WATER RESOURCES MANAGEMENT

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SUMMARY

This comprehensive review of the concepts, professional fields, developments, and issues in water resources management, is based on the latest insights. Attention is given to Integrated Water Resources Management, water and sustainable development, water scarcity, and the more technical aspects of water resources planning. Important issues related to international rivers, the economics of water, and the legal and institutional aspects of water are addressed in detail. New approaches to water conservation, non-waterborne sanitation, and economic valuation are presented and discussed.

1. INTRODUCTION

People from different backgrounds seldom have the same idea about what water resources management implies. To those living in an arid country, it means drought relief, irrigation, food, jobs, the law, and politics. Generally there is an emphasis on groundwater. Rivers are normally dry, or experience flash floods after torrential rains (*wadis* or ephemeral streams). To people living in humid areas, the emphasis is more on surface water. They are particularly concerned with waterworks, flood protection, navigation, hydropower, treatment plants, and related issues. People from different professional backgrounds also tend to view water resources management differently. To the water engineer, water resources management is related to dams, reservoirs, flood protection, diversions, canals, water treatment, and land reclamation. To the ecologist, water resources management is often connected with the deterioration of ecosystems, land degradation, pollution, and destruction of wetlands. To the lawyer, the main issues in water resources management are the ownership of water, the system of water rights (ownership or license to use), the priority of use, water legislation, and international water law. To the economist, water resources management is connected with water use efficiency, cost recovery, the creation of water markets, tradable water rights, and privatization of water supply. To politicians, water resources management means solving conflicts over water, and attaining national objectives such as economic growth, poverty alleviation, employment generation, and food security.

In fact, water resources management includes all these points of view. Water resources management is multi-disciplinary, multi-sector, and multi-objective. Management is only effective if all interested parties – both formally and informally related – are somehow involved in the processes of planning, decision-making, and implementation. Unless all stakeholders feel committed, water projects or policies are likely to fail.

Water resources management refers to a whole range of different activities: monitoring, modeling, exploration, assessment, design of measures and strategies, implementation of policy, operation and maintenance, and evaluation. It also covers support activities, such as institutional reform. Water resources management includes local, national, and international activities, directed at either short-term or long-term goals. As such, water resources management is rather a diffuse field. It includes the whole set of scientific, technical, institutional, managerial, legal, and operational activities required to plan, develop, operate, and manage water resources.

If you tell someone about a certain water management problem and ask how he or she would solve this problem, you will probably get one of two types of answer:

1. Look at the causes of the problem, and who is involved; look also at the effects of the problem on others; consider alternative solutions; analyze the effectiveness, costs, and benefits of each; implement the best solution.
2. Approach all interested parties – the stakeholders – and ask them what they think about the problem; let them suggest solutions; look for compromises on which all parties can agree.

The first approach puts emphasis on scientific analysis of the problem; the second emphasizes the process that should lead to a solution. Water resources management should actually involve both.

Water resources management includes management at two distinct levels. Management at the first level refers to the actual tasks and central objectives of the water manager. This includes all activities directly aimed at the sustainable use of water, provision of clean drinking water to all, allocation of water to different sectors of society, ensuring safety against flooding, and so on. Management at the second level refers to managing the organization and process itself. It is supportive to the actual tasks of the water manager. Management at the first level is also called *external* management, while management at the second level is referred to as *internal* management. Important questions for internal management include:

- what exactly are the objectives of management?
- what institutional structure can best serve the process of attaining these objectives?
- how can this institutional structure be run in an efficient and effective way?

Section 2 of this article puts the field of water resources management into a historical perspective. Section 3 aims to create some understanding of the system to be managed by water managers, and of how different management instruments can be applied effectively to attain their objectives. Section 4 deals with the process of water resources management, while Section 5 addresses institutional aspects. Finally, Section 6 discusses some of the current issues of debate in the field.

2. GROWING INSIGHTS

2.1. Water management in ancient civilizations

Water resources management is probably as old as the human race. Historical writings and archeological research have shown that many ancient civilizations could only flourish as a result of advanced methods of managing their water resources. Examples include the three contemporary civilizations of the Indus, Mesopotamia, and Egypt, and the Greeks and the Romans, but also the ancient civilizations in the Americas. Let us consider just two examples: the civilization of the Indus Valley, and the pre-Inca civilization of the Tiahuanaco in South America.

The Indus Valley Civilization was one of the world's first great urban civilizations. It flourished in the vast river plains and adjacent regions in what is now Pakistan and western India. Around 2600 B.C. the earliest cities together formed an extensive urban culture. This culture continued to dominate the region for at least 700 years. Excavations during the twentieth century have revealed well-planned cities and towns, built on massive mud brick platforms to protect the inhabitants against seasonal floods. Waterways connected the empire and flat-bottomed barges, almost identical to those still used today, plied the rivers between the cities. In the ancient city of Mohenjo-daro (Sindh, southern Pakistan), rainwater was harvested in tanks and brought to the wells of each house through gutters. The drainage system was both elaborate and efficient: carefully graded brick-lined drains flowed down the center of the streets to the Indus. The drains were covered, but there were inspection holes at intervals so that they could be unblocked when necessary. Tributary drains flowed from each house, first into a cesspit where solid matter was deposited. When the pit was half full, the water drained off into the main sewer. The richer houses had their own bathrooms, but the city also had a large bathhouse, which has been well restored.

The Tiahuanaco civilization dates back to about 1600 B.C. On the southern shore of Lake Titicaca, at an altitude of about 4,000 m above sea level, this developed through five periods and was at the peak of its splendor around A.D. 700. At that time Tiahuanaco was the largest city in the world, with more than 100,000 inhabitants. There was an extensive system of roads, aqueducts, and agricultural terraces. In order to increase agricultural yields, the Tiahuanaco people constructed a network of little canals. The current theory, at the end of the twentieth century, is that these canals influenced the local climate in such a way that the strong daily temperature variation at this altitude was mitigated, thus improving conditions for agriculture. Experiments are being carried out in order to discover whether this technique can be introduced again.

2.2. Recent developments

There has never been one single, accepted worldwide "recipe" for how to manage water. Climate conditions and cultures have always varied to such a great extent that we cannot expect that one will ever be developed. Nevertheless, for thousands of years there was something approaching a common human attitude towards water. Water was primarily regarded as a natural resource to be exploited for human benefit. In the areas of the world where floods regularly threatened human life, water was at the same time seen as an enemy to be defeated. Water resources management basically meant planning, building, and maintaining infrastructure, for supplying water to the places where people could use it, and for defending people against flooding. In terms of the historical timescale of the human race, it is only very recently that this common attitude has changed. This change has a lot to do with the consequences of the industrial revolution, and the explosive growth of world population.

The increasing pressure on water resources and the growing competition between divergent interests, particularly during the second half of the twentieth century, has led to the recognition that water is a "scarce resource" that can be "overexploited." Steadily, people started to replace the term "water resources *development*" by the more general term "water resources *management*." Recognizing that water is an intricate part of nature, and that water is actually more than just a "resource," it may be even better to speak simply of "water management." Whatever terminology we use, however, at the turn of the century the issue of water stands high on many political agendas. Today some visionaries even say that, while energy appeared to be the critical issue in the twentieth century, water will be the most critical resource in the twenty-first century.

Looking back, one might say that global attention to water issues started with the International Hydrological Decade 1965–74, under the auspices of UNESCO. The purpose was to advance hydrological knowledge through promoting international co-operation, and by training specialists and technicians. One of the products of the decade was a study on the world water balance, carried out by the USSR Committee for the IHD. The work was based on new material received from various countries as a result of the implementation of the IHD program. In the same period, two other major studies on the global water balance, by Baumgartner and Reichel, and by L'vovich, were published. Global water studies in the twenty-first century still rely heavily on these three studies. Although L'vovich and Korzun pay some attention to the socioeconomic aspects of water demand, the emphasis in all these studies lies on the hydrological aspects of water availability.

A milestone in this early period was the establishment of the "Helsinki Rules" on the use of international rivers, in 1966. These rules, adopted by the International Law Association, were a first step towards a common notion of the equitable use of transboundary river basins. The fourth article of these rules stated that each basin state is entitled, within its own territory, to a reasonable and equitable share in the use of the waters of an international drainage basin. The fifth article added that what is a "reasonable and equitable" share must be determined in the light of all relevant factors in each particular case.

An important event in raising global political awareness of the environment was the United Nations Conference on the Human Environment in Stockholm, Sweden, in 1972. At this conference, the foundation was laid for the United Nations Environment Program (UNEP). In the Stockholm Action Plan, nations agreed that when major water resource activities which may have a significant environmental effect on another country are contemplated, the other country should be notified well in advance. It was also agreed that countries should ensure the best use of water, and avoid polluting it.

The first global conference specifically dedicated to water was the United Nations Water Conference in 1977, in Mar del Plata, Argentina. The Mar del Plata Action Plan stimulated a number of activities, including the International Drinking Water Supply and Sanitation Decade (1981–90). This decade, proclaimed by the UN General Assembly at the end of 1980, had as its primary goal achieving universal access to water supply and sanitation in developing countries. Although this goal was far from achieved by the end of the decade, the campaign was successful in creating awareness of the importance of clean water and sanitation, and in developing workable strategies for further improvements.

During the 1960s and 1970s, it became clear that the old paradigm of growth needed revision. At the beginning of the 1980s, this led to the introduction of the concept of sustainable development. The famous Brundtland Commission defined this as development that meets the needs of the present generation, without compromising the ability of future generations to meet their own needs (WCED, 1987). In the water field, people started to speak about the need for "sustainable water resources management." This is a type of management that guarantees that all humans are provided with their basic water needs, but also that ecosystems continue to be provided with sufficient water to maintain their function. In the same period that the notion of sustainability became widespread, people began to recognize that the traditional reductionist approach towards environmental problems was no longer fruitful. Instead, people started to advocate a holistic or integrated approach – recognizing that seemingly separate problems often form a coherent system of interconnected parts – as the starting point of the search for solutions. In the water field, people began to recognize that problems of water shortage and pollution could not be dealt with separately, and started to look at surface water and groundwater as one system. Some even argued that land and water have so many interactions that water management should be combined with land and soil management.

In the midst of these discussions, the International Conference on Water and the Environment took place in Dublin in 1992. It was during this preparatory meeting for the UN Conference on Environment and Development (UNCED) in Rio de Janeiro that the concepts of sustainable and integrated water resources management were widely discussed, and were adopted by the international community. At this meeting, the Dublin principles on water management were established.

The acceptance of the Dublin principles by 114 countries, 14 UN organizations, and 38 NGOs, can be seen as the official launch of Integrated Water Resources Management worldwide. Although it had been discussed for many years in certain circles, Dublin was, for many countries, the starting point in revising their water policies, and, for many agencies, to start looking over the walls that divide them. The first and the second principle are essential components of integrated water resources management. The third principle, about the involvement of women, is in fact an addition to the second principle. Women are often responsible for water management

The Dublin principles

Principle No. 1
Fresh water is a finite and vulnerable resource, essential to sustain life, development, and the environment. Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer.

Principle No. 2
Water development and management should be based on a participatory approach involving users, planners, and policymakers at all levels. The participatory approach involves raising awareness of the importance of water among policymakers and the general public. It means that decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

Principle No. 3
Women play a central part in the provision, management, and safeguarding of water. The pivotal role of women as providers and users of water, and as guardians of the living environment, has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women's specific needs, and to equip and empower women to participate at all levels in water resources programs, including decision making and implementation, in ways defined by them.

Principle No. 4
Water has an economic value in all its competing uses and should be recognized as an economic good. Within this principle, it is vital to recognize first the basic right of all human beings to have access to affordable, clean water and sanitation.

at local level, both for household supply and agriculture, but are notoriously absent from consultation or planning of interventions, and as a result from the operation and maintenance of systems. This unfavorable situation needs to be given due attention and changed.

The fourth Dublin principle caused the largest debate. Several people opposed it because they interpreted it as stating that everybody should pay the economic price of water. That was a misunderstanding, however. Considering water as an economic good means that decisions on its allocation or use should be taken on the basis of economic rationality. This does not necessarily imply that an economic price needs to be paid by the user. Part or all of the costs can be borne by others or by the government, for example through subsidies. Whether water services should be priced is primarily a question of cost-recovery and demand management, not of economic valuation.

At the UN Conference on Environment and Development in Rio de Janeiro, 1992, Agenda 21 was adopted. For water managers particularly, Chapter 18 on fresh water is interesting. In its introduction it states that:

> Water is needed in all aspects of life. The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving the hydrological, biological, and chemical functions of ecosystems, adapting human activities within the capacity limits of nature, and combating vectors of water-related diseases. Innovative technologies, including the improvement of indigenous technologies, are needed to fully utilize limited water resources, and to safeguard those resources against pollution.
>
> (Agenda 21, Chapter 18)

It then continues to state: "The widespread scarcity, gradual destruction, and aggravated pollution of freshwater resources in many world regions, along with the progressive encroachment of incompatible activities, demand integrated water resources planning and management." As the title suggests, Agenda 21 is primarily a list of activities to be addressed by all nations in the coming decades.

