between different levels in the organizational/institutional hierarchy created. Since the irrigation system from distributary to the lower levels is to be turned over to the FOs, infrastructure modernization should cover distributary and below.

The options are:

- *Improved control of main and branch canals:* replacement of old control structures with overflow gates or composite gates with overflow characteristics to provide good water level control in the branch canals. Full automation of these canals using dynamic control is also needed.
- *Automatic flow measurement and control in distributary, minors, and watercourses:* in this case, the flow rate into the distributary, minors, and watercourses is

kept constant irrespective of the fluctuations in water levels in the supply canals. This uses automatic electric gates to maintain a constant head on a flume.

- *Modernization of distributary, minors, and watercourses:* in order to maintain constant flow rate at the turn out to field channels, at the minor outlets, and the head regulators, water levels in the supply channels like water courses, minors, and distributary need to be kept constant. Therefore, cross regulators such as long crested weirs, hydraulic gates, etc. are to be installed in the distributary, minors, and watercourses. Watercourses, which are unlined, can be lined.
- *Modernization of field channels:* field channels are open ditches and excessive losses take place during conveyance of water due to seepage, as soils are sandy. Therefore, low-pressure pipes can be installed.

This is one of the most controversial interventions in irrigation management. Worldwide, irrigation agencies have been investing in interventions such as lining of canals under irrigation system modernization on the pretext that this would result in water saving. However, recent evidence suggests that this may not be the case always, and on the contrary in many situations, more water would get consumed. The reason for this is that the water that seeps through unlined canals or canals with broken lining actually recharges groundwater. Preventing this seepage actually makes more water available for supplying to the field, thereby increasing the crop consumptive use (Perry, 2007).

17. *Development of microplans for watersheds:* development of microplans will be the responsibility of the local water management institutions. The promoters of the local institutions could help facilitate the process through exercises such as Participatory Rural Appraisal and orienting them about the subbasin and plans. The idea is to make sure that the local management plans fits very well within the larger basin management plan. Once the microplans are developed, the subbasin plans and the basin plan will have to be reviewed and revised to incorporate the location specific changes and deviations that are likely to occur. This can give a complete picture of the proposed management interventions for the basin.

Unfortunately, the past approach has been to develop watershed management plans at the level of microwatersheds based on hydrological assessment of these micro catchments and then aggregate them at the level of large catchments, without considering the “scale effects” (Batchelor et al., 2002; Gupta, 2011; Kumar et al., 2008) and watershed development (Batchelor et al., 2002; Syme et al., 2012).

18. *Enable support from scientific agencies for preparation of technical plans:* if the local management systems are complex, the local institution will require inputs for preparation of technical plans. For instance, the design and preparation of estimates wastewater treatment systems can sometimes be very complex, depending on the type of pollutants present in the effluents from urban areas and industries. The RBO should enable support to these local management institutions from technical agencies such as the National Environmental Engineering Research Institute, Nagpur.
19. *Allocation of groundwater and surface water use rights:* once the agency has complete idea about the quantum of surface water and groundwater, which can be sustainably extracted including the new water generated through management interventions, it can start allocating the use rights among the users, and user group organizations. At the basin level, the rights to use groundwater will be allocated to the local water management institutions, which in turn will allocate the rights among their members. In allocating water rights, the agency will follow the criteria decided by the SWDMB for inter- and intrasectoral water allocation. Further, water right allocation for groundwater will be correlative to surface water use rights. In other words, the total entitlement of an individual user or user group organization from surface sources and aquifers will be equal to the total volumetric right of that user or user group organization from the entire basin.

At the practical level, the groundwater rights will be allocated mainly to the watershed committees, water management committees, and (ground) water users' associations, industrial clusters, Panchayats, Municipalities. The volumetric rights will depend on the sectors these institutions cater to, and the number of users within the sectors, based on inter- and intrasectoral water allocation criteria. Similarly, the rights to use water from surface schemes will be allocated to irrigation department, and other line agencies, which have already invested in appropriating the resource or those who wish to appropriate, depending on the sectors they cater to. The norm used for water allocation in this case will be same as that for groundwater. The irrigation department can subsequently transfer the rights to the farmers' organizations and municipal water authorities. However, if the municipal authorities have already established their infrastructure for water transport, then the RBO could directly allocate the rights to them. The farmer organization at the highest level in the hierarchy can transfer the rights to the lower level.

