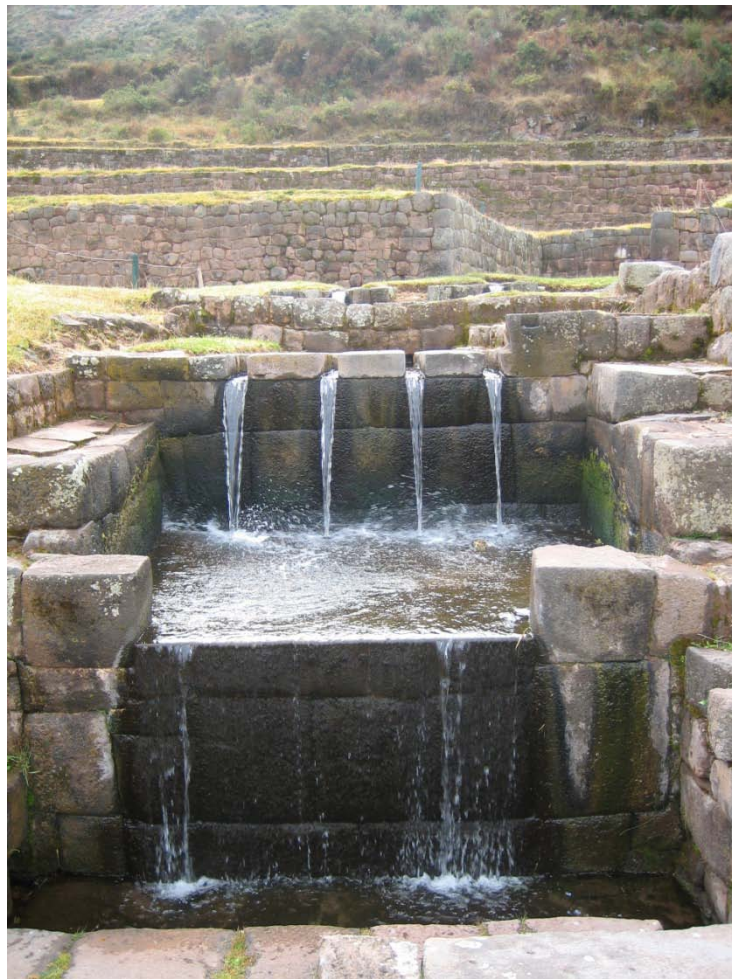


Principles of Integrated Water Resources Management



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Irrigators repairing a canal in Mexico

Chapter 1

Introduction

Pieter van der Zaag

The lecture on Principles of Integrated Water Resources Management is a compulsory subject of the Water Management Course (both for the Water Conflict Management, Water Quality Management, Water Resources Management and Water Services Management specialisations). It provides an introduction to present-day views and techniques regarding the sustainable and integrated management of water resources.

The learning objectives of this lecture are to familiarise professionals with the latest insights, context and concepts in integrated water resources management that are under debate in international and regional forums. It also aims to lay a strong foundation for the remainder of the Course.

After having followed this lecture series, the participant will be able to present the main arguments for an integrated approach to the field of water resources management and will be able to reproduce the main issues of debate; also he/she will be able to list the most important aspects of water resources, water quality and water services management; and be able to demonstrate the essence of government and private sector participation, demand management, water for sustainable development, and the most common institutional arrangements.

This lecture note introduces the most important concepts of Integrated Water Resources Management and their definitions, describing also the main on-going debates (Chapter 2). After describing the water cycle, water balances and water availability (Chapter 3), the demand for water is discussed in some detail (Chapter 4). Some general considerations are made with respect to water allocation between sectors and countries (Chapter 5). Water governance is discussed, since governance is seen by many as crucial in resolving existing and looming water problems (Chapter 6). The lecture note concludes with discussing a number of pertinent issues that are currently widely debated (Chapter 7).



Indigenous rice polders of Niomoun, Basse Casamance, Senegal (Google Earth, April 2007)

Chapter 2

Concepts and definitions

Pieter van der Zaag and Hubert H.G. Savenije

2.1 The water cycle

The annual water cycle from rainfall to runoff is a complex system where several processes (infiltration, surface runoff, recharge, seepage, re-infiltration, moisture recycling) are interconnected and interdependent with only one direction of flow: downstream. A catchment is therefore one single system and more than the sum of a large number of subsystems (Figure 2.1).

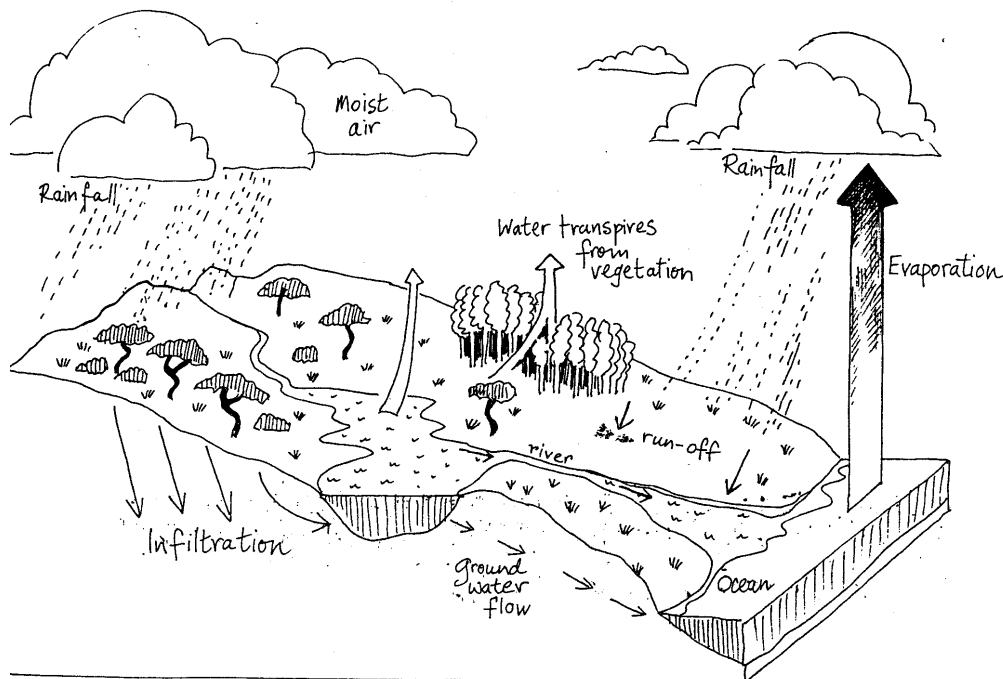


Figure 2.1: The water cycle (Pallett, 1997: 20)

Our water use is embedded in the hydrological system. It is therefore important that we consider the hydrological system and locate our water use in it.

The hydrological system is the source of water. Whereas water is finite, it is also renewable through the water cycle. The hydrological system generates the water that we need for drinking and other domestic use, for agricultural production (both rainfed and irrigated), for industrial production, for recreation, for maintaining the environment, etc.

The hydrological system also receives return flows from human water use. This can be in a form not often recognised, namely as water vapour from transpiration of crops and evaporation from natural and man-made lakes (so-called moisture feedback). “Grey” return flows normally are more conspicuous, such as sewage water from cities and industries that flow back into rivers. Such flows may also percolate into aquifers, often carrying with it pollutants (e.g. from irrigation). In heavily committed catchment areas, downstream users may depend on return flows as the source of their water.

Water use therefore influences the flow regime and has impacts downstream, both in terms of water quantity and water quality. My water use always implies “looking upstream” in order to assess water availability, and “looking downstream” in order to assess possible third party effects of my activity. Most people, however, forget the last part and tend to look only in the upstream direction, concerned as they are with securing the supply of water... (Figure 2.2)

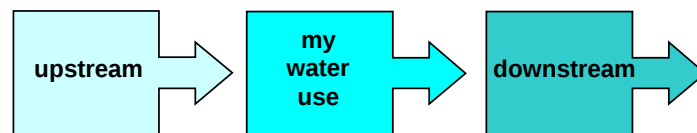


Figure 2.2: Everybody lives downstream..., and looks upstream

2.2 Three characteristics that make water special

Water has at least three important attributes with a bearing on management:

- Fresh water is *vital* to sustain life, for which there is no substitute. This means that water has a (high) *value* to its users.
- Although water is a renewable resource, it is practically speaking *finite*. Many uses of water are therefore *subtractible*, meaning that the use by somebody may preclude the use by somebody else.
- Water is a *fugitive* resource. It is therefore difficult to assess the (variations in) *stock* and *flow* of the resource, and to define the *boundaries* of the resource. This complicates the planning and monitoring of withdrawals as well as the *exclusion* of those not entitled to abstract water. Its fugitive nature makes it also more costly to harness, requiring the construction of reservoirs, for example.

The vital nature of water gives it characteristics of a *public good*. Its finite nature confers to it properties of a *private good*, as it can be privately appropriated and enjoyed. The fugitive nature of water, and the resulting high costs of exclusion, confers to it properties of a *common pool resource*.

Water resources management aims to reconcile these various attributes of water. This is obviously not a simple task. The *property regime* and *management arrangements* of a water resources system are therefore often complex.

It should be noted that there is no other natural resource with the same combination of these three characteristics (Table 2.1)! Water resources management aims to reconcile these various attributes of water. This is obviously not a simple task. The *property regime* and *management arrangements* of a water resources system are therefore often complex.

Table 2.1: Aspects of water and how they apply to other goods (after Savenije, 2002)

	Vital, no substitute	Finite, scarce	Fugitive
Air	+		+
Land	+	+	
Water	+	+	+
Fuel	+	+	
Food	+	+	
...			

2.3 The uses and value of water

Water use

There are a large number of types of water use. Among these are:

- Rainfed agriculture
- Irrigation
- Domestic use in urban centres and in rural areas
- Livestock
- Industrial and commercial use
- Institutions (e.g. schools, hospitals, government buildings, sports facilities etc.)
- Waste and wastewater disposal
- Cooling (e.g. for thermal power generation)
- Hydropower
- Navigation
- Recreation
- Fisheries
- The environment (wildlife, nature conservation etc.)

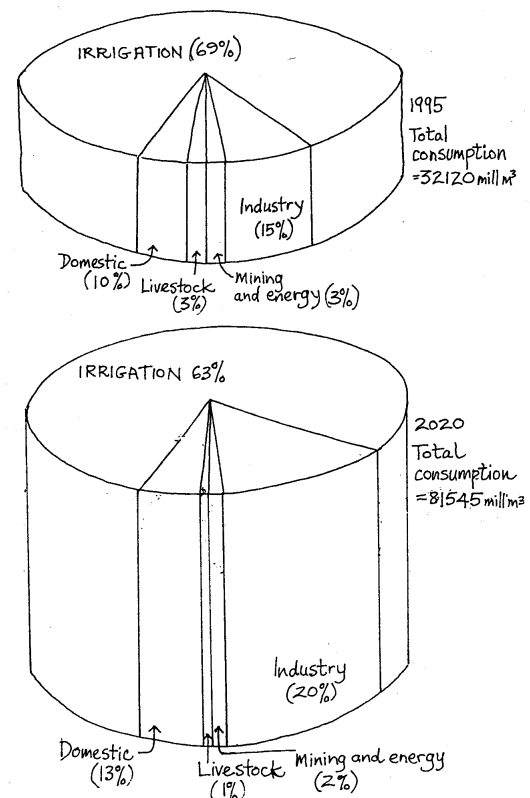


Figure 2.3: Water use in Southern Africa in 1995 and 2020 (Pallett, 1997:38)

Demand for, and use of water

Demand for water is the amount of water required at a certain point. The *use* of water refers to the actual amount reaching that point.

We can distinguish *withdrawal uses* and *non-withdrawal* (such as navigation, recreation, waste water disposal by dilution) uses; as well as *consumptive* and *non-consumptive* uses. Consumptive use is the portion of the water withdrawn that is no longer available for further use because of evaporation, transpiration, incorporation in manufactured products and crops, use by human beings and livestock, or pollution.

The terms “consumption”, “use” and “demand” are often confused. The amount of water actually reaching the point where it is required will often differ from the amount required. Only a portion of the water used is actually consumed, i.e. lost from the water resource system. Return flows from a city, for example, may amount to as much as 20-40% of the amount of raw water abstracted. Return flows from irrigated fields may involve similar fractions of return flows. In both cases the water quality of these return flows may make them unfit for re-use without further treatment or dilution.

A similar confusion exists when talking about *water losses*. It depends on the scale whether water is considered a loss or not. At the global scale, no water is ever lost. At the scale of an irrigation scheme, a water distribution efficiency of 60% indeed means that slightly less than half of the water is “lost”, i.e. does not reach its intended destination (namely the roots of the plants). Part of this water, however, may return to the river and be available to a downstream user. At the scale of the catchment, therefore, it is the net consumptive use, i.e. the transpiration of crops (60% in this example) plus the evaporation part of the “water losses” that can be considered really lost (Figure 2.4)!

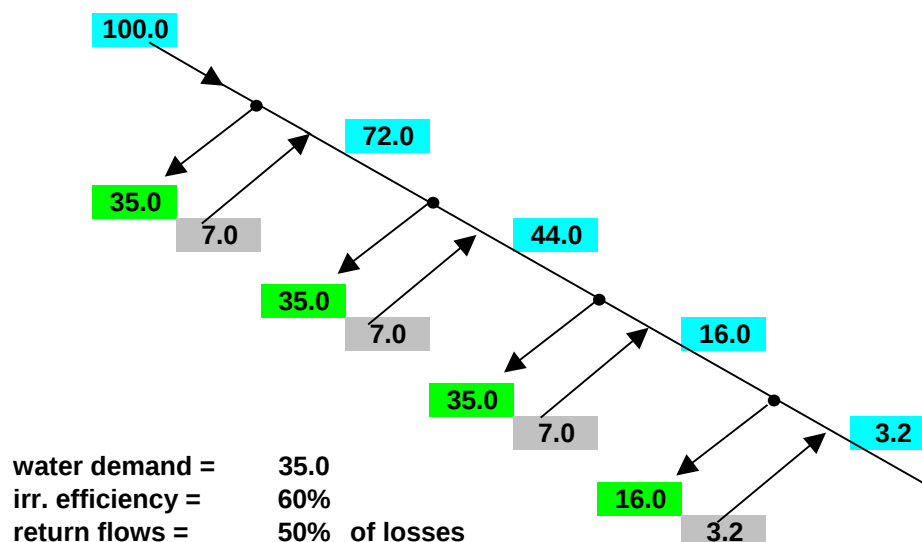


Figure 2.4: A cascade of inefficient irrigators; what is the total basin efficiency?

While the total available freshwater is limited (finite), demand grows. Hence the pressure on our water resources increases. If we also consider the possible implications of climate change, namely an increase in the variability of particular drought and flood events, the usable part of the water may actually *decrease*, further increasing the pressure on, and competition for, water. Hence the importance of the field of water resources management.

The value of water

The various uses of water in the different sectors of an economy add value to these sectors. Some sectors may use little water but contribute significantly to the gross national product (GNP) of an economy (see Table 2.2). Other sectors may use a lot of water but contribute relatively little to that economy. The added value of some uses of water is difficult, if not impossible to measure. Consider for instance the domestic use of water: how to quantify the value of an adequate water supply to this sector? And what is the value of water left in rivers in order to satisfy environmental water requirements?

Table 2.2: Contribution of various sectors in the economy of Namibia to Gross National Product (GNP), and the amount of water each sector uses (Pallett, 1997: 102)

Sector	Water use		Contribution to GNP (%)
	(Mm ³ yr ⁻¹)	(%)	
Irrigation	107	43.0	3
Livestock	63	25.3	8
Domestic	63	25.3	27
Mining	8	3.2	16
Industry & Commerce	7	2.8	42
Tourism	1	0.4	4
Total	249	100.0	100

The damage to an economy by water shortage may be immense. It is well known, for instance, that a positive correlation exists between the Zimbabwe stock exchange index and rainfall in Zimbabwe. The drought of 1991/92 had a huge negative impact on the Zimbabwean economy (Box 2.1).

Box 2.1: The impact of drought in Zimbabwe

During the drought of 1991/92, Zimbabwe's agriculture production fell by 40% and 50% of its population had to be given relief food and emergency water supplies, through massive deep drilling programmes, since many rural boreholes and wells dried up. Urban water supplies were severely limited with unprecedented rationing. Electricity generation at Kariba fell by 15% causing severe load shedding. As a result Zimbabwe's GDP (Gross Domestic Product) fell by 11%.

The value, and price, of water is a hotly debated issue. Often, the focus is on the value, and price, of a specific water service, such as urban water supply. Although being part of one and the same hydrological cycle, the value of water differs, depending when and how it occurs. Whereas rainfall is generally considered to be a free commodity, of all

types of water it has the highest value. This is because rainfall represents the starting point of a long path through the hydrological cycle (infiltration, recharge of groundwater, transpiration, moisture recycling, surface runoff, seepage, re-infiltration) (Hoekstra et al., 2001). Rainfall therefore has many opportunities for use and re-use: in rainfed agriculture, irrigation, for urban and industrial use, environmental services etc.

Water flowing in rivers has a lower value than rainfall. But also this “blue” water has different values, depending on when it occurs. Water flowing during the dry season (the base flow resulting from groundwater seepage) has a relatively high value, because it is a fairly dependable resource just when demand for it is highest. In contrast, peak flows during the rainy season have a lower value, although these peaks provide many important services, such as recharging aquifers, water pulses essential for ecosystems and filling of reservoirs for later use. The highest peak flows occur as destructive floods and have a negative value.

2.4 Integrated water resources management

There is growing awareness that comprehensive water resources management is needed, because:

- fresh water resources are limited;
- those limited fresh water resources are becoming more and more polluted, rendering them unfit for human consumption and also unfit to sustain the ecosystem;
- those limited fresh water resources have to be divided amongst the competing needs and demands in a society
- many citizens do not as yet have access to sufficient and safe fresh water resources
- it is increasingly realised that there is a huge potential to increase crop production and achieve food security through more efficient use of rainfall through improved soil and water conservation and harvesting techniques
- structures to control water (such as dams and dikes) may often have undesirable consequences on the environment
- there is an intimate relationship between groundwater and surface water, between coastal water and fresh water, etc. Regulating one system and not the others may not achieve the desired results.

Hence, engineering, economic, social, ecological and legal aspects need to be considered, as well as quantitative and qualitative aspects, and supply and demand. Moreover, also the ‘management cycle’ (planning, monitoring, operation and maintenance, etc.) needs to be consistent.

