Chapter 14

River Basin Planning and Management

The objectives of this chapter are:

- to introduce the concept of river basin management (RBM);
- to describe tools for RBM, such as integrated basin management models and decision support systems (DSS);
- to discuss related topics, such as public involvement and institutional aspects; and
- to discuss international dimensions and efforts for freshwater management.

Water is the driver of nature. Leonardo da Vinci.

Water is pivotal to our environment, and influences and shapes the landscape. The sustenance of life and economic and social development are not possible without sufficient water of right quality. River basins possess freshwater and are most important from the point of view of water resources development and management. The availability of water at a given place depends on the properties of its upstream basin. Most of the consumptive water use, such as irrigation; and non-consumptive uses, such as hydropower production, recreation, navigation, take place in the basin itself. A basin also receives most of the return flow from irrigation and waste water. Due to these reasons, river basins are the most important management units. The ecosystem approach to water management is a somewhat related concept that aims to integrate social, economic and environmental interests within the wider framework of the basin. The basic motivation behind this is that people depend on their ecosystem and, therefore, the capacity of the ecosystem to deliver goods and services should be maintained over a longer timeframe.

Undoubtedly, river basins are among the earth's most productive ecosystems. Freshwater ecosystems provide a number of goods and services to global, regional, national, and local economies. Besides water, goods and benefits derived from these systems include fish, timber, fuel, bio-diversity, wildlife, fertile lands, and so on. A diverse range of industries, such as agriculture, tourism, fisheries, forestry, and construction, benefit both directly and indirectly from freshwater ecosystems. There is also an intrinsic social value through their links to aesthetic, cultural and heritage aspects. Clearly, freshwater ecosystems generate multiple and wide-ranging economic benefits.

The array of goods and services detailed above can be classified in two groups: public and private. Public goods and services are those whose provision is "non-exclusive" and "non-divisible". This means that once they are provided, anyone can benefit from their provision without diminution of their availability to others. Many of the quality-related facets of goods and services derived from a freshwater ecosystem may be construed as public goods. These include water quality, storage and purification, groundwater recharge, flood control, storm protection, nutrient retention, micro-climate changes, and so on. If public goods are managed properly for one user, the entire society enjoys the benefits. Conversely, when these are poorly managed, the whole society suffers due to mis-management.

In contrast to public goods, the provision of private goods and services is exclusive, i.e., once these are provided to one person, that individual holds them exclusively and the quantity available to others gets reduced by the equal amount. Many of the quantity-related facets of goods and services from freshwater ecosystems are of this nature. For example, once a particular quantity of water is given been a user or group for consumption, it becomes his exclusive property and nobody else can claim a right on it. The public or private nature of a freshwater ecosystem's goods and services determine how it can be managed in the most efficient way. Private goods are best managed by free market-based mechanisms because such markets provide many incentives for efficient management.

The main cause of the damage to freshwater systems, as for any other system, is their overexploitation. It may be through activities, such as excessive water extraction or excessive dumping of waste in them. The resulting damages to these systems are termed as *externalities* and are not included in the traditional benefit-cost analysis. A sustainable use of freshwater systems requires that all users must be made responsible for bearing their share of the cost of maintaining freshwater ecosystems. This philosophy is commonly known as the *polluter pays* principle.

All of these considerations indicate that de-centralisation of the administration of freshwater systems is necessary for efficiently managing them. But one comes across many instances of centralized control and decision making which introduces more complexities by virtue of the range of problems with which a centralized management is concerned.

The demand and use of water has rapidly increased after the middle of the 20^{th} century. In many basins, water resources are overexploited but the demands are still increasing. The consequent reduction in the capacity to meet different demands has resulted in conflicts between different water uses and between upstream and downstream uses. An integrated approach, covering all waters of the basin (surface and sub-surface) is necessary to solve these conflicts. It should consider temporal and spatial distribution of the water quantity and quality; and the interaction of water with land, vegetation, and other resources.

Ideally, it should also ensure integration of social, economic, legal, political, and administrative issues.

Sustainable river basin management (RBM), which is the basic objective, requires a sound understanding of water resources systems and their internal relations (groundwater, surface water; quantity and quality; biotic components; upstream and downstream interactions). The water systems should be studied and managed as part of the broader environment and in relation to socio-economic demands and potentials, with due influence of the political and cultural settings. The water itself should be seen as a social, environmental, and economic resource, and each of these three aspects must be recognized in the decision making process. The management of water resources cannot be addressed in isolation; it is necessary to consider functioning of ecosystems simultaneously at different hierarchical levels, in both space and time. This involves planning and management interventions at local levels (e.g., field, farm, and village) as well as at regional levels (e.g., catchment and river basins).

Sustainable RBM also requires co-operation and political commitment within a country and among the basin nations in case of international basins. In many river basins, pressures on the environment have reached or surpassed the levels that may be sustainable. Consequently, vulnerability from extreme natural events has increased, and conflicts between different water uses and between upstream and downstream uses are increasing. The capacity of many basins to meet growing social demands, including basic human needs such as drinking water, is decreasing rapidly. But the basic water needs of people and ecosystems have to be fulfilled first. This requires that the essential ecological and physical processes should be protected and the harmful effects of overexploitation of the sources of water should be minimized.

14.1 DEFINITION AND SCOPE OF RIVER BASIN MANAGEMENT

A river basin can be defined as *the geographical area demarcated by the topographic limits of the system of waters, including surface and subsurface water, flowing into a common point* (the ground water may, however, not exactly follow this rule). The boundaries of most river basins are clearly defined by topography although there may be instances with ill-defined boundaries. Some rivers have a shared delta and the basin areas in flat topography may not be distinct. In a basin, there are strong interactions between land and water resources, between ground water and surface water, and between water quantity and quality. In a nutshell, a river basin is a coherent system of interacting and interdependent elements.

River Basin Management (RBM) is defined as *the management of water resources of a basin as part of the natural ecosystem and in relation to their socio-economic setting.* The term Integrated Water Resources Management (IWRM) is also frequently used to convey similar concepts. The term 'integrated' was used by Downs et al. (1991) for an intermediate stage in which more than one sectoral interest is linked at both the operational and strategic levels. The schemes that approach the basin as an energy or ecosystem are termed 'holistic'. However, there is no unanimity in use of these terms. Sometimes holistic is used for the actions at the strategic level while integrated is for those at the operational level. Note, however, that the term RBM does not imply that river basins are closed systems or the only relevant geographical areas. Other units, such as administrative areas, are also frequently used management units. Nevertheless, river basins are most logical and important units that should be carefully managed for the benefit of all concerned.

The unified management of a river basin by a single authority looks intuitively appealing too. Such a body can best prepare comprehensive basin-wide development and management plans, can realistically look at the 'big-picture', implement the best available technology, and deploy appropriate models and decision support systems. However, due to a wide range of associated tasks, many river basin organizations become unwieldy and have their offices at many locations. Care is necessary to ensure that additional complexities and communication gaps are not introduced just because of their size and the range of issues that they have to handle. If there is no proper coordination among the various wings in a large basin organization, the basic aim of the unified decision making, non-redundancy, and transparency gets defeated.

Broadly, the aim of RBM is to ensure the use of water and allied resources of a river basin in a sustainable manner. For example, the stated aim of the Mekong Commission (www.mrcmekong.org) is *to promote and coordinate sustainable management and development of water and related resources for the countries' mutual benefit and the people's well-being by implementing strategic programmes and activities and providing scientific information and policy advice.* Since the capacity of a river basin to serve various uses is limited, priorities have to be assigned to different uses. Considerations of a hierarchy of needs suggest that the basic human requirements -- water supply for daily necessities, including basic hygiene -- have to be taken care of first. The next level of priorities depend on the natural, social and economic conditions in the pertinent basin and the values and occupation of its population.

The need for RBM arises because the non-coordinated use of resources is inefficient as well as damaging. A key characteristic of RBM is satisfactory conflict resolution. Despite the intrinsic appeal and obvious benefits, RBM is not practiced in a proper way in many countries. The main reasons are that there are no river basin organizations, the basins fall under incompatible administrative units, or there is not enough will for RBM.

14.1.1 Scope of RBM

To understand the intricacies of RBM, it is useful to distinguish six different activities: planning, construction, operation, monitoring, analysis, and decision making. The river basins and their users are directly affected by operation and management actions (see Fig. 14.1). Of course, at each stage, the basin managers receive feedback from the basin and its users. Planning and construction are primary means to install facilities for operation and management. As shown in the figure, monitoring and analysis provide inputs for planning, construction, and operation.

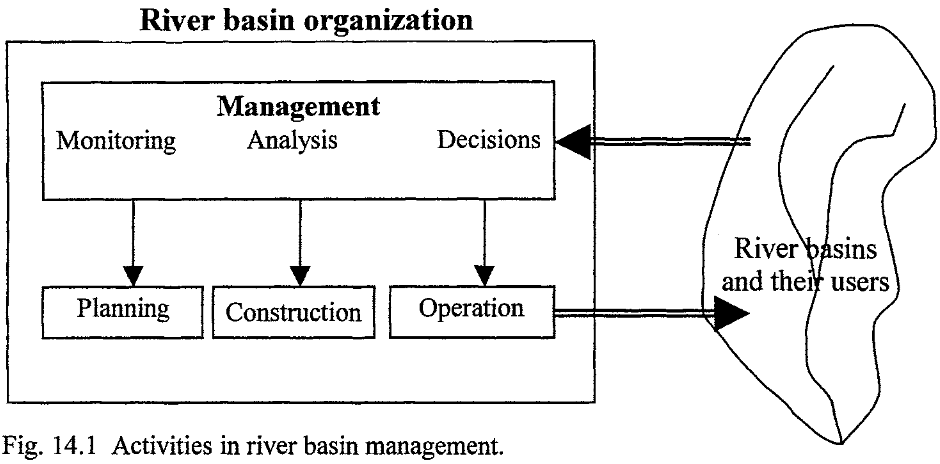

Fig. 14.1 Activities in river basin management.

RBM affects river basins in many ways. It may alter the natural physical processes in a river basin by constructing structures to store and carry water; regulate the use of water with the help of allocation rules, prices, water rights and permits; and apply economic instruments, such as taxes and subsidies to control the water usage. Different inputs are necessary to apply these instruments, such as money, personnel, legal, and appropriate policy directives. RBM may also induce change in the behavior of the users by penalizing or allowing/encouraging certain activities. An effective RBM will require a mix of instruments depending on circumstances. For long-term sustenance, it is necessary to build in-house capacity by training staff and keep the general public well informed. Table 14.1 gives an overview of different types of operational RBM instruments.

The scope of RBM also contains a number of related activities, viz., public participation, professional cooperation between related organizations, and international cooperation. Because of this wide view, RBM has a broader scope than does traditional water management. In fact, it covers all human activities that use or affect freshwater systems; many of these are beyond the scope of this book. The planning process was the theme of Chapter 9 and analytical tools have been discussed in Chapters 3 to 8. Decision support systems will be covered in Section 14.4. Three important topics, viz., operation, water rights and water charges, will be covered in what follows.

14.1.2 Operations

As the infrastructure starts coming up, it is to be put to designated beneficial uses. The term operations (some authors use operational management) implies regulation of facilities; and application of economic, legal, and policy instruments. As shown in Fig. 14.1, operations have direct influence on river basins and their users. Operations are carried out using the analysis and decision support systems (DSS) that are set up specifically for this purpose. These tools and techniques have been discussed in detail in preceding chapters. As far as regulation of structures is concerned, the most important component is reservoir operation. An extensive amount of work has been done on this as explained in Chapter 11.

Table 14.1 Activities and instruments of operational RBM (adapted from Mostert et al. 1999).

Activities	Characteristics	Instruments
Structural	Direct interference and control of water flow	Dams for water regulation Weirs for river flow diversion Embankments to confine streamflows River training works Canals, tunnels, pipes for water conveyance Pumping from aquifers, artificial recharge Catchment treatment Inter basin transfer
Regulation	Influences the users by encouraging or penalising some activities	Rules and regulations Water rights and permits Monitoring and enforcement
Economic instruments	Influence water use by means of financial (dis)incentives	Charges (taxes, levies etc.) Subsidies Tradable water use and pollution rights
Communication and awareness raising	Influences users by providing information	Public involvement Seminars, lectures, open house Exhibitions
Financing	Supports the various activities by providing finances	Funding desirable activities
Institutional support	Supports the previous instruments by providing other necessary resources (personnel, legal competencies, policy directives)	Capacity building Legislation Extension services

14.1.3 Water Charges

An important and very sensitive operational issue in RBM relates to water charges. Charges are an effective and efficient means to finance resource development activities, minimize wastage, and control pollution. If water charges are based on the full cost of providing services, it is easier to attract and involve the private sector. However, a caution is to be exercised here since water is also a social good and, therefore, it should not be so expensive that the poor are not able to afford it. From a management point of view, very high charges are difficult to enforce and there is a resistance to pay. Moreover, high water charges can substantially reduce margins on agricultural products and can have cascading effect on other commodities. Inputs to agriculture are subsidized to varying degrees in most countries and there is always a political opposition and resistance to high water charges.

Nevertheless, water plays a key role in many economic development and by virtue of that, it has a high value although it is politically difficult to reflect this value in water transactions.

Water can be charged in two ways: based on the actual usage or on a lump-sum basis. The charges that are based on actual water use certainly help reduce the water use and wastage to a certain extent. The extent of the impact of price depends on the price elasticity or the sensitivity of water use to the costs of the use. It is generally low in the case of the drinking water use and high for irrigation water. When charges are on a lump-sum basis, wastage is high and recovery of full cost of providing services is difficult.

Ideally, water rates should be based on the opportunity cost of the water use (the value of the next best alternative use). If this is not feasible, charges should be fixed so as to at least recover the cost of providing related services, such as domestic water supply, waste-water treatment, etc. This will ensure that enough funds are available for operation and maintenance. Sometimes the aim could also be to raise money for expansion of services and reduce wastage. By equating prices with their marginal cost, the full benefit of those goods to society will be reflected in equilibrium. Users facing such prices will base consumption decisions on the real economic cost of providing the goods and so should reach the socially optimal level of consumption (Dinar et al. 1997). The fixation of water charges is somewhat easier in case of water supply and irrigation while the evaluation of benefits of drainage and flood control is more complicated. Note that irrigation services are heavily subsidized in many countries. Of late, many countries have privatised water services or are in the process of doing so with a view to improve efficiency.

From practical considerations, marginal cost pricing is hard to implement as it is usually difficult to derive the marginal cost curves. While trying to incorporate the scarcity value of water, it is unlikely that authorities will be able to devote the time or money necessary to find the true marginal cost of provision (Dinar et al. 1997). Additionally, the marginal cost varies over time; this means that prices would constantly need readjusting to take into account the seasonal availability cycle, and the level of demand. The potential magnitude of this difference is illustrated for Zimbabwe, where tariffs to farmers in the various provinces have varied from Z$9 per cubic metre to Z$278 (Winpenny, 1994). Recall that equity issues are one of the primary concerns of the government of Zimbabwe. It is possible that in a dry spell the marginal cost of provision would rise so much that it would become too expensive for lower income users to afford. In fact, charges are more often based on the average prices combined with subsidies to promote equity issues. In many countries, consumers pay much lower prices than necessary to achieve the economic efficiency of allocation.

The scarcity value of water in arid climates can be appreciated by noting that the currency of Botswana, a semi-arid country in Africa (mean annual rainfall in the range of 650 mm to 250 mm) is Pula. In the local Setswana language, the word Pula means rain !

Maintenance of the infrastructure usually is the first casualty in case of shortage of funds. Due to non-recovery of operational expenses, the quality of services at many places has degraded and these have not expanded to the desired extent. Poor users could be levied lower charges, but the economic viability of providing the services should not be undermined. Ironically, if the services are not up to the desired level, it is the poor people who are the first and the worst sufferers. A possible solution is to link the rates with the ability to pay. Evidently, fixing water prices is not a technical or economic issue; it is more a socio-political issue.