The water use rights are likely to vary from year to year based on the amount of water available in the basin in form of surface water storage and recharge. Though the criteria for intersectoral allocation can be kept the same for the region, the criteria for a particular user within the sector have to vary. The best example to illustrate this point is the Cartagena in Spain where rights of irrigators in Segura basin to use water (concessions) imported are decided on annual basis.^a The volumetric allocation was found to be varying from a mere 6 MCM to a maximum of 132 MCM over a 30-year period from 1979–80 to 2015–16, depending on the amount of water available in the donor basin for transfer (*source: crcc.es*).

20. Fund generation through sale of water and collection of pollution tax: the RBOs need huge amount of financial resources to invest in water resource management projects, including those for improving water quality. In addition, it needs funds to take care of its own management cost, and transaction costs of local water management institutions and NGOs. A major source of resource generation for the RBOs will be the fund generated through allocation of water rights in the form of water taxes and pollution tax. The norms for fixing water tax and pollution tax will be as decided by the State Water Development and Management Board. However, the water used to meet basic survival needs could be made free of charge.

The taxes to be paid for the purchase of surface water use rights by the farmers are however likely to be much higher than those for groundwater. This is to recover the capital investment that irrigation department has made for building the infrastructure such as the dams and the canal systems.

China started introducing resource fee for water delivered to farmers in irrigation commands on volumetric basis sometime in 2002, while only domestic and industrial water supply services were charged on volumetric basis till then. The irrigation fee collected from the farmers goes directly to the agency, instead of the state finances. It also charges a water supply tariff

^a In *Comunidad de Regantes del Campo de Cartagena* (Community of Irrigators in De Campo Cartagena), the total irrigation service area was 40,000 ha. The farmers pay an average of around 0.32 euros per m³ of water. These concessions are linked to the size of plot under cultivation, and the quantum varies from year to year depending on the amount of water available from interbasin transfers. Water from the donor basin (Tagus) is dispensed on a monthly basis, and farmers are informed a month in advance of the maximum quantum of water they are likely to receive per unit area of the cultivable land. The rationing had a huge impact on the efficiency of water use (*source: www.crcc.es*).

for hydraulic infrastructure, an urban water supply tariff, a wastewater collection and treatment tariff, and a pollutant discharge fee (Shen and Wu, 2017).

21. *Negotiation of canal water use rights between WUAs and Urban Water Utilities:* for an individual user or a Water Users' Association, the volumetric water use right is fixed for a particular year. Hence, there could be tremendous scope for trading (across sectors, and also within sectors) due to the potential gap between demand and supplies. In drought years, the amount of water that will be allocated for municipalities is likely to fall short of the actual requirements as is evident from the past. If the municipality or corporation or the rural water supply board needs extra water, it could negotiate with the WUAs. The terms of the agreements reached through such negotiations will mainly include the amount of rights WUAs could transfer and the price they would charge. The negotiations can take place through the irrigation department, which will act as mediator and arbitrator if situation calls for. Based on the terms of the negotiations, the irrigation department can reallocate water from the system.
22. *Fund allocation for implementing water management activities:* a major chunk of the resources generated through the sale of water rights and collection of pollution tax (from municipalities and industries) needs to be diverted for implementing the management activities. Thus, it will be routed back to the local water management institutions as implementation funds. The annual fund allocation should be based on the financial outlay for the microplans developed by the local water management institutions and the time frame required. The local management institutions will also include urban water councils, which engage certain agencies to treat wastewater, and the financial resources for this will be made available by the RBO from the (pollution) tax collected from urban utilities and industries, which dispose of untreated effluents.
23. *Agency Intervention for large water management projects:* water resource management interventions in the semiarid river basins are of two types. *First:* those interventions, which involve large geographical areas and technical complexities. *Second:* local water harvesting structures, which are confined to small geographical areas.

One important technological option for regions like north Gujarat and western Rajasthan is impounding of excess runoff from their river basins during excessively wet years and diverting it into decentralized water storage systems. Another option is to use water from large water systems

for recharging the aquifers. In Gujarat, water from the Sardar Sarovar project is being used to recharge the alluvial aquifers in north and central Gujarat by diverting water from the main canal into dry river beds and decentralized storage systems (Kumar and Perry, 2018).