Integrated water resources management, then, seeks to manage the water resources in a comprehensive and holistic way. It therefore has to consider the water resources from a number of different perspectives or dimensions. Once these various dimensions have been considered, appropriate decisions and arrangements can be made. The following are the four dimensions that integrated water resources management takes into account (Savenije and Van der Zaag, 2000; see also Figure 2.5 and Box 2.2):

1. the *water resources*, taking the entire hydrological cycle into account, including stock and flows, as well as water quantity and water quality; distinguishing, for example, rainfall, soil moisture, water in rivers, lakes, and aquifers, in wetlands and estuaries, considering also return flows etc.
2. the *water users*, all sectoral interests and stakeholders
3. the *spatial dimension*, including
 - the spatial distribution of water resources and uses (e.g. well-watered upstream watersheds and arid plains downstream)
 - the various spatial scales at which water is being managed, i.e. individual user, user groups (e.g. user boards), watershed, catchment, (international) basin; and the institutional arrangements that exist at these various scales
4. the *temporal dimension*; taking into account the temporal variation in availability of and demand for water resources, but also the physical structures that have been built to even out fluctuations and to better match the supply with demand.

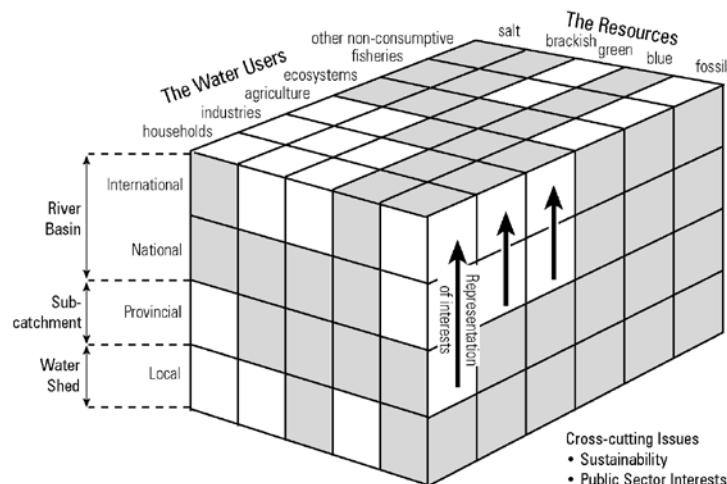


Figure 2.5: Three of the four dimensions of Integrated Water Resources Management
(Savenije, 2000)

Integrated Water Resources Management therefore acknowledges the entire water cycle with all its natural aspects, as well as the interests of the water users in the different sectors of a society (or an entire region). Decision-making would involve the integration of the different objectives where possible, and a trade-off or priority-setting between these objectives where necessary, by carefully weighing these in an informed and transparent manner, according to societal objectives and constraints (Savenije and Van der Zaag, 2000; Loucks et al., 2000). Special care should be taken to consider spatial scales, in terms of geographical variation in water availability and the possible upstream-downstream interactions, as well as time scales, such as the natural seasonal, annual and long-term fluctuations in water availability, and the implications of developments now for future generations. We can now summarise our definition as follows:

Box 2.2: The four dimensions of IWRM (Savenije, 2000)

Dimension 1: Water Resources

The water resources include all forms of occurrence of water including salt water and fossil groundwater. An interesting distinction which can be made is between blue and green water. Blue water, the water in rivers, lakes and shallow aquifers, has received all the attention from water resources planners and engineers. Green water, the water in the unsaturated zone of the soil responsible for the production of biomass has been largely neglected but it is the green water that is responsible for 60% of the world food production and all of the biomass produced in forests and pasture. It is this resource which is most sensitive to land degradation. Fossil water, the deep aquifers that contain non-renewable water, should be considered a mineral resource which can only be used once at the cost of foregoing future use.

Dimension 2: Water Users

There are many different users of water and its functions. Functions can be split into production functions (for economic production activities), regulation functions (for maintaining a dynamic equilibrium in natural processes), carrier functions (to sustain life forms) and transfer functions (as a contribution to culture, religion and landscape). The uses include: households, industries, agriculture, fisheries, ecosystems, hydropower, navigation, recreation, etc. Water users consist of consumptive and non-consumptive (often in-stream) users. Besides on quantity, the users depend largely on the quality of the resource. With regard to the consumptive use an important concept is that of "virtual" water, where products are expressed in the amount of water required for its production. This concept is both useful as a measure for efficiency and for the discussion on food security

Dimension 3: Spatial Scales

Water resources issues are apparent at different levels: the international level, the national level, the province or district level and the local level. Parallel to these administrative levels are hydrological system boundaries such as river basins, sub-catchments and watersheds. Hydrological boundaries seldom concur with administrative boundaries. River basins seem appropriate units for operational water management but present problems for institutions that have a different spatial logic.

Different decisions on water resources management belong at different levels, meaning that the concept of **subsidiarity** (decision making at the lowest appropriate level) needs to be a guiding principle in the development of IWRM. Interests and decisions at lower levels need to be carried upward to be taken into consideration at higher levels, particularly to the national and international level. An important element in this process is the participation of stakeholders in decision-making processes at all levels.

Dimension 4: Temporal Scales and Patterns

Both the water resources themselves and the water uses have distinct temporal patterns. The temporal distribution of water resources is crucial (floods, droughts, base flows, flooding patterns) and so is the distribution over time of the demands (peak demands, constant requirements, cropping patterns, etc.). In water resources assessments the total amount of water available depends strongly on the possibility to capture flood flows. The staging of demands (simultaneous or staggered demands) can have a large influence on the development required.

Integrated Water Resources Management seeks to manage water resources in a comprehensive and holistic way, taking account of the entire water cycle and the interests of all water users, while acknowledging the temporal and spatial variability in availability and the interactions with water quality and ecology.

Managing water resources then requires transparent and participatory decision-making procedures that carefully weigh societal objectives and constraints, integrate these where possible and set priorities where necessary.

An alternative definition of Integrated Water Resources Management, which is widely cited, is the one proposed by the Global Water Partnership:

Integrated Water Resources Management is a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2000).

There are, however, many more definitions on IWRM. See Jonker (2007) for a review.

To accomplish the integrated management of water resources, appropriate legal, institutional and financial arrangements are required that acknowledge the four dimensions of IWRM. In order for a society to get the right arrangements in place, it requires a sound policy on water.

2.5 Policy principles

For a country to change its water management towards a more holistic and integrated management system, it will require to review its water policy. This is currently on-going in many countries world-wide. A water policy often starts with the definition of a small number of basic principles and objectives, such as the need for sustainable development and desirable socio-economic development.

Three key policy principles are known as the three 'E's as defined by Postel (1992):

- a) **Equity:** Water is a basic need. No human being can live without a basic volume of fresh water of sufficient quality. Humans have a basic human right of access to water resources (see Gleick, 1999). This policy principle is related to the fact that water is often considered a public good. Water is such a basic requirement for human life and survival that society has to defend the uses of the water resources in the public interest. From here a number of other issues can be derived, such as security (protection against floods, droughts, famine and other hazards).
- b) **Ecological integrity:** Water resources can only persist in a natural environment capable of regenerating (fresh) water of sufficient quality. Only sustainable water use can be allowed such that future generations will be able to use it in similar

ways as the present generation.

- c) **Efficiency:** Water is a scarce resource. It should be used efficiently; therefore, institutional arrangements should be such that cost recovery of the water services should be attained. This will ensure sustainability of infrastructure and institutions, but should not jeopardise the equity principle. Here comes in the issue of water pricing, and whether or not water should be priced according to its economic value.

Much of water resources management deals with finding suitable compromises between these policy principles that sometimes are conflicting with each other and with the different aspects (dimensions) of IWRM (Savenije and Van der Zaag, 2002). In order to emphasise the consistency of policies, despite the contradictions that will inevitably emerge, policy statements often are summarised in a “vision” statement that define a desired future that the policy contributes to.

An example is the Southern Africa Vision for Water. The Southern African vision has been formulated as a desired future that is characterised by:

Equitable and sustainable utilisation of water for social, environmental justice, regional integration and economic benefit for present and future generations.

A wider public is more likely to identify with, and remember, vision statements that are simple and short. An example is the South African water policy, which has been summarised in the South Africa white paper on water resources as follows:

"Some (water) for all for ever."

Both examples from Southern Africa clearly demonstrate that there are two overriding issues that cut across IWRM however the latter is understood, namely: sustainability and the public interest.

Related to sustainability are: the maintenance of environmental quality (including water quality), financial sustainability (cost recovery), good governance (effective democratic control mechanisms) and the institutional capacity (capacity building, human resources, management instruments, appropriate policy and legal frameworks).

Related to the public interest are: equity (the basic right of access of people to water resources), poverty alleviation (the responsibility of society to nurture the interests of the least advantaged), gender (the central role of women in managing water; at the local level and beyond), security (protection against floods, droughts and hazards), food security and health, and, at a regional level, good neighbourliness and regional peace.

2.6 Sustainability of water resources (Savenije, 2000)

Since the appearance of the Brundtland report "Our Common Future" (WCED, 1987), sustainable development has been embraced as the leading philosophy that would on the one hand allow the world to develop its resources and on the other hand preserve non-renewable and finite resources and guarantee adequate living conditions for future generations. Brundtland defined sustainable development as "Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." Former president of Botswana, Sir 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." (cited in Savenije, 2000)

Sustainable development is making efficient use of our natural resources for economic and social development while maintaining the resource base and environmental carrying capacity for coming generations. This resource base should be widely interpreted to contain besides natural resources: knowledge, infrastructure, technology, durables and human resources. In the process of development natural resources may be converted into other durable products and hence remain part of the overall resource base.

Water resources development that is not sustainable is ill-planned. The American Society of Civil Engineers has recognised the importance of sustainability and has given the following broad definition of sustainable water resource systems (ASCE, 1998):

Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental and hydrological integrity.

In the remainder of this section three types of sustainability are briefly introduced: physical, economic and institutional.

Physical sustainability

Physical sustainability means closing the resource cycles and considering the cycles in their integrity (water and nutrient cycles). In agriculture this implies primarily closing or shortening water and nutrient cycles so as to prevent accumulation or depletion of land and water resources: Water depletion results in desertification. Water accumulation into water logging. Nutrient depletion leads to loss of fertility, loss of water holding capacity, and in general, reduction of carrying capacity. Nutrient accumulation results in eutrophication and pollution. Loss of top-soil results in erosion, land degradation and sedimentation elsewhere. Closing or shortening these cycles means restoring the dynamic equilibriums at the appropriate temporal and spatial scales. The latter is relevant since at a global scale all cycles close. The question of sustainability has to do with closing the cycles within a human dimension.

Economic sustainability

Economic sustainability relates to the efficiency of the system. If all societal costs and benefits are properly accounted for, and cycles are closed, then economic sustainability implies a reduction of scale by short-cutting the cycles. Efficiency dictates that cycles should be kept as short as possible. Examples of short cycles are: water conservation, making optimal use of rainfall where it falls (and not drain it and capture it downstream to pump it up again); water recycling at the spot instead of draining it off to a treatment plant after which it is conveyed or pumped back over considerable distances etc.

Strangely enough, economic sustainability is facilitated by an enlargement of scale through trade in land- and water-intensive commodities (the "virtual" water concept). The use of virtual water is an important concept in countries where the carrying capacity of a society is not sufficient to produce water intensive products itself.

The closing of cycles should be realised at different spatial scales:

- The rural scale, implying water conservation, nutrient and soil conservation, prevention of over-drainage and the recycling of nutrients and organic waste.
- The urban scale, both in towns and mega-cities, implying the recycling of water, nutrients and waste.
- The river basin scale, implying: soil and water conservation in the upper catchment, prevention of runoff and unnecessary drainage and enhancement of infiltration and recharge, flood retention, pollution control and the wise use of wetlands.
- The global scale, where water, nutrient and basic resource cycles are integrated and closed. The concept of virtual water is a tool for an equitable utilisation of water resources. This requires an open and accessible global market and the use of resource-based economic incentives such as resource taxing ("Green tax" which taxes the use of non-renewable or finite resources), as opposed to taxing renewable resources such as labour, which is the general practice today.

Institutional sustainability

In order to ensure sustainability, the right decisions have to be made. This requires that the relevant institutions are in place which can facilitate the proper decision processes. Moreover, institutions need to adequately respond to changing requirements and a changing environment in which they operate. They should have the capacity to adapt to emerging circumstances. Their adaptive capacities indicate whether they will prove to be sustainable institutions. According to Costanza (1994),

A sustainable system is active and able to maintain its structure (organisation), function (vigour) and autonomy over time and is resilient in stress.

Integrated water resources management requires strong institutions; sustainable systems in Costanza's sense. Sustainable institutions require good governance; while institutions that are governed wisely are likely to retain their resilience and will be sustained over time. Thus it appears that sustainable institutions and good governance go hand in hand. They need and presuppose each other.

2.7 Historical developments: towards IWRM

International awareness for the importance of water resources management issues is growing. Originally, the approach was typically sub-sectoral, mostly in relation to water supply, sanitation, irrigation and energy (hydropower). Engineers would predict the demand for water and the need for projects and subsequently provide in those needs. There was often a lack of coordination between sectors, and the needs of the environment were ignored. Recently, however, there is a growing consensus about the need for integrated approaches. Box 2.3 gives an overview of these developments.

Tony Allan has described the evolution of water resources management according to five water management paradigms, from (1) the pre-modern to (2) the industrial paradigm with its "hydraulic mission" of dam construction, followed by (3) the "green" paradigm that acknowledged the need to respect the environment, and (4) the "economic" paradigm which emphasised the scarcity value of water and the role of economic instruments in resolving some of the challenges, to finally (5) the IWRM paradigm which attempts to take a holistic perspective (see Figure 2.6).

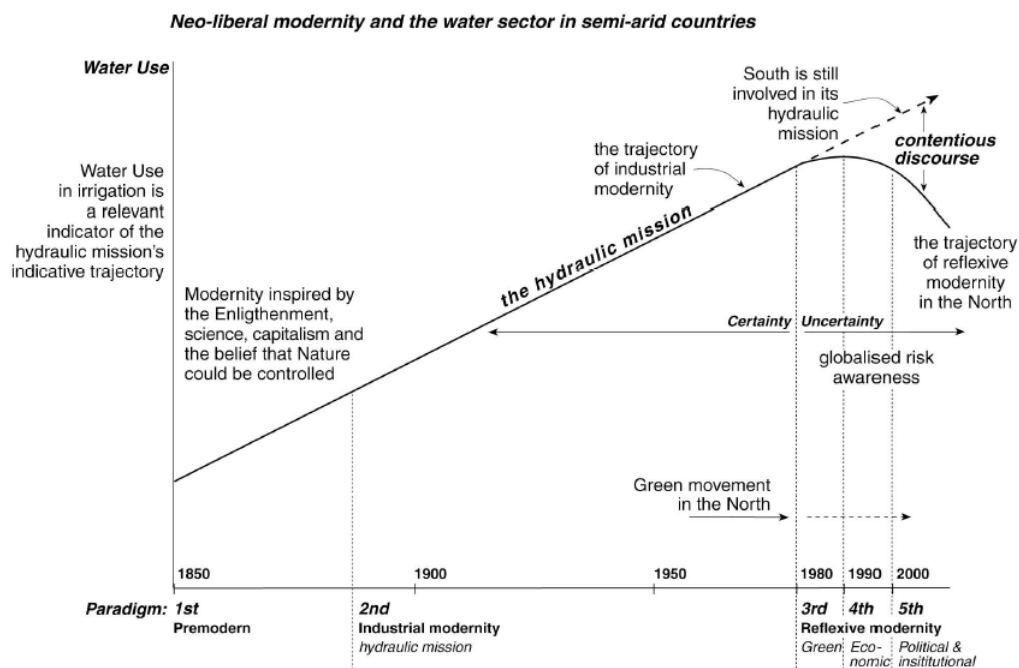


Figure 2.6: The evolution of water resources management according to Allan (2003), with the five water management paradigms

Box 2.3: From water resources development towards IWRM

- 1. Water resources development (1960s-1970s)**
 - Dominant paradigm: water is a resource to be exploited
 - The engineering approach of “predict and provide”
 - Emphasis on infrastructure
 - Individual projects
- 2. Water resources management (1980s-1990s)**
 - Recognition that water can be ‘overexploited’
 - Accounting for ecological and social constraints
 - Regional and national planning instead of a project approach
 - Demand-side measures come into focus
- 3. Integrated water resources management (1990s-present)**
 - Water management embedded in an overall policy for socio-economic development, physical planning and environmental protection
 - Public participation
 - Focus on sustainability

Box 2.4: Chronology of important international meetings and developments

1965-1974	International Hydrological Decade
1966	ILA adopts the Helsinki Rules on the Uses of the Waters of International Rivers
1977	UN Water Conference, Mar del Plata
1981-1990	International Drinking Water Supply and Sanitation Decade
1987	World Commission on Environment and Development submits Brundtland report
1992	International Conference on Water and the Environment, Dublin
1992	UN Conference on Environment and Development, Rio de Janeiro
1994	UN Conference on Population and Development, Cairo
1996	Global Water Partnership
1996	World Water Council
1997	Commission on Sustainable Development submits water assessment report
1997	UN General Assembly adopts the Convention on the Law of the Non-navigational Uses of International Watercourses
1997	First World Water Forum, Marrakech
2000	Second World Water Forum, The Hague
2000	World Commission on Dams submits final report
2000	United Nations Millennium Summit
2002	World Summit on Sustainable Development, Johannesburg
2003	Third World Water Forum, Kyoto
2004	ILA adopts the Berlin Rules on Water Resources
2006	Fourth World Water Forum, Mexico City
2008	International Year of Sanitation
2009	5th World Water Forum, Istanbul
2010	UN General Assembly adopts a resolution that declares access to clean water and sanitation a fundamental human right
2012	6th World Water Forum, Marseille
2012	Rio+20; development of the Sustainable Development Goals
2013	International Year of Water Cooperation

During the last two decades, water has gradually received more and more attention during international meetings. Box 2.4 provides a chronology of important international meetings and developments.

At the UN Conference in Mar del Plata (1977), the emphasis was still on water supply and sanitation. The Brundtland Report of the World Commission on Environment and Development (1987) only mentioned the word “water” in relation to pollution and water supply. It was during the preparatory conferences for the UN Conference on Environment and Development (UNCED) that the concepts underlying Integrated Water Resources Management were widely debated.

The International Conference on Water and the Environment (ICWE) in Dublin (1992), led to the Dublin Principles (Box 2.5). The Dublin Principles formed an important input into Rio 1992 which culminated into the adoption of the Fresh Water Chapter (Chapter 18) of Agenda 21 (UN, 1992).

Chapter 18 (“Protection of the quality and supply of freshwater resources: application of integrated approaches to the development, management and use of water resources”) of Agenda 21 emphasised the need for an integrated approach to managing water resources:

“18.3. 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. Such integration must cover all types of interrelated freshwater bodies, including both surface water and groundwater, and duly consider water quantity and quality aspects. The multisectoral nature of water resources development in the context of socio-economic development must be recognized, as well as the multi-interest utilization of water resources..”