14.1.4 Water Rights

There are two types of water rights: ownership rights and the right to use water. Water bodies can be government-owned, privately owned, or these can be the property of a whole community. The ownership status depends on the national legal system and the type of water body (navigable or non-navigable river, ponds, ground water). The practice of riparian rights is followed in many countries and under this, land owners along natural water bodies have certain minimum rights to water use. The mechanism that is commonly followed in developing countries is through legislative authorisation of major water-related bodies. The non-governmental organisations have a major role in advocating and providing services in water resources. Regarding the ground water rights, mostly the land owner the has right to pump water beneath it.

According to the riparian doctrine, water rights are a component of the property interest that arise from the ownership of the land bordering a natural water course and include the right to make a reasonable use of water on riparian lands. Since 'reasonable' is a relative term, the riparian right is commonly not fixed in magnitude and can vary with time. However, it must be compatible with other uses relying on the same source of water. Commonly, the maximum extent of the riparian land is the boundary of a stream catchment.

Water rights should be flexible and responsive to changing circumstances at both the national and the international level. If the government is the owner of water, the use rights are generally granted by a designated agency by means of permits, concessions, etc. Private ownership, however, does not mean that the owner can use the water as he pleases; he is not supposed to encroach upon the rights of others, his ownership right might be limited by law and permits may be needed for specific uses. If the water is seen as the property of a whole community or as incapable of being owned by anyone, the water use is often regulated by the government. However, in many places local communities of users have their own bodies to manage the water use.

When individuals own a confirmed right to a proportion of the resource, they have an economic incentive to exploit that resource efficiently. If a user has the assurance that he can continue to use the resource, he will invest in maintaining and running the system. The major issues concerning the rights of privately owned waters relate to their flexibility and the extent to which the ownership right can be limited. In the case of water use rights, the major issues are whether these rights are granted for a specific period or in perpetuity and under which conditions they can be revised. A relatively high degree of flexibility – combined with respect for existing rights and if necessary, compensation – seems essential for effective RBM in a changing world.

If the rights are appropriately determined and allocated, the aggregate level of consumption will gradually reach an optimal level. Thus, first the socially optimal level of resource use must be determined and then divided into appropriate rights to ensure that the total use is within limits. For the rights to be acceptable, it is essential that the historical pattern of appropriation is taken into account and is not drastically disturbed and no one should be made worse off. If the allocation of rights leads to a situation in which some existing users are unable to use their share, the equity criterion has not been met. Many customary rights dictate the kind of equipment that can be used rather than the volume of water that must be extracted. The rights to pollute can also be issued to ensure that the concentration of waste in the water body does not exceed the optimal level. Since the type of pollutant, location of deposition, and the kind of use all affect the health of the ecosystem, this heterogeneity must be taken into account.

A careful identification of the exact entitlement and responsibilities associated with the rights and long-term repercussions is essential. For instance, a requirement that the failure "to use a water right for a set number of years can lead to the right's forfeiture or abandonment" would at first sight seem to prevent players from claiming rights speculatively. In reality, the limit can reduce the time horizon of the holder and encourage him to just use water to ensure his entitlement (Anderson and Hill, 1997).

The discussion so far should not give an impression that rights alone will ensure an efficient use of water resources. Water and land resources in a basin are owned by various categories of people and institutions. The water resources ownership is sometimes linked to land ownership. In any case, a clear definition of ownership is essential for sustainable management.

To achieve an economically efficient outcome for society, it is essential that the rights to use the freshwater ecosystem's goods belong to those activities that have the highest marginal social benefit. In a majority of cases, the numbers of users, the heterogeneity of their interests, the asymmetry of information available to the agency determining the rights, and the need to ensure an equitable allocation results in an initially sub-optimal allocation of rights. A free market for rights allows low value users to exchange permits with high value users, get the market price for the goods transferred and be fully compensated for the loss of the right. For a market in permits to allocate rights effectively, the prior agreement of rights and their clear definition are essential for any trade. Secondly, rights must be valid for a period long enough so that owners can assign a value to them. Information about the exact nature of rights and the rules of trading must be clear so that both buyers and sellers understand the full implications of the situation (Dinar et al. 1997).

The concept of *water banks* has been used in the U. S. A. as a method to match sellers with excess rights to buyers who can exchange the rights for a limited period of time. In this concept, water is bought from farmers and then resold 'to those who have the most critical needs' (Le-Moigne, 1994). The state of California has used water banks extensively in years of drought to reallocate rights to scarce water resources. The efficiency of the system has improved over time using the experience gained (Dinar et al. 1997).

Wurbs et al. (1993) have developed the Texas A&M University Water Rights Analysis Package (TAMUWRAP) to handle the prior appropriation ('first in time, first in right') system of legal water rights prevalent in the western United States. This model is capable of simulating river flows, multireservoir operation and diversions to multiple uses with a set of priority allocations, each defined by annual volume, priority number, type of use, and optional water rights group. TAMUWRAP has been applied to the Brazos River system of 12 reservoirs in Texas, where over 1300 permit holders are allowed to use water.

14.2 PLANNING AND RIVER BASIN MANAGEMENT

Plans and policies have an important role to support RBM. Planning helps assess the present situation in the basin, the situation desired, the gap between the two, and how to close the gap. It helps orient operational management and set priorities. Second, it is often not possible or effective to do policy analysis and organize public participation for each individual operational decision. In these cases, planning may offer a framework and focus. Third, open and participatory planning processes will result in more public support or acceptance of the resulting plan/policy. Planning processes can bring different river basin managers into discussion with each other and the resulting plans and policies can act as common focal points.

Planning is an important and often indispensable means to utilize water resources, and in operation of the projects. Planning has four related functions:

a. To assess the current situation (including the identification of conflicts and priorities), formulate visions, set goals and targets, and thus orient operation and management,
b. To provide a framework for public participation and feedback,
c. To increase the legitimacy and mobilize public acceptance, and
d. To facilitate the interaction among concerned organizations and stakeholders.

The topic of water resources planning has been dealt with in detail in Chapter 9. This section focuses on some aspects of planning that are relevant to RBM.

14.2.1 The Planning Process

Although planning requires extensive technical and scientific information, it is not a purely technical or scientific exercise. It must have a human touch since it ultimately affects humans. The following are the important activities of planning for RBM:

1. Identification of the need, scope, and geographical coverage of the area,
2. analysis of the institutional framework for RBM, identification of decisions that are to taken, and the bodies who have to take these decisions,
3. identification of the main stakeholders, their likings, and expectations,
4. preparation of a blueprint, describing the scope of planning; identify different phases and groups to be involved in each phase; and prepare a flowchart of activities.
5. formulation of a plan and its approval, and
6. implementation of the plan.

Note that planning is an iterative process – the first plans are not always the best. But after a plan is ready, it can be widely circulated and suggestions for improvements can be invited. Most people are able to react in clear terms when a concrete proposal is presented to them. A plan may also encourage planners to look for ways to overcome too restrictive constraints which might be limiting overall development.

As an aid in river basin planning and management, electronic spreadsheet-based simulation models have been developed recently. In these models, the formulas governing the working of the system are entered in the cells of the spreadsheet. The basic data of the system (such as the configuration, the inflows) might be fixed and the user can vary pertinent parameters, such as the amount of water withdrawn for municipal uses, power generation, the price of water, the quality of returned water, etc. After defining a new scenario, the operation of the system can be simulated in a few seconds and the revised tables and graphs are readily available. Such models are of significant value in getting a 'feel' for the system and the interaction of its various components. These are also helpful as a teaching aid in the classroom through role-playing. Roles can be assigned to different students – someone can assume the role of water supply utility, another of waste water treatment utility, the third of RBM, and so on. Operation policies and charges for services can be fixed through negotiations and the sensitivity can be examined.

14.2.2 River Basin Planning Systems

Plans and policies relevant to RBM can differ on many dimensions: policy sectors, geographical scope, etc. What types of plans are needed in a specific situation depends on a number of factors, such as the most important policy issues; whether river basins are located in one, two, or more jurisdictions; the funds that can reasonably be spent on planning, etc. These factors differ from country to country and from basin to basin.

RBM is the management of water systems as part of the broader natural environment and in relation to their socio-economic environment. Consequently, river basin planning should ensure consideration of interrelations within water systems (surface and ground water, quantity and quality), the interrelations between climate, land, and water; and interrelations between complete river basins and their socio-economic environment.

The types of plans needed depend on the need for different functions that plans can perform. For instance, if in a basin there is urgent need of providing drinking water to a rapidly growing city, there may be no need for integrated strategic planning that requires an overall description of the basin and sets long-term goals. Generally, the number of plans should be small, especially in countries and basins with a scarcity of competent technical personnel. If too much planning is going on at the same time, too few resources may be available for each planning exercise and coordination between plans can become a problem.

14.3 INTEGRATED WATER RESOURCES MANAGEMENT

A river basin system can be classified in three components (McKinney et al., 1999): 1) source components, such as rivers, canals, reservoirs, and aquifers; 2) demand components which could be off-stream (irrigation fields, industrial plants, and cities) and in-stream (hydropower, recreation, environment); and 3) intermediate components, such as treatment plants and water reuse and recycling facilities. A schematic diagram of the components of a river basin system is given in Fig. 14.2. This figure shows the water supply system (groundwater and surface water), the delivery system (canal network), the water users system (agricultural, municipal, and industrial), and the drainage collection system (surface and subsurface). The upper bound of a river basin is atmosphere through which mass (e.g., precipitation) and energy (e.g., radiation) exchange takes place. These exchanges have important influences on the hydrologic processes that take place in a basin. Besides natural, the human influence has significant bearings on the state of resources in a basin. This influence is exerted through artificial interventions (impoundments, diversions, deforestation, etc.), and the use of water for consumptive uses, such as municipal, agricultural, etc. affecting its availability; and application of chemicals and fertilizers thereby affecting its quality. An integrated basin management model must take into account both the quality and quantity aspects.

Integrated water resources management (IWRM) has been defined in many ways. According to The Technical Advisory Committee of the Global Water Partnership (TAC, 2000) *IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*. This definition emphasizes that IWRM is not a goal in itself but it should be viewed as a process of balancing and making trade-offs between different goals in an informed way. In this process, there are two fundamental categories of integration, the natural system and the human system. The water managers face a variety of challenges, circumstances differ greatly among and within countries, and policies and practices that are acceptable in one place may not be appropriate for another. Therefore, IWRM is not a blueprint, nor does it come with an instruction manual valid for all eventualities. IWRM stresses the interrelationship of actions of different types, working at different levels of influence. Moreover, water cannot be taken in isolation and water policies must also take account of other sectoral policies, in particular land use (GWP, 2002).

A conceptual view of IWRM has been presented by van Beek (2002) who termed it as a 'structured process of policy analysis.' This view, shown in Fig. 14.3, emphasizes the integrating character of IWRM among three systems: natural, socio-economic, and institutional. Integration in the natural system in itself has many components, the first being integration of land and water. The storage and consumption of water depends on the properties of land and vegetation cover. Traditionally, water management tends to pay more attention to *blue water*, water that can be extracted from surface bodies and aquifers. However, equally important is the management of *green water*, water stored in plants. An integrated management of green and blue water can result in substantial saving of water, higher use efficiency, and higher crop yields. The other important components requiring integration are water quality and quantity, upstream and downstream interests and fresh and saline water management. Faced with such a range of issues, IWRM was viewed as an integrating handle by TAC (2000) as shown in Fig. 14.4. In a river basin, water storage/utilization in upstream areas changes the patterns of floods and recharge in the

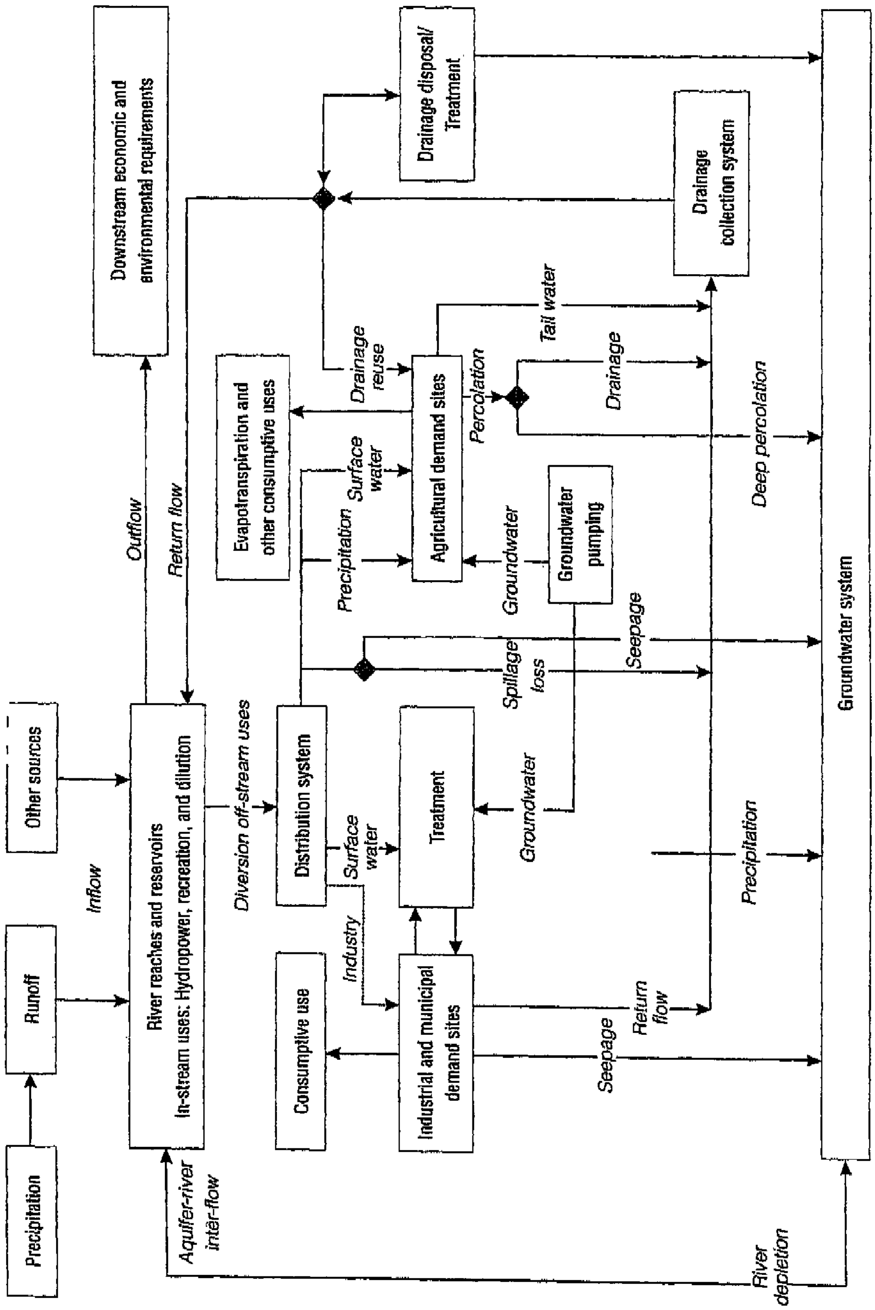

Fig. 14.2 Schematic representation of river basin processes [Source: McKinney et al. (1999). Copyright © International Water Management Institute. Used by permission].