All these are large projects and cannot be implemented by the local communities alone. Therefore, there is a need to involve agencies such as the state water resources departments and Central Ground Water Board in planning, designing, and implementing these projects. Nevertheless, the local water management institutions could implement the smaller components of these projects.

24. *Implementation of watershed management/local water harvesting activities*: the small water harvesting interventions include watershed management, check dams, percolation ponds with recharge tube wells, and surface water storage tanks. They can be remodeled, deepened, and could be equipped with recharge tube wells for directly putting the runoff water into the deeper aquifers.

Watershed management activities could be possible in the upper catchment areas that receive good amount of rainfall and which have steep topography. The local institutions themselves can construct these structures, with little technical supervision from the personnel appointed by the NGOs. For special structures, the RBOs could enable the assistance of the technical staff of water resources department or rural water supply department or state groundwater department, or experts hired from the private sector.

25. *Monitoring of cropping patterns*: the local management institutions shall periodically monitor the cropping patterns in their villages and watersheds in the case of groundwater-irrigated areas. The WUAs will monitor the cropping patterns in the case of canal commands in different seasons. The data can then be fed back to the higher-level institutions. These will help to understand the existing water use priorities and to predict future water uses in the irrigation commands and the basin.
26. *Enforcement of groundwater use rights among tube well companies and well owners*: the enforcement of volumetric use rights among the individual users within the villages will be the responsibility of the local water management institutions. The enforcement of rights among the tube well companies, and owners of tube wells and wells fitted with electric motors will be easy. This is because the data on electricity consumption can be obtained from the EUCs. From the electricity consumption figures, hours of electricity use can be obtained. The local water institution can employ staff to measure the discharges of individual wells for every season. The figures of hours of pumping, coupled with discharge

figures can give more or less accurate figures of groundwater withdrawal. In the case of diesel wells, as the hours of running the pump are not known, one way to tackle the problem is to ask the well owner to record their own use in every season. The local institution could crosscheck using cropping pattern data. However, every user group or user will have to carry out water budgeting in the beginning of the season. This is to make sure that use does not exceed the allocated water right.

The RBO or the SBOs shall conduct or arrange special training programs for local institutions to build their capability to do water budgeting and accounting. The local institutions can decide on the penalties for excessive use and impose them so as to minimize the incidence of free riding.

In northwestern China, two pilot projects are currently underway to control groundwater overexploitation, one with a groundwater quota system enforced on farmers and the other with a tiered groundwater pricing. Studies show that the quota system had a higher impact in reducing groundwater abstraction (Aarnoudse et al., 2016).

27. *Monitoring of groundwater levels and water quality:* monitoring of groundwater levels and quality of surface and groundwater resources is paramount to assessing the resource condition at any given point of time. Thus, periodic monitoring can help analyze the impacts of water resource management interventions at the basin as well as local level. This will also help to understand the overall effectiveness of these interventions. The primary responsibility of monitoring will be vested with the local water management institutions.

In the rural areas, the local institutions need to be equipped with simple water-level recorders and water quality testing kits for this purpose. In the case of groundwater, water-level monitoring and water quality monitoring (WQM) shall be carried out four times a year, including one premonsoon and one postmonsoon. In the case of surface water, the monitoring will have to be more frequent to ensure that the effluents that are discharged into the streams and lakes are of acceptable quality and the wastewater treatment systems are functioning as per the requirements. In urban and industrial areas, periodic monitoring of water quality performed by the State Pollution Control Boards of rivers and lakes will give indications on the effectiveness of water quality management interventions upstream.

The data generated from monitoring can be directly used by the local institutions for (1) understanding their resource conditions; and, (2) analyzing the effectiveness of the local institutions. One of the interventions for which monitoring would be very crucial to analyze effectiveness is use of

microirrigation systems. The key question will be the nature of their actual impact, i.e., whether it is on irrigation return flows or on reduction in non-beneficial evaporation, and therefore the actual change in evapotranspirative demand of water. The main point of enquiry is whether the use of the system actually results in real water saving at the catchment/aquifer level or not. Accordingly, the management strategy will have to be modified. They will be critical to institutional capability building of the local institutions. But the data will have to be eventually shared with the higher-level institutions for analyzing the basin-level impacts of a large number of local management interventions. This can feed into making necessary amendments in the basin management plans.