Chapter 18 in fact gave the first definition of IWRM (Box 2.6).

In 1993, the World Bank published the influential policy paper on Water Resources Management (World Bank, 1993), which emphasises the need for IWRM, economic pricing, cost recovery, decentralisation, privatisation, management of international river basins and incorporation of environmental criteria in planning and management. The Commission on Sustainable Development (CSD) has put IWRM high on the international agenda, when in 1997 it published the first comprehensive assessment of global water resources.

In the same year the UN adopted the Law of the Non-navigational Uses of International Watercourses. This UN Convention is not yet in force, but is a landmark development in international water law (see section 5.3).

After Dublin, with the call for integrated management, the high degree of fragmentation of the water sector in the international community, and in particular the UN family, became strongly felt. The water interest is fragmented over many different organisations, such as WMO, WHO, FAO, UNESCO, UNDP, UNEP and UNICEF.

Box 2.5: Dublin Principles (ICWE, 1992)

- Water is a finite, vulnerable and essential resource which should be managed in an integrated manner
- Water resources development and management should be based on a participatory approach, involving all relevant stakeholders
- Women play a central role in the provision, management and safeguarding of water
- Water has an economic value and should be recognised as an economic good, taking into account affordability and equity criteria.

Associated key concepts:

- Integrated water resources management, implying:
 - An inter-sectoral approach
 - Representation of all stakeholders
 - Consideration of all physical aspects of the water resources
 - Considerations of sustainability and the environment
- Sustainable development, sound socio-economic development that safeguards the resource base for future generations
- Emphasis on demand driven and demand oriented approaches
- Decision-making at the lowest possible level (subsidiarity)

Box 2.6: Integrated water resources management (UN, 1992)

18.8. Integrated water resources management is based on the perception of water as an integral part of the ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilization. To this end, water resources have to be protected, taking into account the functioning of aquatic ecosystems and the perennality of the resource, in order to satisfy and reconcile needs for water in human activities. In developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems. Beyond these requirements, however, water users should be charged appropriately.

18.9. Integrated water resources management, including the integration of land- and water-related aspects, should be carried out at the level of the catchment basin or sub-basin. Four principal objectives should be pursued, as follows:

- (a) To promote a dynamic, interactive, iterative and multisectoral approach to water resources management, including the identification and protection of potential sources of freshwater supply, that integrates technological, socio-economic, environmental and human health considerations;
- (b) To plan for the sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of national economic development policy;
- (c) To design, implement and evaluate projects and programmes that are both economically efficient and socially appropriate within clearly defined strategies, based on an approach of full public participation, including that of women, youth, indigenous people and local communities in water management policy-making and decision-making;
- (d) To identify and strengthen or develop, as required, in particular in developing countries, the appropriate institutional, legal and financial mechanisms to ensure that water policy and its implementation are a catalyst for sustainable social progress and economic growth.

Important steps in the process towards more coordination have been the formation of the Global Water Partnership (GWP) and the World Water Council (WWC), who both have the aim to coordinate the implementation of IWRM principles and practices worldwide. Although there is undoubtedly some overlap between the two organisations, the WWC concentrates on awareness raising at political levels, whereas GWP aims at the implementation of IWRM concepts at the operational level. Together they have been the driving force behind the second, third and fourth world water forums.

At the United Nations Millennium Summit in September 2000 world leaders placed development at the heart of the global agenda by adopting the Millennium Development Goals (MDGs), which set clear targets for reducing poverty, hunger, disease, illiteracy, environmental degradation, and discrimination against women by 2015 (Box 2.7). The eight Millennium Development Goals constitute an ambitious agenda to significantly improve the human condition by 2015.

At least five of the eight MDGs require good water management; they cannot be achieved without it:

- *improved use of rainfall and irrigation water* will increase crop yields and help to eradicate hunger (Goal 1 Target 2); and increased access to productive water will also reduce poverty (Goal 1 Target 1);
- *improved operation and maintenance of existing water supply systems and sanitation and sewer infrastructure, and the construction of new facilities* will significantly increase access (Goal 7 Targets 10 and 11) and thereby reduce child mortality (Goal 4 Target 5) and the incidence of malaria and other waterborne diseases (Goal 6 Target 8), and will have a positive effect on maternal health (Goal 5 Target 6); and
- *the recognition of the environment as a legitimate water user; improved water quality management and watershed management and nutrient recycling* will all contribute to reversing the current trend of environmental resources degradation (Goal 7 Target 9).

Whereas there are many fields that have the potential to contribute to achieving the Goals, the following three would have, in our view, priority:

1. Making rainfed farming systems more productive (doubling of rainfed crop yields) and more resilient to climate shocks and thus contributing to food security, by means of innovative soil and water conservation and water harvesting techniques and nutrient management.
2. Increasing access to safe water and sanitation in peri-urban areas of large cities through (a) increasing the efficiency of urban water supply systems and water demand management, (b) developing and implementing new sustainable forms of sanitation, including ecosan, and (c) innovative financing arrangements.
3. Making catchment organisations more effective in allocating water, in mediating conflicts and in finding a balance between economic development and environmental sustainability, through upscaling of local water management arrangements and through the use of new information technologies. This may fill the institutional void between the local watershed and the river basin scales.

Box 2.7: The Millennium Development Goals and Targets

Goal 1: Eradicate extreme poverty and hunger

- Target 1 Halve, between 1990 and 2015, the proportion of people whose income is less than one dollar a day
- Target 2 Halve, between 1990 and 2015, the proportion of people who suffer from hunger

Goal 2: Achieve universal primary education

- Target 3 Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling

Goal 3: Promote gender equality and empower women

- Target 4 Eliminate gender disparity in primary and secondary education, preferably by 2005, and to all levels of education no later than 2015

Goal 4: Reduce child mortality

- Target 5 Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate

Goal 5: Improve maternal health

- Target 6 Reduce by three-quarters, between 1990 and 2015, the maternal mortality ratio

Goal 6: Combat HIV/AIDS, malaria and other diseases

- Target 7 Have halted by 2015 and begun to reverse the spread of HIV/AIDS
- Target 8 Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases

Goal 7: Ensure environmental sustainability

- Target 9 Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources
- Target 10 Halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation
- Target 11 By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers

Goal 8: Develop a Global Partnership for Development

- Target 12 Develop further an open, rule-based, predictable, non-discriminatory trading and financial system [Includes a commitment to good governance, development, and poverty reduction – both nationally and internationally]
- Target 13 Address the Special Needs of the Least Developed Countries [Includes: tariff and quota free access for LDC exports; enhanced programme of debt relief for HIPC and cancellation of official bilateral debt; and more generous ODA for countries committed to poverty reduction]
- Target 14 Address the Special Needs of landlocked countries and small island developing States (through the Programme of Action for the Sustainable Development of Small Island Developing States and the outcome of the 22nd special session of the General Assembly)
- Target 15 Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term
- Target 16 In co-operation with developing countries, develop and implement strategies for decent and productive work for youth
- Target 17 In co-operation with pharmaceutical companies, provide access to affordable, essential drugs in developing countries
- Target 18 In co-operation with the private sector, make available the benefits of new technologies, especially information and communications

Source: http://www.unmillenniumproject.org/html/dev_goals1.shtml

During the 2nd World Water Forum, held in The Hague in March 2000, delegations of 113 countries met in the parallel ministerial conference, and adopted unanimously the concept of IWRM. A significant number of experts who attended the Forum in The Hague wanted access to water to be declared a human right. This did not materialise. However, two years later UN Committee on Economic, Social and Cultural Rights defined the right to water in General Assembly Comment No. 15 (2002) as the right of everyone “to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses.” It further specifies that signatory states should ensure access to “a minimum essential amount of water [and] adequate sanitation,” develop and implement a national water strategy and monitor progress made on realizing the right to water. The primary responsibility for the implementation of the right to water falls upon the States and their national governments (Box 2.8).

Box 2.8: General Comment on Right of Water by the Committee on Economic, Social and Cultural Rights, November 2002

The General Comment notes that water is a limited natural resource and a public commodity fundamental to life and health. The Committee has been confronted continually with widespread denial of the right to water in developing as well as developed countries. Over 1 billion persons lack access to a basic water supply, while several billion lack access to adequate sanitation, a primary cause of water contamination and diseases linked to water, the comment states. The continuing contamination, depletion and unequal distribution of water resources is exacerbating existing poverty. States parties have the duty to progressively realize, without discrimination, the right to water.

The human right to water entitles everyone to sufficient, affordable, physically accessible, safe and acceptable water for personal and domestic uses, the text states. While those uses vary between cultures, an adequate amount of safe water is necessary to prevent death from dehydration, to reduce the risk of water-related disease and to provide for consumption, cooking, personal and domestic hygienic requirements.

The right to water contains both freedom and entitlements; the freedoms include the right to maintain access to existing water supplies necessary for the right to water; and the right to be free from interference, such as the right to be free from arbitrary disconnections or contamination of water supplies, the text states. The elements of the right to water should be adequate for human dignity, life and health. The adequacy of water should not be interpreted narrowly, by mere reference to volumetric qualities and technologies. Water should be treated as a social and cultural good, and not primarily as an economic commodity. The manner of the realization of the right to water should also be sustainable, ensuring that the right can be realized for present and future generations.

Further, the General Comment notes that States parties have a constant and continuing duty, in accordance with the obligation of progressive realization, to move expeditiously and effectively towards the full realization to the right to water. Realization of the right should be feasible and practicable, since all States parties exercise control over a broad range of resources, including water, technology, financial resources and international assistance, as with all other rights in the Covenant.

Source: Office of the High Commissioner for Human Rights, Geneva; <http://www.unhchr.ch/>

On 28 July 2010, the United Nations General Assembly adopted a non-binding resolution, sponsored by Bolivia, which declares that access to clean water and sanitation is a fundamental human right. The resolution also called on member states and international organizations to offer financial and technical assistance, in particular to developing countries, in order to provide clean, accessible and affordable drinking water and sanitation for everyone. The resolution invited the UN Independent Expert on the issue of human rights obligations related to access to safe drinking water and sanitation, to report annually to the General Assembly. The resolution received the

support of 122 member states, while 41 countries abstained.

In November 2000, the World Commission on Dams submitted its final report. This Commission led an independent, international, multi-stakeholder process that addressed the controversial issues associated with large dams. It provided a unique opportunity to bring into focus the many assumptions and paradigms that are at the centre of the search to reconcile economic growth, social equity, environmental conservation and political participation in the changing global context. The final report (www.dams.org) provides a wealth of information. One of the conclusions was that the benefits and costs of dam developments should be much better estimated before constructing them, including the social costs (e.g. displacement of people living in the area to be flooded by the reservoir) and environmental costs. Follow-up activities can be found on <http://www.unep.org/dams>.

The World Summit on Sustainable Development in Johannesburg in 2002 called for countries to “develop Integrated Water Resources Management and Water Efficiency Plans by 2005”. By end of 2007, a survey among 53 developing countries and countries in transition found that 38% (20) had indeed formulated IWRM/WE plans and were in the process of implementing them (UN Water, 2008)

2.8 Outstanding issues of debate

The developments since Rio demonstrate the global community’s increasing concern with water. One can also discern a growing convergence about most of the concepts underlying Integrated Water Resources Management. There is hardly anybody who would disagree with the first three Dublin principles, namely that water management requires an integrated and participatory approach and that women should play a key role in all aspects of water management. There is also an emerging consensus that in terms of water allocation, basic human needs should receive priority; and that other uses should be prioritised according to societal needs and socio-economic criteria. The river basin is accepted as the logical unit for water resources management.

However, a number of important issues remain unresolved. These include:

- What does it mean if water is considered an economic good?
- Is there indeed water scarcity?
- Why is it so difficult to provide access to sufficient safe water and adequate sanitation services to the entire global population?
- How can we ensure that the private sector plays its - positive - part in the water sector, without the possible negative consequences?
- Should we aim for food self-sufficiency or for food security?
- Can we improve the efficient use of rainfall to increase food production?
- What institutional arrangements are required to implement IWRM? What does it mean if we say that we need good water governance?
- Should catchment institutions have executive functions, or should they only be platforms of coordination, with line institutions implementing decisions?
- Will the increasing pressure on the water resource inevitably lead to an increase in conflicts over water, locally and between riparian countries?
- How can be formalise upstream-downstream linkages, and positively deal with the

- fundamental asymmetry in water resources management?
- How much water does the environment require? Which priority should environmental water have?
 - Do we need more dams?
 - What may be the implications of climate change for water resources management?

There is also an emerging criticism of the IWRM concept (see e.g. Biswas, 2004; Shah and Van Koppen, 2006; Mollinga, 2008; Molle, 2008). There are many points of critique, but the following three stand out:

1. IWRM as a concept is ill-defined, and means different things to different people and audiences. It therefore lacks analytical clarity. To make things worse, the concept often is used with a certain “normative” connotation: IWRM is seen as “good”. People are therefore tempted to (ab-)use it, and re-frame the things that they are used to be doing in new ways, but without fundamentally changing their approach (e.g. the dam, irrigation, drinking water, etc. sectors).
2. IWRM is the embodiment of a trend for the water sector to claim uniqueness, and therefore a special institutional space (see also section 2.2 above!). This has, however, created a problem of “institutional fit” with other sectors and institutions, and also may have enhanced competition over scarce institutional resources. In all this may have decreased the capacity for an integrated approach of water and related development (think of spatial planning).
3. Many development countries point at the fact that what they need is water resources *development* before they can focus on water resources *management* – without hardware there is no way that water resources can be adequately managed (see e.g. Grey and Sadoff, 2007). Whereas in our reading the IWRM concept encompasses both the hardware and the software, many donors indeed tend to favour support for soft measures (e.g. institutional development) compared to hard measures (e.g. infrastructure development).

Most of the issues identified in this section will be addressed in the following chapters of this lecture note and/or will be further elaborated in other course modules.

Before going any further, however, the next chapter first describes the water cycle, and thereafter deals with water balances and water availability. The demand for water will be the topic of the chapter that follows.

2.9 Exercises

- 2.1a What are in your opinion the main policy issues for the water sector in your country?
- 2.1b Which objectives for the management of water resources can be derived from these?
- 2.1c What would be suitable performance criteria for these objectives?
- 2.1d Which institutions should be responsible for the implementation of these objectives?
- 2.1e Which should the tasks and responsibilities be for these institutions?
- 2.2 What is the basin efficiency depicted in figure 2.4?
- 2.3 Which of the eight the Millennium Development Goals (MDGs) require proper water resources management?
- 2.4 Read two articles about water pricing: the paper by Rogers et al. (2002) and the paper by Savenije and Van der Zaag (2002). Describe the debate with respect to pricing of water. What does it mean that water is an economic good?
- 2.5 Read some of the following articles on IWRM: Biswas (2004), Van der Zaag (2005), Shah and Van Koppen (2006), Grey and Sadoff (2007), Mollinga (2008) and Molle (2008). Describe the different interpretations of current developments with respect to IWRM. What are the current key challenges? Which are, in your opinion, the most important and why?



Washing carrots in a river in Tanzania (photo by Jeremiah Kiptala)

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A water point and a small reservoir in southern Zimbabwe

Chapter 3

Water resources

Hubert H.G. Savenije and Pieter van der Zaag

3.1 The hydrological cycle

The hydrological cycle can be studied at different spatial scales. One starts with considering a certain area (e.g. an individual plant, a farmer's field, a watershed, a catchment area, an international river basin, an ocean, the earth). It is crucial for a system's approach to carefully define the boundaries of the area under consideration, and any water fluxes that cross them. These are either inflows into the area under consideration, or outflows. Subsequently all other sources of water into the area are identified, and all types of consumptive uses, as well as any return flows from such uses.

Only a small portion of the rainfall flows into rivers as surface water and recharges groundwater (Figure 3.1). This water is used for domestic water supply, industrial production, irrigated agriculture etc. This is the water that we tend to harness through infrastructure development (e.g. dams, wells) and that we tend to pollute.

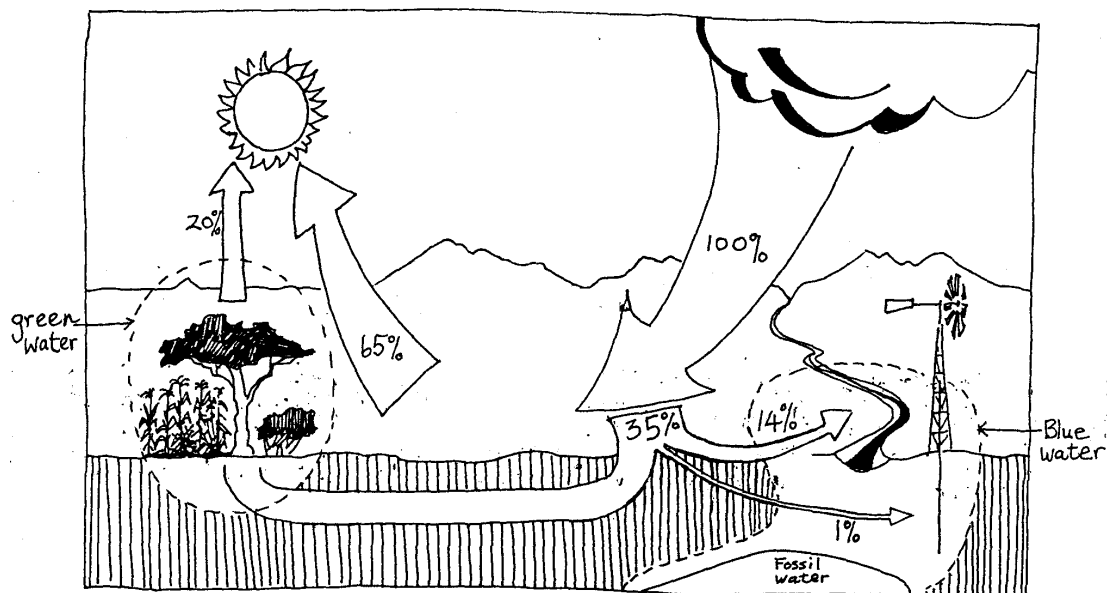


Figure 3.1: Schematic water balance for Southern Africa, showing the average partitioning of rainfall (Pallett 1997: 22)

It is useful to distinguish three different types of water depending on their occurrence in the water cycle (Falkenmark, 1995):

- ‘white’ water: rainfall and that part of rainfall which is intercepted and immediately evaporates back to the atmosphere, as well as non-productive open water and soil evaporation
- ‘green’ water: soil moisture in the unsaturated soil layer, stemming directly from rainfall, that is transpired by vegetation
- ‘blue’ water: water involved in the runoff (sub-)cycle, consisting of surface water and groundwater (below the unsaturated zone).