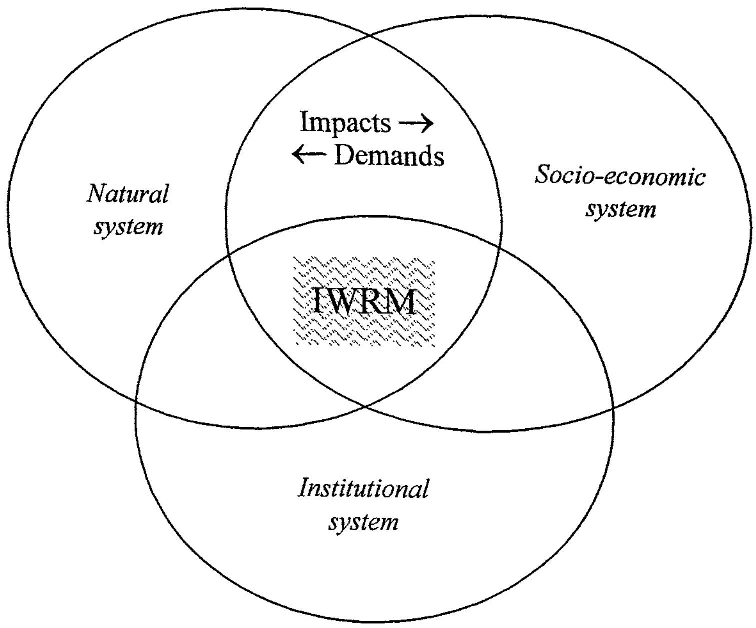

Fig. 14.3 A conceptual view of IWRM, showing interactions among related systems.

downstream reaches and water use upstream influences the quality and quantity of water available to downstream stakeholders. All this is likely to give birth to conflicts. Sometimes, these conflicts become quite bitter if the upstream and downstream areas fall under different political entities (recall the example of the Middle East region in Chapter 1). An integrated management recognizes these physical and social linkages and attempt to manage them properly.

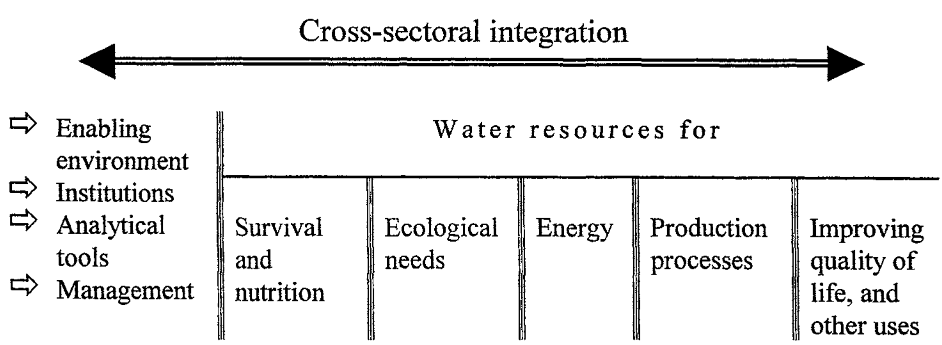

Fig. 14.4 The concept of IWRM as an integrating handle, growing from subsectoral to cross-sectoral management [Adapted from TAC (2000)].

Water resources management modeling of a river basin system should include not only natural and physical processes, but artificial "hardware" (physical infrastructure projects) and "software" (management policies) as well. This classification of management components in two parts was discussed in Chapter 1. An ideal management model also needs some sub-model of human behavior in response to policy initiatives. In a simple way, this can be introduced through price elasticity of demand coefficients.

Alleviation of poverty is the key issue in most developing countries and it is closely linked to provision of good quality water and sanitation facilities to the poor. These services should be priced so that the charges do not put an unreasonable burden on them but at the same time, the wastages are minimum.

In a basin, water is used for in-stream purposes, including hydropower generation, recreation, waste dilution, as well as off-stream purposes that are differentiated into agricultural water uses and municipal and industrial (M&I) water uses. The steps for management of water in a basin are depicted in Fig. 14.5 on the same lines as given in Section 9.4. IWRM is concerned not only with the management of the various projects in a basin but also with the utilization of water for consumptive uses, non-consumptive uses, and in-stream uses. The quality of water that is returned to the system after various uses should conform to the standards laid down.

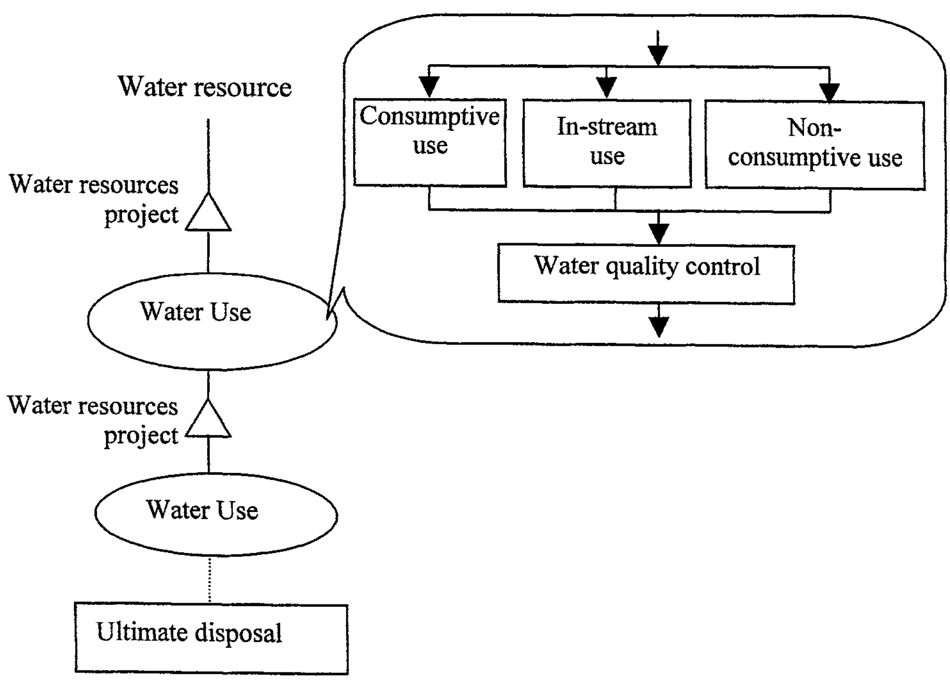

Fig. 14.5 Steps in water resources management.

Following van Beek (2002), an IWRM study can be divided in three phases: inception, development, and selection. During inception or initial analysis, the objectives of the study are defined; and the parameters, such as the base year, the time horizon, the growth rate, the discount rate, the boundaries of the analysis, and its details, etc. are fixed. The commonly studied scenarios include business as usual (BAU), the possibility of large-scale use of new technology, or any other setting that may be appropriate in the prevalent socio-political environment. The development phase consists of extensive data collection, model set-up, and bottleneck analysis. About 10-15 strategies may be examined in the final section phase which includes impact assessment, scenario analysis, and sensitivity analysis.

14.3.1 Conjunctive use of Surface and Ground Water

As rivers and aquifers are two interrelated sources of water in an area, it is rational to manage them jointly. A joint use of surface and subsurface water is necessary for cost-effective environmental friendly water management in a stream-aquifer system. The term *conjunctive use* of water denotes coordinated use of surface and ground water in space and time. Thus, when surface water is scarce, ground water is utilised (subject to the availability) to meet the demands and when surface water is in excess, ground water is recharged. The main advantage of the conjunctive use is an overall increase in benefits and reduction in adverse affects due to non-sustainable use of either of the resources. Such a management is also necessary to control water logging, soil salinity, and increase irrigation efficiency.

Traditionally, surface water is considered as a source of energy while ground water requires energy to pump it out. In view of this, a coordinated use of the two resources is an attractive proposition. Another major advantage of the conjunctive use is higher reliability of meeting demands and reduction in the required storage capacity of surface reservoirs. This can be possible because the underground aquifers are also used as storage. An added advantage of the aquifer storage is that there is no loss of water due to evaporation and the quality of water is also better than surface storages. Despite many obvious advantages of conjunctive use, such practices are not very widely followed. In many places in the world, wells are drilled by farmers to supplement irrigation without any centralized plan. Although farmers may be using both sources, such a utilization is not truly a conjunctive use system because there is no monitoring on withdrawal and no planned schemes for recharge.

The conjunctive use also yields greater flexibility in the choice of source to meet demands. If water from a source is not suitable for some demands, the alternate source can be tapped. The drainage problems are in conjunctive use systems because ground water is pumped in the locations where the water table is at a shallow depth. Note that if aquifers have consolidated due to severe overdraft of groundwater, it may not be possible to restore the status by artificial recharge.

There are three possible strategies in a conjunctive use system: a) conjunctive use in time, b) conjunctive use in space, and c) a combination of (a) and (b). In the first case, surface water is used when it is available in sufficient quantities and ground water is used during lean flow season. In case of (b), parcels of lands are assigned to surface and ground water resources, depending upon topography, hydrogeology, vulnerability to water logging, etc. However, in this system, enforcement may be difficult particularly if the prices of surface and sub-surface water have large differences. The third strategy is undoubtedly the best, since it exploits the advantages of the first and second strategy.

The water resources literature contains numerous models and studies on the conjunctive use of surface and ground water resources. Gorelick (1983), Willis and Yeh (1987), and Coe (1990), among others, provide excellent reviews of integrated water quantity and quality management modeling in aquifer and stream-aquifer systems. Young and Bredehoeft (1972) used a detailed hydrologic simulation model in conjunction with a net benefit optimization model to address a conjunctive use problem in Colorado, U. S. A. They found that centrally controlled groundwater development would probably lead to greater net benefits than would unregulated development. However, usually ground water is pumped both by government-owned and privately-owned wells and there is simply no regulation on its use.

Conjunctive use is an area in which LP and DP techniques have been applied extensively. Billib et al. (1995) developed a multi-step modeling approach for a multi-objective decision problem of a conjunctive use. The system that they studied had a surface water reservoir with a hydropower plant, an aquifer, an artificial recharge area, pumping fields, and a distribution system for five irrigation areas. Their formulation also considered irrigation, hydropower production, water supply, as well as water quality maintenance. The authors applied a three-step procedure to combine the short-term (hydrologic year) decision with the multiyear analysis.

Wong et al. (1997) presented a methodology to determine the multi-period optimal conjunctive use of surface water and ground water with water quality constraints. The methodology included three models: a two-dimensional groundwater flow model, a two-dimensional contaminant transport model, and a nonlinear optimization model. The flow and contaminant transport models were solved separately. Based on the results, a drawdown limit and a concentration limit were established in the optimization model to determine, for each time period, the water supply from the surface water source, the groundwater source, and an imported source. Conjunctive use modeling was an important component of the Ganga-Brahmputra study that was described in Section 9.12.

14.3.2 Models for Integrated Water Resources Management

An early program wherein the concept of river basin modeling was introduced was the Harward Water Program (Maass et al. 1962). The development and application of mathematical models saw a rapid growth in the 1970s and the 1980s with the advent of computers. There is a long list of models that address a wide range of water resources problems – many of these are problem specific and many are general purpose. The first generation of river basin models mainly focused on hydraulic and hydrologic aspects such as flood routing, reservoir regulation, etc. Side by side, models for water quality simulation and sediment transport were also developed. The Streamflow Synthesis and Reservoir Regulation (SSARR) model of USACE (1987) was a widely used model in the 1980s. The

SIMYLD-II model of Texas Water Development Board (1972), USA, was based on network flow programming techniques to simulate a river-reservoir-diversion system. The HEC-5 model of the Hydrologic Engineering Center is widely used to simulate operation of a system of reservoirs.

The models that are able to consider both hydrologic and water quality aspects could be labeled as second generation models. With wider availability of personal computers and use of graphical user interfaces, the models began to employ interactive analysis and graphical display of results. The Interactive River-Aquifer Simulation (IRAS) model by Loucks et al. (1995) simulates flows, storage, water quality, hydropower, and energy for pumping in an interdependent surface water-groundwater system. It made an extensive use of graphics capabilities in system simulation. The later improvements in the model included sediment transport modules, interfacing with a watershed runoff component, or other user-defined modules. This model has been used in many countries.

Basin-scale models that require hydrologic, crop, and economic input data and simulate the behavior of various hydrologic, water quality, economic, or other variables under a fixed set of water allocation and infrastructure management policies are being increasingly used to assess the performance of water resources systems. A useful outcome of simulation of operation of a water resources system under a range of conditions is identification of the system components that are likely to fail. The models that use detailed hydrometeorological input data can also be employed to assess the system performance under various scenarios of climate change, and changing demands, such as those due to population growth, change in command areas, cropping patterns, etc.

The European Hydrological System (SHE) model has been developed as a joint effort by the Institute of Hydrology in Great Britain, SOGREAH (France), and the Danish Hydraulic Institute (DHI) (Abbott and Refsgaard, 1996). SHE is a distributed and physically based modeling system for describing the major flow processes of the entire land phase of the hydrologic cycle. Note that this is not a system management model but results from such models can be useful in RBM. MIKE SHE is a version of this model that is supported by DHI (1995) and it has a number of add-on modules for specific problems, like water quality, soil erosion, or irrigation. MIKE SHE is being used by several academic and research organizations, and consulting companies. However, large requirements of input data, computer resources, and trained staff mean that such models are mostly applied by major government and academic/ research institutions or consulting firms. The philosophy and role of distributed hydrological models in water resources management has been described by Abbott and Refsgaard (1996).

Increasingly, the water quality simulation capability is a standard feature of river basin models. Early water quality models were one-dimensional and could compute only temporal variation of relatively few water quality variables, such as temperature, dissolved oxygen (DO), and biochemical oxygen demand (BOD). Subsequent models that accounted for spatial variability were one-dimensional and allowed for simulation of more complex variables subject to adsorption or decay processes, such as nutrients and coliforms. Recently, three-dimensional, time-dependent models incorporating more realistic description of processes affecting water quality have appeared. A widely applied water quality model is the Enhanced Stream Water Quality Model (QUAL2E) of the United States Environmental Protection Agency (EPA 1998). QUAL2E simulates temperature, DO, BOD, chlorophyll A, nitrogen (organic, ammonia, and nitrate), phosphorus (organic and inorganic), and coliforms in addition to constituents with user-defined decay properties. It is a widely used tool as far as water quality modeling is concerned. The Water Quality for River Reservoir Systems (WQRRS) developed by the Hydrologic Engineering Center (USACE 1998) simulates DO, total dissolved solids, P, ammonia, nitrate, alkalinity, total carbon, organic constituents, and a range of aquatic biota.

The third generation of models refers to interactive models that are supported by graphical user interfaces, GIS for input and analysis of spatial data, and screen display of results. These models are gradually becoming common in river basin simulation. The WaterWare model was developed by a consortium of European Union-sponsored research institutes under a collaborative research programme Eureka EU 487 (Jamieson and Fedra, 1996a). WaterWare has a GIS component and modules for expert systems, a two-dimensional, finite-difference groundwater model. It has modular architecture and components for demand forecasting, water resources planning, and ground and surface water pollution. WaterWare has been applied to the Thames River basin in the U. K., and the Rio Lerma basin in Mexico (Jamieson and Fedra, 1996b).

The Tennessee Valley Authority (TVA) Environment and River Resource Aid (TERRA) model is a reservoir and power generation operations management tool linked to a local area network for real-time functioning of the complex TVA system (Reitsma et al. 1994). A unique feature of TERRA is that it manages hydro-meteorological input and processed output data for a range of users with different levels of security access. TERRA model has been developed specifically for the TVA system and, therefore, cannot be applied to other river basins without modifications.

RIBASIM (River Basin Simulation Model) developed by Delft Hydraulics (2002), the Netherlands, is a powerful software for river basin simulation and modeling. This software is capable of simulating the behavior of river basins under various hydrological conditions. The model is a comprehensive and flexible tool which links hydrological inputs at various locations with specific water uses in the basin. It is also capable of evaluating a number of alternatives related to infrastructure, operational and demand management through an advanced DSS. RIBASIM has facilities to link to a GIS. The important modules of RIBASIM are:

WADIS is a generic district water balance model. It calculates the water demand or water surplus of districts (hydrological units, i.e., watersheds or parts thereof). It makes use of other models, such as AGWAT, to calculate the water demand of certain use categories.