In 1993, the World Bank published an influential policy paper on water resources management, which emphasized the importance of Integrated Water Resources Management, economic pricing, cost recovery, decentralization, privatization, management of international river basins, and incorporation of environmental criteria in planning and management.

A step forward in international water law was taken in 1997, when the UN adopted the Law of Non-Navigational Uses of International Watercourses, which was prepared by the International Law Commission. By that time, the Helsinki Rules were already about thirty years old and no longer addressed some key issues. In addition, the Helsinki Rules were the work of a private body, the International Law Association, while the International Law Commission, mandated by governments, drafted the new law. Nevertheless, the new law heavily draws on the Helsinki Rules. Article 5 states that "watercourse states shall utilize an international watercourse in an equitable and reasonable manner," and that "watercourse states have both the right to utilize the watercourse and the duty to co-operate in the protection thereof." Article 7 says "watercourse states shall take all appropriate measures to prevent the causing of significant harm to other watercourse states."

Twentieth-century developments include the establishment, in 1996, of both the Global Water Partnership and the World Water Council. The Global Water Partnership aims to support integrated water resources management programs by collaboration with governments and existing networks, and by forging new collaborative arrangements. The World Water Council has the aim to promote awareness of critical water issues. In March 1997, the "First World Water Forum" was held in Marrakesh, Morocco. The "Second World Water Forum" was held in March 2000, in The Hague, the Netherlands. At this second meeting, the so-called "World Water Vision" was presented.

2.3. Water resources management at the beginning of the twenty-first century

In the international debate, there is a growing consensus with regard to priorities in water resources allocation. The supply of water for basic human needs should have first priority. Second priority is given to the requirement to maintain essential life support ecosystems. All other needs – for industry, agriculture, or other societal purposes – should be prioritized according to socioeconomic criteria, whereby water is considered an economic good. Here, it is important to note that while cost recovery and economic trade-off are over-riding principles, cross-subsidies within sub-sectors to benefit the poor are considered necessary where equity or social well-being are at risk.

Another common notion is the need for adequate participatory approaches to planning and management, and mechanisms for accountability and democratic control. This is closely related to the principle of decision-making at the lowest appropriate level (subsidiarity), which also implies that some decisions – for instance, on the sharing of international waters – should be taken at higher levels. Clearly in these cases, mechanisms of democratic control and stakeholder participation should operate at the highest level of government.

Globally, and with regard to the sharing of international waters, food security is an important issue. Since agriculture is the largest consumer of water, it is important that nations start to realize that food self-sufficiency is not always possible, and may sometimes be highly uneconomic. Present thinking emphasizes food security: food is grown in those parts of the world where it is most economic, and where conditions are most favorable, while countries produce sufficient income to allow them to import the food. Clearly, where countries become dependent on food imports, adequate and reliable market arrangements should be in place. Poor countries need to have opportunities to develop activities that bring in foreign exchange.

In recent years, as a result of increasing pressure on water, the scope and complexity of water resources management has broadened. The problems associated with rapid economic development, population growth, urbanization, and industrialization have clearly demonstrated the inadequacy of traditional water management at sector level. Until the early 1990s, different aspects and interests of water resources – such as water quality, groundwater, water supply and sanitation, irrigation, and hydropower – were generally managed separately, and often independently, in different institutions. Modern water resources management aims at dealing with conflicting interests in a multi-sector, co-ordinated, interdisciplinary, participatory, transparent, and flexible manner. The term for this approach is "Integrated Water Resources Management." There are several definitions for this term, but it is generally agreed that it has the following components:

- It addresses all the natural aspects of water (for example, quantitative, qualitative, and ecological aspects), and also considers the linkages between these various aspects.
- It places water management in a broader context of socioeconomic development policy and environmental management.
- It takes full account of all the sector interests related to the functions and values of the water system, in a participatory process with the stakeholders.
- It considers the spatial and temporal variation of resources and demands.
- It considers the full spectrum of relevant policy objectives and constraints.
- It takes into account the different institutional levels involved in water resources management.

Although integrated and sustainable water management lie close to each other, and are often mentioned in the same sentence, there is a subtle difference between the two. Sustainable water resources management requires an integrated approach, but following an integrated approach does not in itself guarantee sustainability. Integrated management particularly refers to a type of holistic, participatory approach (see also *"Integrated water resources management,"* EOLSS on-line, 2002). Sustainable management adds to that certain financial, environmental, technical, and social constraints on the outcome of the decision process. Where integrated management does not necessarily include a firm statement about the main objective of development, sustainable management does include such a statement (see also *"Water and sustainable development,"* EOLSS on-line, 2002).

There is growing recognition, particularly in regions that depend on surface water, that the river basin is the most appropriate unit for water resources management. A river basin can be defined as a geographical unit within which water flows naturally towards a common outlet. The term river basin is generally used for the entire basin that drains into a sea, an ocean, or an inland lake. However, the concept can also be applied at a smaller scale. In such cases, people often speak about sub-basins or catchment, sub-catchment, or watershed areas. The management of water resources within such geographical boundaries is called river basin management. Many river basins include the territory of more than one nation. International river basins encompass nearly 50 percent of global land area, so a large part of the world's population depends on water resources shared by neighboring countries. This has led to a growing number of transboundary water conflicts, but also to increased cooperation between neighboring countries (see also *"Trans-boundary water resources management,"* EOLSS on-line, 2002).

3. THE WORKING FIELD OF WATER RESOURCES MANAGEMENT

3.1. Definition of the field

The working field of the water manager covers those parts of the environment and society that relate to the use of water, or to protection against water. The field includes both water resources and water users. The term "water resources" is used here to refer to a broad range of physical aspects: water stocks, water infrastructure, water flows, and a large number of processes that affect water quality. The term "water users" refers to a broad range of societal aspects of water: "offstream" water use for domestic, agricultural and industrial purposes, but also "instream" water use for fishing, navigation, recreation, and hydropower generation. As well as activities that use water directly and intentionally, there are activities that affect water unintentionally. Land use changes, for example, can affect the water system through changing evaporation, groundwater recharge, and erosion processes. Also, activities that contribute to climate change can indirectly affect the availability of water. Finally, people often speak about "functions" of the water system, not only referring to the societal functions of water but to its ecological functions as well. Therefore, it would probably be better to replace the term

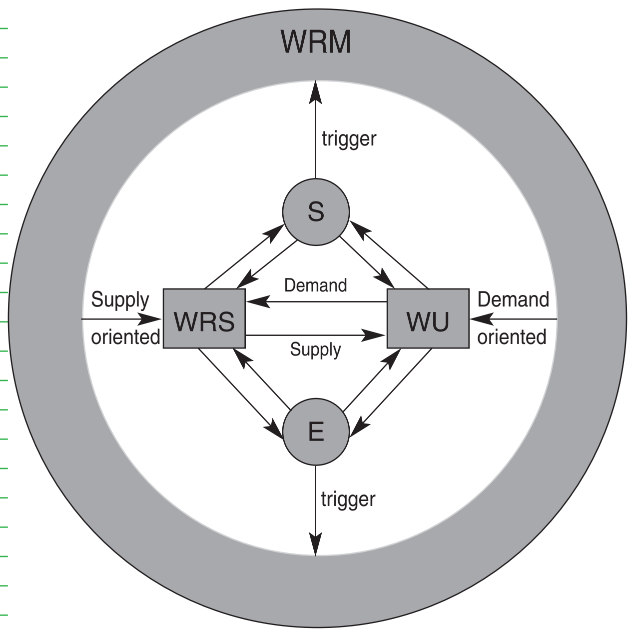

Fig. 1. The field of water resourcs management

"water users" by the more general description "actors with some interest in water and its functions, or that affect water somehow." Insight into this broad field – into the physical, ecological, and societal aspects – is needed for effective water resources management. One should have a clear picture of the field in order to know where, and how, effective management can make things change.

The water resources manager interferes with the system in two ways: through supply-oriented measures, such as building infrastructure, drilling boreholes, or building dams; and through demand-oriented measures to influence demand. The water resources manager is prompted to take action by triggers from the state of the resource base of society, or from the environmental resource base.

3.2. Key issues in water resources management

What are the key issues that trigger the need for water resources management? There have always been two problems: too little water, or too much water. The key issue in water resources management has therefore often been seen as the improvement of the allocation of water in space and time. It is widely recognized today that reality is more complex. Problems are not always caused by having the wrong amount of water at a certain place and time. There is also the problem of rapidly increasing water demand all over the world, leading to pollution, over-exploitation of aquifers, increased evaporation, and dry rivers. Dams, for decades regarded as the pre-eminent solution to stabilizing river runoff, are more and more often the objects of severe criticism. The opponents of dams argue that negative side effects – loss of valuable land and ecosystems, forced displacement of people, evaporation losses – far outweigh the benefits. Today it is often held that the increasing demand for water is the real problem, not the optimization of water allocation in space and time.

It has been recognized that intensive use of land and soil can affect a water system heavily, often with negative impacts on various economic activities, and on the natural functioning of ecosystems. A key issue in water management is therefore also land and soil management. One can also highlight the importance of considering the water system in spatial planning. Too often cities have been built in places where there is no water, or in places where flooding risks have not been properly accounted for. Another possible key issue is climate change, which will imply changing spatial and temporal patterns of precipitation, evaporation, and runoff. In coastal zones, where about 60 percent of the world population lives at present, sea level rise might become a serious issue of concern: particularly in areas that are actually sinking, either due to tectonic movements or to soil subsidence as a result of lowering groundwater levels.

The key question asked most often in water resources management is no longer how to re-allocate water in order to satisfy all demands, but rather how to prioritize different demands and make trade-offs between diverging interests. Where in the past technological knowledge was regarded as of primary importance, today economics, ethics, and politics all come in. The content of a national water policy depends strongly on how a society wants to secure its food supply, what emphasis is given to the preservation of valuable ecosystems, and what allocation mechanisms are preferred if shortages occur. For a water-poor country it makes a world of difference whether the policy is to secure food supply by growing crops within the country itself (food self-sufficiency), or by importing water-intensive products (import of "virtual" water) and exporting products that need less water.

Finally, institutional issues in water resources management are too often neglected. In 1990, 1.2 billion people in the world still lacked access to a proper water supply, and 1.7 billion people lacked access to proper sanitation facilities. This fact has little to do with the absence of water, because human water needs for drinking, cooking, and sanitation are relatively small. Poor water quality, although a problem, is not the root issue. The real problem relates to the absence of proper institutional mechanisms guaranteeing a sustainable supply of public water and sanitation facilities. It has been proven that it is easy to dig a new well, but it often appears to be difficult to maintain this well in good condition, to establish proper agreements of responsibility, and to recover the costs needed for repair.

3.3. Management instruments

A management instrument is a tool that can be used by a manager to promote the achievement of management objectives. Typical instruments in water resources management are building water supply structures, water defenses and water treatment plants; setting water tariffs; issuing permits for water abstraction and wastewater disposal; and making proper water law. Depending on his responsibilities and authorization, a manager can apply different kinds of management instruments. The manager of a water board has different approaches from the manager of the Ministry of Water. For example, the former can give permits to local industries to discharge their wastewater, while the latter can make up rules to be followed by water boards when issuing such permits. Management instruments can be applied at different strategic levels. At the basic level, a manager can take a single "measure," which is no more than applying one particular management instrument, in one particular case and for one particular objective. At a more strategic level, a manager can develop a "strategy," consisting of a number of measures. These measures form a coherent set, and together aim at meeting one or a number of objectives. To reduce water shortages, one strategy could be to increase the water supply, by building new infrastructure such as dams and canals. Another strategy could be to reduce water demand by subsidizing more efficient techniques of water use. Different strategies together can form a "policy." A policy combines various strategies in order to obtain an optimal result with respect to as many of the management objectives as possible.

Measures can be classified by asking the following question: will the application of the measure directly result in the desired change in the field, or will the desired effect be realized indirectly through the effect of the measure on the behavior of the actors in the field? Measures that result directly in the desired effect fall under the heading "production of goods and services." There are many possible examples, including the construction of dams, diversion structures, water supply systems, sanitation facilities, sewer systems, and treatment plants. Because these measures imply a direct change in the physical infrastructure, they are also called structural measures. The counterparts of the structural measures are the non-structural measures. These are also called incentives, because of their intention to urge actors to change their behavior. Incentives are meant to contribute to the management objectives in an indirect way, and can be subdivided into four categories:

- regulation instruments
- economic instruments
- communicative instruments
- covenants.

The first type of management instrument includes legal or administrative regulations. These may include: licensing (issuing of permits to dispose of wastewater); setting quotas for fish catches; landuse zoning; prohibition actions (for example, protection against exploitation or pollution); setting operation rules or rules for resource utilization; and enforcement. Enforcement is often combined with imposition of fines and penalties. Operation rules define the correct working of infrastructure used for resource allocation or conservation. At the highest level of abstraction, water legislation and regulations are often based on certain principles, such as the prior appropriation doctrine (the oldest water user has the first rights), or the priority-of-use doctrine (some types of users deserve priority over other types of users). The following are some of the principles often used. Some of these principles merge with each other, but others are clearly conflicting.