Figure 3.2 gives a schematic representation of the hydrological cycle, distinguishing between these three flows. The processes occurring within the three “colours” of water, as well as their interconnections, determine the characteristics of each natural hydrological system.

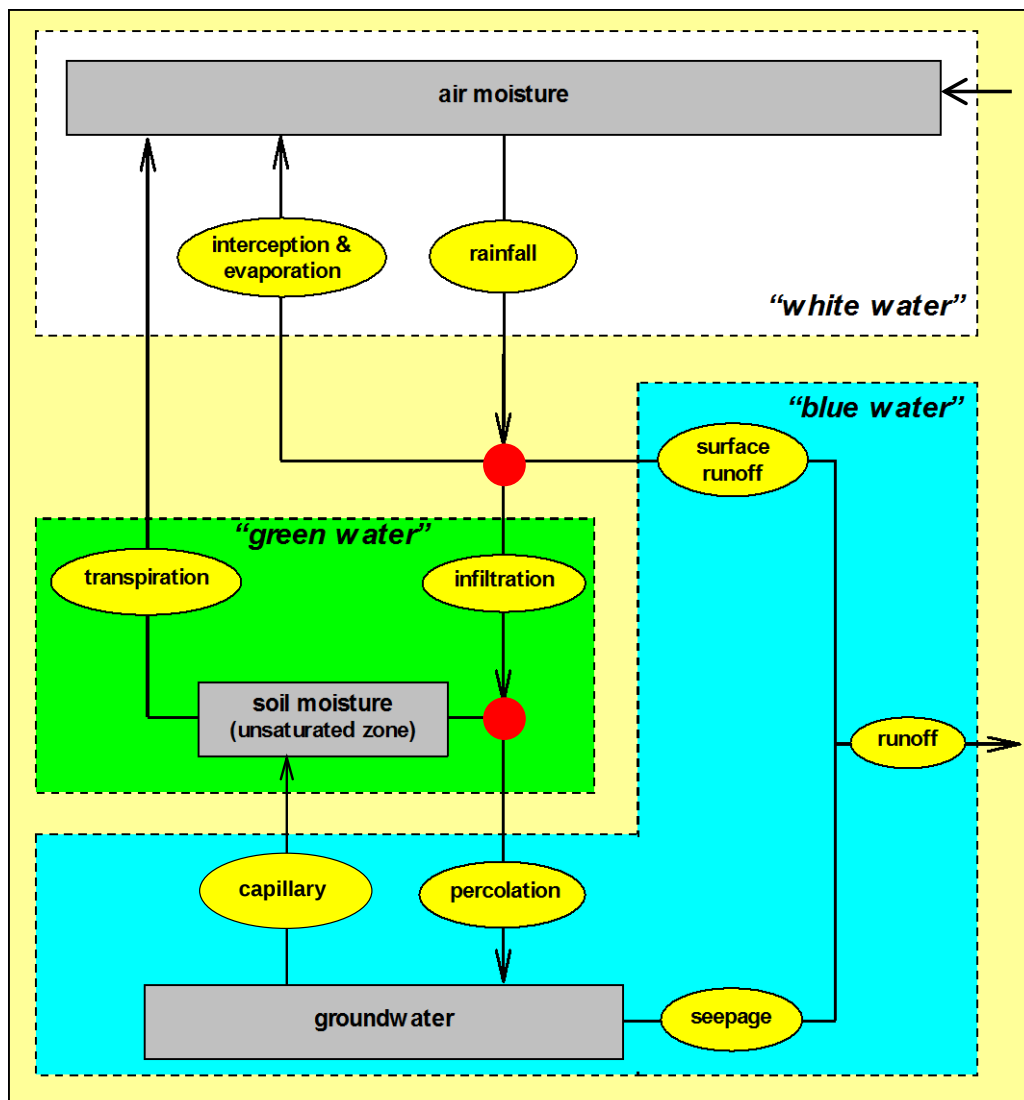


Figure 3.2: The hydrological cycle, with ‘white’, ‘green’ and ‘blue’ water, and the two partitioning points (red dots)

The two black dots in Figure 3.2 represent the two processes that determine how rainfall is partitioned into interception (direct evaporation from the soil, leaves and other surfaces), infiltration, transpiration, percolation and surface runoff. These two “partitioning points” therefore influence how much of the rainfall ends up in our rivers, and when. They are also important intervention points by humans in the hydrological process.

The first partitioning point occurs at the surface where a drop of rainwater will either (a) return to the atmosphere as water vapour through interception; or (b) infiltrate into the upper soil layer (the “unsaturated zone”) where it appears as soil moisture; or (c) runs off directly into a stream or river.

The manner in which rainfall will be distributed over these three routes depends on surface characteristics, such as permeability, slope, canopy of crops etc. On impervious tarmac some rainfall will evaporate directly from the surface (interception), no water will infiltrate and by far the largest part will run off as surface water. In contrast, an undisturbed rainforest will capture much of the rainfall on its canopy before the raindrop even reaches the soil. A large part of the remaining rainfall may infiltrate and relatively little will run off directly over the surface.

The second partitioning point is located in the upper soil layer, the so-called unsaturated zone. The water from rainfall that has infiltrated into the soil will either (a) be taken up by the roots of plants which will use it to transport nutrients to the leaves where the water will transpire into the atmosphere as water vapour; or (b) percolate deeply beyond the root zone and eventually join the water table, recharging the aquifer.

If the soil is sandy, with a coarse structure, more of the infiltrated water will percolate beyond the root zone. With a well-developed root system chances are higher that the soil moisture will be taken up by the crop and transpire.

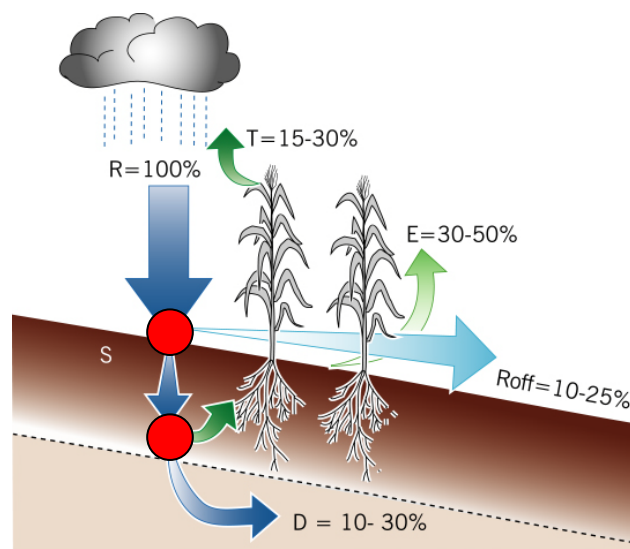


Figure 3.3: Rainfall partitioning in farming systems in the semi-arid tropics of sub-Saharan Africa (Rockström et al., 2003)

3.1.1 Watershed management

The major human interveners in the above two partitioning points are farmers who manage their soils and crops (Figure 3.3).

Bad soil management and poor cultivating practices will have detrimental effects on the hydrological cycle: more water will run off directly, leading to high storm flows, and less water will infiltrate. Less water will therefore be available to crops and the base flow in the rivers downstream is likely to decrease. Certain exotic (alien) species have very large water requirements (such as certain exotic trees) and because of their high transpiration, percolation is reduced. As a result base flows are affected and rivers dry up.

Watershed management, understood as soil and water conservation and management, has as its principal objective to favourably influence the two partitioning points, so as to (a) increase infiltration and decrease surface runoff and the resulting erosion; and (b) increase crop production through enhanced availability of soil moisture. The resulting flow regime of blue water is often that storm flows have lower peaks and carry less soil particles from erosion, and that the base flow is hardly affected, or indeed increases.

3.1.2 Groundwater as part of the hydrological cycle

Renewable groundwater takes active part in the hydrological cycle and hence is "blue water". (In contrast, fossil groundwater is non-renewable and can be used only once (mined).) Groundwater feeds surface water and vice versa. One can say that all renewable groundwater becomes surface water and that some of the surface water was groundwater. Especially in dry climates the existence of underground storage of water is important.

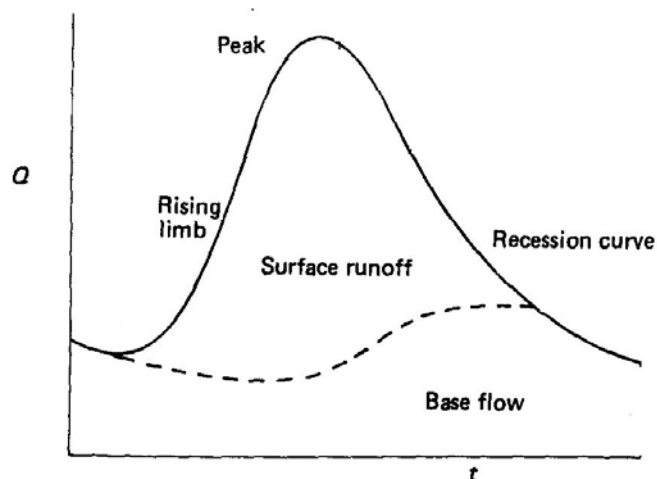


Figure 3.4: Hydrograph separation between surface and ground water

The water stored in the subsoil becomes available in two ways. One way is by artificial withdrawal (pumping), the other is by natural seepage to the surface water. The latter is an important link in the hydrological cycle. Whereas in the wet season river flow is dominated by surface runoff, in the dry season rivers are almost entirely fed by seepage

from groundwater (base flow). Thus the groundwater component acts as a reservoir which retards the runoff from the wet season rainfall and smoothens out the shape of the hydrograph (Figure 3.4). This also means that abstractions from groundwater will diminish the base flow in downstream rivers.

3.2 Water balances

In hydrology water balances are widely used. Water balances are based on the principle of conservation of mass. This can be expressed with the equation:

$$\frac{\Delta S}{\Delta t} = I(t) - O(t) \quad (3.1)$$

where I is the inflow in $[L^3/T]$ [L = unit of length; T = unit of time]
 O is the outflow in $[L^3/T]$
 $\Delta S/\Delta t$ is the change in storage over a time step $[L^3/T]$

The equation holds for a specific period of time and may be applied to any given system provided that the boundaries are well defined. Other names for the water balance equation are Storage Equation, Continuity Equation and Law of Conservation of Mass.

The water balance equation is based on a systems understanding of the water cycle by considering its inputs and outputs. The water system interconnecting the input and the output is represented by the storage component (Figure 3.5).



Figure 3.5: Input-Storage-Output model

The water balance consists of a flux and a stock. The flux is represented by the incoming and outgoing flows of water, and has as its unit volume per time. The stock is the capacity of the system to store the flux of water. This storage capacity has as its unit volume.

Dividing the stock by the flux, yields a useful measure, namely the average residence time of a water particle in the stock:

$$\text{Residence time} = S / I(t) \quad (3.2)$$

Several types of water balances can be distinguished. In the following, three water balances are briefly elaborated: the water balance of the earth, that of a drainage basin, that due to human interference, and of a rainfed crop.

3.2.1 The water balance of the earth (Savenije, 2000)

The water balance of the earth is given in tables 3.1 and 3.2. Sahagian et al. (1994) drew very interesting conclusions from the information presented in Tables 3.1 and 3.2.

Table 3.1: Amount of water on earth (UN World Water Development Report, 2003)

Water occurrence	Volume 10^{12} m^3	Amount of water	
		% of all water	% of fresh water
World oceans	1,338,000	96.5	
Groundwater (non-fresh)	12,870	0.93	
Salt water lakes	85.4	0.006	
Ice and snow	24,364	1.76	69.6
Groundwater (fresh)	10,530	0.76	30.1
Atmospheric water	12.9	0.001	0.037
Fresh water lakes	91	0.007	0.260
Marshes & swamps	11.5	0.001	0.033
River water	2.12	0.000	0.006
Soil moisture	16.5	0.001	0.047
Water in organisms	1.12	0.000	0.003
Total fresh water	35,029	2.53	100
Total water	1,385,985	100	

Table 3.2: Annual water balance of the earth (Holy, 1982)

	Area 10^{12} m^2	Precipitation $10^{12} \text{ m}^3/\text{a}$	Evaporation $10^{12} \text{ m}^3/\text{a}$	Runoff $10^{12} \text{ m}^3/\text{a}$
Oceans	361	403	449	-46
Continents	149	107	61	46

Table 3.3: Selected water fluxes and residence times (UN World Water Development Report, 2003)

Water occurrence	Volume 10^{12} m^3	Annual flux $10^{12} \text{ m}^3/\text{a}$	Renewal time
World oceans	1,338,000	505	2,500 yr
Ice in Greenland	2,340	0.24	9,700 yr
Ice in mountains	40.6	0.025	1,600 yr
Ground ice (permafrost)	300	0.03	10,000 yr
Water in lakes	176.4	10.38	17 yr
Marshes and swamps	11.5	2.29	5 yr
Soil moisture	16.5	16.5	1 yr
River water	2.12	43	18 days
Water in atmosphere	12.9	600	8 days

3.2.2 The water balance of a drainage basin (Savenije, 2000)

The water balance is often applied to a river basin. A river basin (also called watershed, catchment, or drainage basin) is the area contributing to the discharge at a particular river cross-section. The size of the catchment A increases if the point selected as outlet moves downstream. If no water moves across the catchment boundary, the input equals the precipitation P while the output comprises the evaporation E and the river discharge Q at the outlet of the catchment. Hence, the water balance may be written as:

$$\frac{\Delta S}{\Delta t} = (P - E)A - Q \quad (3.3)$$

ΔS , the change in the amount of water stored in the catchment, is difficult to measure. When computing the water balance for annual periods, the beginning of the balance period is preferably chosen at a time that the amount of water stored is expected not to vary much for each successive year. These annual periods, which do not necessarily coincide with calendar years, are known as hydrological years. For a hydrological year, $\Delta S/\Delta t$ may generally be neglected. Table 3.4 gives the water balance for some river basins of the world.

Table 3.4: Indicative average annual water balances for some river basins

River	Catchment Area A	Rainfall P		Evaporation E		Runoff Q		Runoff coefficient %
	10^9 m^2	mm/a	$10^9 \text{ m}^3/\text{a}$	mm/a	$10^9 \text{ m}^3/\text{a}$	mm/a	$10^9 \text{ m}^3/\text{a}$	
Mississippi	3,924	800	3,100	654	2,540	142	558	18
Ob	2,950	450	1,350	325	965	131	385	29
Nile	2,803	220	620	190	534	30	86	14
Lena	2,430	350	850	140	335	212	514	60
Zambezi	1,300	990	1,287	903	1,174	87	113	9
Parana	975	1000	980	625	610	382	372	38
Orinoco	850	1330	1,150	420	355	935	795	70
Mekong	646	1500	970	1,000	645	382	325	34
Rhine	200	850	170	500	100	350	70	41
Incomati	47	733	34	656	30	77	4	12

3.2.3 The water balance as a result of human interference

Some river systems have been significantly altered due to human interference with the hydrological cycle. This is the case, for example, in the Incomati river basin. This basin is shared by South Africa, Swaziland and Mozambique. In this basin more than half of the average amount of water generated is being consumptively used; mainly for irrigation, rural domestic use, and urban and industrial use. In addition, water is transferred out of the basin into adjacent river systems. Most of these uses required the construction of dams and reservoirs. Commercial plantations of exotic forest species (mainly for the paper industry) have increased transpiration and decreased runoff.

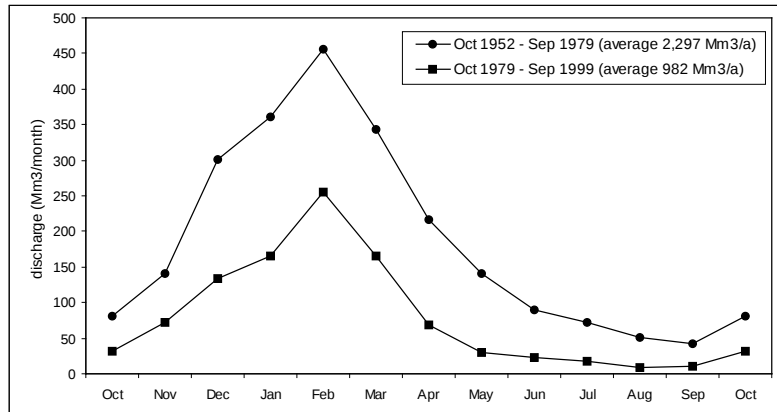
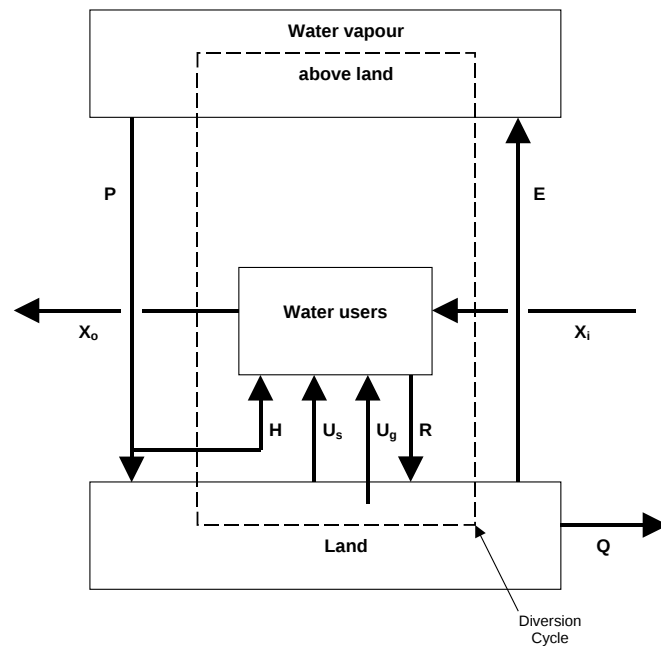


Figure 3.6: Average discharge of the Incomati at Ressano Garcia (station E23); 1953-1979 and 1980-1999 (Van der Zaag and Carmo Vaz, 2003)

As a result of these human interventions the flow regime of the Incomati has been altered. Figure 3.6 shows this effect, by comparing the average runoff in the Incomati pre- and post-1980 at the border between South Africa and Mozambique, just after the confluence of the Komati and Crocodile rivers. Average runoff during 1980-1999 was less than half of that during 1953-1979.

Attempts have been made to incorporate the interference of man in the hydrological cycle through the introduction of the water diversion cycle, which includes water withdrawals and return flows (Figure 3.7).