AGWAT is a generic agricultural water demand and impacts model that can be linked to RIBASIM/ WADIS as a subroutine.

HYMOS is a hydrological data processing and analysis system.

The MIKE BASIN is another water resources management tool developed by DHI. It is structured as a network model in which rivers and their main tributaries are represented by a network consisting of branches and nodes. MIKE BASIN uses a graphical user interface with a linkage to ArcView GIS. The model output includes information on the performance of each individual reservoir and irrigation scheme within the simulation period, illustrating the frequency and magnitude of water shortages. The combined effect of selected schemes on river flows can also be handled through simulation of the time series of the river flow at all nodes (DHI 1997, 1998).

McAimen et al. (1999) have grouped the basin scale models in two types: models that simulate water resources behavior in accordance with a defined set of rules governing water allocations and infrastructure operations and models that optimize and select allocations and infrastructure based on an objective function. In their opinion, the assessment of system performance can be best addressed with simulation models while the optimization models are more useful if the main goal is the improvement of system performance.

14.3.3 Impact of Climate Change on Basin Management

Climate is a dynamic system, subject to natural variations on all time scales, from years to millennia, and is also influenced by anthropogenic activities. Over the past century, the concentration of radiatively active greenhouse gases, mainly carbon di-oxide (CO_2), nitrogen oxide (N_2O), methane (CH_4), and chlorofluoro-carbons (CFCs) in atmosphere has steadily increased. It is widely believed that a fall out of this greenhouse effect is the gradual rise of atmospheric temperature or global warming. Estimates indicate (Mimikou, 1995) that a doubling of the concentration of greenhouse gases may cause the annual temperature to increase by 3.0 ± 1.5 °C over the next 50 - 100 years.

The results of many recent studies have firmly established that the global climate is undergoing long-term changes. Global concentrations of carbon dioxide have increased by about 25% since the industrial revolution (Lattenmaier et al., 1996) and are expected to double within about next 80 years. The results of paleoclimatic and atmospheric general circulation model (GCM) studies show that global temperature is related to concentration of carbon dioxide in the atmosphere. According to indications, it is broadly expected that the average atmospheric temperature will gradually increase in the future – the increase will be more at poles compared to the equator. Warmer temperatures are likely to lead to more snowmelt, higher precipitation, and higher evaporation. An important consequence of the changes in the behavior of these variables will be changes in the hydrologic cycle (see Fig. 14.6). It may be cautioned that there is considerable uncertainty and difference of opinions about the extent of climate change and its consequences. Nevetheless, the implications of changes are important in water resources planning and management.

A range of mathematical models are used to simulate the climatic processes. The GCMs are three-dimensional models that have a detailed representation of the atmospheric motion, heat exchange, and land-ocean-ice interactions. These models are highly complex, require huge data, and large computer resources to run. But GCMs have coarse spatial resolutions and limited representation of surface hydrology. Besides, there are no unanimous opinions on phenomena, such as increased stomatal resistance and high water use efficiency of plants in the high CO_2 environment. Many atmospheric processes are not yet fully understood and hence, the changes in the components of the hydrologic cycle are still poorly understood. Despite these limitations, currently GCMs are the best tool to obtain information on possible future climate changes in hydrological variables, such as temperature, radiative fluxes, precipitation, evapotranspiration, and runoff.

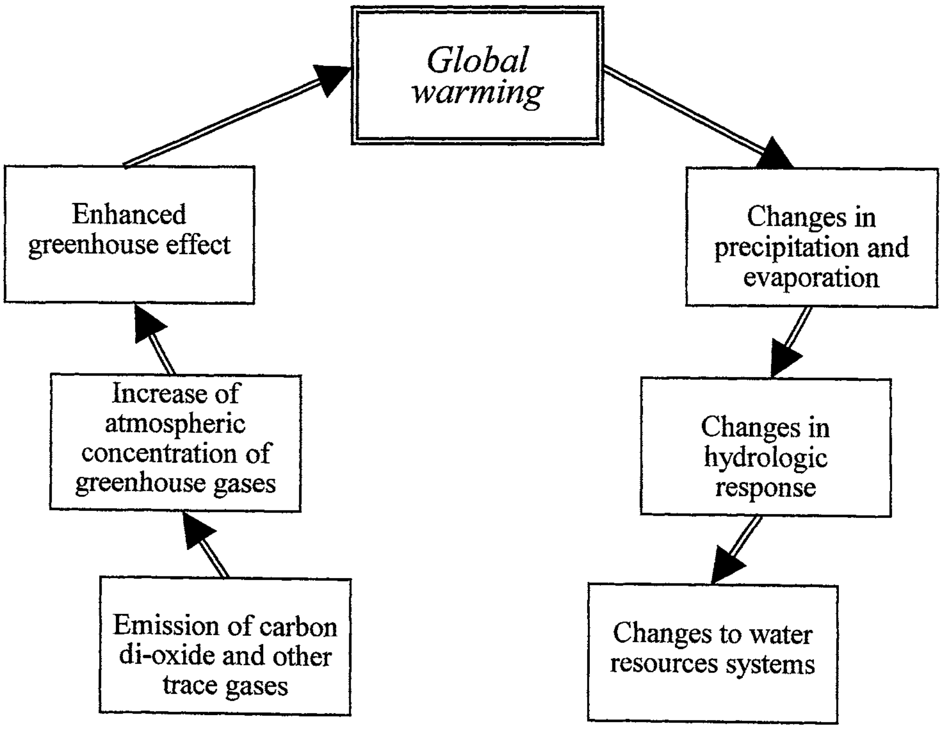

Fig. 14.6 The hydrologic cycle in the greenhouse effect [Source: Mimikou, 1995].

Although people have different opinions on impacts of climatic changes, for the managers of river basins, it is necessary to understand and assess the impacts of these changes on hydrologic processes in the basin so that the design and management policies of the projects are updated to overcome additional problems that are likely to arise. The consequences of global warming that will require attention of water managers are the impact on precipitation, snowmelt, volume and peak of runoff hydrograph, and recharge to groundwater. In general, it is expected that higher temperature will result in higher of snow and ice melt, leading to shrinkage of snow and glacier-covered areas, including polar snow cover. A likely fall out will be a rise in the ocean water level and flooding in coastal areas.

Warmer global temperatures are expected to result in higher evaporation. However, this is a general and non-quantified statement which does not indicate how the hydrological processes in a river basin will change due to climate change. An important component in understanding the change in river flows is the sensitivity of runoff to precipitation. This is the ratio of the percent change in river flow to the percent change in precipitation; typically it is large for catchments in arid regions, indicating higher changes in runoff as compared to humid regions. Streamflow is less sensitive to changes in potential evaporation. In catchments where snowmelt has significant contribution to streamflows, the change in the pattern of snowmelt introduces additional complexity. A consequence of higher temperature would be a change in the time distribution of streamflows. Most current models which are employed to predict the change in runoff as a result of climate change do not account for all the linkages of climate processes. For example, warmer temperatures would lead to higher evaporation and higher precipitation but this may also be accompanied by higher cloudiness. Consequently, there may be lesser net radiation input to catchments and thereby less evaporation. The capacity of atmosphere to hold water vapors also increases with temperature and it is not clear as to how this will affect precipitation. Studies also suggest that the transpiration process in the plants may also be different in the changed climate scenario. The patterns of surface wind might also undergo major changes which are not completely known. In general, more frequent occurrence of severe storms and more severe floods and droughts are expected.

Regarding the recharge of groundwater consequent to precipitation and evaporation changes, the picture is still more complex. A warmer climate would lead to increased evaporation from land as well as inland water bodies and this will reduce infiltration. However, infiltration is also highly dependent on the intensity and distribution of precipitation and it is not known how these will behave in future. Moreover, infiltration mostly takes place in the upland areas of a catchment, while groundwater pumping takes place mostly in the downstream agriculture areas. In the countries where extensive agriculture is carried out, irrigation water is an important source of groundwater recharge. In warmer climates, this recharge is likely to be less because of higher evapotranspiration and improved water management practices are likely to be widely adopted. When all the above factors are combined, it leads to a very uncertain scenario of hydrology, should major changes in the global climate take place.

It is important to highlight that the complexity of weather processes makes it difficult to quantify the changes either in spatial or temporal domain. The models that are currently being used to generate climate scenarios have coarse spatial resolutions and the models to assess the sensitivity of hydrological processes to climate change are based on simplifying assumptions. Therefore, looking at the overall scenarios, the attempts to predict the socio-economic consequences of climate change are highly uncertain at this stage.

The assessment of the impact of climatic changes on water resources involves (Mimikou, 1995): a) quantitative estimate of changes in the long-term indices of the major climatic variables, such as temperature, precipitation, and evapotranspiration; b) simulation of the hydrologic cycle for a basin of interest using the scenarios developed in the previous step; and c) assessment of the implications of the previously identified hydrologic variations for the performance and reliability of reservoirs, canals, aquifers, etc.

The storage of water, either at surface or below earth's surface is an important part of water resources management. The major question that is to be answered is how well the existing systems would perform when the variabilities in input and demands that could be induced by the climate change take place. No doubt the operational policies will have to be modified to account for additional variabilities produced by the climate change. The design practices may also require some changes. Typically, under the new scenario, flood peaks may be higher and the duration and severity of dry periods longer. It is likely that some of the existing systems might be inadequate to provide the services at desired reliability in the changed scenario. Some of the measures to quantify the climate change impact are the magnitude, number, and length of periods of deficits. In flood control systems, the flood damages in the current and new scenario could be the performance criteria. For hydropower projects, the reduction in the firm power or overall power generation can be used as a performance measure. The existing generalized models of developing operational policies can be used to modify management policies in the new scenario too.

The aim of water resources management is to provide the services at a reliable scale even in presence of climate variability. However, it is certain that climate change would throw open more serious problems in an already complex stage of water resources management. In the United States, some studies have been completed to reallocate storages in reservoirs as a result of changing water demands and users. Studies have also been undertaken to find out how the reliabilities of surface storage would change due to seasonal shape in the snowmelt dominated streamflow of north American rivers. For example, Sheer and Randall (1989) evaluated the performance of California State Water Project and Central Valley Project for several climate change scenarios. A broad conclusion of some studies was that, in general, the reliability of the system to meet water supply demands was mainly related to the size of the reservoir and less to the operation policies.

Since the climate change and the resultant affect will not be sudden but rather would occur gradually, it will be useful to review and modify the operation policies of a system after a certain time interval. This will permit the system operation to gradually adapt to the new scenarios and the limitation of the system can also be brought out as they begin to hamper the operation. As a result, sufficient warning and adjustment time will be available to undertake a system re-orientation or expansion.

14.4 DECISION SUPPORT SYSTEMS (DSS)

The management of natural resources requires an integration of large volumes of disparate information from diverse sources. A framework is required to couple this information with efficient tools for assessment and evaluation that allow broad, interactive participation in planning and decision making process and effective methods of communicating results to a broader audience. Better and useful information needs to be made available to a larger number of participants in more open and participatory decision making if information is to be effectively integrated into decision making processes. It is a challenge to integrate new information technologies with traditional methods of analysis and to put these tools to work in practice. A DSS helps in attaining this objective. The integration of techniques, such as database management, GIS, simulation and optimization models, interactive, graphical user interfaces, animated graphics, hypertext, and multi-media systems, has the necessary power and flexibility to support environmental planning and management (Fedra, 1994).

Advances in information technology have made it possible to easily access large volumes of information and databases. Since the people involved in decision making may include analysts, technical managers, policy makers, as well as the affected public, a new paradigm of man-machine systems is needed to handle the various phases of the problem definition and solving. The information being provided should be adequate and understandable to all those involved in the decision making process. An information system that can cater to all these needs must be well conceived with due attention to psychological, cognitive, and institutional aspects. Mallach (1994) has provided a discussion on human decision making process.

Nowadays, almost everyone who is involved in water resources planning and management uses mathematical models, typically to estimate the inputs to the system, to understand the system in a better way, or to examine the consequences of a decision or policy. However, many decision-makers are not able to effectively use the models either because the inputs are not readily available, or cannot be put in the desired format, they are not in a position to interpret the output, etc. An effective and widespread application of models requires development of user-friendly interfaces so that a bigger group of users utilize them to obtain the desired information.

14.4.1 Definition and Objectives

'Computer-based models together with their interactive interfaces are typically called decision support systems (DSSs)' [Loucks, 1995]. Morton (1971) viewed a DSS as "an aid for those management problems that are large, unstructured, ... and that involve management judgment." The typical user of a DSS might be a decision maker who may want to view a problem in various perspectives and solve it rapidly or those who require results to make an informed decision. The common objective of all DSSs is to provide timely information that supports decision making. Note that time is critical here. Decision makers need information when the opportunity to use that information exists, for any information provided thereafter is of not much use. This need is the key consideration that motivated the development of DSSs.

The key to useful computer based decision support is integration. It implies that in a real-world application, several sources of information or databases, more than one problem representation or model, and a multi-faceted and problem-oriented user interface, ought to be combined in a common framework to provide a realistic, timely, and useful information. At the level of data and background information, numerous and often incompatible, non-commensurate data from disparate sources have to be compiled together. The user should be provided processed data of controlled quality. The objective of a computer based DSS for water resources management is to improve planning and decision making processes by providing useful and scientifically sound information to the user.

14.4.2 Need and Types of DSS

The need for DSSs probably came from two main reasons. First, there is the necessity of wider practical application of systems analysis models. An important reason behind scanty application of these models is that the real world problems are often big in size, complex, and less structured. An application of models may require properly organizing a lot of input data. Often those responsible for handling real world problems are not skilled in using computers and models. If these modeling tools are to be used effectively on a broad scale, the field personnel need support, help, and a framework in which these can be easily applied. DSSs are supposed to help in this.

The second reason is the need for timely information to arrive at decisions. In fact, the information needs in decision making process are the key motivators for development of DSSs. The decision making can be improved by a judicious pooling of humans and machines. Loucks (1995) presented an illustration (see Fig. 14.7) of objectives and information characteristics associated with various levels of decision making.

Depending upon the purpose that they serve, DSSs can be divided into seven types [Mallach, 1994]. The *file drawer systems* retrieve data from a database. The *data analysis systems* additionally perform some analysis of the data. An *analysis information system* can combine information from several files. In *accounting models*, the calculations are performed using the data from that time period. A computerized spreadsheet is an example of accounting models. *Representational models* forecast the future effects of a decision. An *optimization system* selects the best among several alternatives. *Suggestion systems* can provide an optimal solution when decisions are highly structured. In some ways, these systems are close to expert systems discussed in Chapter 3.

14.4.3 Components of a DSS

The design of a DSS largely depends on the purpose(s) that it is to serve. The information needs of a decision-maker depend on the issues being addressed and the level of decision making required. Therefore, the DSS developers need to know what information is used in decision making and the appropriate format. The analysis tools in a DSS include models of environmental, economic, and social processes. Typical components of a DSS are:

a. Tools to help in system design and determine operation policies;
b. optimization and simulation models to determine values of decision variables or system performance indicators, given inputs and constraints;
c. algorithms to calibrate environmental models;
d. empirical models that can be used for quick calculations with limited data;
e. geographic information systems (see Section 3.2), for analyses and display of spatial data;
e. knowledge based expert systems (see Section 3.4) that can process rules and data to draw conclusions and can provide an explanation of how those conclusions were reached;
f. management information systems (databases and analysis tools); and
g. statistical, graphical, and spreadsheets software for data analyses and display.