Economic incentives are instruments used to influence human behavior through economic means such as charges, subsidies, taxes, or the creation of markets. "Water pricing" is a general term for setting water prices for different users. Because water users in most parts of the world have traditionally been charged only part of the actual costs of water, "water pricing" is generally seen as synonymous with "increasing prices." It also refers to choosing more appropriate tariff structures. For example, an increased price per liter may be charged if total use exceeds a certain limit, or – at worst – instead of a fixed price per user irrespective of the total amount used.

Communicative instruments aim at raising awareness among the general public or certain target groups. This can be done by provision of information or education programs. Malin Falkenmark, a distinguished Swedish hydrologist, has pointed out that

Table 1. Types of management instruments

Type of management instrument	*Examples*
Structural measures	
• Production of goods	Construction of dams, water supply systems, sewer systems, sanitation facilities
• Production of services	Operation of structures Maintenance of structures
Non-structural measures (incentives)	
• Regulation instruments	Legal and administrative regulations on water use or discharge Permit structures Fish quota Allocation of water rights Water quality standards Land use zoning; earmarking of regions for certain purposes
• Economic instruments	Water taxes or subsidies Water tariff structures Charging for wastewater disposal and treatment Creation of water market
• Communicative instruments	Provision of information, awareness raising Education
• Covenants	Agreements with major industries on water-use efficiency

Guiding principles in water resources management

Principles related to sovereignty:

Absolute territorial sovereignty. According to the so-called Harmon doctrine, states can do what they want with the natural resources within their territory.
Absolute territorial integrity. No state is allowed to alter the natural conditions of its own territory to the disadvantage of the natural conditions in a neighboring state.
Restricted territorial sovereignty. States can use their own territory in whatever manner they chose, but they are not allowed to cause harm to other states (for example, downstream states).

Principles related to resource use:

Rule of minimum flow. There should be sufficient water left for downstream users.
Prior appropriation doctrine. First in time, first in right.
Priority of use doctrine. Some types of water use deserve priority.
Basic need principle. Each individual has the right of access to resources for his or her basic needs.
Water-as-an-economic-good principle. Users should pay the full economic value of the water used, provided that the price of water is affordable.
Intergenerational equity principle. Future generations should not be deprived of access to an adequate resource base, although the resource base itself may change in composition (for example, knowledge, technology, infrastructure).

Principles related to the environment:

Prevention principle. If there is scientific proof that a certain activity causes a problem, measures must be taken to prevent it.
Precautionary principle. Preventive action should not be delayed, particularly if the problem is likely to be irreversible, even there is not yet incontrovertible evidence that the suspected cause activity is to blame.
Stand-still principle. The quality of the environment should at least remain at its present level.
Best-available-technology principle. People should use the best available technology, in order to minimize the pressure on the environment.
Polluter-pays principle. The individual or organization that inflicts damage on the natural resources system should pay for rectifying the damage.

Principles related to organization and procedure:

Prior notification. If people plan to carry out activities that may harm others, notification should be given.
Prior consultation. If people plan to carry out activities that may harm others, consultation should be organized at an early stage.
Prior impact assessment. Activities that may seriously affect the functioning of society or the environment should be preceded by a thorough social and environmental impact assessment.
Interest-taxation-representation principle. A principle which establishes a link between the right of stakeholders to have a say in planning and management, and their duty to pay for the services provided.
Subsidiarity principle. For a government to be efficient, decisions should be taken at the lowest appropriate level; if a task can be decentralized to a lower level of government one should do so. Central government should retain those tasks that properly belong to that level, however.

increasing public "water literacy" can contribute substantially to a wiser use of water.

Covenants are "gentlemen's agreements" between actors in the field. The central government can, for example, make an agreement with a major industry that it will reduce certain emissions by an agreed percentage. The advantage of this instrument is that the agreements often only come into being after intensive discussion, which will generally result in some common understanding and commitment from the industry. This can be more effective than enforcement.

Along with the structural measures and incentives, there is a third category of measures, aimed at improving the institutional environment in which management takes place. These are supportive to the whole management process, and aim to create a better environment for effective management. They will be further discussed in Section 5, dealing with the organization of the water management process. This category of measures is mentioned here only to show that there are two levels of management. At the first level, actual management of the water resources field takes place; at the second level, the management of the first level management itself takes place. If we look at water legislation in an arbitrarily chosen country, it will be seen that part of the legislation comprises rules dealing with the use of water, while another part governs the tasks and responsibilities of the various water institutions.

Applying one type of management instrument is generally insufficient in itself to reach a certain objective. Applying economic instruments, such as taxes, subsidies, and tariffs, requires that they be embedded in some kind of legal framework. At the same time, incentives often need enforcement. Rules, agreements, and laws should have "teeth" to make sure that agreements are obeyed, and that violation of the agreements leads to sanctions.

In general, in order to address a given management problem, a balanced combination of structural and non-structural measures is needed. For example, in the case of flood protection, structural measures may consist of building dykes and construction and operation of hydraulic works, but landuse management and floodplain zoning may also be required.

3.4. The context of water resources management

Whether or not we succeed in reaching qualitatively high and sustainable levels of water supply worldwide, sanitation and ecosystem health will depend, to a large extent, on two factors that are largely out of the reach of the water manager: population growth and economic development. From the viewpoint of sustainability, the world population must stabilize, and economic growth should be based on the renewability of resources. Although in many developing countries there is still ample scope for development, in the industrialized world there are strong indications that the sustainable level of development has already been exceeded. The consequence of this, in the developed countries, is a need to find ways of reshaping economies. In developing countries, it is essential that the population be kept in balance with the environmental carrying capacity, which, in most cases, implies strict limitations to population growth.

At the International Conference on Population and Development held in Cairo in 1994, important population control issues were addressed. An important conclusion was that the responsibility of how many children a family should have lies with the parents, and primarily with the woman. The conference concluded that, in order to help with that responsibility, women should have access to reproductive health care, and should be empowered to take good decisions regarding the health and prosperity of their own families. An important recommendation of Cairo was that women, particularly girls and young women, should have access to schooling and education. The general feeling was that educated and empowered women will generally take the best decisions for their families, for a sustainable future, and hence for society. Consequently, natural resources managers can best influence population growth by facilitating education and access to reproductive health care for women. Such measures should be part of national strategies for natural resources management. Moreover, it is likely that where adequate living conditions are present (water supply, sanitation, health care and education, and sound economic prospects), people are more likely to consider family planning than in situations where these conditions are lacking.

Although Cairo has opened new approaches to limiting population growth, the question of reshaping economies in overdeveloped countries remains unaddressed. Unfortunately, both population growth and economic development are generally considered separately from water resources management.

4. THE PROCESS OF WATER RESOURCES MANAGEMENT

4.1. The management cycle

The last few decades of the twentieth century has seen a worldwide shift in national water politics, from a project to a policy approach. This trend is likely to continue, implying that the way water resources are actually being managed is gradually changing. In former times, the emphasis lay on individual water projects devoted to a particular aim or problem. The biggest projects were often "irrigation projects," in which whole regions were adapted for irrigated agriculture, or "hydropower projects," in which rivers where tamed by large dams to deliver energy for regional development. Over time, experience with these large projects resulted in increased organizational knowledge, and an appreciation of the steps to be followed to guarantee successful completion of the project. The first step was the recognition in itself that a project must proceed systematically in a number of stages. Analyzing problems and demands, and defining project objectives, should precede the design of various alternative options. Impact assessment should precede the evaluation of these options. Decision-making should come only after a thorough evaluation procedure, and the weighing of "pros" and "cons," but should happen before work begins. Finally, construction should be followed by effective operation, maintenance, and project evaluation.

Later on it was recognized that this linear project approach could not always hold. The approach sounds rational, but in reality new information continuously becomes available, and this often calls for reconsideration of earlier steps. This experience resulted in the concept of the "project cycle," which still recognizes the sequence of steps in a project but also provides regular opportunities to assess progress. This makes it possible to return to one of the previous stages if this is thought necessary. People also started to talk about "cycles": after evaluation of one project a new project often followed, sometimes with adapted targets based on evaluation of its predecessor's results. This development was actually the start of a transition from the project approach to the policy approach. Within the policy approach, one recognizes that there is a continuous demand for a broader "policy," which cannot be satisfied by undertaking individual projects one after another. The difficulty with the project approach was that each project had a rather limited scope, with particular targets and a limited time horizon. In addition, projects were generally devoted to certain developments (a new irrigation scheme, hydropower plant, or water defense works), so issues such as water pollution, erosion, or preservation of valuable ecosystems remained unaddressed. People felt a need for a more comprehensive plan with respect to the use of water resources than would ever be possible within the scope of a single project.

Since the project approach has been replaced by a more policy-oriented approach in many countries, the idea of a cyclic process has not changed. The project cycle concept has evolved into a management cycle concept. Management is not a one-time exercise, leading to a plan that must be implemented in order to arrive in the desired state. Rather, it is a continuous updating and adjustment of planning, taking action to adapt to changing circumstances.

Today it is widely recognized that the management of water resources is a highly dynamic and complex process. Its cyclic character is shown in Fig. 2. The two main components of water resources management are (a) planning, and (b) implementation and control. Planning refers to preparation for action, while implementation and control refers to the action itself. In the planning stage, policy is prepared, established, and evaluated. The stage of implementation and control includes the actual policy implementation, operation and maintenance, and monitoring. To some extent, different activities are sequential: problem identification comes before defining solutions; decision-making comes before implementation of measures. However, there are numerous places in a management process where feedback occurs, where new information urges new views, and where new decisions have to be taken. The management cycle is not to be viewed as a rigid structure, but rather as a framework for thinking. Depending on the demands of a situation, one step can be bypassed or repeated several times before the next step is taken. For this reason, the management cycle concept should be applied with a high degree of flexibility, allowing shortcuts and feedback loops, and continuous involvement of stakeholders.

4.1.1. The planning phase

Water resources planning refers to the planning of the development, conservation, and allocation of a scarce resource. It matches water availability and demand, taking into account the full set of national objectives and constraints, and the interests of stakeholders. It includes:

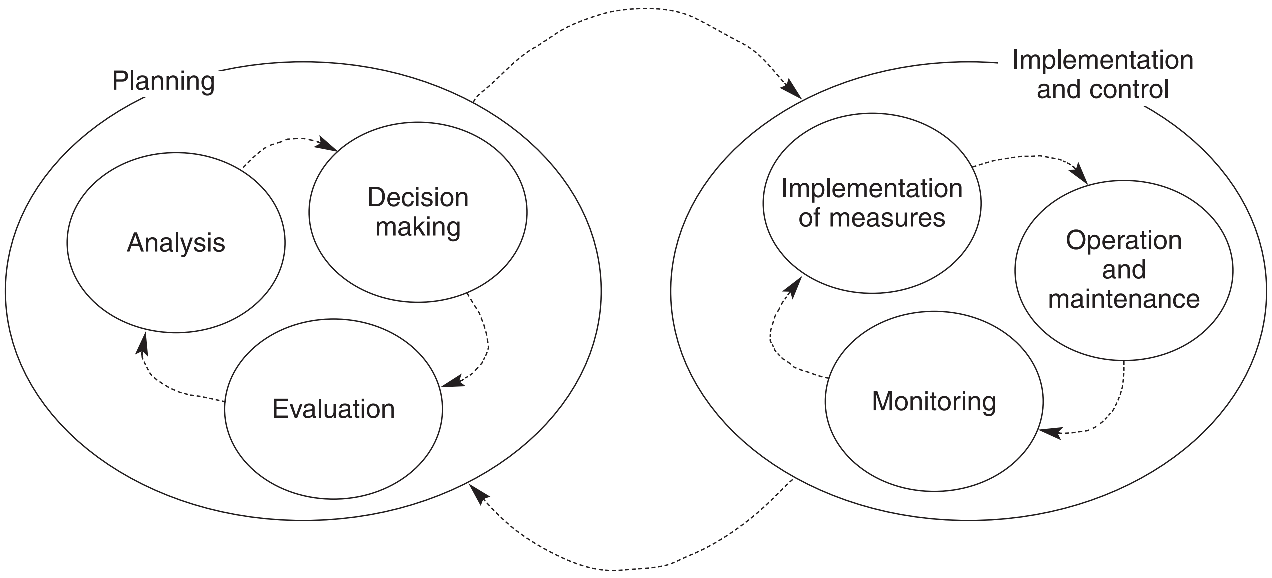

Fig. 2. The management cycle

- evaluation of existing water management practices and previous strategies
- analysis of the present situation and possible policies for improvement
- deciding on the policy to be adopted.

Evaluation of previous policy strategies – known as "post-ante" evaluation, because it takes place *after* implementation – is often omitted. This is a pity. It can provide a lot of useful information about the effectiveness of certain measures, which may become essential information for the formulation of future strategies. The phase of analysis includes problem identification and description, formulation of management objectives, identification of constraints and external criteria, identification of possible measures and strategies, impact assessment, and ("ex-ante") evaluation of alternative strategies. In order to facilitate the decision-making process, an increasing number of planning methods are being used and studied. Most of these place emphasis on the interactions between the different interests involved, and somehow try to simulate the situation in the field to give decision-makers a feel for the wider societal implications of their roles. This happens, for example, in case of role-plays, policy exercises, and theoretical game-plays. There is an increasing awareness that each decision maker is part of a network of other actors – each one a decision maker in his or her own right – and not a "ruler" who can steer all processes in the field.