28. *Demonstration of on-farm water management practices in farmers' fields*: the farmer management support unit (FMSU) of the irrigation department can collaborate with Water and Land Management Institute to carry out demonstration of on-farm water management practices in farmers' fields in canal commands. The demonstration will include small border irrigation, furrow irrigation, and farm leveling. This will provide opportunities for farmers to compare these practices against the conventional irrigation practices in terms of their impact on irrigation water use and motivate them to take up such practices in their fields. The demonstration can be arranged before the starting of the crop season in several locations.
29. *Demonstration farms for land and water management practices; water use technologies*: the efforts of institutions such as WALMI have so far concentrated their efforts on only canal-irrigated areas. No attention is paid to groundwater-irrigated areas. But, there is a tremendous scope for improving the physical and economic efficiencies of water use through land and water management practices even in well commands.

The basin organization or the subbasin organization can collaborate with state agricultural universities to establish demonstration plots of organic farming in the fields of progressive farmers. The team from the agricultural universities can constantly provide scientific inputs to the farmers on preparation of biofertilizers through efficient use of the available biomass; and, their efficient use in the farms for proper management of soil organic matter and moisture.

The basin organization or the subbasin organizations can help microirrigation companies to set up demonstration plots for their cost-effective technologies in sample villages across the basin. This will provide farmers with first-hand experience of these technologies vis-à-vis their advantages

against conventional technologies such as easy adaptability, and low maintenance requirements apart from water saving, and increase in crop yields.

30. *Monitoring of local water management activities and their impacts:* the basin organization and the subbasin organizations shall monitor the water management interventions being taken up by the local institutions in order to analyze their performance and effectiveness. Performance evaluation is critical to reviewing and redefining the objectives. This will include close monitoring of the physical activities and the “enforcement of volumetric water use rights,” performance of wastewater treatment systems, and the hydrological monitoring work carried out by the local institutions. The basin or the subbasin organization can set up independent committees to assess the performance of the local institutions. They can also use the in-built mechanisms to check free riders in certain instances. For example, to what extent, the volumetric use rights are enforced can be understood by examining the electricity consumption figures that can be obtained from the electricity users’ co-operatives or the State Electricity Board. The basin organization can also crosscheck the data (groundwater levels, groundwater quality, etc.) gathered by the local institutions with those compiled by the State Water Resources Monitoring and Planning Board.

In northern China, prepaid energy meters are used to enforce a quota system for groundwater, volumetrically defined on the basis of land holding and livestock holding size of farmers, introduced for controlling abstraction. The swipe card transactions are transmitted through the internet to a Digital Water Resource Information Centre. This center meticulously records the number of units consumed by each farmer based on the swipe card transactions (Wang et al., 2017).

As regards performance of the agencies treating wastewater, the RBO can analyze the data generated by the state pollution control board on water quality of rivers, lakes, and groundwater in order to assess the performance of the wastewater treatment systems set up by the service providers to improve the quality of the effluents.

31. *Periodic water accounting and water balance exercises:* as the situation with regard to water availability, water diversion, and water use changes annually, the RBO should carry out periodic water balance and water accounting studies of the basin. They are essential for determining sustainable levels of groundwater abstraction and surface water utilization, and the volumetric water use rights. They change from time to time

with variations in rainfall, runoff and recharge, and with changes in water allocation policies. The water accounting will give clear ideas as to what extent the actual water use by different sectors, deviates from the intersectoral water done by the basin authority. This will be a direct indicator of the effectiveness of market instruments such as tradable private property rights on demand management.

The basin authority can also use the data to evaluate the changes in overall basin efficiency with changes in water allocation patterns, the “third-party effects” of water transfers and thereby taking necessary precautionary measures. The institutional processes resulting from the change in the institutional paradigms and the dynamics of interaction between various institutions are summarized in the flow diagram (Fig. 11.2).