The input and output data of a DSS can be in a wide variety of forms. Most commonly, the interactive input is in terms of numbers that might be obtained through a

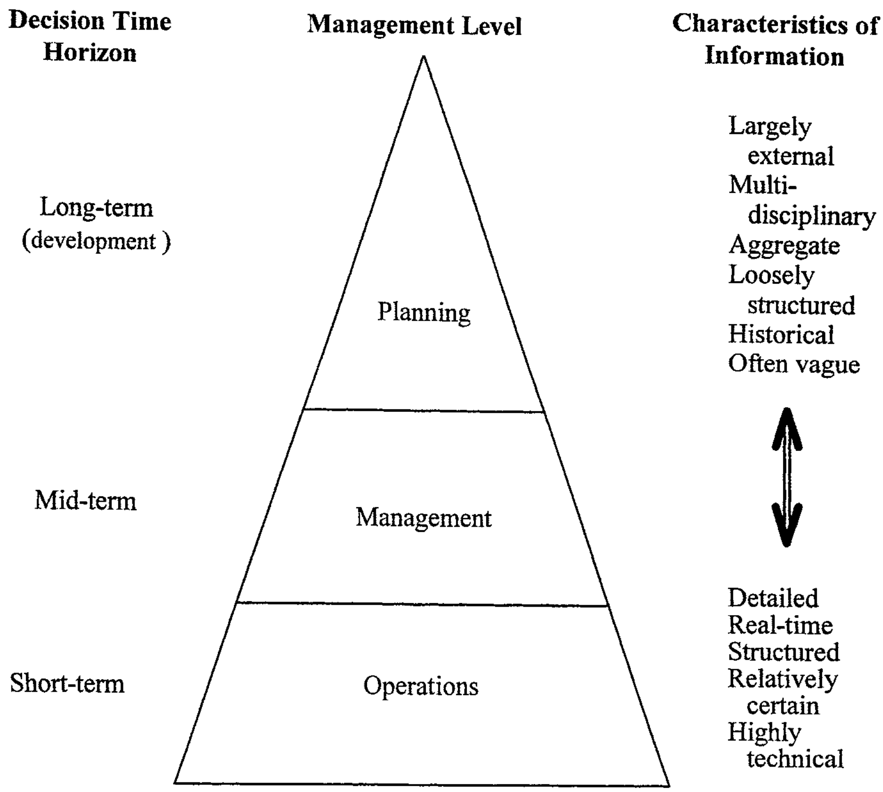

Fig. 14.7 Decision pyramid and information characteristics associated with various types of decisions [adapted from Loucks (1995)].

series of questions. In a GUI, the user may click one of several buttons to indicate his choice. The output can be tables, text, time- or space-series graphs, maps, and video animation.

The input data to a model may be: control parameters, such as time step size; global parameters, such as the density of water; dynamic data, such as the time series of river stages; and spatially distributed data, such as the landuse map. These data will come from numerous sources, in different formats and with different quality. Their integration into one unifying information system requires a number of tools to process the original data and store it in a common format. A database management system, discussed in Chapter 2, is necessary for this purpose.

Input data preparation is often the main effort while applying a model. Hence, the integration of databases and models, that allows users to automatically retrieve and load input data for modelling, is a natural step. Computerised databases of water resources, and social and economic variables are now increasingly available in digital form and many of these can be accessed through Internet. Some organizations maintain databases of time series and the user has to only specify which series is needed and its duration. A user can obtain data from a computer database irrespective of his or database's location, can analyse the data, and share the results in text as well as graph forms with other users. These capabilities clearly provide tremendous options for information processing and communication.

Mathematical models are an important component of a DSS. The commonly used mathematical models include optimisation, simulation, statistical models, decision analyses, genetic algorithms, and neural networks. The choice of a particular model depends on a number of factors, such as the type of problem, data available, personal preference and the result that the decision maker is looking for. Often, an integrated use of different methods, e.g., simulation and optimization is also made. The simulation and optimization models have been discussed in detail in Chapter 5.

14.4.4 Designing a DSS

It is a good idea to spend some time to get an understanding of the main objectives of a DSS, the issues to be addressed, the information needs, and preferences of the potential users. Involving one or two key people from the user organization also helps in development efforts. Many useful tips on the requirements of users are difficult to specify beforehand and get clarified during product development. Without close association of the users in various stages of the DSS development, the chances of implementation and real use of the system are considerably diminished. Though the association of the users is easier said than done, the benefits are worth the efforts. This interaction also makes the users acquainted with the system and increases their confidence in the results.

Before commencing the development of a DSS, extensive discussions with the users of the concerned organisation help understanding their mental model and expectations from the DSS. Potential users can be approached to define the various tasks that they perform, the kind of help they expect from the DSS, the type of information needed in their analysis and how this is gathered, etc. A review and evaluation of existing DSSs should be taken up to learn their capabilities, including their model types and programming features, data input and display capabilities, documentation, model calibration and verification, interfaces, and reasons behind their success or failure.

The next stage is to translate these ideas into a framework or system architecture. Only after this, the development of various modules may be taken up. This approach will lead to a flexible and open architecture which will be easy to expand as the need arise. A flexible DSS architecture developed by Jamieson and Fedra (1996a) is shown in Fig.14.8. The main advantage here is that models of various complexities can be developed and incorporated in the system.

Evidently, many persons will be involved in programming of such a large system which requires different kinds of expertise. The team to work on visual and user interfaces will be different from those working on mathematical models; these groups can work in parallel and the development work can simultaneously proceed on many fronts. A good practice is to clearly define the variables of each module and insert sufficient comments in the code. This is helpful when a new person has to work with a program written by someone else. After each module is developed, it is first independently tested. Next, it is integrated in the system and then tested again. A good strategy is to add the components one by one and test the whole system after a new component is added. Special care is needed about data flow among the various modules. Keeping a log of the changes that have been made and preparing detailed notes for programmers obviates many future headaches. A detailed manual should be prepared for general users with illustrative examples. Besides the hard copy manuals, online help should also be provided. Since a DSS may have to be implemented on different hardware, it would be better if programming is hardware independent. Many current programming languages, such as Java, are highly portable.

When a workable prototype of the DSS is ready, it should be given to the actual users to carry out real work and their reactions should be observed and followed up. The feedback of these users should result in modifications and improvements. The development is an iterative process - designing, coding, testing, feedback, and improving. The process may never end as long as a particular DSS is in use.

Even with all user-friendly features, a certain amount of training of users is necessary. Training is an essential component of any large software package and it should be structures in such a way that a new user is brought to a reasonable level within a period of one week or so. The DSS documentation and training should cater to the requirements of the end users and for those who may be responsible for programming modifications and extension. The users guide can also be online, i.e., readable on-screen when the system is being used and should have search facility using key words. One may never lose sight of the fact that the user is the best judge of the suitability or otherwise of various modelling assumptions, interface design, and implementation. Therefore, aspects, such as user training, data entry, maintenance of the systems, its adaptations and updates, etc. should be given due attention at the design stage itself.

While the earlier DSSs used to run on a standalone system, these days client/server computing is in vogue because it offers many advantages. This configuration is also advantageous for DSSs that help a group of people to make decisions jointly, or group DSSs. Finally, like any other product, the measure of success of a DSS is in its usage and the additional benefits that arise from its implementation.

User Interface

Interaction is a central feature of any man-machine system and poorly designed interfaces are responsible for rejection of many versatile and powerful packages. A good interface allows the user to define and explore a problem incrementally in response to questions from the system user. Graphical displays are preferred media to communicate complex information. A good interface communicates the results to the users in a form that they can easily understand and facilitates interactions between the users and the computer. The visual interfaces also make it simpler to interpret the model output.

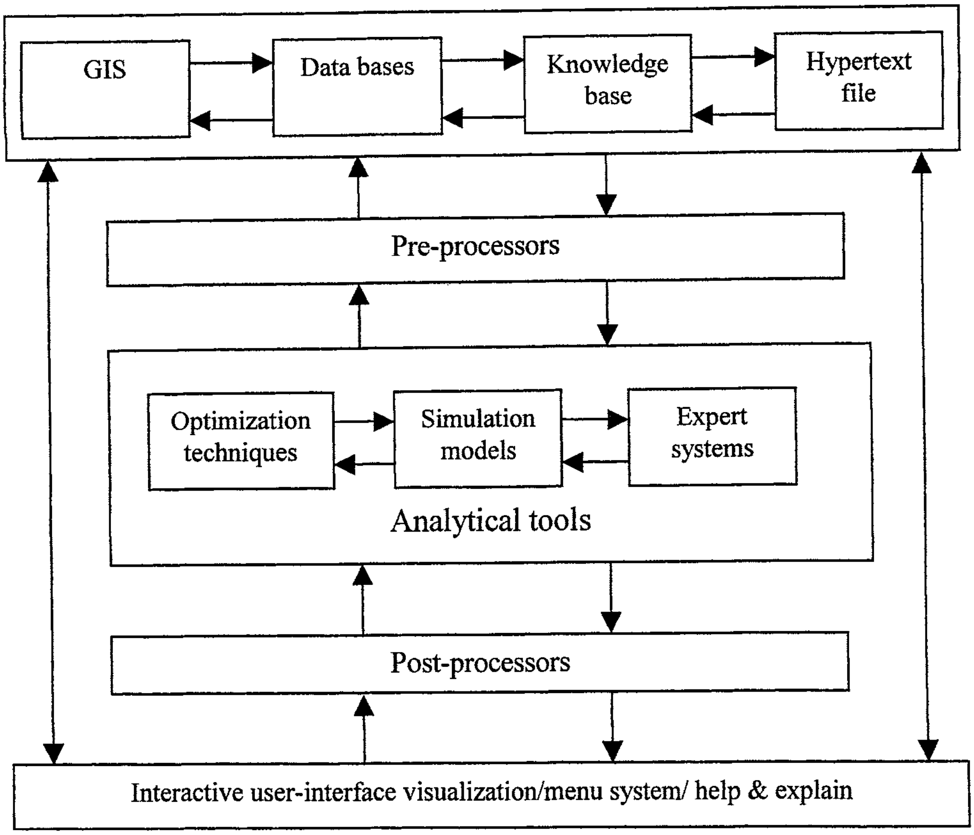

Fig. 14.8 The DSS system architecture of Jamieson and Fedra (1996a).

Many real-world planning or management concepts, such as risk or reliability, are rather abstract. Such concepts are better understood through graphical representation. Visualization is very effective to communicate and understand large amounts of highly structured information, and helps in intuitive understanding of processes, interdependencies, and spatial and temporal patterns.

Extensive guidelines for the development of DSS user interfaces are available (Mallach, 1994). It is a good practice to ensure consistency of data entry, display, control actions, and operational procedures. Repeated entry of long data should always be avoided. An interesting, informative, and enjoyable to use a DSS will surely have a greater value to the user. A good interface saves user's time, is versatile and easy to use, the user is able to recall how to use the system after he has not used it for sometime, provides on-line help, is adaptable to the users' needs, and should be interesting to use. Colors can give an attractive view to an interface.

The central idea to develop and implement a DSS is to support the users in the management and decision making process. Many of the potential users of DSSs would be experts or people with many years of practical experience and it would be advantageous to include their expertise and experience in the system. Another advantage of involving the users in design and development is that they begin to consider themselves to be part of the system and the problems of user acceptance are automatically solved. The users can also provide valuable suggestions in design of the interfaces and the input screens can be the same as the hardcopy forms that are used in their offices. For example, in a case in India, the acceptability of a data entry system was found to increase manifold when the screen layouts were changed to resemble the hardcopy forms that the users were familiar with.

The development of user interface is a simpler task these days due to numerous interactive graphics-based toolkits that eliminate the need to write modules for the graphical user interface (GUI). For ease of updating and portability, the interface should be an independent module of DSS. This allows easy customization to meet the needs of different users who may be using different languages, and having different skills and preferences. In fact, many popular operating systems, such as Windows, and software packages, such as word processors now have options to customise the pull down menus. Software tool kits to assist in developing the object oriented programs and visual interactive interfaces are widely available these days.

The development of user interface is a process of incremental improvements. Typically, a simple working skeleton is developed and the views of users on it are obtained (Loucks, 1995). The design is then modified based on their inputs and the process is repeated. One of the ways to get the reaction of users is the thinking-aloud method. While using the DSS, the user is asked to speak out his thoughts, what he is trying to do, what questions or confusion arise, what he expects will happen next, etc. The observations of the user and his reactions are noted by an observer. Such studies help pinpoint problems in users' understanding of DSSs, to identify problems, detect any annoying or confusing stage, and learn the users' feeling about the DSS.

14.4.5 Applications

Many DSSs are being applied to a wide variety of problems. The growth in the DSS development and use has been substantial in the water resources fields (e.g., Labadie, 1989; Loucks and da Costa, 1991; Santos, 1991). Some versatile tools have been described by Fedra (1992); and Diersch and Grundler (1993). Other studies describing the implementation of DSSs include a program for integrating hydraulic models with a supervisory control and data acquisition (SCADA) simulator in Illinois (Schulte and Malm, 1993). DSSs for simulating river system design and operation include those developed by Andreu et al. (1996), Basson et al. (1994), the Center for Advanced Decision Support for Water and Environmental Systems (1992), Ford (1990), HEC (1993), Kuczera (1990, 1993), Loucks et al. (1995), and Randall et al. (1995). Fedra et al. (1992) and Loucks and da Costa (1991) also discuss some of the applications of DSSs.

The WaterWare DSS was developed by Jamieson and Fedra (1996a) as a tool for river basin planning. It can address issues, such as what, where, and when new resources should be developed; formulating strategies for river and ground water pollution control programmes; assessing the environmental impact of water-related developments; determining the limits of sustainable development; and evaluating the impact of new environmental legislation. This software integrates the capabilities of GISs, database management systems (DBMS), modeling techniques, optimisation procedures, and expert system. The system architecture shown in Fig. 14.8 depicts an open, modular system with different degrees and mechanics of coupling at various levels of integration. The basic architecture comprises: 1) a main program to coordinate individual tasks and provide access through a menu of options, 2) a GIS to store, display and analyse geographical data (this could be a commercial product or user developed model), 3) a DBMS to provide access to non-spatial data (this also could be a commercial or a custom-designed dedicated system), 4) simulation, optimisation, expert system models which can access data from both the GIS and DBMS, 5) a set of pre- and post-processors which support mainly editing of input data and visualisation of model output, 6) a user interface with access to different functional components of the system and help files, 7) a set of utility functions which assist in data preparation and management tasks. A river-network editor can be used to configure the physical system.

The WaterWare system has a spectrum of analytical models of different sophistication giving the user a choice depending on his requirements. This package has been successfully applied to several systems. Jamieson and Fedra (1996b) have described studies for Thames River in England and Rio Lerma Basin in Mexico. These two basins had different types of problems; the Larma basin application was concerned with planning of basin-wide infrastructure while the Thames was an operation study. Such application results have clearly brought out the possible range of problems of water resources to which DSS can be applied.

The current technology allows integrating multimedia into a DSS which will improve the presentation of information, on-line help and interactive tutorials. In a multimedia environment, the user can also see the consequences of various decisions through video animation. Now that DSSs and the requisite computer hardware are widely available, the attention is to use the power of these tools to achieve higher levels of system performance.

14.5 INSTITUTIONAL ASPECTS OF BASIN MANAGEMENT

A vast and well-organized institutional structure is necessary to carry out the various tasks of RBM. Institutional structures consist of formal and informal working rules. The *operational rules* provide a framework for operations (sometimes also known as operational management), e.g., policy directives regarding storage and withdrawal of water from reservoirs and aquifers. The institutional structure for RBM should facilitate the necessary coordination within the water management sector and between the water management sector and other sectors, such as land-use and environment to achieve sustainable water use and maintain the balance of the river system. The institutional structure should also be a means of empowerment. All stakeholders, including economic interest groups, local communities, environmental NGOs, and women should be encouraged to play an active role in RBM.

Policy formulation, mediatory, regulatory and other management tasks should be well-defined, clearly allocated and made transparent. Since RBM is often characterised by parochial interests and intractable problems, leadership, and political commitment are essential to achieve progress.