In the past, there was a strong bias in water resources planning towards optimization. This was so strong that, to some people, water resources planning and optimization (linear programming, dynamic programming, and so on) were almost synonymous. Nowadays, it is widely recognized that optimization techniques serve a limited purpose. The reason for this lies in two key elements of planning, which together are largely responsible for the complexity of water resources planning: uncertainties, and conflict of interest.

Uncertainties are omnipresent: in hydrologic and climate scenarios, in scenarios of technological developments, in economic scenarios, and in the political environment. Water managers have reasonably good tools to deal with uncertainties in physical processes, but as soon as humans come into play, prediction becomes a tricky business! Oil prices, agricultural commodity prices, exchange rates, interest rates, and other factors are highly unpredictable, yet they are essential in any water policy analysis. An additional problem is that not only is it difficult to understand the functioning of societal mechanisms at any given point in time, but these mechanisms also change. The governmental and political boundary conditions – such as objectives, laws, and regulations – change over time, but governments themselves also change. Recent years have seen numerous governmental changes and revolutions worldwide, which have had serious impacts on governmental policies and the legal and institutional framework. In addition, there have been several economic crises with large impacts on prices, exchange rates, and markets. On top of these uncertainties, there are the conflicts of interest. Decisions are seldom taken on the basis of an "optimal" scenario. They are taken because an alternative is acceptable to the relevant stakeholders, or offers an attractive compromise. The final decision reflects the balance of power. Optimization is only useful as a component of water resources planning where boundary conditions can be considered as fixed.

Even if there were no uncertainties and conflicts of interest, the planning of a water resource development cannot be a simple *optimization* exercise due to the complexity of the systems involved. The processes involved are not static but dynamic, requiring *optimization* over time. Many processes are non-linear, which makes optimization a lot more difficult. Above that, there are numerous feedback mechanisms, which means that factors that are generally dealt with as boundary conditions actually become part of the system. Finally, even if the system could be fully understood and deterministic, chaos theory has shown that this does not necessarily mean useful predictions can be made.

It has become clear that the complexity of the planning process cannot be addressed properly by regarding it as a matter of calculating the best solution. Instead, it requires an inter-disciplinary approach and continuous involvement of all stakeholders. In addition, a flexible approach should guarantee that one could adequately respond if new information requires the adjustment of an earlier point of view.

4.1.2. The phase of implementation and control

This embraces all tasks required to fulfill a certain water management strategy. It includes the detailed design of planned measures, the implementation of these measures, operation and maintenance, monitoring of effectiveness, and enforcement of laws and regulations. Some of the activities in this phase, such as building a physical structure or implementing an institutional reform, are once-only exercises. Other activities such as maintenance, however, require continuous effort over time. This might sound obvious, but it is emphasized here because the required efforts in the longer run have often been neglected in the past, and they represent a major reason for failures of water policy plans. The absence of proper maintenance of structures, and lack of regulatory enforcement, are often the most important factors behind failing policies. As has been mentioned before, endless projects in developing countries have shown that the mere construction of drinking water supply structures does not improve the situation if they are not maintained in the long run. This process includes not only physical maintenance of the structures, but also taking care of cost recovery, and ensuring proper functioning of the responsible organizations. Another type of failure occurs if the policy is not properly translated into clear measures that can be readily implemented and will achieve the desired result. For example, in the Rhine Action Program of 1987, the basin states of the Rhine agreed to reduce concentrations of a number of "priority substances" in the North Sea by 50 percent in the period 1985–1995. This target was not achieved for all substances because the program contained insufficient measures that could contribute to this. This example is by no means the worst, as a number of specific targets were achieved. It makes clear, however, that in the end it is the actual measures themselves that will effect changes, not the plan and its targets.

4.2. Involvement of stakeholders

Many water resources management projects, although technically and economically successful, have accentuated inequalities between people. Social impacts and the distribution of benefits are often not taken into account sufficiently. Efforts often concentrate on finding a solution to an existing problem, such as flooding. Possible negative impacts of a flood protection project, however, may include loss of access of the poor to resources (land-ownership changes), effects of land acquisition (loss of homestead or fertile land), and decreased fishing potential. Such impacts could reverse an intended positive project output, leaving the poor majority in a worse situation than before. Such an outcome represents a failure for any development intervention. When people do not feel the benefits of development, or if a project affects their lives negatively, technical and economical successes are of no value.

Another common problem in water resources management is that projects fail to be sustainable in the long term, because people lack incentives for proper operation and maintenance. Intended beneficiaries of the project may have no interest in maintaining it if they were not committed to the project ideas from the beginning, or were not committed to bearing the responsibility of the development. Moreover, the organization responsible for operation and maintenance often does not have the financial and physical resources to run the project efficiently.

For a water policy plan to work, whether at a local, river basin or national scale, it is necessary that all parties involved are committed to the plan's goals. A prerequisite for getting commitment from all parties is generally that they are involved in all management stages. People have to become convinced that a sound water policy is in their own interest. The only plan that will actually work is one based on strong involvement by the relevant stakeholders, leading to a consensus or accommodation. The "best" plan is the one which stakeholders accept as such, not one that results from calculation of the optimal solution by a few clever civil servants.

There is an additional argument for involving people who are directly interested in the proper management of water. If people encounter direct costs, or receive clear benefits, related to the consumption or use of water they will have a strong incentive to get involved in the management of the resource. People that are formally responsible for the proper utilization of water are often not really involved, and thus not interested in efficient use of the resource. In the Netherlands this has led to the guiding principle "interest–taxation–representation." This means that an actor with an interest in the use of the resource should contribute to its management, in money or in kind, and hence derive a right to participate in decision-making. This maxim keeps the management of resources close to peoples' needs, and maintains wide involvement in the decision-making process.

One of the main conclusions of the Dublin Conference was that water management should be based on a participatory approach. This means that stakeholders should be involved in all stages of the management cycle, starting from the inception of a plan during the identification phase. The manner in which people may participate changes through the various stages of management and implementation. In parallel with the main steps in the management cycle, the following participation steps should take place:

- needs assessment (in the planning phase)
- consultation (in the implementation phase)
- group formation and institutionalization (in the control phase).

Needs assessment can take place through interviews and workshops with users, elected local officials, and NGOs. The process should be interactive, and not merely top-down. Needs assessment should be made by a multi-disciplinary team. Consultation during the implementation phase should be carefully prepared with selected, qualified representatives to participate in the design and construction of infrastructure, and the design and implementation of non-structural measures. During the phase of control, institutions representing target beneficiaries should be responsible for the operation, maintenance and performance monitoring, and evaluation of strategies. These insti-

Table 2. People's participation in the management cycle

Process	*People's participation*	*Activities*
Planning	Needs assessment	Interviews and workshops with stakeholders, local groups, elected officials, NGO's, interdisciplinary teams
Implementation	Consultation	Hearings with selected representatives, local coordinating committee, etc.
Control	Institutionalization	Establishment of mandates, enforcement mechanisms, training, manuals, operating rules

tutions should have clear mandates and benefit from proper training. If institutions are made responsible for operation and maintenance, proper manuals and training should be provided.

Since the Dublin Conference in 1992, particular attention has been paid to the involvement of women in water resources management. The third Dublin principle states that women play a central role in the provision, management, and safeguarding of water. This principle calls for positive policies to address women's specific needs, and to equip and empower women to participate at all levels in water resources programs. The principle is particularly relevant in many developing countries where women are not only responsible for the household water supply and sanitation, but often are also key players in agriculture. Projects where men were the main players in implementing water resources development activities at local level – largely because they were seen as the "logical" representatives of the community – have often failed, simply because the facilities delivered did not respond to the direct needs of the water users, or because those responsible for the collecting and using water (often women) were not involved in their operation and management.

5. THE ORGANIZATION OF WATER RESOURCES MANAGEMENT

5.1. The role of government

The role of government is to represent the interests of society. Many kinds of questions about the state's role may arise. What are the interests of society? Is it in the interest of society that a government takes care of producing bottled mineral water? Is it in the interest of society that the government minimizes flooding risks in densely populated areas? And, if we would agree on the latter, is it in the interest of society that public servants build a dyke, or is it sufficient that the government commissions private enterprises to do so? In short, there is no generally valid statement on government role and non-government role. These issues depend very much on what a society wants, and responses may differ greatly among regions and cultures in the world. Opinions on these matters change continually over time. However, it is clear that in the case of water, as a public good, a government has an important responsibility. There are numerous motives for governmental responsibility. These may include social considerations ("water for the poor," or "water for future generations"), the need to conserve valuable ecosystems, the protection of "common pools," the need to protect people and land against flooding, and to arbitrate in case of ill effects upon others arising from individuals' actions.

With respect to water, government's primary role is to make sure that the public interest is taken into account adequately in the allocation and use of the resource. In this role, the government is responsible to society. Besides this public interest role, governments often operate as deliverers of goods and services. Many governments, for example, construct and maintain dykes, irrigation works, drinking water supply plants, and wastewater treatment plants. They operate water supply plants, send bills to the consumers, and perform other tasks. The government often intervenes where it is felt there is no other market in place. Hence, in water resources management the government often plays a dual role: as caretaker of a public resource, and as a provider of goods and services

In its role as caretaker, the government is concerned with the interests of society as a whole. It sets rules and regulations for users of water, and enforces them. The regulations should guarantee a fair distribution of water, provide safety, and prevent misuse and over-exploitation of water resources.

In its second role, the government produces goods and services in response to the demands from individual members of society, but also in response to demands for it to take a "caretaking" role. Where, in its first role, government sets boundaries to the economic system, in its second role it takes part in the economic system. The extent to which government takes part as a producer (and consumer) of goods and services varies between countries. In a free market economy, the government assumes a productive role only where markets are not interested because of low profits or high risks, or where markets fail. Providing for flood protection or regulating river flows through reservoirs are typical examples of such a production activity. Water treatment, delivery, and disposal can often be handled more efficiently and effectively by basin authorities, communities, utilities, or the private commercial sector. In a centrally planned economy, most production functions are part of government, or are closely linked to it. They usually have a monopoly as they operate under exclusive government protection without any competition, not even for those functions where high profits can be made at low risks.

5.1.1. Spatial levels of management

In water resources management one may identify users and interest groups at different spatial levels. At the local level, there are individual consumers (households, farmers, boat owners) and small user associations. On a larger geographical scale, one can often find water boards or water districts, and larger user associations. At a national level, there are user groups that represent more aggregated or general interests. Examples are major river basin authorities, and government agencies responsible for nature conservation, defense of the country, or sustainable development. At the international level, there are river basin authorities for transboundary river basins, intergovernmental organizations, and international NGOs. It is essential to recognize that water resources management is a multilevel affair, and interests must therefore be represented at different levels. Although each level has its own particular governmental institutions, water resources can never be properly managed if one considers only one particular level.

A proper "tuning" of tasks and responsibilities, in accordance with the various interests, across the different levels of management is of extreme importance. Control mechanisms should reside as close as possible to the level where the resource is used or consumed, and where direct interest lies. This is not always possible, since instruments for planning, financing, and enforcement often reside at higher administrative levels. As a general rule, however, the guiding principle should be that tasks and responsibilities should reside at the "lowest appropriate level." This means that, wherever possible, responsibilities should be put at the lowest level of management where management is still effective; and that decisions on the management and allocation of resources should not be taken at a higher level than strictly necessary. This principle is also called the "subsidiarity principle."

The subsidiarity principle is sometimes wrongly interpreted by people who argue that most, if not all, decisions should be taken at local level. Decisions related to international rivers do not belong at the local level, although appropriate consultation and communication processes are needed because the decisions affect people's lives and activities. The situation is less obvious, however, regarding care for a healthy environment or prevention of pollution. At a local level, the most attractive solution for disposal of waste is often to dump it outside one's own territory. Another example is the pressure experienced in local municipalities to extend housing or industrial development into a river floodplain. The resulting constriction and loss of space mainly affects the interests of other communities, resulting in a gradual increasing pressure on floodplains, especially during extended periods without major floods. In all these cases, unsustainable behavior seems attractive from a local point of view since the local community does not carry the burden. Hence there is a definite need for decision-making at higher levels of government, to guarantee sustainability and environmental quality.

In the following sections we will consider what water resources management means at different levels, from the local to the international. Examples are given of user groups at different levels, their tasks and responsibilities, and typical instruments and actions.

5.2. Local level

At the local level, users or user groups consist of individuals and households that may or may not be organized in community councils and committees, or who represent economic activities such as shipping and industry. These users or groups usually have a single interest or purpose. These might include, for example, farming, village water supply and sanitation, social forestry, transport of goods, industrial production, or supply of irrigation water. At the water-user level, user groups' interests relate to the sustainable utilization of the natural resources within the confines of laws and regulations:

- efficient utilization and allocation of available resources
- creation of awareness of sustainable resources utilization among users
- financial management of local sources
- handling of conflicts between individual users
- expressing demands to higher levels and to other sectors which compete for the same resources.

Typical instruments and management actions at the local level might include operation of a local water pump or pond, collection of fees and charges, monitoring, maintenance of infrastructure (for example, dykes), and social control and application of "sanctions."