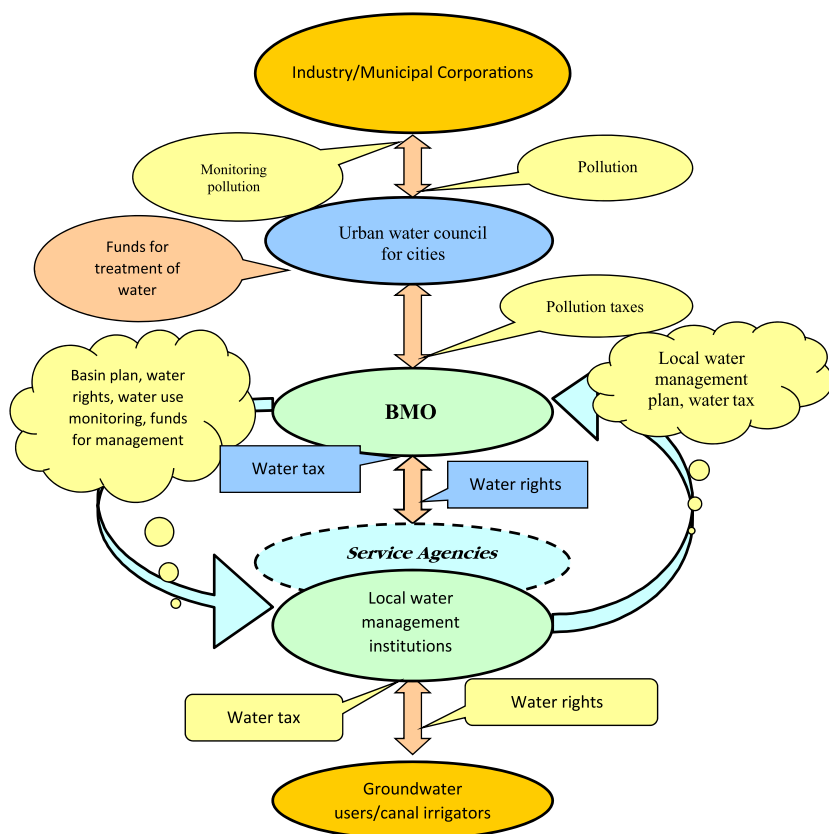


Fig. 11.2 Institutional arrangements for integrated water resources management in river basins. (Adapted from Kumar, M.D., 2010. *Managing Water in River Basins: Hydrology, Economics, and Institutions*. Oxford University Press, New Delhi.)

11.4 Conclusions

Several countries have adopted IWRM principles in their water policies and programs (Jøneh-Clausen, 2004). However, too little has been achieved on the ground in terms of operationalizing the concept and implementing the practices (Biswas, 2008). One of the biggest reasons for this limited success is the inability to develop a model of IWRM to fit the socioeconomic context, and design appropriate institutions to implement and operate it, following sound institutional design principles for effective water resources management. While IWRM envisages taking cognizance of the interaction between various components of the hydrological system that affect the effective water availability, viz., catchments, groundwater and surface water, and water quantity and quality, the institutions designed to implement water resources management actions should have the capability to plan, design, and execute WRM activities at the basin level in an integrated manner considering these factors, and monitor the basin performance in terms of progress toward achieving water resources management goals set. Often, the various processes and actors (institutions) and the desirable level of coordination between various institutions at various levels to achieve integrated resource management are difficult to foresee. Problems are also faced with simulating various physical processes (land use changes, increase in groundwater withdrawal, import of surface water for irrigation through canals, introduction of microirrigation) that truly capture the hydrologic system characteristics.

Similarly, while IWRM envisages taking cognizance of the interaction between various socioeconomic systems and ecosystem that demand water from the hydrological system, the institution that is designed to cater to various water demands should have the capability to handle intersectoral water allocation, especially when water scarcity becomes acute, with minimum conflicts. But the agencies concerned with water allocation often fail to predict the likely changes in water demand of different sectors affected by behavioral change induced by the changes in water allocation and pricing policies, and the resultant changes in the hydrological system characteristics, and their overall impacts on the various users of water. These are some of the key challenges in operationalizing IWRM concept. In this chapter, we have laid out sound design principles for effective water management institutions; and discussed the overall institutional framework required for affecting integrated water resources management in the Indian context, and the scientific and institutional processes that need to be initiated to overcome some

of these challenges in implementing IWRM concepts at the basin level. The discussion of the action plan for IWRM suggests that implementation of IWRM has to be an evolving process and there can't be a standard blue print that can be implemented at one time.