The infrastructure requirements depend on the tasks to be performed in RBM. Four major tasks of a RBM organization are planning, construction and operation, The infrastructure and expertise needed for these are completely different. In light of this, normally the organizations have separate wings headed by an experienced officer to look after each of these. Although planning receives much attention in the initial years, it is in fact a continuous activity. If the requisite expertise is not available within the organization, it is necessary to involve experts from other institutes, sometimes through commissioned studies. The construction activities are the most important usually during the initial years when infrastructure is being developed and a large share of funds as well as man-power is allocated for the same. This, however, diminishes appreciably after the infrastructure is in place and this wing may be later responsible for routine maintenance jobs. In addition, the RBM organization may also be responsible for enforcement and implementation of decisions including legal issues.

14.5.1 Models of RBM

Normally, catchment boundaries do not coincide with political and social boundaries. Many human boundaries exist within and across a catchment, such as individual farms, villages, ethnic groups and provincial boundaries. This 'mismatch' between a basin perspective and socio-political perspective has important place in RBM. Mostert (1998a) has discussed three different models for RBM. The first is the *hydrological model* in which the organizational structure for water management is based on hydrological boundaries, i.e., sub-basins and so on. In the hydrological model, administrative boundaries coincide with hydrological boundaries and there is the least chance of upstream-downstream conflicts. At the topmost level, the entity that is responsible for overall management is the 'river basin authority'. Although this model is highly suitable for water management it may isolate water management from other relevant policy sectors, and intersectoral coordination may become a problem. Moreover, this model implies centralization of water management activities and it will not be preferred in countries with decentralized water management. This model is also not likely to suit international river basins. Due to these reasons, the hydrological model of RBM is a good option for smaller national basins only.

In the *administrative model,* the zones of control follow the political/administrative boundaries. Various bodies, viz., provincial, municipal, etc. may be assigned responsibilities for water management in the area of their jurisdiction. Clearly, in this model, the water management responsibility is not based on hydrological boundaries. An advantage of this model is that the relevant policy sectors, such as land-use planning, can be kept together and thus there can be better inter-sectoral coordination. However, there is a risk of upstream-downstream conflicts and the lack of a platform or mechanism to discuss these problems. The *co-ordinated model* is a mixture of the hydrological model and the administrative model. In this set-up, water management is performed following the administrative model but there are river basin commissions with a coordinating task. These commissions also provide a platform to discuss and resolve conflicts. They may consist of representatives of different bodies and ensure coordination in water planning and management.

14.5.2 Decentralization and Privatization

Some tasks related to RBM, such as irrigation water management, water quality control, etc. require at-site monitoring and require a decentralized management. There are several advantages in decentralization, the main being that it brings the government as close as possible to individual citizens. Second, decentralized administration is better informed about local circumstances. It also allows for local participation in the decisions which can be tailored to suit local circumstances and preferences.

Decentralization is also possible for tasks with a supralocal character, provided the decentralized governments cooperate with each other or are supervised by a higher level government. Supervision also improves enforcement of regulations in case the decentralized governments have too close relations with the persons and organizations they have to regulate. Decentralization is not possible for tasks, such as establishing the institutional structure and formulating policies that apply to a large region. Decentralization may also not be possible if the decentralized governments lack the necessary management capacity. This could be overcome by local capacity building and advisory services by specialized central governments. However, decentralized governments have superior information on local conditions because of their (usually) closer contacts with the population.

Another form of decentralised management involves participation of users in the supply of freshwater ecosystem goods at the local level. *User associations* are becoming popular in India and other parts of Asia and these help to ensure efficient allocation of water resources at the local level. Communication between farmers and governmental officials greatly increases after the formation of users associations. In addition, cooperation among users themselves reduced conflicts over water use. User associations are particularly effective where an efficient allocation of freshwater ecosystem goods requires intra rather than inter-sectoral reallocation (Dinar et al. 1997).

Privatization is frequently advanced as a solution to overcome bureaucracy, and inefficiency; the basic premise being that it leads to efficient services. The private companies have to reduce costs and make profits in order to survive in business. However, there may not be many competitors because of the involvement of higher costs and expertise. The basic purpose of privatization may be defeated in the absence of competition. To overcome this, it would be desirable to have a strong regulator who can control prices and quality of services. The regulator may, additionally, monitor the environmental parameters because many private agencies are not keen to improve or maintain the quality of environment.

Privatization is possible for specific services only; most commonly privatized services include construction and operation of dams, powerplants, water supply and wastewater treatment infrastructure, supplying materials and equipment, and maintenance works. Of late, projects are being handed over to private companies on the basis of build-operate-transfer (BOT) of facilities. Some functions, such as regulatory and policy making, have to necessarily remain with the government. In fact, private parties with departmental supervision frequently do construction. In many countries, projects like hydropower generation are being offered on a build-own-operate-transfer basis. Often, the infrastructure remains in the hands of government but the maintenance is on a contract basis. Finally, private firms may even own, operate, and maintain the infrastructure.

Another management option is to assign the responsibilities of water services through public limited companies. This option is midway between the above two options. These companies can have flexibility in decision making and raising money through various financial instruments. Their efficiency can be as good as a private firm and they can pay adequate attention to environmental aspects too. However, care is to be taken to ensure that they do not fall under the clutches of bureaucracy and become another organ of it.

Local institutions and NGOs also play an important role in managing river basins. Their involvement may prevent misuse and wastage. There are also instances of beneficiaries organising themselves to develop or manage a particular resource and prevent overexploitation. Based on their intimate knowledge of the resource, they may devise rules to limit use and may set up self-financing systems, self-monitoring systems, and conflict-resolution procedures.

Ten regional water authorities were created in England and Wales in 1974, dealing with both water utility and river basin functions (Merrett, 1997). In 1989, the utility functions of the water providers were transferred to independently regulated private agencies, while the environmental functions, e.g., flood defence and pollution control, remained in the control of a public agency. The U.K. experience shows that the benefits of privatising water utilities were limited. First, the main operational efficiency gains within regional water authorities came before they were sold, in order to encourage the initial privatisation (Kinnersley, 1993). Secondly, the backlog of capital spending and the EU's environmental legislation necessitated a large capital-spending programme, driving up overhead costs and pushing the rate of increase in charges well above the inflation rate (Merrett, 1997). In addition, the rationalisation of the utilities involved large-scale job losses. Shareholders seemed to gain to a large extent and the proportionate increase in salaries to directors was much higher than to other workers. As a result, the problems that privatisation had aimed to solve were replaced by another set of problems (Kinnersley, 1993).

14.5.3 Monitoring and Analysis

Monitoring of critical indicators of basin state is an important task of RBM. In many river basins, routine hydrometeorological observations are made by automatic equipment and these are communicated to a control station in real-time. In some countries, the real-time data of a few variables, such as river stage, water temperature, are available on Internet in real-time.

With the advancements in information technology, it is possible to combine on-line measurements with computer models to formulate forecasts. Flood early warning systems have been installed in many important basins in the world. Another possibility is to issue early warnings for water quality indices and alert public in events, such as accidental spills. Yet another step forward is the automatic operation of controls, such as canal gates, pumps, sluices, etc. A pre-programmed computer which receives input data as measured by sensors at regular intervals can control the operation of these devices. As a result, human operators are relieved of some of their routine works and the risk of human errors is eliminated.

Most of the efforts related to development of solutions to RBM problems have been directed to specific cases. Usually, software are developed in response to specific requirements. The efforts and challenges in developing general purpose and comprehensive RBM tools are considerably more. It is rather difficult to find a funding agency which may be willing to commit funds for an effort which is not immediately rewarding and well focussed. Further, the diversity of the RBM problem can be very large and extensive data of several basins with divergent settings will be required to test such software. It is unlikely that such data will be available with a single organisation.

Generally, there is a lack of data to fully describe and understand the complex processes that take place in a river basin and their interaction with the socio-economic system. In the absence of these, it is an enormous task to incorporate all considerations in a comprehensive tool at the river basin level. An important aspect is that many basin processes operate at various levels and scales. This calls for development of tools for different geographical scales and levels. Many such tools have been described in earlier chapters of this book. RBM also has an element of negotiation and the decisions taken may be dependent on the negotiating skills and strength of the concerned parties. Due to these reasons, the decision taken may not be consistent over a large basin and may differ from one decision maker to another.

14.5.4 Practical Aspects of RBM

It is one thing to know how river basins should be managed, it is another thing to actually manage them. Since RBM involves conflicting interests, naturally there is always a trade-off. The important question is how to achieve the best trade-off. In view of complexities and diversities of problems, at best some guidelines can be issued. But any guideline will be implemented only if it is "realistic". The guidelines should reflect the differing hydrological, socio-economic and cultural contexts and should be technically/scientifically sound.

Without a basic national legislative framework, RBM is not likely to succeed. For example, it should be clear who has jurisdiction over different waters. The concerned organization should also have adequate authority, support, and power to enforce rules. Plans loose their worth unless these are implemented in a timely fashion. The purpose of plans is to orient operational RBM and improve its effectiveness. Implementation is, therefore, a pivotal step in any RBM strategy.

Any strategy can benefit greatly from a feedback and periodic evaluation. Were the targets, and goals attained? Were the planned measures all implemented, and if not, why not? Were the measures effective? Could the planning process have been better, and were there any crucial bottlenecks in the legislative and organisational framework? Evaluations, such as these, can provide valuable input for a new round and contribute to a continuing improvement of RBM.

14.5.5 Role of Financiers

Many water resources projects require large financial outlays and it may be necessary to seek loans or funding from international financiers. Since the fund available with these financiers are limited and many of them are under obligation to advance the policies of their promoters, the proposed projects are scrutinized before funds are allocated. If the project fails to meet their norms, the funds may be denied till the design or operation is suitably modified. The adverse impacts of a project on environment are viewed very seriously these days and it is difficult to find a reputed funding organization willing to support a project which does not pass strict environmental tests. The international funding agencies are sometimes able to significantly influence the management policies by providing funds to the activities that are designed and operated by following relevant international treaties and agreements. Of late, most international agencies treat water as an economic commodity and emphasize on active participation of stake holders. For example, according to the new policy of the World Bank, water is treated as an economic good. The World Bank (1993) also emphasizes decentralized management and active participation by stakeholders.

14.5.6 Co-operation among Basin Management Organizations

New knowledge and technology are necessary to improve any set-up including RBM. The issues involved in technology and knowledge transfer and research cooperation are as diverse as the types of technologies and knowledge. Transfer of knowledge and technology are best attained in response to the needs in the receiving organization and should match its capacity to absorb. In practice, the technology transfer might also be motivated by the interests of the providers of a specific technology rather than by the needs of the recipient. One possibility to avoid this trap is through cooperation among the organizations responsible for basin management.

The cooperative activities include joint site visits, discussions and presentations, and exchange of information and staff. Usually, the aim is mutual learning with respect to the operational, policy and institutional aspects of RBM. To this end, short seminars are also organized where people from various organizations including academic institutes can interact with each other. Such cooperation always leads to development of improved expertise in the participating organizations. However, the ultimate outcome depends on the quality, interests, and motivation of the personnel involved.

14.5.7 Some Important River Basins Organizations

A large number of river basin organizations are functional all over the world. The

Tennessee Valley Authority (TVA) in U.S.A. (www.tva.gov) is one of the earliest river basin authorities. In its early years, TVA initiated a wide range of regional planning and development activities, including afforestation, extension programs for improved soil and land use management, and community development.

In U.S.A., the Mississippi River Commission (MRC) was created by Act of Congress on June 28, 1879. The general duties of the MRC include the recommendations of policy and work programs, the study of and reporting upon the necessity for modifications or additions to the flood control and navigation project, recommendation upon any matters authorized by law, inspection trips, and holding public hearings. The work of the MRC is directed by its president and carried out by the six Army Engineer Districts in St. Paul, Rock Island, St. Louis, Memphis, Vicksburg, and New Orleans. Current activities of the MRC are in three broad categories: a) general investigations to determine needed improvements, construction of new facilities, and maintenance and operation of existing systems. Included in its responsibilities are the main river from Cairo, Ill., to Head of Passes, and the basins of the St. Francis, Tensas, Yazoo, Atchafalaya, Lower Red, Lower Arkansas, Lower White, and west Tennessee rivers. The address of the website of the MRC is http://www.mvd.usace.army.mil/MRC.

The Thames Water Authority in the U.K. (www.thameswater.co.uk) is a classic example of integrated river basin management. The authority supports about 3500 abstractions -- 1200 for agriculture, 500 for domestic water supplies, and 1800 for industrial and other uses. The river receives industrial effluents at 6500 locations and effluents from sewage treatment works at 450 locations. Besides, the river is used for fishing and boating. The river flows are regulated and managed to ensure that discharges do not pollute water supplies and abstractions do not effect the level of the river to the extent that it puts at risk natural life or the enjoyment of those who use the river for recreation.

The Murray-Darling Basin Commission of Australia (www.mdbc.gov.au) has been managing the waters of one of the very dry basins in the world successfully and has contributed considerably to the economic development of that continent. In France, the river basin management is primarily based on water laws of 1964 and 1992. The law of 1964 divided France into six river basins, created River Basin Committees and Water Agencies, and a system of financial management. The 1992 law recognises water as a single unitary resource irrespective of its physical and geographical distinctions. The management of water is done in the framework of a river basin. The French system is basically founded on the following features:

(i) The water user pays for the water he is using and polluter pays for the water quality deterioration he is causing. The system takes into account the capacity to pay for each category of users (domestic, industrial and farmers for irrigation).

(ii) The water resources development and management are financially self-sustaining. The water charges are proposed by the Agency's Board of Directors and later on agreed upon by the River Basin Committee. Since elected representatives are also members of the River Basin Committee, there is general consensus on the water charges and recovery of water charges is satisfactory.

(iii) More than 90 percent of the money collected is afterwards redistributed under the form of financial assistance (loans and grants) either for pollution control action or for the development of water resources and their sustainability.

In Asia, the Mekong River basin covering the whole of the Lao PDR and Cambodia, one third of Thailand and two-fifth of Vietnam, is under a Mekong Committee. This was established by the ESCAFE now ESCAP (Economic & Social Commission for Asia and Pacific) in 1957 with its secretariat office in Bangkok and it coordinates the work of collection of basic data and river basin planning. The Mekong River Commission was created by four basin countries, namely, Cambodia, Laos, Thailand and Vietnam, under an agreement on the cooperation for the sustainable development of Mekong basin. In a study on Mekong basin, Chenoweth et al. (2001) found that the Mekong River commission has lacked the institutional capability to achieve integrated management of water resources of the basin. Good organisational capacity and a sufficiently strong environment are prerequisite for IRBM.

In China, the 1988 water law requires that basin plans should serve as the basis for water development, utilisation, and prevention of damage. There are seven commissions covering the six major river basins and one lake basin. These are central agencies having planning and regulatory functions under the Ministry of Water. The Yellow River conservancy commission has additional responsibility of flood management in lower Yellow River basin and operation of all the reservoirs. It has considerable financial strength and autonomy as a consequence of water and power receipts from operation of projects. However, major basins are not managed by a single agency.

The Mahaweli Authority in Sri Lanka is a body for both development and management of major storage and irrigation projects. It is also provided with a secretariat for planning and other water management activities.

India is a union of States and most of India's river basins are inter-state in nature. India's constitution provides power to the states to develop water resources within their boundaries, subject to the parliament empowering union government to regulate and develop inter-state rivers to the extent to which such regulation and development are declared by the parliament by law to be expedient in the public interest. The National Water Policy adopted in 2002, among other things, recommends: "*Water resources development and management will have to be planned for a hydrological unit such as drainage basin as a whole or for a sub-basin, multi-sectorally, taking into account surface and ground water for sustainable use incorporating quantity and quality aspects as well as environmental considerations. All individual developmental projects and proposals should be formulated and considered within the framework of such an overall plan keeping in view the existing agreements / awards for a basin or a subbasin so that the best possible combination of options can be selected and sustained.*"

Among the major Indian river basin organizations, the Bhakra Beas Management Board (bhakra.nic.in) manages waters in the Sutlej basin in the Himalayas. The Damodar Valley Corporation (www.dvcindia.org) manages most of the projects in Damodar basin and Brahmputra Board has been set-up for systematic exploitation of water resources of this basin. The Narmada Control Authority (NCA) (http://nca.nic.in) has been setup under the final orders and decision of the Narmada Water Disputes Tribunal as a machinery for implementation of its directions regarding utilization of the water resources of Narmada River.