5.3. Intermediate level

The gap between local and national level is often large and difficult to bridge. There is a clear need for an intermediate level of management. This intermediate level is often absent or underdeveloped: a missing link between strongly "top-down" organized and centralized national governments, and the community-oriented development efforts by NGOs and donor organizations. The advantage of the intermediate level is that agencies and organizations are close enough to the local stakeholders to be practical, but at the same time the general interests of society may be represented with sufficient responsibility and power for enforcement. This can facilitate a realistic trade-off between private and public interests.

The intermediate level refers to districts, provinces, river basins, or regions. User and interest groups at this level are either decentralized government agencies, or aggregate local water users. National governments often delegate the tasks and responsibilities for groundwater management, water quality management, and surface water management of regional water bodies to this level. At this level, aggregate user organizations can be councils or committees that represent collective interests going beyond the individual or community level. Interest groups at this level might include water boards, recreation boards, district water councils, provincial environmental departments, and river basin authorities.

Responsibility at the intermediate level typically relates to the integrated management, planning, and co-ordination of sustainable resources utilization, in particular:

- Monitoring, storage, and analysis of relevant catchment area information.
- Efficient utilization and allocation of resources, for example from regional aquifers or water bodies.
- Screening and issuing of licenses.
- Financing of works beyond the capacity of local groups.
- Co-ordination and conflict management between different users and sub-regions.
- Enforcement and policing of laws and regulations at catchment area level.
- Co-ordination with other sectors of government, such as planning authorities.

- Compliance with national or international environmental quality standards.
- Compliance with regional land-use plans.
- Publicizing information about protection and conservation zones.
- Regulation, pricing, and financial management of local resources.
- Creation of awareness with respect to an efficient use of natural resources.
- Representation of local interests at national level.

Typical instruments and management actions include:

- Collection of fees for water consumption and wastewater charges.
- Rural water supply.
- Monitoring of water quality and groundwater levels.
- Operation and maintenance of regional infrastructure, such as regional dams and intake structures.
- Regional land-use plans.
- Regional water development plans.
- Training and capacity building at lower levels.
- Establishing the mandates of local water organizations.
- Issuing water and land-use rights, licensing.
- Policing and application of sanctions.

5.4. National level

The national level refers to nations or states where a substantial constitutional responsibility, and legislative and administrative power, is concentrated. Traditionally, their main role is exercising a control function. They deal with international arrangements, and the defense of national interests. User and interest groups typically consist of ministries or more specialized government agencies, which either represent water-related sector interests (such as agriculture or mining), or deal with more resource-oriented management (for example, through ministries of land and water, or environment). At national level, interest groups also include major river basin authorities, and non-governmental organizations. The typical resources management responsibility at national level relates to the co-ordinating, legislative, supporting, and guiding role of government, in particular:

- Definition of a framework for management.
- Development of national water policies and strategies.
- Co-ordination with the national planning process (for example, on spatial planning).
- Co-ordination of donor contributions and involvement.
- Formulation of environmental quality standards.
- Financing and operation of major infrastructure (coastal defense, flood protection and navigation in major rivers).
- Provision of legal framework.
- Monitoring of decentralized forms of resource management, to prevent unwanted side-effects of decentralization or privatization.
- Enforcement and policing of laws and regulations at national level.
- Maintenance of a national water resources database.
- Capacity building, research, technology development, and education in resources management.
- Creation of awareness with respect to the scarcity of natural resources.
- Maintenance of international contacts and co-ordination regarding the sharing of common resources.

Typical instruments and management actions at the national level include national legislation, regulations, concessions, research and development (for example, related to techniques for efficient water use), land use planning and management, maintenance of the coastal defense system and primary water courses, awareness building, training and capacity building at lower levels, and intergovernmental agreements.

5.5. International level

As a result of globalization, mass communication, and large-scale interventions related to economic development, the international level seems set to become more and more important. This is causing concern, since possibilities for democratic control at this level are limited or completely absent.

At the international level, the number of interest groups – it is now more difficult to talk about user groups – is growing rapidly. They present a complicated picture, as they encompass international commissions connected to bodies such as the EU, SADC, or OECD, international river basin authorities, international NGOs (such as Greenpeace or the World Resources Institute), and multinational organizations such as the World Bank, IUCN, and UN agencies. The responsibilities of these groups are limited, as implementation of agreements and their enforcement resides with national governments. International obligations and agreements and financial arrangements, however, increasingly limit these national governments' freedom of movement.

One of the problems facing the international community is that there is no UN organization that deals specifically with water resources. The water interest is fragmented over many different organizations, such as UNDP, UN/DPCSD, WMO, FAO, UNESCO, WHO, UNEP, and UNICEF. Important steps towards more co-ordination have been the formation of the Global Water Partnership (GWP) and the World Water Council (WWC), both of which aim to co-ordinate the implementation of integrated water resources management principles and practices worldwide. Although there is undoubtedly some overlap between the two organizations, the WWC concentrates on awareness-raising at political levels; the GWP, by contrast, aims at implementation of integrated water resources management concepts (particularly the Dublin principles) and practices at the technical and operational levels. Both these organizations and the other main international players, such as the World Bank and UNDP, emphasize the need for regional and national capacity building in the water sector.

Instruments and actions at the international level are rather limited. On some occasions international institutes play a role in monitoring and vigilance. The United Nations plays a role in setting international standards for environmental quality, and developing guidelines for international agreements. Furthermore meetings between governments, and open publication of information on governments' compliance with policies and agreements, can be powerful instruments in forcing them to adopt desired policies and behavior. International sanctions may act as an enforcement tool. At the international level, however, there is generally little executive power.

5.6. Water sector capacity building

"Water sector capacity building" refers to the process of building organizations, human resources, and the legal and regulatory framework needed for effective and efficient water resources management. Since the First UNDP Symposium on Water Sector Capacity Building, held in Delft in 1991, capacity building has become a common concept in water resources management. Capacity building in water resources management is required to guarantee institutional sustainability. The concept was elaborated at the Second UNDP Symposium on Water Sector Capacity Building, held in Delft, in 1996. Water sector capacity building was then defined as the process of providing individuals, organizations, and other relevant institutions with the capacities that allow them to perform individually in such a way that the sector as an whole can perform optimally, now and in the future. Capacity building helps to initiate and support institutional strengthening and reform. It is the process of implementing institutional development. The capacity building process: (a) assists in the diagnosis of sector performance and institutional strength and weakness; (b) articulates and prioritizes the required capacities that need to be imparted to the individuals and institutions; and (c) implements support measures using a variety of tools and instruments. Capacities are the knowledge, skills, and other faculties – held by individuals or embedded in procedures and rules – both inside and around sector organizations and institutions. Capacity building consists of three main elements:

- Creation of an enabling environment with appropriate policy and legal frameworks.
- Institutional development, preferably building on existing institutions.
- Human resources development and strengthening of managerial systems.

Key actors in capacity building include government at various levels, external support agencies, non-governmental organizations (NGOs), education and training institutes, professional associations, national and international corporations, consulting firms, and individuals.

Instruments typically applied in capacity building measures are:

- Educational and training programs, including distance and modular education programs.
- Effective and innovative educational techniques, for example methods emphasizing "learning by doing."
- Transfer of new skills and attitudes, for example integrated and strategic thinking, risk forecasting.
- Network communication, for example by thematic workshops, e-mail groups.
- Twinning arrangements between peer organizations from different regions.
- Local and international technical assistance to counterpart organizations.
- Enabling access to knowledge and information pools and systems.
- Information and communication through, for instance, the Internet.
- Development of database and management information systems.
- Development of research capacity in universities and similar organizations.
- Creation of opportunities through international meetings.
- Enabling access to training materials, libraries, databases, and journals.

It is often thought that capacity building refers particularly to developing countries. Nothing could be less true! Industrialized countries also need to adjust their institutional arrangements continually to changing circumstances. One can see, for example, the increasing need to have "environmental planning offices" at different levels, in addition to "economic planning offices."

6. CURRENT ISSUES OF DEBATE

6.1. Availability of water

Our knowledge of terrestrial hydrology has advanced greatly in the past decades. This means that, for many areas, we can now give more accurate data for precipitation, evaporation, and runoff, and understand the underlying processes better than ever. Many of the uncertainties that remain are due to a lack of sufficient measuring locations. While many specific things remain to be studied and understood, this field is not an area of heavy debate. If we go to a higher spatial level, however, and speak about the global hydrological cycle and climate change, the situation is more difficult. Despite major efforts during the past few decades, we must admit that we cannot predict what a change in global climate would mean for hydrology at a regional level. It has also emerged that there are numerous feedback mechanisms between processes at the earth's surface and climate, which make this kind of prediction very difficult. It is not simply that the concentration of greenhouse gases in the atmosphere determine temperature patterns on earth, that temperature patterns determine evaporation and precipitation patterns, and that temperature and hydrology together dictate the conditions for plant growth. In turn, land cover and photosynthesis significantly influence regional hydrology and climate. Estimating the future availability of water in a certain region therefore involves a great deal of speculation.

There is another type of problem concerning water availability. This does not relate so much to the question of how much water there *is* or will be, but more to the question of how much water there is or will be *available for humans*. It appears that various authors apply different definitions to "water availability" in considering this.

The most common approach is to treat the total annual runoff in a river basin as a measure of the water availability in that basin – on the assumption that fresh water is a renewable resource, and the renewal rate is therefore a measure of water availability. An advantage of this "total runoff approach" is that water availability is defined in an unambiguous way, leaving no room for dissent other than over the validity of the runoff data itself. A major drawback, however, is that it does not account for losses due to flood runoff, runoff in remote areas, and pollution, and thus it gives a serious overestimate. Another criticism is that it only considers the possible supply of fresh water, ignoring the possibility of desalinating seawater. From this point of view, the approach yields a conservative measure of water availability.

The "total runoff approach" is generally applied at river basin level. If properly applied, both river runoff from the basin and subsoil groundwater outflow are measured. The latter is often left out of the equation, because it is considered to be relatively small. However, numerous studies have taken total water availability in a basin to equal the total river runoff plus total groundwater recharge in the basin. This is a good example of double counting, because generally the largest part of groundwater recharge becomes river runoff.

Various authors regard the total (river plus subsurface) runoff from a river basin as the upper limit to water availability, and propose reductions for losses due to flooding and runoff in uninhabited areas. This approach results in a much lower assessment of water availability than if one were to consider total runoff (Fig. 3). In addition, some authors allocate part of the stable runoff to diluting wastewater disposal, leaving only the remaining part for other purposes. A final important factor in water availability is climatic variability. It can be argued that it would be better to use a dry year for calculations, rather than an average one, to ensure that the measure of water availability also applies in dry years. The "reduced runoff approach" may have the advantage of carrying carefully balanced information on water availability, but the range of definitions used may lead to many different interpretations and calculations.

It has become so common to express water availability as a function of the amount of water flowing in rivers, lakes, and aquifers that scientists and engineers have started to think that any need for water should be supplied from one of these resources. In doing so, one actually neglects the most abundant and locally available source: rainfall. Worldwide about 40 percent