References

- Aarnoudse, E., Wei, Q., Bluemling, B., Herzfeld, T., 2016. Groundwater quota versus tiered groundwater pricing: two cases of groundwater management in north-west China. *Int. J. Water Resour. Dev.* <https://doi.org/10.1080/07900627.2016.1240069>.
- Batchelor, C., Singh, A., Rao, M.S.R.M., Butterworth, J., 2002. Mitigating the potential unintended impacts of water harvesting. In: Paper Presented at the IWRM International Regional Symposium 'Water for Human Survival', 26–29 November, 2002, Hotel Taj Palace, New Delhi.
- Biswas, A.K., 2008. Integrated water resources management: is it working? *Int. J. Water Resour. Dev.* 24, 5–22. <https://doi.org/10.1080/07900620701871718>.
- Connell, D., 2011. Water reform and the federal system in the Murray-Darling basin. *Water Resour. Manage.* 5 (15), 3993–4003.
- Glieck, P.H., 1997. Human population and water: meeting basic needs in the 21st century. In: Pachauri, R.K., Qureshi, L.F. (Eds.), *Population, Environment and Development*. Tata Energy Research Institute, New Delhi, pp. 105–121.
- Government of India, 2010. *Ground Water Quality in Shallow Aquifers of India*, Central Ground Water Board, Ministry of Water Resources. Government of India, Faridabad, India.
- Gupta, S., 2011. Demystifying 'tradition': the politics of rainwater harvesting in rural Rajasthan. *Water Alternatives* 4 (3), 347–364.
- Howe, C.W., Schurmeier, D.R., Douglas Shaw Jr., W., 1986. Innovative approaches to water allocation: the potential for water markets. *Water Resour. Res.* 22 (4), 439–445.
- Jönch-Clausen, T., 2004. Integrated Water Resources Management (IWRM) and Water Efficiency Plans by 2005 Why, What and How? *Global Water Partnership*. (January 2004).
- Kumar, M.D., 2006. *Water Management in River Basins: A Study of Sabarmati River Basin in Gujarat*. Ph.D. Thesis Submitted to Sardar Patel University, VV Nagar.
- Kumar, M.D., 2016. Status and institutional arrangements of river basin management in India: some analytical insights. In: Presented at the EU-India Water Partnership Capacity-Building Workshop on River Basin Management Planning and Governance, Park Hotel, New Delhi, 14–15 June, 2016.
- Kumar, M.D., Perry, C.J., 2018. What can explain groundwater rejuvenation in Gujarat in recent years? *Int. J. Water Resour. Dev.* <https://doi.org/10.1080/07900627.2018.1501350>.
- Kumar, M.D., Ankit Patel, A., Ravindranath, R., Singh, O.P., 2008. Chasing a mirage: water harvesting and artificial recharge in naturally water-scarce regions. *Econ. Polit. Wkly* 43 (35), 61–71.
- Kumar, M.D., Prathapar, S.A., Saleth, R.M., Reddy, V.R., Narayanamoorthy, A., Bassi, N., 2017. New 'water management paradigm': outdated concepts? *Econ. Polit. Wkly* 52 (49), 89–94.
- Perry, C., 2007. Efficient irrigation, inefficient communication, flawed recommendations. *Irrig. Drain.* 59, 367–378.

- Rosegrant, M., Binswanger, H.P., 1994. Markets in tradable water rights: potential for efficiency gains in developing country water resource allocation. *World Dev.* 22 (11), 1613–1625.
- Shen, D., Wu, J., 2017. State of the art review: water pricing reform in China. *Int. J. Water Resour. Dev.* 33 (2), 198–232.
- Syme, G., Reddy, V.R., Pavelik, P., Croke, B., Ranjan, R., 2012. Confronting scale in watershed development in India. *Hydrogeol. J.* 20 (5), 985–993.
- United Nations Educational, Scientific and Cultural Organization (UNESCO), 2008. IWRM Guidelines at River Basin Level, Part 2. Guidelines for IWRM Coordination, Paris, p. 1.
- van der Zaag, P., Savenije, H.H.G., 2014. Principles of Integrated Water Resources Management. UNESCO-IHE Institute for Water Education, Delft. (October 2014).
- Wang, X., Shao, J., van Steenberg, F., Zhang, Q., 2017. Implementing the prepaid smart meter system for irrigated groundwater production in northern China: status and problems. *Water* 9, 379. <https://doi.org/10.3390/w9060379>.

Further reading

- Kumar, M.D., 2010. Managing Water in River Basins: Hydrology, Economics, and Institutions. Oxford University Press, New Delhi.
- Murray Darling Basin Authority (MDBA), 2009. Issues Paper: Development of Sustainable Diversion Limits for the Murray–Darling Basin. MDBA, Canberra. <http://www.mdba.gov.au/files/publications/sustainable-diversion-limits-issues-paper-12-11-09.pdf>.