P = precipitation

$E = E_o + E_T + E_s + E_l$ = total evaporation from open water and land surface

Q = runoff from land to ocean

X_i, X_o = interbasin transfer into or out of the basin

H = direct use of rainwater

$U_s + U_g$ = abstraction from surface and groundwater

R = return flows to surface and groundwater

Figure 3.7: The hydrological cycle of a river basin with the diversion cycle (after Rodda and Matalas, 1987)

3.2.4 The water balance of a crop

A simplified water balance of a rainfed crop is presented in Figure 3.8, and can be expressed by the following equation:

$$P = E_I + E_S + E_T + R + Q_S + \Delta S/\Delta t \quad (3.4)$$

where P : precipitation (L^3/T ; e.g. m^3/day or, if divided by area mm/day)
 E_I : interception (L^3/T)
 E_S : soil evaporation (L^3/T)
 E_T : transpiration (L^3/T)
 R : deep percolation = recharge of aquifers (L^3/T)
 Q_S : Surface run-off (surface outflow from field to downstream) (L^3/T)
 $\Delta S/\Delta t$: change of soil moisture over the considered period (L^3/T)

A similar balance could be made for an irrigated crop, by adding irrigation water I as an input term and open water evaporation E_O as a loss term (e.g. water evaporated from irrigation canals, ponds etc.):

$$P + I = E_I + E_S + E_T + E_O + R + Q_S + \Delta S/\Delta t \quad (3.5)$$

A water balance such as given by equation 3.4 is useful, because it shows how much of the water available to the crop was effectively used by it. If we neglect the change in soil moisture ($\Delta S/\Delta t$) over an entire growing season, than a measure for the water efficiency could be given as:

$$\frac{E_T}{P} \quad (3.6)$$

Should we also include the other evaporation fluxes in eq. 3.6?

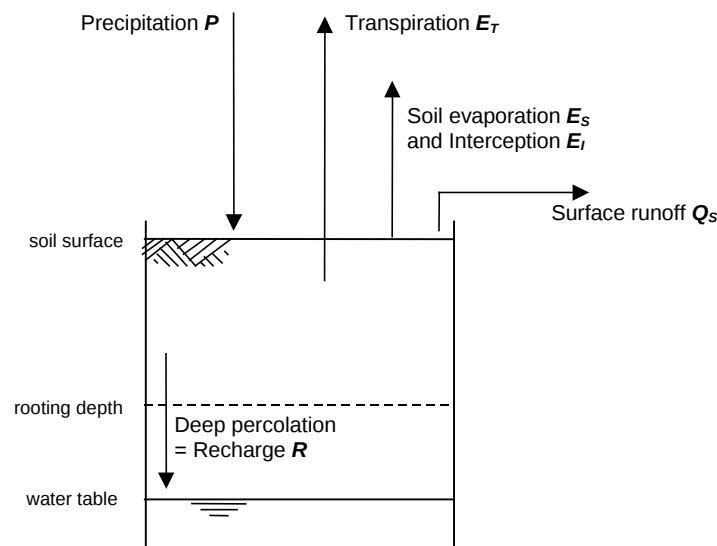


Figure 3.8: Simplified water balance for a rainfed crop

3.3 Groundwater resources

Groundwater can be split up into fossil groundwater and renewable groundwater. Fossil groundwater should be considered a finite mineral resource, which can be used only once, after which it is finished. Renewable groundwater is groundwater that takes an active part in the hydrological cycle. The latter means that the residence time of the water in the sub-surface has an order of magnitude relevant to human planning and considerations of sustainability. The limit between fossil and renewable groundwater is clearly open to debate. Geologists, that are used to working with time scales of millions of years would only consider groundwater as fossil if it has a residence time over a million years. A hydrologist might use a time scale close to that. However, a water resources planner should use a time scale much closer to the human dimension, and to the residence time of pollutants.

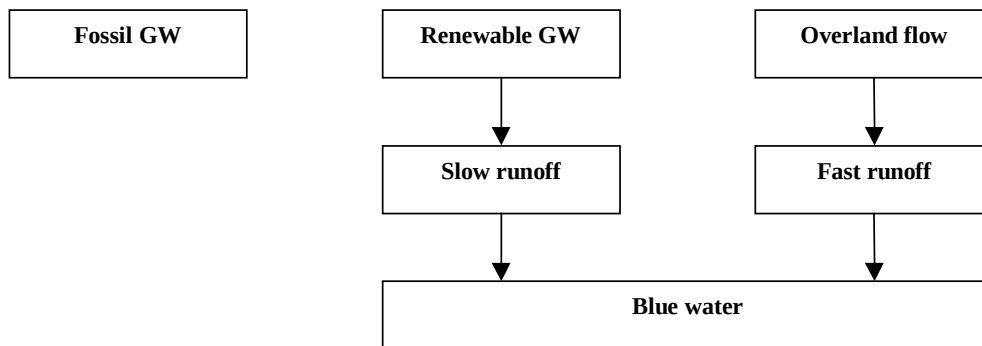


Figure 3.9: Blue water is surface runoff plus seepage from renewable groundwater

In our definition, the renewable groundwater takes active part in the hydrological cycle and hence is "blue water". Groundwater feeds surface water and vice versa. In the Mupfure catchment in Zimbabwe, Mare (1998) showed that more than 60% of the total runoff of the catchment originated from groundwater. Hence most of the water measured at the outfall was groundwater. One can say that all renewable groundwater becomes surface water and most of the surface water was groundwater.

Two zones can be distinguished in which water occurs in the ground:

- the saturated zone
- the unsaturated zone.

For the hydrologist both zones are important links and storage devices in the hydrological cycle: the unsaturated zone stores the "green water", whereas the saturated zone stores the "blue" groundwater. For the engineer the importance of each zone depends on the field of interest. An agricultural engineer is principally interested in the unsaturated zone, where the necessary combination of soil, air and water occurs for a plant to live. The water resources engineer is mainly interested in the groundwater which occurs and flows in the saturated zone.

The type of openings (voids or pores) in which groundwater occurs is an important property of the subsurface formation. Three types are generally distinguished:

1. Pores: openings between individual particles as in sand and gravel. Pores are generally interconnected and allow capillary flow for which Darcy's law (see below) can be applied.
2. Fractures, crevices or joints in hard rock which have developed from breaking of the rock. The pores may vary from super capillary size to capillary size. Only for the latter situation application of Darcy's law is possible. Water in these fractures is known as fissure or fault water.
3. Solution channels and caverns in limestone (karst water), and openings resulting from gas bubbles in lava. These large openings result in a turbulent flow of groundwater which cannot be described with Darcy's law.

The porosity n of the subsurface formation is that part of its volume which consists of openings and pores:

$$n = \frac{V_p}{V} \quad (3.7)$$

where: V_p is the pore volume and V is the total volume of the soil

When water is drained by gravity from saturated material, only a part of the total volume is released. This portion is known as specific yield. The water not drained is called specific retention and the sum of specific yield and specific retention is equal to the porosity. In fine-grained material the forces that retain water against the force of gravity are high due to the small pore size. Hence, the specific retention of fine-grained material (silt or clay) is larger than of coarse material (sand or gravel).

Groundwater is the water that occurs in the saturated zone. The study of the occurrence and movement of groundwater is called groundwater hydrology or geohydrology. The hydraulic properties of a water-bearing formation are not only determined by the porosity but also by the interconnection of the pores and the pore size. An aquifer is a water-bearing layer for which the porosity and pore size are sufficiently large to allow transport of water in appreciable quantities (e.g. sand deposits).

For the water resources engineer groundwater is a very important water resource for the following reasons:

- it is a reliable resource, especially in climates with a pronounced dry season
- it is a bacteriologically safe resource, provided pollution is controlled
- it is often available *in situ* (wide-spread occurrence)
- it may supply water at a time that surface water resources are limited
- it is not affected by evaporation loss, if deep enough.

It also has a number of disadvantages:

- it is a limited resource, extractable quantities are often low as compared to surface water resources
- groundwater recovery is generally expensive as a result of pumping costs
- groundwater is sensitive to pollution
- groundwater recovery may have serious impact on land subsidence or salinisation
- groundwater is often difficult to manage.

Especially in dry climates the existence of underground storage of water is of extreme importance. The water stored in the subsoil becomes available in two ways. One way is by artificial withdrawal (pumping), the other is by natural seepage to the surface water.

The latter is an important link in the hydrological cycle. Whereas in the wet season the runoff is dominated by surface runoff, in the dry season the runoff is almost entirely fed by seepage from groundwater (base flow). Thus the groundwater component acts as a reservoir which retards the runoff from the wet season rainfall and smoothens out the shape of the hydrograph.

The way this outflow behaves is generally described as a linear reservoir, where outflow is considered proportional to the amount of storage:

$$Q = K * S \quad (3.8)$$

where K is a conveyance factor with the dimension of s^{-1} . In combination with the water balance equation, and ignoring the effect of rainfall P and evaporation E , Equation 3.4 yields an exponential relation between the discharge Q and time t .

$$\frac{\Delta S}{S} = -K * \Delta t$$

hence:

$$S = S(t_0) e^{-K(t-t_0)} \quad (3.9)$$

and hence, using Equation 3.8:

$$Q = Q(t_0) e^{-K(t-t_0)} \quad (3.10)$$

Equation 3.10 is a useful equation for the evaluation of surface water availability in the dry season (Figure 3.10).

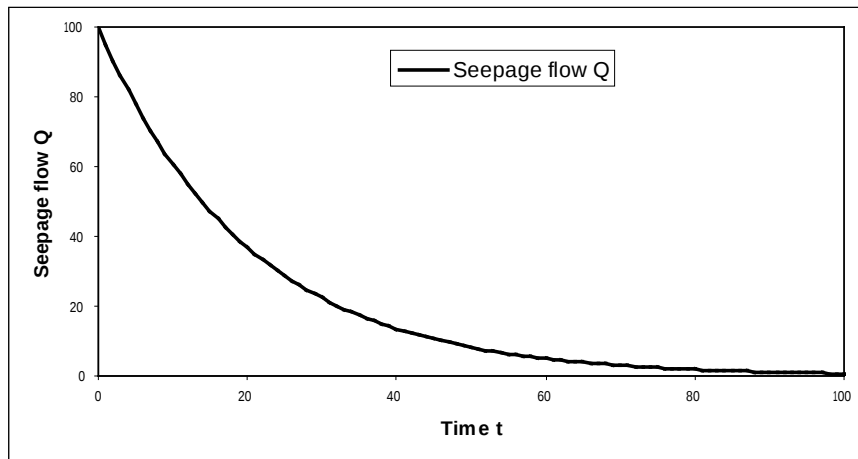


Figure 3.10: Seepage flow from a depleting aquifer
($Q(t_0)=100$, $K=0.05$, and $t_0=0$ in eq. 3.10)

3.4 How to determine the blue and green water resources

Precipitation (P) and the blue water (Q) can be determined through measurement. The difficulty lies with evaporation, whereby we distinguish the productive evaporation flux, which has been called green water and which is transpiration (E_T) and the non-productive evaporation (white water), which comprises direct evaporation from small stagnant pools, bare soil evaporation and interception. Savenije (1997) showed that under the assumption that the soil moisture storage variation at a monthly time step is small, the value for interception can be computed as:

$$E_I = \text{Min}(P, D) \quad (3.11)$$

where: D is the threshold evaporation (from interception) on a monthly basis

The effective precipitation can now be defined as the remainder of the rainfall after interception has occurred:

$$P_{eff} = \text{Max}(P - D, 0) \quad (3.12)$$

After interception has occurred, and neglecting bare soil evaporation and open water evaporation, water will either become blue water (through groundwater or surface flow), or become green water.

From gauged data of Q and P , and given the threshold value D , the effective runoff coefficient c , on a water year basis, can be calculated as follows:

$$c = \frac{\sum Q}{A \sum P_{eff}} \quad (3.13)$$

where $\sum P_{eff}$ and $\sum Q$ are the annual effective rainfall and annual runoff on a water year basis.

The runoff coefficient indicates the part of the effective precipitation that will become blue water. Thus, on a monthly basis, blue water can now be computed as:

$$Q + \frac{\Delta S_g}{\Delta t} = c A P_{eff} = c A \text{Max}(P - D, 0) \quad (3.14)$$

Transpiration must now be the balance between the effective precipitation and blue water:

$$E_T = (1 - c) A P_{eff} = (1 - c) A \text{Max}(P - D, 0) \quad (3.15)$$

Equations 3.11, 3.14 and 3.15 complete the "rainbow of water". Equation 3.11 accounts for the white water; equation 3.15 for the green water, and equation 3.14 for the blue water. To find adequate values for E_I and E_T now depends on finding an appropriate value for D .

Figure 3.11 presents the distribution of monthly values of transpiration E_T , the direct evaporation from interception E_I and the rainfall P over time in the Pungwe catchment in Mozambique. Of the total rainfall, only the evaporation from interception is a loss to the water resources in the catchment. The remainder is the green water and the blue water.

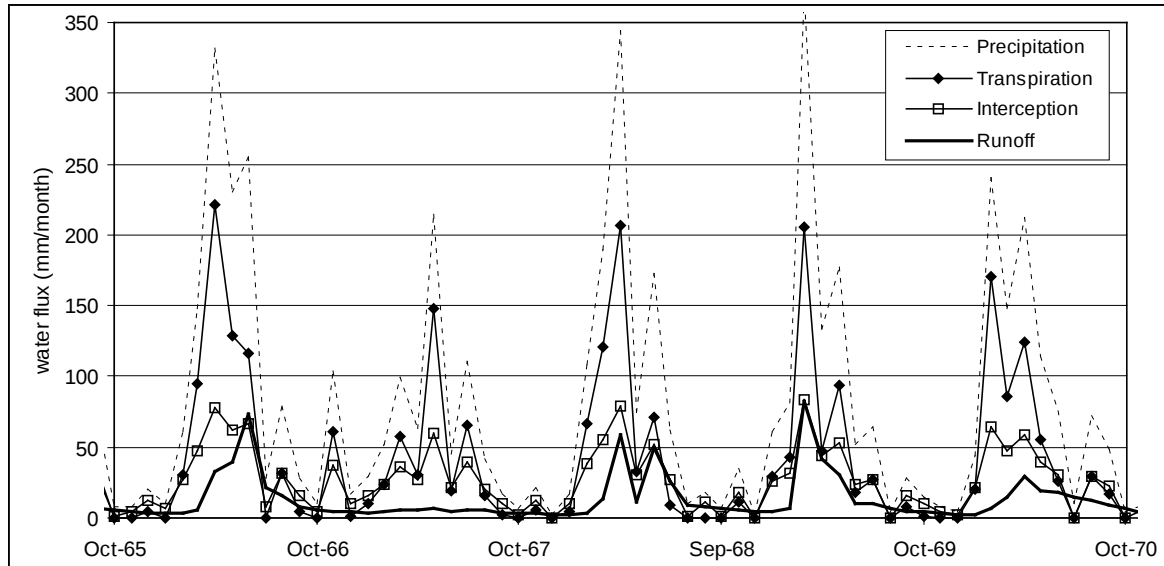


Figure 3.11: Precipitation, interception, transpiration and runoff in the Pungwe catchment

3.5 The rainbow of water revisited

Of all water resources, "green water" is probably the most under-valued resource. Yet it is responsible for by far the largest part of the world's food and biomass production. The concept of "green water" was first introduced by Falkenmark (1995), to distinguish it from "blue water", which is the water that occurs in rivers, lakes and aquifers. The storage medium for green water is the unsaturated soil. The process through which green water is consumed is transpiration. Hence the total amount of green water resources available over a given period of time equals the accumulated amount of transpiration over that period. In this definition irrigation is not taken into account. Green water is transpiration resulting directly from rainfall, hence we are talking about rainfed agriculture, pasture, forestry, etc. The average residence time of green water in the unsaturated zone is the ratio of the storage to the flux (the transpiration). At a global scale the soil moisture availability is 110 mm (see Tables 3.1 and 3.2: 16.5/149)

In tropical areas the transpiration can amount to 100 mm/month or more. Hence the residence time of green water in tropical areas is approximately 1 month. For shallow rooting vegetation the residence time in the root zone may be shorter; for deeply rooted crops it may be longer. In temperate and polar areas where transpiration is significantly less the residence is much longer. At a local scale, depending on climate, soils and topography, these numbers can vary significantly.

Green water is a very important resource for global food production. About 60% of the

world staple food production relies on rainfed agriculture, and hence green water. The entire meat production from grazing relies on green water, and so does the production of wood from forestry. In Sub-Saharan Africa almost the entire food production depends on green water (the relative importance of irrigation is minor) and most of the industrial products, such as cotton, tobacco, wood, etc.

There is no green water without blue water, as their processes of origin are closely related. Blue water is the sum of the water that recharges the groundwater and the water that runs-off over the surface. Blue water occurs as renewable groundwater in aquifers and as surface water in water bodies. These two resources cannot simply be added, since the recharge of the renewable groundwater eventually ends up in the surface water system. Adding them up often implies double counting. Depending on the climate, topography and geology, the ratio of groundwater recharge to total blue water varies. In some parts the contribution of the groundwater to the blue water can be as high as 70-80%; in some parts (on solid rock surface), it can be negligible. Generally the groundwater contribution to the blue water is larger than one thinks intuitively. The reason that rivers run dry is more often related to groundwater withdrawals, than to surface water consumption.

Engineers tend to have a preference for harnessing blue water. For food production, engineers have concentrated on irrigation and neglected rainfed agriculture, which does not require impressive engineering works.

Table 3.5: Global water resources, fluxes, storage and average residence times

Resource	Fluxes	[L/T] or [L ³ /T]	Storage	[L] or [L ³]	Residence time	[T]
			e			
Green	E_T	100 mm/month	S_u	440 mm	S_u/E_T	4 months
White	$E_I+E_S+E_o$	5 mm/d	S_s	3 mm	$S_s/(E_I+E_S+E_o)$	0.6 days
Blue	Q	$46 \times 10^{12} \text{ m}^3/\text{a}$	S_w	$124 \times 10^{12} \text{ m}^3$	S_w/Q	2.7 years
Deep blue	Q_g	$5 \times 10^{12} \text{ m}^3/\text{a}$	S_g	$750 \times 10^{12} \text{ m}^3$	S_g/Q_g	150 years
Atmosphere	P	$510 \times 10^{12} \text{ m}^3/\text{a}$	S_a	$12 \times 10^{12} \text{ m}^3$	S_a/P	0.3 month
Oceans	A	$46 \times 10^{12} \text{ m}^3/\text{a}$	S_o	$1.3 \times 10^{18} \text{ m}^3$	S_o/A	28,000 yr

Table 3.5 presents the quantities of fluxes and stocks of these water resources, and the resulting average residence times, at a global scale. The stocks S_u , S_s , S_w , S_g , S_a and S_o represent the life storages of the unsaturated zone, the surface, the water bodies, the renewable groundwater, the atmosphere and the oceans, respectively. For catchments and sub-systems similar computations can be made. The relative size of the fluxes and stocks can vary considerably between catchments. Not much information on these resources exist at sub-catchment scale.