14.6 PUBLIC INVOLVEMENT

Public Involvement (PI) plays an important role in planning and policy-making. This topic has also been discussed in Section 9.7 and so this discussion will be limited to the aspects that are relevant to RBM. Increasingly, PI is being viewed as a means of improving the quality, effectiveness, and acceptability of the decision-making process by involving the stakeholders in decision-making. Another view could be that PI is a legal right or a means to empower individuals and social groups. Three components that are considered pillars of PI are: access to information, involvement in the decision-making process, and access to justice.

Governments of many countries increasingly endorse the view that the public is to be involved in the environmental decision-making process. This idea is expressed in international policy documents, such as the Rio Declaration and Agenda 21. The Dublin Statement on Water and Sustainable Development specifically echoes this concept for freshwater resources management.

The Rio Principle 10 says: "Environmental issues are best handled with the participation of all concerned citizens, at the relevant level…". Note that the Principle does not guide as to how one should establish the "relevant level". This level may be the local, the river basin, the national, or the international level. For international rivers, in addition to PI at intra-national level, the need for PI at the international level may also be felt. Many times, there are conflicting water use interests in different basin countries, e.g., an industrial plant in the upstream country may be discharging waste water into the river and the water from this river might be used for municipal needs in a downstream country. Before attempting PI at this level, it will be useful to attempt PI at the national level. There might be large differences in social, cultural, languages, etc. among nations and hence in the perceptions of the people. Therefore, the involvement of the public at the international level is still a more complex activity. For many international basins, a river basin commission has been established where important decisions are taken.

Concerning the first pillar of PI – access to information – the information that can be disseminated is often categorized in different groups. Possible categories are: 1) official (approved) information, including international agreements, action plans and programs; 2) working documents and drafts; 3) hydrological and water demand/use data, maps; and 4) financial and personnel information. Of course, some of these data may be classified and not available to everyone. It should be ensured that all non-classified information is accessible on a non-discriminatory basis and the user should be charged minimal or only reproduction expenses.

PI, as a means of community development, is closely related to decentralization. The participation of public so as to improve the quality and efficiency of decision-making is the most relevant reason behind PI. The public can come up with information that would otherwise not be available and with innovative solutions. PI in the decision-making process enhances the legitimacy of the process and the acceptance by the public of the resulting decisions and often costly and time-consuming litigation can be prevented. Despite all the benefits, PI is easier said than done. Recall that it involves a lot of interaction with public at large at various levels and the entire process will have to be carefully handled. If PI is to realize its potential, a number of issues need to be addressed. The important ones are discussed below (see also Section 9.7).

14.6.1 Approaches for PI

Different approaches are appropriate for different target groups. The type of information to be provided and the method of delivery for NGOs which may have some professionals also would be quite different than for local communities. The approach will also be guided by the type of issues at stake – whether any controversial issue is involved or not and how much emotionally surcharged the environment is. The social and cultural background of the participants is also very important. For instance, in a culture where consulting the public is seen as a sign of weakness on the side of the leaders, the usual "Western" methods of PI could be a kind of political suicide and other methods have to be devised (Mostert et al., 1999). Whenever the specific methods chosen allow for large numbers of participants, the public should be able to select itself for involvement – after it got sufficient information in an appropriate form.

PI should be organised early enough so that the feedback could be used to improve decisions, but not too early because different plans and ideas should be specific enough to interest the public. A possibility is to organise PI in different phases and target different segments of the public: in early phases (semi-) professional NGOs, and in a later phase the local population and individuals. In any case, it should never appear that the decisions have already been made and the public has been called just to communicate the same. The river basin authorities may make the meetings with public a regular feature. They may also earmark a day as 'open-house' day and organize activities, such as seminars, and question-answer sessions, by involving public.

14.6.2 Information Dissemination and Follow-up

If the decision-makers do not follow up the outcomes of PI sincerely, the net result could be that it will lose interest of people, legitimacy, and acceptance. Also, once people become disenchanted, it will be very difficult to involve them again. In this respect a legal-administrative approach to PI could be useful. This entails a legal requirement to publish and react to the comments received (an action-taken report) in combination with access to justice.

The use of the Internet has proved to be a valuable tool for making information widely accessible. Many river commissions already have a Home page where the approved information can be viewed. For example, Mekong River is an international river in Asia and the home page of Mekong commission (www.mrcmekong.org) provides a lot of information about this basin. The web-site has a separate section 'information resources' with sub-sections on publications, data, and maps. Likewise, the homepage of Murray Darling basin commission (www.mdbc.gov.au) contains links to information about the basin, natural resources management, action room, news room, and a tour of the basin. The website of the Bhakra Beas Management Board (www.bhakra.nic.in) provides a historical account of the projects in the basin, the power generation and reservoir operation data, technical papers, and tenders announcements. It is helpful to see the "what's new" section on websites to know the latest interesting developments.

The meetings of the plenary body and/or subsidiary bodies of some river basin commissions are open to all. However, in most cases the general public cannot participate in the meetings, but sometimes NGOs can get observer status. Their admittance is usually made dependent on some criteria of recognition. Pragmatic modalities are found in those situations where public involvement is not formally or insufficiently provided for. Such modalities include 1) representatives of NGOs as members or experts in the national delegation; 2) involvement of NGOs in national preparatory meetings for the plenary meetings of the joint body and/or its subsidiary bodies; and 3) special consultative meetings with NGOs organised by the river commission. Moreover, several river basin commissions invite NGO members to their meetings as experts. Involvement as an observer or expert in meetings of the commission automatically involves access to information which otherwise might not have been disclosed.

14.7 INTERBASIN WATER TRANSFER

When there is a shortage of water in an area with respect to the demands, two options are available: supply management and demand management. In supply management, steps are taken to increase the availability of water and the means that can be adopted include interbasin transfer of water, artificial recharge, desalinisation of water, etc.

The term *water transfer* refers to transport of water through engineering structures, usually across river basins for some beneficial purpose. Interbasin Water Transfer (IBWT) is one of the possible solutions of water deficiency and is somewhat similar to other alternatives, such as dams, desalination, groundwater extraction, etc. The interbasin water transfer involves transportation of surplus water from a basin to another basin which is deficient in water. The starting point of inter-basin water transfer is an unsustainable situation in the receiving basin in the sense that it suffers from recurrent water shortages. If the surplus and deficient basins are not near each other, which is quite often the case, this will involve transfer of water over large distances, sometimes of the order of thousands of kilometers. IBWT is an ancient approach and under certain conditions, it is a rational and often indispensable measure. In fact, most water resources development projects involve some kind of water transfer, though usually over short distances. Diversion of water by IBWT increases the resilience of the water system and decreases the risk of shortages. The most common purpose of IBWT projects is water demand of agricultural areas or mega cities. Typically large distance water transfer is carried out to improve national/regional economy, self-sufficiency in national/regional agricultural outputs and to remove regional disparities in development activities. As the human settlements are not always near the places of water occurrence or the available water may be inadequate to meet all demands at a place, waters have been transferred from one basin to another since time immemorial.

The special attributes of a long distance water transfer are:

1. Large amounts of water involved in transfer, often exceeding 1 billion cubic metres per year.
2. Large distances of water transfer, often exceeding 500 km.
3. Large costs of infrastructure and possibility of extensive and irreversible environmental consequences.
4. Significant influence on the economy of the receiving area.

Most commonly, canals are used to carry water from one basin to another; tunnels and pipelines are used to negotiate ridges. However, the final selection depends on the topography of the area, climate, soil properties en-route, and the volume of water involved. Many interbasin transfer projects involve pumping of water in some stretches when a mountain is to be crossed and construction of a tunnel is not feasible. To the extent possible, a gravity flow system is preferred over a system that involves pumping, even if slightly longer route is to be taken. The running cost of a system with pumping is significantly higher and this places an additional burden on the infrastructure particularly in those countries which are deficient in electric energy. Additional maintenance problems arise if the water that is to be pumped contains sediments because these cause much wear and tear. GISs are being increasingly used these days to finalize the route of the transfer link.

14.7.1 Planning for IBWT Projects

Large-scale interbasin water transfer has been an essential component of water management since long time in many parts of the world and will remain so in the future. Generally, the water being exported from a basin must be surplus after meeting all the needs of the basin in the foreseeable future. The requirement of the water importing basin should be minimized by water saving measures, but without impairing the efficiency of water uses.

Before any large-scale water transfer project is taken up, it would be helpful to mull over the following questions:

- Is water transfer the only option to overcome the present and likely problems ?
- Is water transfer the most efficient alternative ?
- What are the tradeoffs involved in the water transfer ?
- Is the requisite institutional and infrastructural support available ?

As per the practice being followed in India, if the water available in a basin is more than the demands that are likely to arise in the foreseeable future (time span of 25 years or so), then this basin is considered as a water surplus basin. The volume of water over and above the projected demands is labelled as surplus for that basin and this can be made available for transfer to other deficient basins.

An important issue in IBWT is the sharing of water resources between the donor and receiving basin. Sustainable development in both basins should be practiced through shared economical and social benefits from the project. In the donor basin, water transfer must not have negative impacts on the sustainability of water use. Water transfer agreements should take care of monitoring and periodical assessment, with the possibility of adjustments of the mutual obligations. If water transfer involves two countries, it may hopefully contribute to wider political cooperation between the countries.

14.7.2 Evaluation of IBWT Projects

IBWT projects are generally cost-effective solutions and technical problems are seldom the limiting factor except for those projects that involve long distances of transfer. The water transfer projects should always be compared with other water management instruments. Since these projects may also involve a large-scale population displacement, adequate compensation to the project affected persons must be an essential component of the project proposal. The necessity or otherwise of an IBWT project can be evaluated by the following criteria:

1. The recipient basin must have a substantial deficit in meeting the present or projected future water demands after considering alternative water supply sources and all reasonable measures for reducing the water demand.
2. The future development of the donor basin must not be substantially constrained by the water scarcity.
3. An IBWT project should be taken up after comprehensive environmental impact assessment (EIA) indicates that it will not substantially degrade environmental quality within the area of origin or area of delivery.
4. A comprehensive assessment of socio-cultural impacts must indicate a reasonable degree of certainty that the project will not cause socio-cultural problems in the donor or recipient basins.
5. The net benefits from transfer must be shared equitably between the donor and recipient basins.

EIA is a necessary step in the evaluation of any major IBWT project. However, due to serious and long-term environmental implications, such considerations should be an important part, and not just an addendum or formality for project clearance. Importantly, EIA should not be viewed as an obstacle to the project – the environmental assessment may direct to initiate IBWT. Due to water transfer, the ecological balance in the recipient basin may improve, and the transfer of water can help sustain cultural and emotional values that are associated with a water body. Environmental norms widely differ between countries – stringent norms are followed in developed countries while developing countries give preference to economic and social progress. The environmental aspects of water resources projects are discussed in Chapter 7.

While trying to identify the environmental impacts, a distinction has to be made between impacts in the exporting area, the water importing area, and the transfer path. It is necessary to consider impacts on water quantity, water quality, micro and macro-climate changes, impacts on soil erosion, and sedimentation, etc. These projects are also likely to have a significant influence on regional economy, agricultural production, energy availability, employment as well as impact on aquatic life. Since the techniques and methodologies for evaluation of the impact of large-scale water transfer are not fully developed, it is essential to carry out monitoring on a continuous basis.

Sometimes EIA is limited to only water quality studies. But the concept includes the protection of biodiversity, the possible transfer of species between the two basins, as well as the impact of the new water on existing ecosystems in the receiving basin. While there are no generally accepted quantitative indicators of the required in-stream water quality and flow regimes from an ecological perspective, the attempt is to maintain or re-create the natural flow regime to the extent possible. Environmental, aesthetic and human interests in the affected regions must be respected. In certain cases, large-scale project initiatives had to be abandoned mainly because of environmental implications, and also owing to political and economic developments in the region.

The institutional support includes relevant laws, policies and administrative setup. An analysis of past projects shows that these could be implemented without much fuss and opposition because these were small, not technically complex and finances involved were not large. Many of these projects were confined to a single administrative unit and the environmental issues were either not raised at that time or the awareness was limited. However, current projects are facing considerable opposition because the technical problems are complex, the size of project is large, and the environmental and social issues have gained significant importance. Many such projects involve more than one state of a country and some of them are international in nature, such as projects in North America.

In many instances, IBWT projects are the cheapest and most effective solution to overcome water deficit in an area. The necessity of these schemes may become even more crucial if the crisis due to hindrance of economic growth on account of water deficiency becomes serious. Some aspects which may further enhance attraction of these projects in future include technological advances which reduce costs of water transport, lessening of adverse socio-environmental consequences, and changes in climate which make more water available in donor regions.

14.7.3 Examples of IBWT Projects

Long distance inter-basin transfer of water is a concept has been in practice for a long time. In arid and semi-arid regions, IBWT is sometimes crucial to alleviate acute water shortages and to strengthen the resilience of water systems in case of droughts. The Western Yamuna Canal and the Agra Canal in India were built about five centuries ago and carried water from the Himalayas to the distant parts of Punjab, U.P. and Rajasthan. The Kurnool Cuddappah Canal (1860-1870) and Periyar Vaigai (1896) are other examples of interbasin water transfers executed in India in the 19^{th} century. The Indira Gandhi Canal Project diverts water from the Himalayas to the deserts of Rajasthan. This scheme comprises a large multi purpose project constructed across the Beas River at Pong, a barrage at Harike and a grand canal system. The Sardar Sarovar project (discussed in Chapter 7) involves transfer of water from Narmada River in central India to Saurashtra and Kutch in western regions.

In many countries, interbasin water transfer projects are amongst the most controversial issues of water resources utilisation. Nevertheless, these projects are proposed and taken up because they often offer the most attractive solution to a given water problem. These projects are often necessary because in many instances, the regions where water resources are abundant are not necessarily the regions where most of the population resides or where the industrial or agricultural activities are concentrated. For example, about 60% of water in Canada flows towards the north while 90% of the population and majority of industries are concentrated within 300 km of its border with the United States (Sewell, 1985). Some existing and under construction IBWT projects in Canada include Kemano, Churchill Diversion, Welland Canal, James Bay, and Churchill Falls.

The Lingua Canal (completed in 214 BC) and the Grand Canal (completed in 605 AD) are two examples of IBWT from ancient China. Recently completed projects in China include Biliuha-Dalian interbasin water supply system and transbasin transfer of water of Luhana River to Tiajian and Tengshan. The southern part of China is abundant in water resources whereas the northern part is water deficient. The basin of Huang He, Huai He, and Hai He rivers suffer from water deficiency. The Chang Jiang River basin is abundant in water resources and this will be the main basin to supply water to North China. Hence, the south-to-north water transfer was conceived as a long-term solution to this problem. In fact, this project includes three components: the west, middle and east route with respective serving areas. The east route component was to be taken up first in view of inadequate water requirements. In the middle route component, a large amount of water from Han Jiang and Chang Jiang (middle reaches) rivers will be transferred. Diversion of Quiantang River water and diversion of Yellow River surpluses are other ambitious proposed projects.

The major water transfer projects that have been proposed for the United States include the North American Water & Power Alliance, the Texas Water Plan, and the California State Water Project. The Texas Water Plan envisages redistribution of water in Texas and New Mexico to meet the needs of the year 2020. The California State Water Project, the first phase of which was completed in 1973, provides for diversion of 4 cubic km of flow from better watered northern California to the drier central and southern parts of the state. The conveyance system comprises 715 km California Aqueduct, a complex system of lined and unlined canals, pumping stations, siphons and tunnels. The lift involved is nearly 1000 m (IWRS, 1996). Similarly the waters of the Colorado River (an international river between U. S. A. and Mexico) are being diverted outside the basin to the imperial valley in California. In Mexico, the project for water supply of Mexico city through transfer of ground waters from the Lerma basin was completed in 1958. The Mahaveli-Ganga project of Sri Lanka includes several interbasin transfer links.