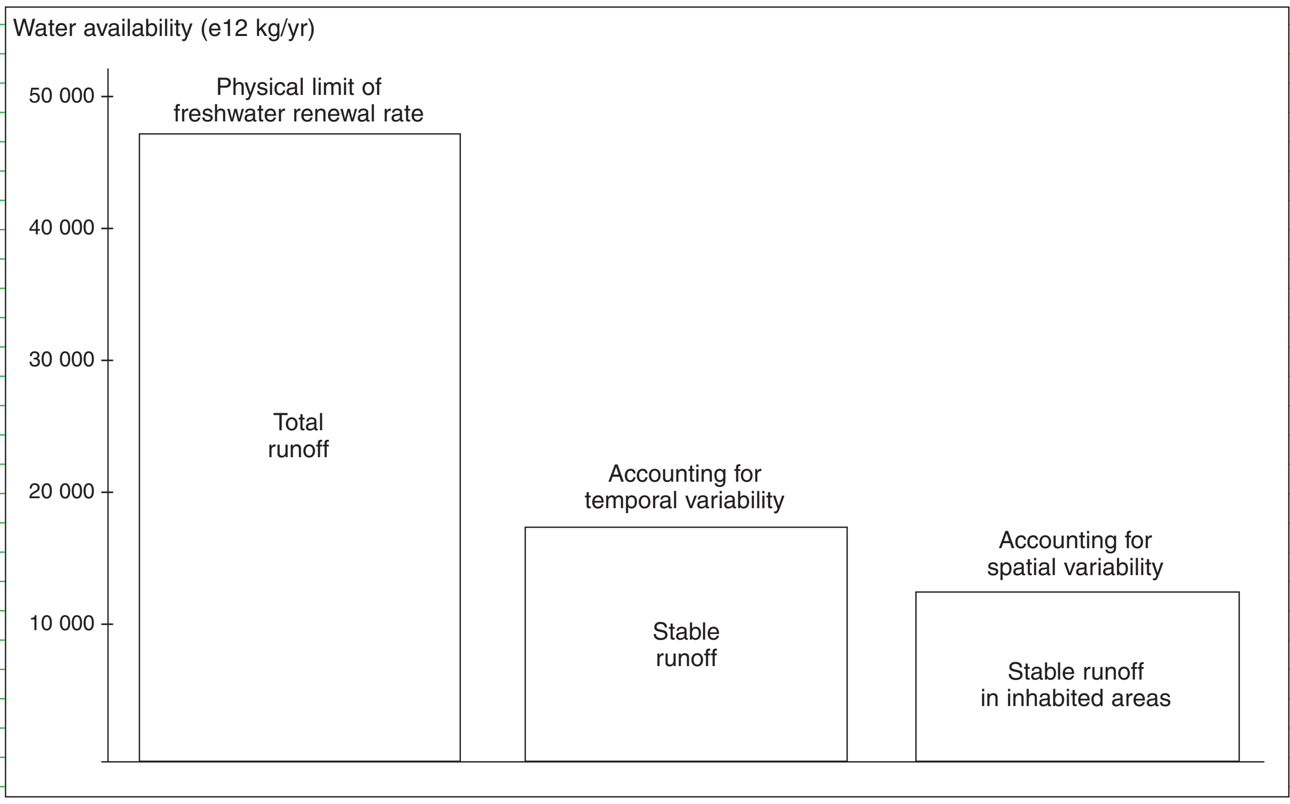

Fig. 3. Some perceptions of global water availability

of the rainfall becomes surface and subsurface runoff, together called "blue water." In semi-arid regions no more than 10 percent of rainfall becomes blue water. The remainder either returns directly to the atmosphere (through interception, open water evaporation, and bare soil evaporation), or it enters the unsaturated soil, where it is used by vegetation (transpiration). The latter is called "green water," defined as that part of the rainfall that replenishes the unsaturated zone and is eventually consumed through transpiration. In terms of this definition, rain-fed agriculture uses green water, and irrigated agriculture blue water. About 60 percent of world food production is provided by green water and 40 percent by blue water. In many parts in the world, possibilities to expand the use of blue water further have become exhausted, so that possibilities for green water use have to be reconsidered. The potential for increased food production using green water is probably large, particularly with supplementary irrigation during the wet season. Another reason to give due attention to green water is from a development perspective. Particularly poor people often rely fully on rain-fed agriculture. Addressing poverty, therefore, implies giving due attention to green water, and to ways to enhance production systems that depend on it.

Above, water has always been perceived as a renewable resource. It can, however, also be regarded as a non-renewable resource, especially in cases where humans must rely on groundwater. This happens, for instance, in areas where the water in rivers and lakes is too heavily polluted for human use, or where there is hardly any surface water during large parts of the year. In many regions in the world, intensive groundwater withdrawals lead to falling groundwater tables, sometimes by up to several meters per year. It is often said that groundwater withdrawal rates should not exceed natural replenishment, but in reality groundwater levels will have started to decline long before withdrawals equal recharge. One can best appreciate this by thinking of a bucket filled with sand and a few liters of water. Somewhere near the bottom of the bucket there is a hole where the water flows out. If we recharge the bucket from above with as much water as the inflow, the water level in the bucket will remain constant. If we withdraw as much water as we recharge, however, there will be a net inflow of zero, and the water table in the bucket will steadily fall (with a decreasing rate) until the drainage becomes insignificant. In a case like this, the recharge rate is an improper measure of total water availability. In these circumstances, it is better to estimate water availability on the basis of an acceptable decline of the groundwater table.

Although the various concepts of water availability differ considerably, they agree in their recognition of some form of limitation. However, it is by no means generally accepted that a limit to water availability actually exists. Both engineers and economists display some opposition to the so-called "water barrier" concept. Their technological optimism leads them to believe that problems of scarcity will be solved through new technologies that can enlarge supply, or make water use more efficient. A confirmation of this view is found in the growing capacity of desalination plants in many water-poor regions. In Saudi Arabia, for example, desalination of salt or brackish water already accounts for about 20 percent of the total water supply. Because the oceans can be regarded as both the primary source and the ultimate sink of all water on earth, the possibility of obtaining our water from the sea implies – in principle – that there is no limitation on water availability, apart from a possible restriction from an energy perspective. Another possibility is water re-use, after treatment, for either the same or a different purpose, thus creating a large new source of fresh water; only actual losses would have to be made up for from outside this recycling system. Other unconventional technologies to extend our resource base – attracting attention in recent decades but still in an experimental and conceptual stage, and often regarded as mere fantasies – are weather modification through cloud seeding, and towing icebergs to wherever water is needed.

A final remark must be made on the issue of water recycling. Most water engineers regard evaporation as loss. This idea needs revision. The real loss of fresh water is water flowing into the sea and thus becoming saline. All evaporated water from land will eventually lead to rainfall again, either in the same region or somewhere else. Only the fraction that falls above the oceans is a real loss. For example, in the Sahel it has been estimated that recycling of moisture through evaporation is responsible for 90 percent of rainfall.

6.2. Water demand and scarcity

Many authors have given warnings about a looming worldwide "water crisis." A confusing factor in this debate is the existence of radically different perceptions of the concepts of water demand and scarcity. Three main schools of thought follow, each having its own specific, stereotypical approach to the concepts of demand and scarcity.

The first and most common view is to consider water demand as a need that can be estimated, and that should be met. This approach takes population growth, urbanization, and developments in the agricultural and industrial sectors as given processes that imply certain water requirements. One can find this "requirement approach" for example, in reports of the World Resources Institute. This school of thought starts from the premise that there is a certain demand, which will or will not be met. If not, there is a "shortage." The actual issue is understood to be provision of enough water of sufficient quality for the relevant sectors of society, leaving enough to fulfill ecological requirements. Water scarcity is thus a *supply problem.* According to this view, water policy should aim at proper management of the physical water system. Attention is given principally to the analysis of available water quantities and qualities, and the construction of a proper water supply infrastructure. If relevant, studies should include possible effects of erosion, consumptive water use, and climate change. Water pollution is described in terms of the violation of water quality standards. Wastewater should be treated to bring it up to the required standards. It is perhaps not surprising that this line of thought is found particularly among engineers.

The second view is that water use is a necessity only if it is related to the fulfillment of "basic needs," such as drinking and cooking. Water demand above this minimum requirement is regarded as a luxury. From this view, water availability is limited so that demand cannot continue to increase. Water scarcity is thus a *demand problem*. Growing demand is seen as the actual driving force behind growing water scarcity. Underlying forces driving this are population growth and economic development. In nearly all parts of the world water utilization level are increasing, which is a signal for action in regions that have reached critical levels. Water quality deterioration is a further consequence of the increasing pressure on the water system, and this problem has to be solved at its roots. Wastewater treatment is not sufficient, and wastewater production should be reduced. Solutions for water scarcity should somehow manage demand, and thus human behavior. In this view, minimum water requirements (small but important) should be fully met, but other demands (both large and of secondary importance) should be reduced. A reduction in water use could be achieved by, for example, increasing "water literacy" among the population, and charging the full costs of water provision to users with – if necessary – an additional amount in the form of a tax. The price of water for primary needs should also reflect peoples' ability to pay.

The third view is an economic one, in which water demand is primarily considered to be governed by the price charged. The price (or cost) of water is seen as the correct indicator of water scarcity, which, according to this school, better reflects the real problem of scarcity than indicators comparing volumes of water demand and availability. If the price mechanism functions well, factors such as droughts, pollution, increasing demand, technological innovation, and the ability of society to adapt will automatically, and properly, be accounted for in the water costs. According to this view, water demand and supply achieve (or should achieve) equilibrium through the pricing mechanism. Increasing water scarcity leads to higher prices, which result in lower demand and incentives to develop more efficient technology. Solutions to increasing water scarcity are sought through introducing water markets, charging true costs to water users, and privatizing water supply companies.

These three different schools of thought differ in respect to their important assumptions. The economic view presupposes that the market mechanism in itself can do all that is necessary, a position that is open to debate. The view that scarcity is primarily a demand problem presupposes that water availability is limited, and that we cannot place our trust in future technological innovation. It also assumes that human behavior can (and should) be influenced in order to reduce the pressure on the water system. The view that water scarcity is primarily a supply problem presupposes that the infinite recycling of water in the hydrological cycle provides ample possibilities for exploitation, and that the real problem is to make water flows readily available for use. It also assumes that water needs are quite inelastic, and thus awareness-raising and increasing prices will have only minor effects.

Probably each view embodies useful elements. The challenge will be to become able to estimate which assumptions hold under which conditions, and – as long as uncertainties and debate remain – to develop ways to deal with the risks attached to these uncertainties.

6.3. The value of water

Many regions in the world have to cope with risks of peak runoff and the danger of flooding in wet periods, and problems of water scarcity during dry periods. Both peak flow problems and water scarcity problems are expected to increase in the future. Underlying explanatory factors include landuse changes such as urbanization (increased peak runoff), climate change (changing flow conditions), and economic growth (increasing water demand, water shortages during dry periods). Problems of flooding and water scarcity are strongly connected: they are both the immediate result of a certain distribution of water over time. In countries where water flows are strongly regulated, one would expect water to be allocated so that the net socio-economic and ecological benefits are optimized, but nothing could be less true. In actual fact, the overall performance of a water system is generally not properly evaluated when making decisions with respect to spatial planning and infrastructure. A precondition for such evaluation is that we put a proper (positive) value on water if it is scarce, but also that we put a proper (negative) value to water if it constitutes a risk factor. A proper valuation of water would enable us to make more rational decisions on all kinds of activities that change the river regime. Here we encounter a major problem: the valuation of water is an undeveloped field of research. As recently stressed by Abu-Zeid, the president of the World Water Council, the cultural and socioeconomic values of water are still very elusive subjects, requiring close attention from the scientific community. Fundamental research in this area could contribute to more rational decisions on the use of water and the spatial planning within river basins.

Traditionally water is considered a "free" resource, which acquires a value only if man has to incur costs in exploiting it. In many parts of the world, this has led to unsustainable use of water. It has been widely recognized that water should be properly valued, which means that one should look at the *total costs* and the *total benefits* of a project or policy strategy. In economic terms, the total cost involved in the provision of water is the sum of capital costs, operation and maintenance costs, opportunity costs, and negative externalities. The total benefit (or value) of a certain body of water is the sum of the net benefit to the users, the positive outcomes, the net benefit from return flows, the additional value gained in attaining societal objectives, and the intrinsic value of the water. Societal objectives, for instance, can be security against flooding, poverty alleviation, or food security. Economists' work means that this theoretical framework is widely accepted, but for practical implementation many questions remain. In particular, quantification of many of the costs and benefits remains difficult. In addition, it is not clear how the natural variability of water in space and time can be accounted for in calculating the value or costs of water. No link between natural dynamics and economic valuation has yet been made. Another problem is that there is, as yet, no satisfactory way to express the "capital value" of the water system. Certainly there is a theoretical framework for the valuation of goods and services produced by the water system. However, in the case of groundwater mining, the production of "goods and services" (groundwater supply) can still be at a high level, while the "capital value" (the capacity to produce and remain producing) decreases.

Another issue that has remained largely unexplored is to what extent economic theory can provide a sufficient basis for the ultimate valuation of water. A large number of scientists believe that economic theory does not cover the whole field of water valuation, particularly since water is neither a private nor a market good. According to this view, valuation requires the input of other disciplines as well, including the natural and social sciences. It has, for example, often been stressed that the value of water is to a large extent culturally determined. Alternatively, however, natural scientists have proposed various "water scarcity indices" that could be used as indicators of the value of the water.

Some scientists have argued that the value of water can be split into three categories: the social value (in relation to the quality of life, such as health, security, well-being, merit, and beauty); the economic value (in relation to economic productivity, such as agriculture, industry, hydropower, navigation, and tourism); and the ecological value (in relation to the maintenance of ecosystems, and biodiversity). Of these, only the economic value can be expressed in monetary terms. The other types of value are important, but difficult to express in money terms. An interesting way to analyze the merits and issues of a given water resources system is to compare the functions and values of that system in a function–value matrix.

In the valuation of water, it seems essential to distinguish between different types of water on the basis of characteristics such as appearance, residence time, and quality. "Blue water" runs off through rivers, lakes, and aquifers. Residence time varies from a few days (small rivers), to a year (shallow groundwater), or even hundreds of years (deeper groundwater). Currently, blue water is the only type of water that is sometimes assigned an economic value, and then only if costs have to be incurred to exploit it. "Green water," that element of precipitation that returns to the atmosphere through transpiration by plants, generally has a residence time of a few months. Currently, people never attribute a value to "green water," although it is an important production factor in rain-fed agriculture. "White water" returns to the atmosphere through evaporation after interception or through evaporation from the soil. The residence time of this water is often only a few hours. Evaporation is generally considered as a loss – a waste of a valuable resource – but this idea needs reconsideration. Regional evaporation can contribute significantly to regional precipitation, thus maintaining the regional hydrological cycle. Only from this perspective it is to be debated whether evaporation is better or worse than runoff to the sea.