The study of the Mupfure catchment in Zimbabwe by Mare (1998) is an exception. Table 3.6 illustrates the importance of green water and renewable groundwater in a country where these resources have been mostly disregarded. Figure 3.12, based on 20 years of records (1969-1989) in the Mupfure basin in Zimbabwe (1.2 Gm^2), shows the separation of rainfall into interception (White), Green and Blue water. The model used for this separation is described in Section 3.4 (above). There is considerably more green water than blue water available in the catchment. Moreover, the model showed that more than 60% of the blue water resulted from groundwater.

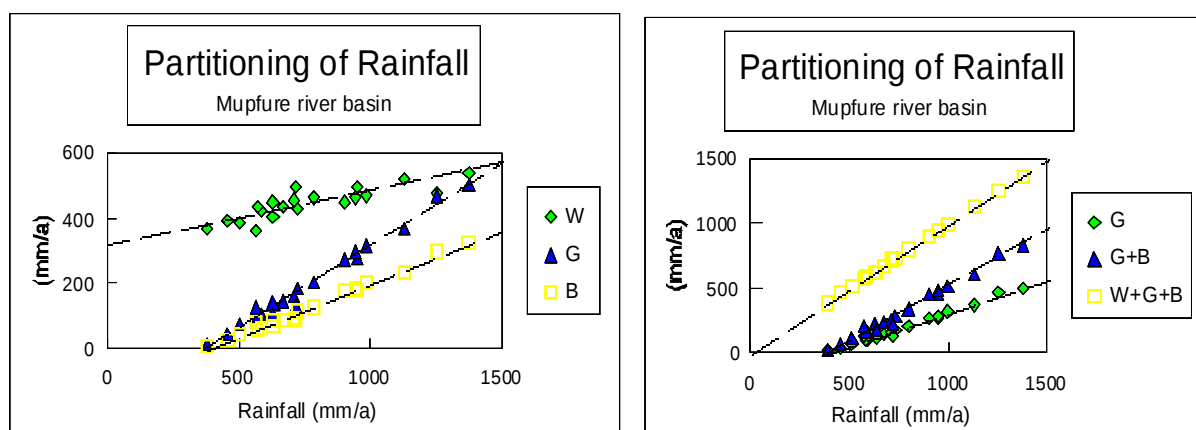


Figure 3.12: Partitioning of rainfall between "White", "Green" and "Blue" water in the Mupfure sub-catchment in Zimbabwe (records of 1969-1989)

Table 3.6: Water resources partitioning and variability in the Mupfure river, Zimbabwe

Mupfure river				
Station: C70	Source		Vertical component	Horizontal Component
Catchment area: 1.2 Gm ²				
Record length: 1969-1989				
Resource type	Rainfall (P)	"White" (W)	"Green" (G)	"Blue" (B)
Mean annual flux (μ)	775 mm/a	446 mm/a	202 mm/a	126 mm/a
Partitioning	100%	62%	23%	15%
Standard deviation (σ)	265 mm/a	48 mm/a	135 mm/a	87 mm/a
Inter-annual variability (σ/μ)	34%	11%	67%	69%

It can be seen from Table 3.6 that the variability of the "white" water is much lower (11%) than the variability of the "green" (67%) and "blue" water (69%). This is a general phenomenon, which can be understood from the fact that interception is the first process to occur and that this process has an upper boundary. The maximum amount of interception per day is limited by the amount of interception storage and the potential evaporation.

Finally, the last colour of the rainbow is the ultra-violet water, the invisible water, or the "virtual water". Virtual water is the amount of water required to produce a certain good. In agriculture, the concept of virtual water is used to express a product in the amount of water required for its production. The production of grains typically requires 1-2 m³/kg, depending on the efficiency of the production process. Trading grains, implies the trade of virtual water (Allan, 1994).

Nyagwambo (1998) demonstrated that in the Mupfure basin, blue water applied to tobacco has a productivity of around 3.40 Z\$/m³, whereas productivity of water for wheat is only around 0.50 Z\$/m³. Since wheat and tobacco can be both traded on the international market, the best use of water resources of the Mupfure would be to produce tobacco, export it and buy the required wheat on the international market. One cubic metre of water applied to tobacco would allow the importation of 7 m³ of "virtual water" in the form of grains. A net gain to the basin of 6 m³ of water! Supplementary irrigation during the rainy season of rainfed crops has a relatively high productivity. In

the communal areas, one cubic metre of blue water applied to a rainfed crop as supplementary irrigation results in production gains valued at Z\$ 1.00 to Z\$ 1.30 (1996 prices), equivalent to some US\$ 0.10. Pazvakavambwa and Van der Zaag (2000) found even higher figures.

In water scarce regions, the exchange of water in its virtual form is one of the most promising approaches for sharing international waters. It allows a region such as Southern Africa, to produce water intensive products there where land and water conditions are most favourable, while the interdependency thus created, guarantees stability and sustainability of supply (Savenije and Van der Zaag, 2000).

3.6 Exercises

- 3.1 Draw a water balance for a rainfed maize crop. Precipitation is 700 mm, of which 100 mm is intercepted and evaporates, 100 mm runs off into stream. Of the remaining 500 mm that infiltrates into the soil, 100 mm percolates to the subsoil and recharges aquifers.
- 3.2 What is the effect of improved soil conservation measures on the downstream hydrology?
- 3.3 Generally, what will be the effect of an increase in crop production on the hydrology downstream?
- 3.4 If all fossil groundwater would be used, how much would the sea level rise?

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A water bailiff in a Mexican irrigation scheme changes the course of the water flow

Chapter 4

Water demand

Pieter van der Zaag and Hubert H.G. Savenije

In Chapter 2, some general observations were made about the various uses of water. There is a generally increasing demand for water throughout the world. As populations and living standards grow and economies develop, the demands made upon water resources continue to increase (Figure 4.1).

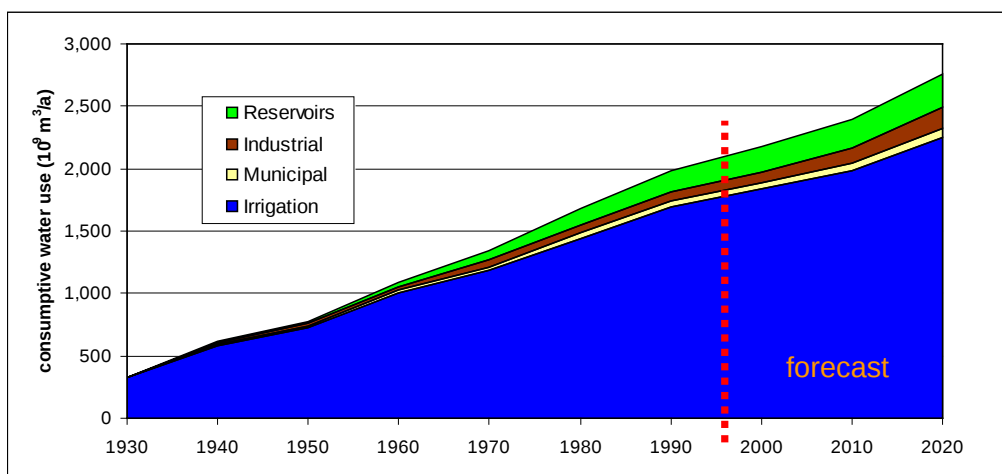


Figure 4.1: Global consumptive water use (after Shiklomanov, 2000)

But if the demand grows, then what about the supply; can the supply continue growing as well? Clearly the basic resource does not alter; the total amount of water entering the hydrological cycle is limited, and hence the amount we can withdraw from it. Already in many developing regions, much of the demand is unsatisfied because of inadequate water supplies. Can technology help to reduce or limit the demand?

Future demands for water by the different users may be affected by technological developments. Technological developments that will increase the demand for water are for instance water cooled nuclear power generation and gas production from coal.

Technological developments that may decrease future demands for fresh water are for instance:

- Wind and solar (through photovoltaic cells) energy generation
- Dry sanitation / ecological sanitation
- Recirculation of cooling water (“dry-cooling”) of thermal power plants
- No-rinse washing technology
- Drip irrigation
- Desalination of sea water

Although technology may help to reduce demand, this will probably not be enough. To prevent the mining of limited resources, it will be necessary to reduce the demands of the individual users.

There are substantial differences in per capita demands between countries and between regions. Differences in demand are attributed to both natural and economic factors. More water is used in warm and dry regions than in temperate and humid areas, due to irrigation, bathing and air conditioning. Of the various climatic influences, precipitation appears to have the greatest effect on per capita demand, primarily as a result of irrigation water demands. The living standard of the population also affects the demand. Water consumption increases with an increase in living standard.

This chapter will provide some approaches and tools to estimate, and influence, the demand for water. The focus will be on the urban water sector. In the final three sections the water requirements for the environment, for agriculture and for hydropower are very briefly mentioned.

4.1 Estimating urban water demand

Urban water demand depends, among other things, on:

- a. number of people within the considered area
- b. connection rates for different types of supply; e.g. stand pipe, piped supply (private connection)
- c. per capita consumption, which depends on such factors as level of development, type of supply and price of water
- d. losses in infrastructure for transport, treatment and distribution

In addition, the demand for water is also influenced by climate (rainfall, temperature), standard of living of (different categories of) users, rationing measures, tariffs etc.

Table 4.1: Recommended Water Requirements for Basic Human Needs (Gleick, 1996)

Purpose	Minimum level (l/c/d)
Drinking water	5
Sanitation Services	20
Bathing	15
Food Preparation	10
Sum	50

Notes: (a) This is a true minimum to sustain life in moderate climatic conditions and average activity levels.
 (b) Excluding water required to grow food. A rough estimate of the water required to grow the daily food needs of an individual is 2700 litres.

Table 4.2: Standards for water demand by consumer category, Harare

Consumption category	Unit	Annual average daily water demand
<i>Residential</i>		
High density	l/stands/d	900
Medium density	l/stands/d	1,800
Low density	l/stands/d	2,500
Flats	l/unit/d	1,000
<i>Commercial</i>		
Hotels	l/bed/d	800
Offices, Shops	l/employee/d	30
<i>Industrial</i>		
Dry industries	l/ha/d	20,000
Wet industries		To be calculated individually
<i>Institutional</i>		
Hospitals	l/bed/d	500
Clinics	l/100 m ² /d	1,000
Day schools	l/pupil/d	30
Boarding schools	l/pupil/d	90

The bottom line of water consumption can be defined as the 'lifeline' per capita water consumption. This lifeline water requirement is nowadays often set at 50 litres of clean and safe fresh water per capita per day: Note that this figure excludes water required for food production and for other economic activities.

Water demand is generally estimated applying standards for the various categories of users. Table 4.2 gives the unit water demand standards as used in the City of Harare, Zimbabwe:

Connection rates refer to the percentage of the population which has access to a certain kind of supply, e.g. house connections (piped supply) or stand pipes. Rough 'coverage' percentages are inadequate. The usual consumption ranges in developing countries are:

- 20-45 litres per capita per day for stand pipe supply
- 70-120 litres per capita per day for piped private supply.

In developed countries total consumption rates can be as high as 1,000 litres per day in dry regions where lawn watering is not limited. Normal figures, however, for developed countries range between 200 and 500 litres per day. In developing countries, consumption of safe water is often below 50 litres per day, which could be considered as a minimum for public health purposes. In such situations connection rates and per capita consumption become social and political target values. Cost-benefit considerations are not relevant under such conditions and generally are replaced by cost-effectiveness approaches: how to reach target levels at minimum costs.

The ownership of water-based appliances, such as washing machines and dishwashers but also swimming pools, greatly influences water use. Since the use of water-based appliances is related to the relative wealth of households, which again is related to neighbourhood, for accurate projections it may be necessary to distinguish water demand in the various neighbourhoods, and make separate projections. Moreover, climate has an obvious impact on water consumption (Table 4.3).

Table 4.3: Average Water Consumption (l/c/d) of households (Davies and Day, 1998: 325)

	California, USA	UK	South Africa
Washing machine	32	12	23
Toilet	95	37	48
Bath/Shower	73	22	65
Kitchen	27	36	24
Total	227	107	160

Growth of water demand

An important element in the demand assessment is the projection of demographic developments (for the life period of the new infrastructure). Population developments have two components: autonomous growth and migration. Care should be taken that a proposed water resources management strategy may itself have a substantial impact on migration.

Autonomous growth models vary from a simple trend analysis - which in its simplest form extrapolates the monitored growth over the past few years - to more complicated population projection models, taking into account the build up of age groups, and the differentiated birth (*b*) and death rates (*d*) for the different age groups. Only with such more elaborate models can the effect of family planning programmes be assessed.

As a result of the exponential character of population growth, the outcome of population forecasts is highly sensitive to the assumed value of the fertility rate. Population projections should be made for the short term (2-5 years) and for the medium term (5-10 years). Projections for the long term (more than 10 years) are unreliable, though they may serve as an indicative estimate. Long term forecasts have seldom been close to correct. All over the world surprise changes have occurred that caused growth rates to seriously deviate from projections. Some of these unexpected changes are: the outbreak of wars, migration by refugees, political changes, economic recession or economic revival, migration to urban areas etc.

On the short and medium term, an inaccurate forecast would generally mean that the schedule of implementation of a group of phased projects must be speeded up or slowed down. However sometimes serious problems arise: a project may be a financial (or economic) failure if inadequate revenues (or benefits) are realized due to over-optimistic projections.

Model of population growth based on the population balance (Savenije, 2000)

Population growth can be modelled through the equation of the population balance:

$$\frac{dP}{dt} = B - D + I - O \quad (4.1)$$

where dP/dt = change in population during time step t , e.g. year (capita)
 B = number of birth per unit of time, e.g. per year (capita/year)
 D = number of death per unit of time (capita/year)
 I = immigration (capita/year)
 O = emigration (capita/year)

It can be seen at once that equation 4.1 has a large similarity with the water balance, in which the population represents the storage, the births the precipitation, the deaths the evaporation, the immigration the inflow and the emigration the outflow.

The number of births can be expressed as the product of the birth rate b and the population:

$$B = b \frac{P}{L} \quad (4.2)$$

where L is the life expectancy in years. The birth rate is the amount of children born per person during his/her lifetime. Hence, the birth rate equals one if each woman, on average, gives birth to two children. In publications often mention is made of the fertility rate f , which is the amount of children born per woman. It is obvious that $f=2b$. Similarly, the number of deaths can be computed from the death rate d :

$$D = d \frac{P}{L} \quad (4.3)$$

In a steady state situation, $d = 1$ and $D = P/L$. However, if a population is growing, meaning that there are, in relative terms, far more young people than old people, then d can be less than unity. Similarly, if $b < 1$ (as is the case in China) a time will come when there are relatively far more elderly people than young people, resulting in a death rate higher than unity. If we neglect, for the sake of the argument, the emigration and immigration, combination of Equations 4.1, 4.2 and 4.3 yields:

$$\frac{dP}{dt} = \frac{(b-d)}{L} \cdot P \quad (4.4)$$

If b and d are constants, then the solution of Equation 4.4 is an exponential equation of the type:

$$P(t) = P(0) \cdot e^{\frac{(b-d)t}{L}} = P(0) \cdot e^{r \cdot t} \quad (4.5)$$

with $P(0)$ $P(t)$ = population at time = 0, and at time = t (capita)
 $r = (b-d)/L$
 e = exponential function ($e=2.718$)

If $(b-d) > 0$, meaning that per capita more children are born than that people die, then

the population increases exponentially. If $b = d$, the population is constant. In China, where $b = 0.5$, this point has not yet been reached. The adjustment to a lowering of the birth rate takes time, because the death rate is not equally distributed over the age groups. If $b=1$, the birth rate is equal to the replacement rate, which eventually will lead to a constant population but the time scale for reaching a death rate d equal to $b=1$ is the life expectancy L .

To illustrate this phenomenon, the following example shows what happens if in an initially stable situation, where $b = d = 1$, the birth rate is instantaneously doubled to $b = 2$ at $t = 0$, and where at $t = 60$ years, as a result of government policy, the birth rate is restored to the sustainable level of $b = d = 1$. Fig. 4.2 shows the variation of the total population P over time. The initial population distribution over age classes (also called population pyramid) at $t = 0$ is stable since the same number of people die and are born annually. The baby boom then lasts 60 years. Subsequently, it takes another 100 years, the lifetime of a person, for the baby boom to disappear completely and for the population to stabilise.

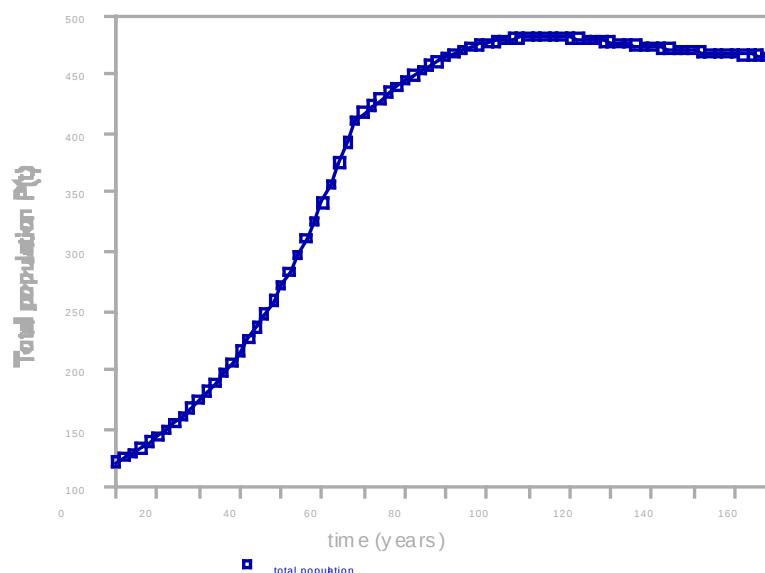


Figure 4.2: Variation of the total population $P(t)$ over time

Other factors influencing water demand

Apart from population growth, there are other factors influencing water demand, including (Singh, 1999, HR Wallingford, 2001):

- rainfall and droughts
- economic development
- rationing
- water pricing.

Here an example is given for the City of Masvingo, Zimbabwe, for which a multiple

linear regression (MLR) analysis was carried out of the influence of population, rainfall, economic development and rationing, on water demand (Dube and Van der Zaag, 2003). The influence of pricing on water demand will be discussed later.

Annual data for population and rainfall were available for Masvingo. For economic development, national data for GDP growth were used as a proxy. For rationing, a dummy factor was used with a memory of 5 years, which decreases from 1 to 0 in steps of 0.2 per year.