A notable interbasin transfer scheme executed in the former USSR is the Irtysh Karganda scheme in the central Kazakhistan. The link canal is about 450 km long with a maximum capacity of 75 m^3/s and the lift involved is 14 to 22 m. There is another plan to transfer 90000 million m^3 from the north flowing river to the area in south. Other proposals include partial redistribution of water resources of northern rivers and lakes of European part to the Caspian Sea basin involving 2 million hectare-m of water. More examples include IBWT for urban drinking water supply in Spain, France, and Germany; for irrigation, drinking water and hydropower in India, navigation and environmental aspects in Europe, and for environmental improvement in U. S. A. and Australia. Glubev and Biswas (1985) and IWRA (1986) contain many case studies of IBWT projects.

14.8 MANAGEMENT OF INTERNATIONAL RIVER BASINS

About half of the land area of the earth is occupied by international river basins. The management of international river basins poses unique problems. The international basins are usually less homogenous and there are wide variations in socio-economic, cultural, language and administrative matters. The consequences of an action in the headwater regions in a country may significantly influence the conditions in the downstream areas which may be in a different country. In view of this, it is necessary to have a high level of cooperation and coordination in international basins to prevent or solve upstream-downstream conflicts. In case where a river basin falls under the jurisdiction of three or even more states, the need of multi-lateral cooperation is even greater. Mostert et al. (1999) have suggested the approach of 'lowest common denominator' in the management of international basins. They explain that few obligations can be imposed on countries without their own consent and, therefore, many international agreements simply reflect the commonalities in the national policies of the concerned states. They have also presented nine mechanisms to overcome the lowest common denominator problem. These are given in Table 14.2.

River basin treaties and other forms of international cooperation should reflect the relevant principles of international law, primarily the principles of equitable and reasonable use, the obligation not to cause significant harm, and the duty to notify and exchange information. International river basin authorities with decision-making and enforcement powers may be a good option for specific operational tasks, such as the restoration of water quality, shipping and the joint operation and management of infrastructure.

14.8.1 International River Basin Organisations

The basic premise behind management of international river basins is that the interest of international community is supreme, superseding the interest of individual countries. There area a number of bi- and multi-lateral agreements among the basin countries for the management of international river basins. The cooperation in management of international basins depends on the mutual relations of the countries involved. If the relations are good, e.g., the Danube River in Europe whose basin is shared by a large number of countries, problems can be easily resolved through across the table discussions and meetings. However, in case the basin states do not have good understanding, the cooperation in management of basins is the first casualty. There are a number of bi- and multi-lateral agreements among the basin countries for management of international river basins.

Table 14.2 Nine mechanisms for reaching international agreements that go beyond the lowest common denominator [adapted from Mostert et al. (1999)].

Mechanism	Explanation
1: Issue linkage	It implies that a contentious issue on which national interests conflict (e.g., upstream-downstream conflict) is linked to another issue where the distribution of (perceived) costs and benefits is the reverse. Solving such issues simultaneously can result in a net gain for all parties involved, thus overcoming the conflict of interests. The second issue might be either an RBM issue or a totally different issue, but the former is usually more effective since on both issues the same parties are involved and costs and benefits fall on the same groups.
2: Diffuse reciprocity	A situation in which countries accept less favourable agreements in order to keep good relations and create a "reservoir of goodwill" from which they can draw in the future.
3: Side payments	These are payments – directly or through increased subsidies or reduced contributions – in return for a concession. Side payments will be most effective in cases of agreements affecting the economy or the finances of countries. They will be less effective when deeply held values or basic human needs are involved and can be experienced as bribery. Moreover, side payments for pollution reduction conflicts with the polluter pays principle.
4: Large geographical scope	Strict national environmental standards may limit the competitiveness of industry in a basin, but the effects are much smaller if several countries adopt similar standards for their whole territory.
5: Appealing goals/ mobilising vision	Ambitious agreements can also be reached if they contain goals or a vision of the future that is attractive for large sections of society in the countries concerned. Such goals and such a vision can act as a form of awareness raising. Moreover, they can implicitly incorporate forms of issue linkage and diffuse reciprocity.
6: Slack cutting	It occurs when national government bodies use international agreements for introducing a more ambitious policy domestically or for promoting enforcement of existing.
7: Intended non-compliance	It refers to the fact that countries may be willing to accept ambitious international agreements if they expect that the agreements will not be enforced. Obviously, agreements reached in this way are usually not implemented.
8: Unforeseen consequences	Ambitious agreements can also be reached if their consequences are not foreseen. Negotiators might be too confident about their national situation and assume too easily that no adaptation will be necessary. Furthermore, international courts may give unexpectedly strict interpretations to agreements. Finally, the negotiators may be inexperienced or the time to study proposals may simply be lacking, especially in case of last-minute changes.
9:Majority voting	In some rare cases, international agreements are the result of majority voting. In these cases, the more conservative countries can be overruled, at least in theory. However, the more conservative countries can link the issue to another issue where their co-operation is needed, either because unanimity is required for that issue or to obtain a majority.

A major aspect of many river basin treaties is the establishment of a river basin organisation. There are two types of national river basin organisations: river basin commissions with a primarily coordinating task and river basin authorities with decision-making and policing powers. The same type of organisations can be found in international basins.

The importance of international river basin commissions has been widely recognised. River basin commissions may coordinate monitoring and research efforts, add legitimacy to the monitoring and research results and in this way provide a common, generally agreed upon factual basis for management. Furthermore, they offer the basin states a platform for co-ordinating their policy and management. River basin commissions can also prepare RBM plans and programmes, but these have to be adopted by the basin countries. River basin commissions may also oversee the implementation of plans and programs if the basin countries agree to these. Finally, river basin commissions can play a significant role in resolving river-related international conflicts. They constitute a relatively informal forum for discussion, may help in selecting fact finders and arbitrators, or may even do fact-finding or act as arbitrators themselves.

Mutual understanding, trust, and information sharing are the basis for international co-operation. Technical co-operation involving the collection and dissemination of information promotes the acceptance of this information by all basin states and stimulates mutual understanding and trust. In times of international conflicts at least technical co-operation should be maintained. Several mechanisms could be used to overcome conflicting (upstream – downstream) interests. Contentious international issues could be linked with other issues. Moreover, countries may accept less favourable agreements in the expectation that other countries will do the same in the future ("diffuse reciprocity"). In some cases financial compensation from the benefiting country to the country having to incur costs could be justified, provided the polluter-pays principle is respected.

International river basin commissions can perform many useful functions in management of international basins, such as coordination of research and monitoring, co-ordination of river basin management between participating basin states, planning, compliance monitoring and conflict resolution. International river basin commissions are almost indispensable for international basins. States sharing several international waters may also establish joint water commissions.

For river basins falling within one jurisdiction, intersectoral planning offers good opportunities for intersectoral coordination. The unrestricted exchange of data and knowledge is a prerequisite to efficient management and cooperation in both national and international river basins. Monitoring data collected with public funds should be publicly available and easily accessible, nationally and internationally.

The importance of mechanisms for promoting river basin cooperation is becoming more widely recognised and implemented, and is reflected in support for the International Network of River Basin Organizations (INBO). About 102 organizations in 42 countries are members of this network. At the International Conference on Water and Sustainable

Development, held in Paris in 1998, INBO recommended the establishment of a legal framework that takes into account five objectives regarding river basin management that should be organized:

1. On the relevant scale of large river basins and aquifers;
2. With the participation in decision-making of the local authorities concerned, different categories of users and associations for environmental protection besides the appropriate governmental administrations;
3. Based on master plans that define the long-term objectives to be achieved as regards water resources management in times of scarcity or flooding and that enable the management of users integrated into land use planning and preserve the quality of ecosystems;
4. Within priority investment programs that result from these master plans;
5. With the mobilisation of appropriate financial resources, based on the polluter-pays principle and user-pays systems.

14.8.2 International Initiatives for Freshwater Management

The first step in cooperation among riparian countries is the technical cooperation which may begin with sharing of information and joint monitoring of developmental activities. This can be followed by cooperation on more substantive issues and exchange of ideas at a higher level. This matter has also been the theme of many international conferences. The first global conference which paid specific attention to fresh water issues was held in Mar del Plata in 1977. It was recognized and emphasized here that people have a right to water for their basic needs. A list of important international conferences relevant to management of freshwater resources is given in Table 14.3.

Among the United Nations agencies, Unesco has a long-term program in the water sector in the form of the *International Hydrological Program* (IHP). IHP is a vehicle through which countries can upgrade their knowledge of the water cycle and thereby increase their capacity to better manage and develop their water resources. It aims at the improvement of the scientific and technological basis for the development of methods for the rational management of water resources. The Program started as the International Hydrological Decade (IHD, 1965-1974) and was followed as a long-term program executed in phases of a 6-year duration. IHP-I lasted from 1975 to 1980. IHP-II, on the other hand, was of a shorter duration (1981-1983). The IHD was mainly research oriented. IHP-I, which followed on from the IHD, maintained much of the same research orientation. However, the next phases were oriented to include practical aspects of hydrology and water resources. Hence, IHP-II (1981-1983) and IHP-III (1984-1989) were planned under the theme 'Hydrology and the scientific bases for rational water resources management'. The theme for IHP-IV (1980-1995) was 'Hydrology and water resources: sustainable development in a changing environment,' while the theme of the fifth phase (1996-2001) was 'Hydrology and water resources development in a vulnerable environment.' In recognition of the shift in thinking about water from fragmented compartments of scientific inquiry to a more holistic integrated approach, the general theme for IHP-VI (2002-07) has been defined as *"Water interactions: systems at risk and social challenges"*.

Table 14.3 List of international conferences relevant to management of freshwater [Source: Mostert et al. (1999), Internet].

Title	Place, Year	Highlights
United Nations Water Conference	Mar del Plata, 1977	• First global conference on freshwater • Emphasis on development, agriculture drinking water and sanitation
Global Consultation on Safe Water and Sanitation for the 1990s	New Delhi, 1990	• Drinking water and sanitation • Attention to financing, integrated management of water resources, institutional aspects and role of women
International Conference on Water and the Environment	Dublin, 1992	• Sustainability recognized as a key issue • Four principles: freshwater is a finite and vulnerable resource, participatory approach, the role of women, and water as an economic and social good
United Nations Conference on Environment and Development	Rio de Janeiro, 1992	• The Dublin principles are reconfirmed • Protection of ecosystems • Need for integrated planning and management on the river basin scale is emphasised • Development of strategies and action programmes for transboundary waters • Improved co-ordination between global organisations and programmes.
Ministerial Conference on Drinking Water and Environmental Sanitation	Noordwijk, 1994	• Drinking water and sanitation • Partnerships between stakeholders • Change behavior patterns • Technical innovations
United Nations General Assembly Special Session	New York, 1997	• Evaluation of the implementation of Agenda 21 • River basin management • Information management • Emphasised the need for concrete actions and (financial) commitment of states • Decided to hold a dialogue under auspices of the Commission for Sustainable Development (CSD)
Expert Meeting on Strategic Approaches to Freshwater Management	Harare, January 1998	• Advice of the inter-sessional ad hoc working group of the CSD and CSD VI • International co-operation • Mainly a repetition / rehearsing of already formulated/ adopted principles
Ad hoc Inter-sessional Working Group on Strategic Approaches to Freshwater Management	New York, February 1998	• Specific attention to information on policy, institutions, capacity building, participation, technology transfer and co-operation in research, financial resources and mechanisms
Cooperation for Transboundary Water Management	Petersburg (Bonn), March 1998	• Transboundary water management • Emphasis on regional co-operation, river basin organisations, political commitment, and mutual trust.
International Conference on Water and Sustainable Development	Paris, March 1998	• Little news on principles and points of departure • Decided on the development of an "agreed statement of principles" • "Programme of priority actions"
Commission on Sustainable Development,	New York, April/ May	• Governments are encouraged to co-operate on transboundary water resources and set up river

Sixth Session www.un.org/esa/sustdev	1998	basin institutions. • Governments may report to the CSD on a voluntary basis. • The importance of UN organisations is underlined, including the need for a more transparent way of working and more co-ordination within the UN.
Ministerial conference of Second World Water Forum	Hague, March 2000	• To mobilize political support to counter global water predicaments. • Identified seven challenges to water security in the 21st century (see section 1.10).
Earth summit 2002 (Rio+10 Meeting) www.earthsummit2002.org	Johannesburg, August/ September 2002	• Reaffirmed sustainable development as a central element of the international agenda • Set a target to halve, by the year 2015, the proportion of people without access to safe drinking water • Develop integrated water resources management and water efficiency plans by 2005.
Third World Water Forum www.worldwaterforum.org	Kyoto, 2003	• To be held in March 2003.

The relevant IHP-VI topics on hydrologic research, water resources management and education are framed under five themes, with the transition and interaction from the global scale to the watershed scale being the overall driving force for consideration of the complex relationships between water and society and the overall need for knowledge, information and technology transfer: 1) Global changes and water resources; 2) Integrated watershed and aquifer dynamics; 3) Land Habitat Hydrology; 4) Water and Society; 5) Water Education and Training. Two crosscutting programme components: FRIEND (Flow Regimes for International Experimental and Network Data) and HELP (Hydrology for Environment, Life and Policy) have been identified that, through their operational concept, interact with all themes.

IHP constitutes a framework for applied research and education in the field of hydrology and water management. It is a dynamic concept whose aim is to improve links between research, application and education and to promote scientific and educational activities. Further information about IHP is available at the IHP website: www.unesco.org/water/ihp.

The World Meteorological Organization (WMO) has many programs related to water resources and have brought out a large number of publications which are extensively referred to by water resources professionals. Many other agencies of the United Nations, notably, the Food and Agriculture Organization (FAO), and United Nations Environment Program (UNEP), are actively involved in the water sector. The web sites of these agencies (see Appendix B) contain a large number of useful publications and data that are of immense use for practitioners.

14.9 CLOSURE

The United Nations observed the decade 1981-1990 as the *International Decade on Water*

Supply and Sanitation. The aim was to provide access to clean drinking water and sanitation for all people by the year 1990, a target that could be achieved only to a limited extent. Two important conferences were held in 1992: International Conference on Water and the Environment at Dublin and the UN Conference on Environment and Development at Rio de Janeiro. A noteworthy outcome of the Rio Conference was the Agenda 21 which has provided a program of action for attaining sustainable development. Chapter 18 of Agenda 21, entitled "Protection of the Quality and Supply of Freshwater Resources: Application of Integrated Approaches to the Development, Management and use of Water Resources" is relevant to management of freshwater resources. The main objectives enunciated in it are: 1) access should be ensured for all people to safe and sufficient water supplies, or at least water supplies to meet the basic drinking and food-growing requirements, 2) public participation and management at the lowest appropriate level should be enhanced, and 3) integrated development and management of water resources should be attained. The year 2002 was declared as *the International Year of Mountains* and the year 2003 is declared as *the International Year of Freshwater.*

Decision making for hydrosystems is gradually becoming more complex. The last few decades have witnessed that the role of social and political factors is becoming equally important as the technical inputs. Seven strategic priorities for water and energy resources development have been advanced by Asmal (2002). The charges for various uses should be fixed in a manner that leads to savings and the polluter should pay for the damage caused by him. It will be necessary that the development alternatives are arrived at after comprehensive examination of all options, these should have acceptance of public, and the benefits are shared fairly. The touchstone for future development strategies will essentially be sustainability, poverty alleviation, participatory decision making, and conflict avoidance. The water resources professionals will have to provide solutions that are scientifically sound and socially acceptable.

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