Another type of water is "black water" or fossil groundwater, a so-called non-renewable resource with a residence time of hundreds to thousands of years. Until now, people have only considered the production costs (mainly pumping costs), leaving the aspect of depletion out of the valuation. "Brown water" is wastewater and can be reprocessed into "gray water," which can be used by humans and then reused for another or the same purpose. In many cases, recycling of water is more efficient than withdrawing new groundwater or surface water. It is generally felt inappropriate to drink purified wastewater, however, although it is proven that it can be as safe as that from the usual sources.

The different types of water are continually being transformed from one into another, by natural processes but also through human interference. In addition, each type of water can appear in a number of different quality levels, depending on the occurrence of pollutants. Each transition from one form into another means a change of value. The value of a water particle at a certain place and a certain point in time depends on its value *in situ*, and on its value at a later stage (downstream).

Currently the most confusing issue in the valuation of water is probably that most scientists do not make a sharp distinction between its value and price. The origin of this debate is probably that some people feel that water is a public good, that it therefore belongs to the people, and thus should be freely available. At first sight, this seems to contradict the position that if water is scarce it has a high value (and thus a high price according to some). It is probably useful to split up this discussion into two components: its valuation, and its pricing. A high value does not automatically mean that we should charge a high price (for example, drinking water to the poor, water flowing in a valuable river ecosystem), nor does a low value mean that we should automatically charge a low price (one can decide to tax industrial water to stimulate water reuse).

6.4. Virtual water trade

The official policy in many water-scarce countries has been to strive for food self-sufficiency. In practice, this implied striving for water self-sufficiency also.

When considering the global total of freshwater, and comparing this with global human needs, one can hardly say that there is a shortage of water. The problem with water is related to the temporal and spatial distribution. Unlike other essential commodities, such as oil and gas, water is a very bulky substance that cannot efficiently be transported over large distances. We can, however, transport water easily in its "virtual" form. In fact, this is what water-scarce countries are already doing.

A kilogram of grain, grown under favorable climatic conditions, rain-fed, corresponds with about 1–2 m^3, or 1,000–2,000 kg, of water. This represents a concentration of more than one thousand times. Importing grain, instead of trying to grow it oneself, implies the import of water in a very condensed, "virtual" form. In an arid country, growing the grain oneself under much less favorable climatic conditions (irrigated and with high evaporation losses) may mean that 1 kg of grain corresponds with several cubic meters of water.

Expressing a commodity in terms of the amount of water required to produce it ("virtual water") gives insight into how better distribution of water might be achieved, both within countries and within regions. For example, in the Southern African region, one could consider growing grains in the parts of the region where rainfall and water is abundant, and where soils are favorable (in other words, in the north of the region), instead of concentrating the grain production in the south, where the infrastructure and the technology may be better but water resources are more constrained. Such an approach, indeed, requires a lively and reliable regional and international market, and a situation of political stability. As the European Union has demonstrated, however, the creation of an economic entity is an important instrument in bringing about this stability.

The concept of virtual water may seem abstract. However, in a large part of the world it is very real. In the Middle East and North African countries a water deficit is already present. This deficit, however, is not balanced by hydrological and water resources systems: it is the economic systems that achieve water security for the economies of the region. In practice more water flows into the Middle East each year in its virtual form, embedded in cereal imports, than is used for annual crop production in Egypt. Half of the water needed to feed the people of the Middle East and North Africa in the 1990s lay in the soil profiles of temperate humid environments in North America, South America, and Europe.

6.5. Privatization

The call for a larger role for the private sector in different activities of water resources management becomes more emphatic. The rationale behind privatization is that governments appear to be notoriously inefficient in operational management activities. Since the private sector is generally quite successful in dealing with operational management, many water managers believe that privatization is the answer to many problems.

The biggest misunderstanding in the discussion on privatization is that it is needed to make an inefficient and unqualified government more effective. If the trigger behind privatization is actually an inefficient government, this is at the same time the strongest reason *not* to privatize. Privatization requires a well-equipped and highly qualified government to supervise the process, and to see that privatized and decentralized institutions do the things that they were set up to do. If a government is weak and inexperienced, then one should be extremely cautious about starting a privatization process. It would probably at least need substantial public sector reform, and work towards putting in place the necessary support. Privatization is complex, and cannot be done overnight.

Another misunderstanding is that private enterprises would replace government. This can only ever be partly true. As stated earlier, an important role of governments is "caretaking," preserving national assets for future generations, and promoting sustainable and balanced development. This role cannot be taken over by private companies. Privatization only reflects the other activity of governments: the production of goods and services. Privatization of the production of goods and services requires, at the same time, an enforcement of government's "caretaking" role. Private actors require a clear institutional legal and economic framework within which they are empowered to play their role. Particularly when private actors are asked to manage essential life support resources, goods, or services, the controlling tasks of government are complex and essential.

Recognizing the need for a careful approach when privatizing, however, one question still remains: should water-related services be privatized at all? In this respect people hold a variety of positions, but most agree that each country needs its own analysis and approach. Furthermore, it has been recognized that different water-related services require different institutional arrangements. The optimal arrangement for the production of a particular good or service depends strongly on the good or service's typical characteristics. In this context people often speak about the extent of "excludability" and "subtractability" of a good or service. Excludability refers to the degree to which users can be excluded from the good or service. Subtractability expresses rivalry: the extent to which consumption by one user reduces the possibility of consumption by others.

Goods with high excludability and high subtractability are termed private goods, and typically are suitable to be handled by the private sector. The high excludability of private goods makes it possible that they are privately owned and traded on a market. Bottled water can be regarded as a typical private good; indeed, it is traded everywhere in the world. However, water from the tap is also principally a private good, but in most countries it is provided by the government. There is a heavy debate worldwide on whether drinking water companies should be privatized. Both advocates and opponents of privatization try to dominate, leaving little room for a thorough discussion of the factors actually determining success or failure in drinking water supply. The best solution will probably depend strongly on regional circumstances, cultural preferences, historical factors, and so on. In the discussion about privatization, it is also often forgotten that it is not necessarily "yes" or "no." Between the extremes of public and private utility, there are various in-between modes of organization, such as the corporatized utility or the public-owned public limited company.

So-called "toll goods" differ from private goods in that they have low subtractability. Classical examples in the area of water resources are navigation and recreation in protected areas, such as natural parks. Use by one consumer does not really reduce the utility for others, provided it does not become too crowded with ships or holidaymakers. Toll utilities have a high degree of excludability; one may exclude those users who do not want to pay. While traditionally owned and exploited by governments, they can also be handled by a market: toll roads or bridges financed by the private sector are the best examples.

The real opposite to private goods are public goods, which have both a low excludability and a low subtractability. An example is the service of flood protection offered by the construction of dykes. People living in such a protected area cannot easily be excluded from the benefits of flood protection, while the fact that they benefit from it is not affecting their neighbors' benefit. Public goods continue to provide the same benefits to everybody as long as they are not damaged or over-utilized. Governments enter into the production of a common good whenever they judge that it is for the benefit of society as a whole. A private enterprise will not easily take the initiative to build a coastal defense system, for instance, because it will be difficult to cover the cost. The enterprise can ask all people who will benefit to make a contribution voluntarily, but there will be many "free riders" who do not pay but benefit nonetheless. Government can enforce payment in the form of a tax, for example. Taking initiatives, setting safety standards, and collecting taxes will remain the domain of government, but actually building a dyke can be done by a private enterprise as well as by government. Worldwide, there is a trend to leave clear-cut operational tasks to competing enterprises. However, there are also examples of public goods where government has no involvement at all. In the case of an offshore fishery, for example, there is generally little incentive for regulation or control as long as fish are abundantly available. However, if fish become scarce, subtractability will increase and the public good will turn into what is called a "common pool resource."

Common pool resources are goods with a low excludability, but a high subtractability. For example, fishing from a river, lake, or sea has a high level of excludability if the fish stock is at a critical level. The same holds for pumping water from an aquifer, if total pumping exceeds natural recharge. In these cases agreements and cooperation among the appropriators (users) is required. Classical common pool resources are rivers, lakes, wetlands, and aquifers: these can be relatively small scale systems, but we see nowadays that even seas and oceans have become common pool resources that need to be managed. The high subtractability of common pool resources is generally due to problems of environmental degradation or over-utilization. As in the case of public goods, a threat to common pool resources is "free rider" behavior. A free rider is somebody who exploits that part of the common pool resource formally reserved by the users to ensure its sustainability, generally to allow future regeneration, thereby living at the cost of the others. As soon as a free rider moves in, other users are also motivated to increase the exploitation of the resource, because it seems better to take the last bit of a resource before it is finished rather than have nothing at all. In the case of common pool resources, free market mechanisms are likely to fail because low excludability will give anybody access, and the opportunity to over-utilize for selfish benefit at the expense of the community. As a result, a free market is unlikely to lead to the optimum use of the resource. In economic terms, free riders (over-users) impose burdens on others. Within the market this could be solved by issuing fishing rights, or groundwater abstraction rights, which can then be traded. However, the "transaction costs" needed to organize this might outweigh the advantages of the market, so that one could prefer the solution of an institutional arrangement other than a market. A possible solution could be to found a User Association with obligatory membership, co-ordinating the use-intensity of the common pool.

In conclusion, in the case of privatization of water-related goods and services there is a definite need for government supervision in the form of an adequate legal and regulatory framework, law enforcement, and sanction mechanisms, to prevent market distortion, monopolies, and "mafia"-type practices. Privatization is only possible for those components of the water sector that provide private goods or services, and where market failures can be prevented. Moreover, the supervision of privatized activities requires a strong and well-equipped government and serious capacity-building efforts. In contrast to what is commonly believed, countries that have weak and inefficient governments should not embark on privatization ventures to solve their inefficiency problems.

KNOWLEDGE IN DEPTH

In-depth knowledge of this subject is available in several chapters in the on-line *Encyclopedia of Life Support Systems*, organized as follows:

Water Resources Management

1. Integrated Water Resources Management, *Hubert H. G. Savenije, Arjen Y. Hoekstra, Department of Environmental Science and Water Resources, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE - Delft), the Netherlands*

Water and sustainable development, *Hubert H. G. Savenije, Arjen Y. Hoekstra, Department of Environmental Science and Water Resources, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE - Delft), the Netherlands*

Trans-boundary water resources management, *Hubert*

H. G. Savenije, Department of Environmental Science and Water Resources, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE - Delft), the Netherlands, and P. van der Zaag, IHE - Delft, the Netherlands

Water law and institutions, *P. van der Zaag, IHE - Delft, the Netherlands*

Uncertainties and risks in water resources management, *Arjen Y. Hoekstra, and Hubert H. G. Savenije, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE - Delft), the Netherlands*

2. Water Scarcity, *Hubert H. G. Savenije and Arjen Y. Hoekstra, Department of Environmental Science and Water Resources, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE - Delft), the Netherlands*

Water demand management, *Hubert H. G. Savenije and Arjen Y. Hoekstra, Department of Environmental Science and Water Resources, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE - Delft), the Netherlands*

Water conservation in arid and semi-arid regions, *Piet Heyns, Department of Water Affairs, Namibia*

Economic valuation of water, *Peter Rogers, Ramesh Bhatia,and Annette Huber*

Non-waterborne sanitation and water conservation, *B. Gumbo, Department of Civil Engineering, University of Zimbabwe*

3. Water Resources Planning, *Daniel Pete Loucks, School of Civil and Environmental Engineering, Cornell University, USA*

Water resources systems analysis, *Lucien Duckstein, Ecole Nationale du Genie Rural, des Eaux et des Forêts (ENGREF/GRESE), France*

Performance evaluation of water resources systems, *Lucien Duckstein, Ecole Nationale du Genie Rural, des Eaux et des Forêts (ENGREF/GRESE), France*

Reliability of operation of water resources systems, *Lucien Duckstein, Ecole Nationale du Genie Rural, des Eaux et des Forêts (ENGREF/GRESE), France*

Multi-criterion analysis in water resources management, *Lucien Duckstein, Ecole Nationale du Genie Rural, des Eaux et des Forêts (ENGREF/GRESE), France, Aregai Tecle, School of Forestry, Northern Arizona University, USA*

GLOSSARY

Blue water: The renewable water that exists in rivers, aquifers, and lakes. It is that part of a water resource that can be manipulated and diverted by engineering works. Hence engineers normally confine their interest to blue water, disregarding the green water, a resource of about equal magnitude stemming directly from rainfall used to produce biomass through transpiration.

Calibration: Calibration of a model is the process of changing parameter values in order to correlate simulation results with observed data.

Consumptive water use: Consumptive (or irrecoverable) water use is the part of a freshwater withdrawal that is lost through evaporation. Consumptive water use is always smaller than total water use. Some authors also use the term *water consumption*, but this causes confusion among economists who then read this as *water supply*.

Demand management: Demand management is the development and implementation of strategies aimed at influencing demand, so as to achieve efficient and sustainable use of a scarce resource. It entails a set of actions to be taken by the water manager to encourage more appropriate levels of demand – generally involving reduction. These include awareness raising, education and training, and the formulation and application of economic (pricing, subsidies, taxes) and legal (quota, restrictions, licenses) incentives to influence the demand for water.

Externalities: Economic impacts (positive or negative) of certain developments or projects that are not taken into account in the financial analysis of the project: they are external to the financial analysis. They often refer to environmental or social impacts, but can also refer to economic costs or benefits that are experienced elsewhere or at some other scale.