For the MLR, the following formula was used:

$$Q = a + b*N + c*P + d*G + e*R \quad (4.6)$$

Where Q = annual treated water pumped (1,000 m³/a)
 N = population of Masvingo (1,000)
 P = deviation of the annual precipitation from the long term mean (mm/a)
 G = GDP growth (%)
 R = factor for rationing, with a memory of 5 years (decreasing from 1 to 0 in 6 years)
 a, b, c, d and e are constants

The MLR analysis yielded the following values for the constants a, b, c, d and e :

$$Q = 618 + 90.2 * N - 1.47 * P + 26.8 * G - 837 * R$$

$$r^2 = 96.5 \quad (4.7)$$

Formula (4.7) implies that:

- Constant a ($618 * 10^3$ m³/a) represents water uses that are more or less fixed and independent of population, rainfall, GDP and rationing. These uses include some of the city's unavoidable water losses and some institutional water uses.
- Constant b (90.2 m³/capita/a, equivalent to 247 lcd) represents the “crude” per capita water consumption, and includes some industrial and commercial uses. Population alone explains 88% of total water supply.
- Constant c ($-1.47 * 10^3$ m³/mm) means that if rainfall is 100 mm above average (600 mm/a), water consumption decreases with 147,000 m³/a; if rainfall is 100 mm below average, consumption increases with the same amount. Including rainfall improves the correlation with 5%.
- Constant d ($26.8 * 10^3$ m³/a) implies that change in GDP has relatively little effect on water consumption: a 1% increase in GDP leads to an increase in water consumption of 27,000 m³/a. Including this factor increases correlation with only 0.4%.
- Constant e ($-837 * 10^3$ m³/a) indicates that rationing has a significant impact on water consumption: in a drought year consumption drops by 837,000 m³/a. Including this factor improved correlation with 3%, yielding a total correlation of 96.5%.

The multiple linear regression analysis gave a good fit (Figure 4.3). Future water use can be projected based on past water use and various scenarios can be considered which take into account variations of the factors that influence water use.

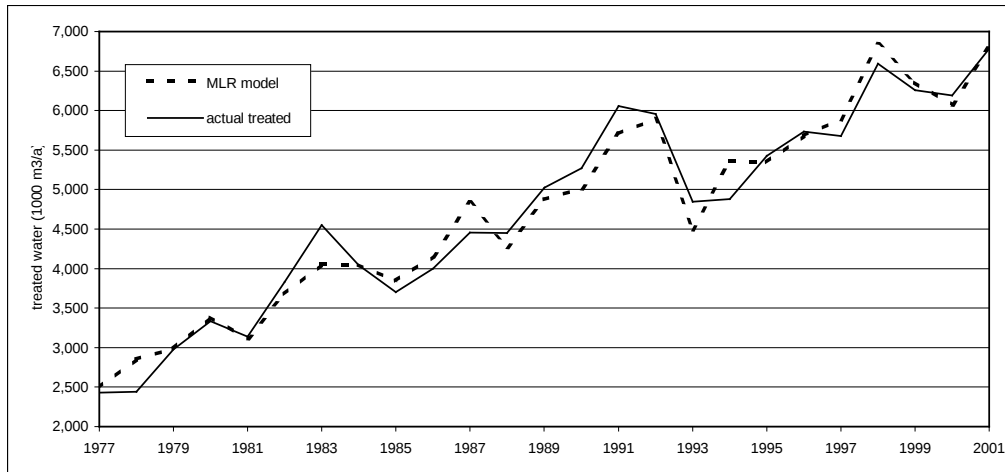


Figure 4.3: Actual and modelled water use, Masvingo, Zimbabwe, 1977-2001

Errors in extrapolating demand based on historical data

An example of some of the problems that can occur with the extrapolation of historical data is shown in Figure 4.4. The figure shows the total water produced to supply the city of Masvingo in Zimbabwe. Between 1991 and 1992 there was a serious drought in Zimbabwe that had a significant impact on water demand for most urban areas. If a forecast of future water demand had been made in 1991 by fitting an exponential curve to the available data between 1977 and 1991 the forecast water demand for the year 2001 would have been almost 10 million m³/year. However, in 1992 a series of demand management, economic and water rationing measures led to in the rate of growth of water demand decreasing significantly. In 2001 the actual quantity of water produced for the city of Masvingo was some 6.8 million m³/year. The figure forecast for 2001 using a simple exponential curve fitting technique for the recorded data between 1977 and 2001 is over 47% higher than the figure actually recorded. This clearly illustrates the dangers of using simple curve fitting techniques to forecast future water demand.

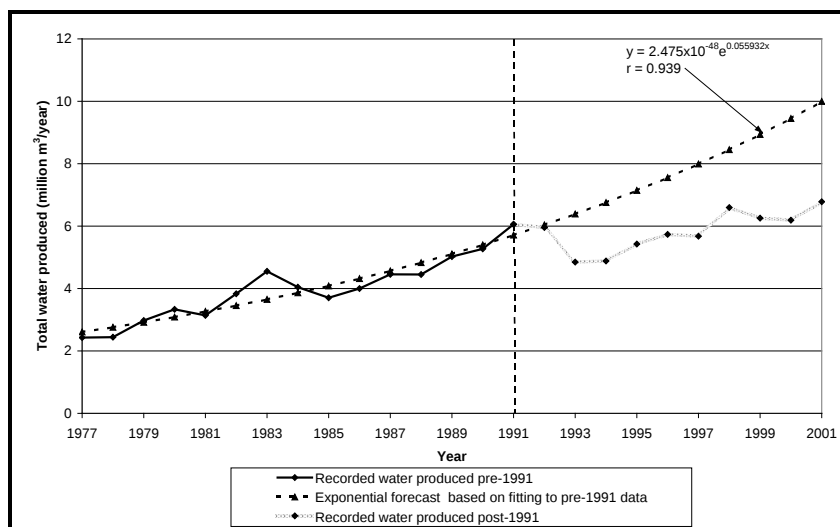


Figure 4.4: The dangers of using extrapolation techniques for forecasting water demand for Masvingo in Zimbabwe

4.2 Water demand management

Water demand management has been defined in many different ways. We offer the following definition:

Demand management aims at achieving desirable demands and desirable uses. It influences demand in order to use a scarce resource efficiently and sustainably (Savenije and Van der Zaag, 2002).

Note that:

- WDM is not necessarily the same as decreasing water demand; in certain situations managing the demand may mean to stimulate the demand that had been suppressed (e.g. in many rural areas in Africa water use is undesirably low; here we have to improve water services and increase water consumption).
- WDM is not necessarily the same as the pricing of water!

Demand management uses technical, legal and economic incentives in combination with awareness raising, information provision and education; in order to achieve more desirable consumption patterns, both in terms of distribution between sectors and quantities consumed, coupled with an increased reliability of supply.

Water demand management is always concerned with increasing the efficient use of water. Minimising leakages is often the most cost-effective strategy towards system's improvement. Water losses in a piped urban water supply network reduce the system's capacity, cost money, and may cause environmental problems and water borne diseases. Consequently, reducing physical water losses increases a system's capacity to deliver water, saves money and reduces environmental and health problems.

Unaccounted-for water

An essential component of water demand for public water supply may be the losses in transport, treatment and distribution systems. These losses are normally dubbed 'unaccounted-for water' and may reach levels of 60% in old and deteriorated systems. Normal percentages are 15 to 25%, including a 5% "consumption" in treatment plants. In addition to quantitative considerations, leaking systems may present substantial threats to public health, because of possibilities for infiltration of contaminated groundwater under low pressure conditions in the distribution network.

Unaccounted-for water can represent a substantial financial loss to any water undertaking. In Harare, unaccounted-for water is around 37% (see box 4.1). In England, following the publication in 1980 of the guidelines on leakage policy and control, the water authorities and water supply companies made an effort to introduce active leakage control policies (Table 4.4).

Table 4.4: Reduction in net night flow in England (Borrows and Bloomfield, 1984; Setford, 1985)

Water Authority	Reductions in net night flow (l/property/h)	
	Before	After
Thames Water Authority (Hounslow)	18.2	7.5
Mid-Kent Water Company (Ashford, Canterbury)	11.8	6.0

In order to cope with the 1992 drought, the City of Kwekwe in Zimbabwe (150,000 inhabitants) introduced a water loss management programme using electronic leak detection. This resulted in a reduction of water losses from 30% in 1992 to 14% in 1996. Together with other water demand management measures, water consumption in 1997 (1.3 Mm³/month) was still less than during the pre-drought period (1.5 Mm³/month). As a result, the Z\$ 40 million upgrading of the city's treatment works, planned for 1995, has been deferred indefinitely, saving the city a substantial capital burden (Goldblatt et al., 2000).

Box 4.1: Council losing \$180m to water leakages

Harare City Council is losing \$180 million [US\$ 10 million] worth of treated water every year because of leakages which can be controlled through a detection and control system. The mayor, Clr. Solomon Tawengwa, said about 37 per cent of the city's treated water was lost to the ground because of leaks. ... A \$77.6 million tender for leakage detection and control and infrastructure management was finally awarded to Biwater International on Thursday night. ...

It costs the council more than \$30 million a month [US\$ 1.7 million] to purify its water. The water account relies heavily on sales and any loss of water results in the council failing to recoup all its expenses.

Harare pumps 150 million litres of water a day and loses about 60 million cubic metres [sic]. ... The director of works, Mr. Christopher Zvobgo, said yesterday that it would not help much if the multi-million-dollar Kunzwi Dam project was to start while there were a lot of leaks.

Source: The Herald, 20 December 1997

Retrofitting

Reducing the demand for water is possible in many situations - without necessarily compromising the quality of the water service. In general, doing more with less makes economic sense, will improve access to the resource by newcomers, and may be beneficial to the environment. Especially in a situation where no prior attention to demand management was given, the first measures will be relatively cheap to implement, and have a large impact. Retrofitting of water appliances in households is a good example (Box 4.2).

Retrofitting of irrigation systems, for instance replacing furrow irrigation by drip systems, is often prohibitively costly. But the results may be astonishing: drip irrigation may more precisely provide the required amount of water at the required place, resulting not only in reduced water consumption, but often also in increased yields (Box 4.3).

Box 4.2: Retrofitting plumbing fixtures in urban water supply systems

Retrofitting plumbing fittings, such as installing low volume water closets and low volume shower roses, may reduce overall water use by 25% of domestic water consumption (Martindale and Gleick, 2001). One immediate and cheap measure that can be implemented is to reduce the cistern capacity of toilets. Gumbo (1998) estimated that water used for flushing constitutes about 30% of total domestic water use. Adjusting floats in existing installations, or simply putting one or two standard bricks in the cistern would reduce cistern capacity by 10% or more. This means that each household would reduce its consumption by approximately 3%, without requiring any significant investment, thus saving money through a reduced water bill, without compromising the quality of the service enjoyed.

In New York 1.33 million inefficient toilets were replaced by efficient ones during 1994-1997, reducing the city's consumption by 0.3 Mm³/day. Other demand management measures were also implemented. As a result, per capita water use dropped from 738 l/day in 1991 to 640 l/day in 1999 (Martindale and Gleick, 2001).

Box 4.3: Retrofitting irrigation water systems

An example is a sugar estate in Swaziland, where a state-of-the-art drip system replaced sprinklers. Whereas water consumption decreased with 22%, sucrose yields increased by 15%. Overall water use efficiency (expressed in kg sucrose per m³ irrigation water applied) consequently increased by 45% (Merry, 2001).

Reduction of water demand in Windhoek (Macy, 1999)

In Windhoek, water demand was 242 litres per day per person in 1995, with unaccounted for water being only 11%. Windhoek adopted an integrated policy on water demand management in 1994, which is financed by a 0.5 percent levy. Efforts that started in the 1950s have primarily focused on re-use of water. Nowadays, Windhoek can re-use all its waste water for the watering of parks, sport fields and cemeteries through a two-pipe system and the reclamation of waste water to a potable standard. Of all domestic water use, 13% is treated for reuse. About 60% of all water used in up-market households is for gardens. Its infiltration into lawns and gardens makes it unavailable for reuse. Water for gardening still represents a large sector for water savings.

An important part of the water demand management programme involves appropriate tariffs. When tariffs are sufficiently high, they tend to keep exterior irrigation demands reasonable. Water tariffs were recently raised by 30% and any water demand exceeding 45 m³/month per household or enterprise was billed at US\$ 1.30 per m³.

Other water demand measures include:

- Public awareness and education
- No irrigation of gardens between 10:00-16:00 hrs (mandatory)
- Use of swimming pool covers (mandatory)
- Use of low-flush toilets (mandatory for all new buildings since 1997)
- Metering of all connections
- Reuse of purified effluent for irrigation and reclamation to potable standard
- Water conservation guidelines for wet industries

The combined effect of all these measures is that per capita water consumption decreases: in 1996 per capita water use decreased from 242 litre per day per person to 196 litres per day. Whereas the residential population grew 5%, total residential water consumption decreased from 10 to 7.8 $10^6 \text{ m}^3 \text{ yr}^{-1}$.

The benefits from water conservation are mostly obvious:

- up to 30% of long-term savings can be achieved; short-term savings may be double
- less waste water has to be treated, and less energy is used
- the environment will benefit from reduced alteration of flow patterns and from less or reduced dams and other infrastructure
- financial savings from reduced capital as well as operating costs.

Figure 4.5 illustrates savings due to delay in construction of “the next dam”.

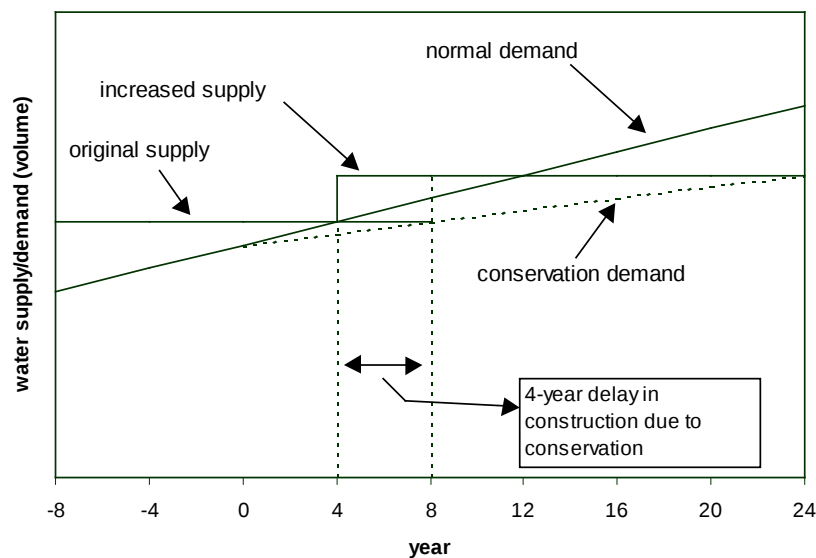


Figure 4.5: Decrease of water demand will delay the need for new water infrastructure (Macy 1999: xv)

4.3 Pricing of urban water

At the Dublin and Rio conferences, as reported in Agenda 21, it has been recognized that water should be managed as an economic good, provided water for drinking purposes and other basic needs are made available at prices that are widely affordable locally. Providing water free of charge, or heavily subsidized, in the past has led to serious mis-allocations of water resources, inefficient use and overexploitation.

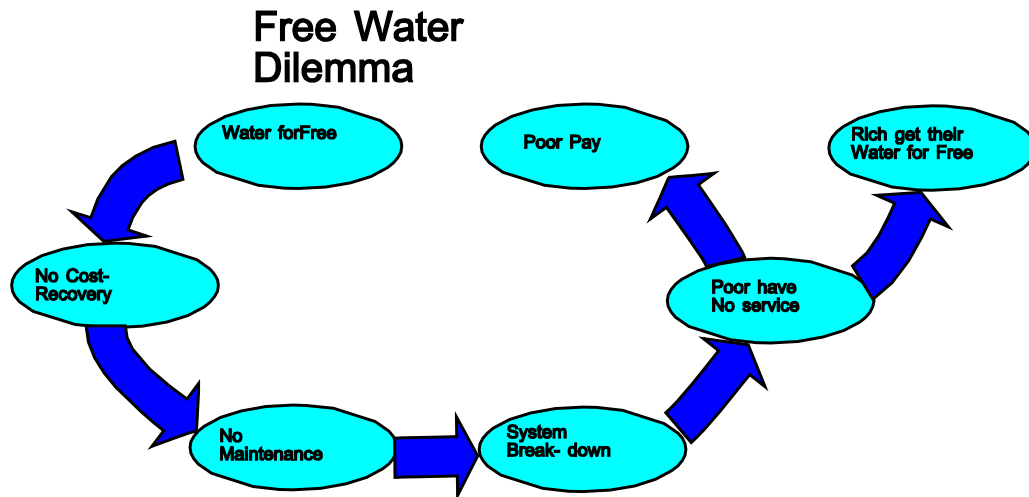


Figure 4.6: The "Free Water" Dilemma (Savenije, 2000)

A good illustration of this problem is the “free water dilemma” (Figure 4.6). If water is for free, water industries do not receive sufficient payment for their services. Consequently, they are not able to maintain their systems adequately and, hence, fail to maintain the quality of their services. Consequently the system collapses, people have to drink unsafe water or pay excessive amounts of money to water vendors, while wealthy people receive piped water directly into their houses, for free. So the water-for-free policy results in rich people getting water for free and poor people buying water at excessive rates or drinking unsafe water.

Water pricing has a number of important consequences, which makes it a key instrument for the implementation of demand management:

- increased price reduces demand;
- increased price increases supply (firstly, because marginal projects may become affordable; and secondly, because it becomes attractive to reduce losses);
- increased prices facilitate reallocation among sectors;
- increased prices improve managerial efficiency.

Water pricing has now been taken up by a number of donors or “external support agencies”, particularly the World Bank (1993), as the most important tool for demand management. Indeed, water pricing is an important element of demand management, but it is not the only issue that requires attention. Other facets of demand management, dealing e.g. with various aspects of improved efficiency, merit attention as well. See the boxes on previous pages for the benefits of retrofitting.