Feedback: *Negative feedback* is a cyclic process which suppresses the signal that originally started the process. *Positive feedback* is a cyclic process reinforcing the original signal.

Freshwater recharge: The freshwater recharge, or freshwater renewal, rate in an area is equal to the net precipitation in that area in a year.

Green water: Green water is the water used by vegetation through transpiration. It is the part of the rainfall that directly contributes to the production of biomass, and sustains rain fed agriculture, lifestock grazing, and ecosystems. Green water from rainfall is stored in the soil moisture. It returns to the atmosphere as water vapor through the leaves of living plants. Green water is often disregarded as a water resource in comparison to blue water, which is the water we can withdraw from rivers, aquifers, and lakes. Green water accounts for more than 60 percent of world grain production, and almost all of the meat production.

Groundwater recharge: Groundwater recharge or percolation is the process of water flowing from the unsaturated upper zone of the soil down to the saturated zone, the groundwater.

Growth elasticity: The growth elasticity of demand for a commodity is a measure of its sensitivity to economic growth. It is defined here as the percentage by which the quantity demanded changes for each one percent change in gross national product per capita.

Hydrograph: A hydrograph or runoff curve shows the river discharge of a river as a function of time. A hydrograph is often drawn for one particular year, but it can also be drawn for an “average” year.

Indicator: An instrument to communicate key information about a system in a simplified manner to policy makers and the public. An indicator is not necessarily quantitative: it can just as well be qualitative, or a method of visualization.

Integrated water resources management: Integrated water resources management (IWRM) integrates all aspects and functions related to water. IWRM is defined as water resources management that takes full account of:

1. All natural aspects of the water resources system: surface water, groundwater, water quality (physical, biological, and chemical) and its physical behavior.
2. The interests of water users in all sectors of the national economy (agriculture, water supply, hydropower, inland transportation, fisheries, recreation, environment, nature conservation).
3. The institutional framework and stakeholders (national, provincial, local).

4. Relevant national objectives and constraints (social, legal, institutional, financial, environmental).
5. Spatial variations in resources and demands (upstream/downstream interaction, basin-wide analysis, inter-basin transfer).

Model: A representation of a part of reality. A model is not the same as a *system*, which is a part of reality itself. Instead it is a description of a particular system. In this study the term generally refers to a computer model, but a computer model is of course only one of many possibilities to describe a system.

Perspective: A coherent perception of how the world functions and how people act. In this study, we use four of the five perspectives described in the cultural theory: hierarchical, egalitarian, individualist, and fatalist.

Potential water re-use: That element of freshwater withdrawal that can possibly be re-used. It is the counterpart of *consumptive water use*.

Potential water supply: The maximum amount of freshwater that can reasonably be withdrawn from natural water sources annually. Opinions on what is "reasonable" differ. If an area under consideration has water coming into it from upstream, a distinction can be made between potential water supply from internal and external sources.

Price elasticity: Price elasticity in demand for a commodity is a measure of the good's sensitivity to a change in its price, and is defined as the percentage by which the quantity demanded changes for each one percent change in the price.

Public water supply coverage: The fraction of a population with public water supply.

River basin: A river basin or catchment area is an area from which net precipitation flows off through one particular watercourse into a common terminus (e.g. an ocean, a sea, a lake without outlet, a desert). A large river basin is composed of several smaller sub-basins, because each tributary of the main river has its own basin. The terminology used for river basins ranging from large to small scale is: river basin–catchment–watershed.)

Runoff: Water flow through gravity. The precipitation minus the evaporation and soil moisture change in an area is available for runoff. This net precipitation is divided into *direct surface runoff* and *groundwater runoff*. Part of the groundwater runoff reaches the earth's surface again within the same area and becomes *delayed surface runoff*; the other part becomes *subsurface runoff*. Direct and delayed surface runoff together form *river runoff*. River runoff and subsurface runoff together form *total runoff* from the area. *Stable runoff* is the part of the total runoff which is available throughout the year, and is often assumed to be equal to the groundwater runoff. In this study, stable runoff is defined precisely as the sum of natural groundwater recharge, artificial groundwater recharge, drainage of irrigation water, and the stable runoff contribution from artificial surface reservoirs, but minus groundwater withdrawals. *Natural stable runoff* refers to natural groundwater recharge only.

Sanitation coverage: The fraction of a population with access to proper sanitation facilities.

Scenario: A term used for various purposes by different authors. In the broadest sense, a scenario is an imagined sequence of future events. Policy analysts and modellers sometimes use the term to refer to a future development which is used as *input* for some analysis (in this case, people often speak of an *exogenous* or *input* scenario). At other times, the term "scenario" refers to the *output* of an analysis. Some authors use the term to refer to a particular set of measures, or a strategy, but this is not recommended.

Sensitivity analysis: In a sensitivity analysis of a model one considers how, and to what extent, uncertainties in the input values (for example, parameter values) result in uncertainties in the model results.

Specific water demand: The term specific water demand, or water-use intensity, is used to express water demand per unit. Specific domestic water demand, for example, is the per capita demand; specific irrigation demand the demand per hectare; industrial water demand the demand per dollar of value added, or per ton of manufactured goods.

Sustainable development: The most cited definition of sustainable development is that in the influential report *Our Common Future* of the World Commission on Environment and Development: a development which "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987.) The president of Botswana, K. Masire stated: "Our ideals of sustainable development do not seek to curtail development. Experience elsewhere has demonstrated that the path to development may simply mean doing more with less (being more efficient). As our population grows, we will certainly have less and less of the resources we have today. To manage this situation, we need a new ethic, one that emphasises the need to protect our natural resources in all we do."

System: A part of reality, conceived as a coherent whole of entities (elements, or components). An *open* system is a system which is connected to, and interacts with, its environment. A *closed* system is a system that neither takes from, nor outputs to, the surrounding environment. In reality closed systems do not exist, but for certain purposes it may be reasonable to regard a system as closed. This does not, however, apply in the context of this article.

Virtual water: Growing a kilogram of grain requires – under favorable, rain-fed climatic conditions – about 1 m^3 (1,000 kg) of water. Importing grain, instead of trying to grow it oneself, implies the import of water in a very condensed, "virtual" form. In an arid country, growing the grain oneself in unfavorable climatic conditions (irrigated, and with high evaporation losses) may imply that several cubic meters of water are consumed per kilogram of grain grown. In general, virtual water is defined as the water "hidden" in an agricultural or industrial product, referring to the quantity of water used in the production process. While farmers use water *directly* for irrigating their fields, consumers of food use this water *indirectly*. International exchange of virtual water takes place in the form of trade in water-intensive products.

Wastewater treatment coverage: The fraction of the total wastewater flow that is treated before discharge into the environment.

Water availability: This term refers to the availability of freshwater stocks, the availability of freshwater flows, or the availability of water in an even wider sense (for example, including salt water), depending on the context. The concept of *potential water supply* is introduced in this study as a formal and stricter definition of water availability.

Water demand: This can be loosely defined as the volume of water that has to be withdrawn in order to meet some human purpose. The term is used in a more specific sense in different ways. Economists often define demand in the sense of "revealed demand," which is equal to the actual supply. Others consider water demand rather as a certain *need* or *desire* for water, whether supplied or not. The difference between need and desire is that a need is regarded as a fact, while a desire can be debated and influenced.

Water literacy: Peoples' knowledge about the effects of water use on the environment, the possibilities of water conservation, and other topics.

Water policy: In this study, water policy is understood to represent any government (local, national, or international) plan of action with regard to water use, water management, or any other water-related issue. According to this definition, water policy may also include climate policy or land-use policy.

Water policy analysis: Examination of current or future water-related problems, and of possible government measures to address them.

Water pricing: In most places in the world, the actual water supply cost per litre does not correspond to the water tariff: the price paid by the user. Water pricing policy implementation generally means an increase in prices by lowering subsidies.

Water re-use: Water re-use or recycling means that water which has been used once is used again, for the same or another. Before water is re-used, it generally undergoes some kind of treatment.

Water management: The operational management of water within a given sub-system, for example an irrigation or water supply scheme.

Water resources management: Activities aimed at managing the allocation, conservation, and development of water resources in a broad societal context.

Water scarcity: Water scarcity refers to the quantity of water demanded for human purposes compared to the potential water supply. Water scarcity occurs when at any point in time or place this demand exceeds the potential for supply. Opinions differ on the proper measure of water scarcity. Presently indicators for water scarcity are mostly deficient. Proper indicators should consider all forms of water (blue and green), the temporal variability, the probability of water scarcity, the spatial variability, and the type of water demand (primary, such as life support water demand, or secondary and luxury demands)

Water sector: The complex of interests involved in the utilization of water resources by society.

Water sub-sector: A specific water interest group, such as the water supply and sanitation sub-sector, or the irrigation sub-sector.

Water sector capacity building: This concept was introduced at the UNDP/IHE Symposium on "A Strategy for Water Sector Capacity Building." Water sector capacity building was said to consist of: four elements: the creation of an enabling environment with appropriate policy and legal frameworks; institutional development including national, local, quasi-governmental, public and private institutions, and community participation; human resources development; strengthening of managerial systems at all levels.

Water supply: Water supply is mostly defined as the volume of water withdrawn from any natural water source for human purposes. In this sense it is interchangeable with the terms "water use" and "water withdrawal." Some scholars use the term to refer to "water availability" or "potential water supply," which is rather confusing to economists. A distinction is generally made between domestic, agricultural, and industrial water supply. Domestic water supply refers to households, municipalities, commercial establishments, and public services. Agricultural water supply includes irrigation and livestock use. Industrial water supply refers to use by different industrial sectors, and includes groundwater withdrawals by mining industries and water use for thermoelectric power generation. The use of water for generating hydropower does not fall within this definition of industrial water supply, as "instream water use" does not require any withdrawal.

Water transition: The concept of water transition refers to the changing interaction between water and development in terms of three phases: exponential growth of water demand, balancing the desirable and the possible, and stabilization.

Water use: See *Water supply*.

Water-use efficiency: Irrigation efficiency is defined as the fraction of total water withdrawal that actually benefits the crop. The remainder consists of water losses through evaporation and groundwater recharge. The maximum possible irrigation efficiency has a natural upper limit of 100 percent. For domestic and industrial water use efficiency is a relative concept, in that an efficiency value has meaning only if compared to a previous efficiency value. Assuming the maximum possible efficiency in an initial year to be 100 percent implies that the maximum possible efficiency in later years can exceed 100 percent. If actual efficiency reaches maximum efficiency, this can be understood as the absence of water losses; further water conservation will inevitably result in a reduced performance of the activity which depends on the water.

Water-use intensity: See *Specific water demand*.

Water withdrawal: See *Water supply*.

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BIOGRAPHICAL SKETCHES

Professor Dr Hubert H. G. Savenije (born 1952) is Professor in Water Resources Management and Vice-Rector of Research at IHE Delft. He is a hydrologist by training, and has specialized in river hydraulics and water resources management. He derives his expertise from extensive studies of river systems worldwide, with an emphasis on Southern Africa (notably the Limpopo, Incomati, and Zambezi Rivers) and southeast Asia. He has undertaken many consultancy assignments. He also has extensive international experience in education and training; he has given short courses and guest lectures in many countries of Africa, the Middle East, and Asia. He has published widely in scientific journals and sits on the editorial board of two such journals; he has presented papers at a number of international conferences on water resources and hydrology. He is president of Hydrological Sciences in the European Geophysical Society (EGS), for which he regularly acts as convener of specialist sessions during the Society's annual conferences.

Before Hubert Savenije joined the IHE in 1990, he was a consultant hydrologist with Euroconsult, Arnhem, for five years. From 1978 to 1985 he was advisor to the Department of Water in Mozambique. Prof. Savenije graduated in Hydrology from Delft University of Technology in 1977. He received his Ph. D. from the same university in 1992, with a dissertation entitled *Rapid Assessment Technique for Salt Intrusion in Alluvial Estuaries*.

Dr Arjen Y. Hoekstra (1967) has been a scientific staff member of Natural Resources Management at IHE Delft since January 1999. He gives lectures in Water Resources Management, Sustainable Development, and Natural Resources Valuation. His primary interest is Integrated Water Resources Management. His current research focuses on methods for estimating the value of water.

He received his M.Sc. degree in Civil Engineering, *cum laude*, at the Delft University of Technology. He wrote his Master's thesis in Indonesia, on improving water-monitoring networks in that country. In 1991, he received an award from the Delft University Fund as the best civil engineering student of the year. After his studies, Dr Hoekstra worked at Delft Hydraulics for about two years. In 1992 he participated in the Young Scientists' Summer Program of the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. In the period 1993–7 he was employed at the Delft University of Technology, on secondment to the National Institute of Public Health and the Environment (RIVM) in Bilthoven, where he worked within the Global Dynamics and Sustainable Development Research Program. He obtained his Ph.D. in 1998 on the basis of research in the field of integrated water modeling and assessment. After his research at RIVM Hoekstra undertook post-doctoral research for the Netherlands Organization for Scientific Research (NWO), working on a project on the sustainability and environmental quality of transboundary river basins. This project was carried out at the University of Technology in Delft, and the Institute of Environmental Studies of the Free University, Amsterdam.