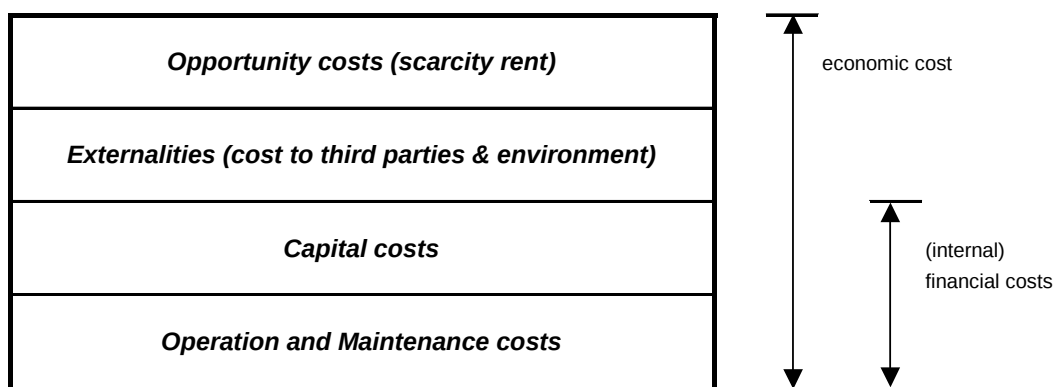


Figure 4.7: General principle of the cost of water

Water pricing is often promoted for at least two purposes: (a) to recover costs, and (b) to enhance water use efficiency. In cost recovery, a distinction should be made between internal financial costs and external (or social) costs. From a financial point of view, the water should be priced to cover the operational costs made to supply the water related goods and services, and the depreciation of the infrastructure (capital costs). Hence the financial costs are the sum of the capital and the operational costs (Figure 4.7).

The economic costs include, in addition to the financial costs, also external costs (economic externalities), such as environmental damage, pollution, effect on downstream users and societal costs (health hazards, resettlement, etc.). Taking these costs into account in the financial costs is what is called internalising externalities. The money received by internalising this cost should be paid to the actors that have incurred the damage.

Until this point the price reflects the total costs incurred by society in the production of the commodity. If the water price is to represent the full economic cost, it should also reflect the scarcity of the resource, which is generally expressed in the opportunity cost (the cost of not being able to use the resource for an alternative social or economic activity that has a higher economic value).

The willingness to pay of water users is a function of the quantity that users consume and their ability to pay. It can be represented in price elasticity curves (see below). Only if the economic value attributed by society to the water is larger than (or equal to) the economic costs, is water resources development feasible. In that case there are two possibilities: the willingness to pay is larger than the economic cost, in which case the government could apply a surcharge or tax to enhance the efficiency of water use (i.e. for demand management); or the willingness (or ability) to pay is less than the economic costs, in which case the government can subsidize water consumption to the level of the economic cost (which is also a form of demand management).

The economic value and the willingness to pay are not easily determined. Some users are willing to pay a higher price than others. Since these are often financial rather than economic (societal) considerations, willingness to pay is not always the right argument to establish the economic price (in order to prevent that water would always go to the highest bidder). In addition, willingness to pay is dynamic, depending on many parameters which include affordability, scarcity of the resource, and appreciation for the resource. Since all these parameters are time dependent and can be influenced by external and internal factors, the willingness to pay is a volatile parameter.

Although Figure 4.7 is useful as an illustration of how the price of water should be established to reflect societal costs, water economists at the World Bank have come to the conclusion that the water price should not be based on opportunity costs or long-term marginal costs, but that it should be a reasonable price between zero and the cost of desalination (about 1 US\$/m³) which should at least reflect the financial cost, and which should send out the message to users that we are dealing with a precious and finite resource.

Relation between price and demand

The (extreme) example of Selebi-Phikwe town in Botswana shows the influence of water pricing on water consumption (see Box 4.4). In cases where tariff differentials are small, the effect of water pricing is however much less pronounced or even absent.

With ordinary economic goods there is a relation between price and demand following a demand curve. The dimensionless slope of this demand curve is called the price elasticity of demand. It is defined as the percentage of increase in demand resulting from a percentage of increase in price. This elasticity is a negative number since demand is expected to decrease as price increases, and normally ranges between -1 and 0. The general equation for the demand-price relation (the demand curve) is:

$$Q = cP^E \quad (4.8)$$

where Q is the quantity of demand for the good
 P is the price of the good
 c is a constant
 E is the elasticity of demand.

Figure 4.8 gives the typical form of a demand curve. The demand curve is constructed on the assumption of constant prices for other goods, constant incomes, and constant preferences. When any of these change, the demand for system outputs may shift.

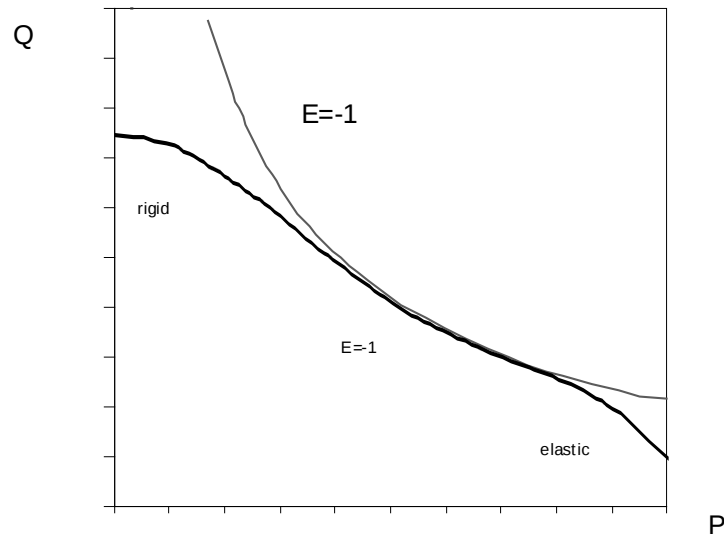


Figure 4.8: Relation between price P and water consumption Q for domestic water

Box 4.4: Residential water consumption in Selebi-Phikwe, Botswana (Arntzen et al., 2000)

Selebi-Phikwe has the highest per capita water consumption of the urban areas in Botswana. In 1995/96, its per capita potable water consumption was 273 l/c/d. The figures for Gaborone and Francistown were much lower at 236 and 146 l/c/d respectively. The high water consumption in Selebi-Phikwe has been attributed to, among others, subsidisation of water by the local BCL mine for its employees. BCL houses without water meters were fully subsidised. "Standard staff" did not pay for the first 150 m³ of water consumed per month, whereas "senior and executive staff" did not pay for the first 200 m³ water per month.

To determine the impact of the water subsidy on water consumption, 40 households were interviewed in the high-income area of Selebi-Phikwe, where employees of the BCL copper nickel mine, civil service, and other sections of the private sector stayed. A multiple regression analysis was used to determine the relations between water consumption and the independent variables of access to water subsidy, incomes of the head of households, type of households, and household size. A significant relationship was found between potable water consumption and independent variables of income and the dummy for water subsidy. The regression equation of this relation was as follows:

$$W = 0.016 Y + 41.85 S - 25.94$$

$$R^2 = 0.54$$

Where W is monthly potable water consumption in m³/month,
 Y is income of the head of households in Pula/month, and
 S is the dummy variable for water subsidy (0: no subsidy, 1: subsidy)

The income of the head of households and access to water subsidy are important determinants for water consumption, such that water consumption increases as income increases and access to water subsidy is attained. A household with an income of P 3,000 per month and not receiving any water subsidy consumes 22 m³ per month. A household with the same income with subsidies consumes 63 m³ per month or almost three times as much. The subsidies appear to lead to a culture of wasteful use of water and insensitivity to report any water leakage. The clearest example of waste was the common practice of cooling roofs with water in summer!

However, equation 4.8 is difficult to apply for the water sector as a whole, but for certain sub-sectors (urban water use, industrial water use, irrigation) it may serve the purpose of analysing the effects of tariff changes. The problem with this equation is that E is not a constant. It depends on the price, it depends on the water use and it varies over time. So it is an equation with limited applicability.

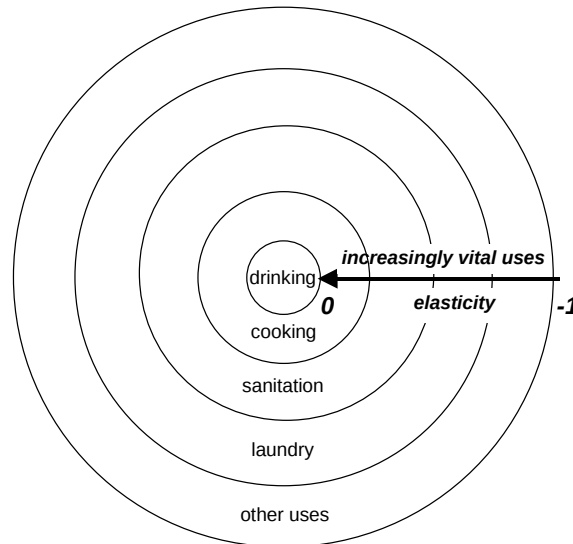


Figure 4.9: Schematic figure of different uses of domestic water and their elasticities of demand

Primary uses of water have a special characteristic in that the elasticity becomes rigid (inelastic; E close to zero) when we approach the more essential needs of the user (Figure 4.9). People need water, whatever the price. And for the most essential use of water (drinking) few alternative sources of water are available. For sectors such as industry and agriculture demand for water is generally more elastic (E closer to -1) which is more in agreement with the general economic theory. This is because alternatives for water use exist in these sectors (e.g. introducing water saving production technologies, shifting to less water demanding products/crops). For basic needs, however, demand is relatively inelastic or rigid. In urban water supply, elasticities are therefore generally close to 0, unless additional (non-financial) measures are taken. Poor consumers often only can afford to use small amounts of water (the basics), and any increase in tariffs will have little effect because they cannot do with less water. For large consumers (the ones that irrigate their gardens, own cars that need to be washed etc.) the ability to pay is such that the need to save money on water is limited. In the latter case, awareness campaigns, regulation, policing, leak detection, renewal of appliances, etc. are often more effective than the price mechanism per se.

One can argue that with respect to drinking water the demand-price relation is under normal conditions not going to be more elastic than -1. If someone has \$100 to spend on water ($QP=100$), then for QP to remain constant, a price increase of 10% should be compensated by a consumption reduction of 10% ($E=-1$). This is assuming that there is no cheaper alternative for water (e.g. buying it from water vendors). However, there is no need to save more water than 10%, since that would imply spending less than \$100 on water. Hence price-demand relations for drinking water are always inelastic ($-1 < E < 0$).

Box 4.5: Patterns of domestic water consumption (Dube and Van der Zaag, 2003)

Figure 4.10 illustrates the different patterns of water use during the year for high-density (poor) and low-density (rich) consumers for the city of Masvingo in Zimbabwe. The residential areas of Rhodene and Clipsham were considered affluent, comprising 1,050 households. The residential areas of Rujeko and Mucheke were considered non-affluent, represented by a sample size of 3,350 households. The sample represented 34% of all domestic connections in the town. The figure shows that there is a large difference in water consumption between affluent (consuming 60 m³/month on average) and non-affluent households (20 m³/month). Moreover, water consumption fluctuates much more in affluent households (coefficient of variation CV of 31%) than that of non-affluent households (CV = 12%). This fluctuation is related to rainfall, as water use tends to be higher in the hot dry months, especially for non-essential purposes such as the use of treated water for watering gardens. In the hot dry month of October, for instance, affluent households may consume as much as 80 m³/month or more, whereas their non-affluent counterparts consume at most 25 m³/month, i.e. less than a third. In the poorest section of the city (500 households within Mucheke residential area) average household consumption was only 12 m³/month. This amount may be considered the basic minimum or "lifeline" amount, and is, with an average household size of 8 persons, equivalent to 50 lcd (cf. Gleick 1996, 1999).

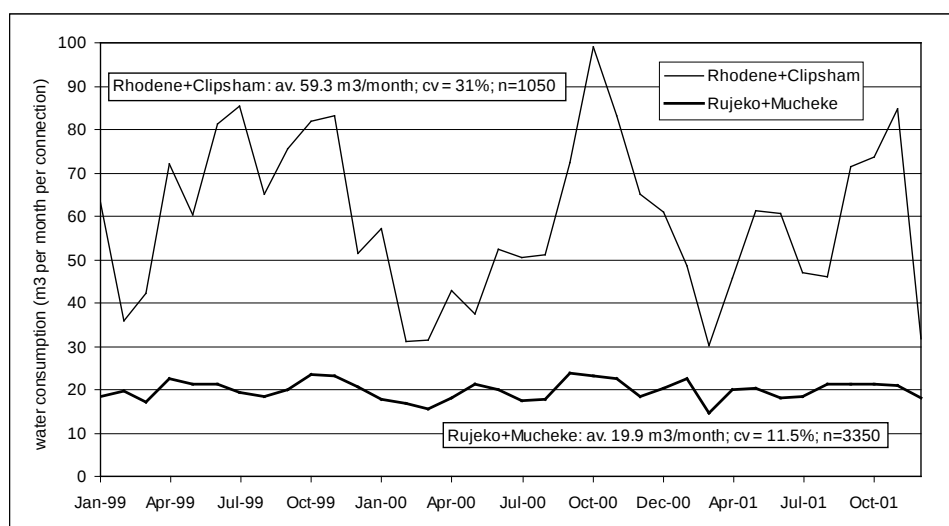


Figure 4.10: Monthly billed water consumption by affluent and non-affluent households, 1999-2001 (Dube and Van der Zaag, 2003)

The explanation for the observed trend is clear: poor households cannot afford to use a lot of water because of their inability to pay. In addition, they have relatively small plot sizes (200-300 m²) which puts an upper limit to the use of water for gardening if they did have the ability to pay. As a result, the seasonal variation in their water use is relatively small, since water is mainly used for the most essential purposes. For the affluent household the opposite is true: their ability and willingness to pay is large, and water use is seemingly restricted by the size of their gardens (4,000 m² on average), the presence of a swimming pool as well as the number of cars they wish to wash. A large part of water is thus applied to non-essential uses.

Demand for water is relatively inelastic

Only in extreme situations, when the water price increases such that people cannot afford it any longer, will demand respond elastically, and people will either look for alternative sources of water (for certain uses), such as digging a well, using untreated water, or move out of the area. Only then has the demand-price relation become elastic ($E < -1$). Price-demand relations that are based on a fixed amount of money that people can spend on water are all of the type:

$$Q = \frac{c}{P} \quad \text{or:} \quad Q \cdot P = c \quad (4.9)$$

where c = amount of money people are will, or able, to spend on water [e.g. \$/year]

These functions have a constant elasticity $E = -1$. More generally, the price elasticity E of demand may be defined as:

$$E = \frac{dQ/Q}{dP/P} = \frac{PdQ}{QdP} \quad (4.10)$$

with E = elasticity [-]

Q = water use [in volume per time unit, e.g. m³/d]

dQ = change in water use [volume per time unit, e.g. m³/d]

P = water price [e.g. \$/m³]

dP = price change [e.g. \$/m³]

Economists classify elasticity either as elastic or inelastic as follows:

If $E < -1$, the response to a price increase is said to be **elastic** or **reactive**.

If $-1 < E < 0$, the response to a price increase is said to be **inelastic** or **rigid**.

If, for example, the price is increased by 100% ($P_1 = 2 \cdot P_0$), and this results in a 20% decrease in water use ($Q_1 = 0.8Q_0$), then

$$dP/P = (P_1 - P_0)/P_0 = (2P_0 - P_0)/P_0 = 1$$

$$dQ/Q = (Q_1 - Q_0)/Q_0 = (0.8Q_0 - Q_0)/Q_0 = -0.20$$

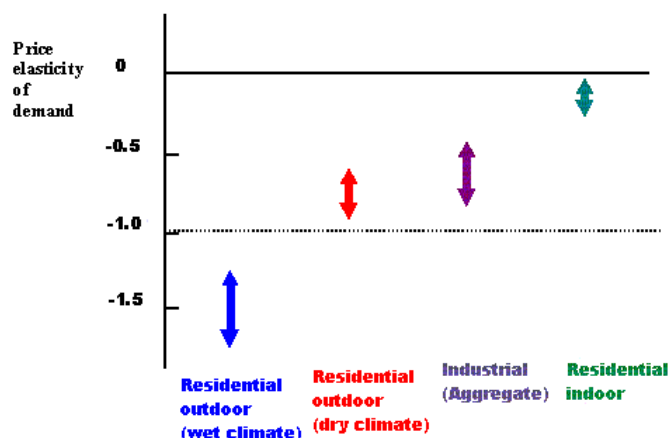
thus $E = -0.20/1 = -0.20$.

The rigidity is normally higher for necessities for which there is no substitute (such as water for domestic use) than for luxury goods, or goods that have a cheaper alternative (e.g. butter and margarine). Since water is no luxury, water demands reduce relatively little with an increase in price.

Residential and industrial demand for water (except for cooling water) are inelastic while agricultural demands are more elastic. This has to do with the availability of alternative options for water use. For domestic use there is no alternative for water, and people are willing to pay a lot more for the same quantity (rigid). People must have minimum amounts of water in some form to survive, and households often pay extraordinary high prices to water vendors for small amounts of water.

Table 4.5: Price elasticity ranges for urban public water supply (OECD, 1987)

Country	Price elasticity (range)
Australia	-0.04 - -0.75
Canada	-0.25 - -1.07
England and Wales	-0.3
Finland	-0.11
Sweden	-0.15
United States	-0.06 - -0.61

**Figure 4.11: Range of price elasticities of demand for water in the United States** (Briscoe, 1996)**Box 4.6: Increase in revenue due to price increase**

Since the elasticity of water demand is generally between -1 and 0 ($-1 < E < 0$), a price increase of water always results in an increase of income by the water supplier. This can be easily demonstrated by combining equation 4.10 with the equation for the relative change in revenue (QP):

$$\frac{dQP}{QP} = \frac{QdP}{QP} + \frac{PdQ}{QP} = (1 + E) \frac{dP}{P} \quad (4.11)$$

Since $(1+E) > 0$, an increase of the price results in an increase of revenue. If $E = -1$, the revenue does not increase, which is in agreement with equation 4.11.

Box 4.7: Block tariffs and conventional economic theory

Note that the increasing block tariff system charges the water for the most vital human needs *lowest*, and the uses for less vital needs *highest*. This tariff system therefore seems to be at odds with conventional economic theory, which would price the most valued uses highest.

However, since an increasing block tariff system enables poor people to satisfy their basic needs thanks to rich people's frivolous water use, the implied cross-subsidy must be considered economically efficient: the marginal value of non-vital uses is less than vital necessities. Therefore, a transfer from people who consume the former to those who consume the latter represents a gain in value (Seckler, 1986: 1013).

In industry and agriculture the elasticity, although still low, is somewhat higher. In arid areas there is no substitute for irrigation or industrial water leading to low elasticity, but farmers and industrialists can invest in water saving technology and farmers can change cropping patterns (leading to higher elasticity).

Concluding:

- the elasticity of water consumption is generally low.
- the price elasticity is greater when the price is higher.
- in the household sector, the price elasticity varies between -0.15 and -0.70.
- with respect to drinking water the demand-price relation will never be elastic ($E < -1$)
- in the industrial sector, the majority of estimates are in the range of -0.45 to -1.37.

When the demand for water is relatively inelastic, as is the case for urban water, the water provider may be tempted to raise tariffs, since this will always result in higher revenues, while water consumption drops only slightly (Box 4.6). The provider may not be interested in curbing water demand through other means (e.g. through awareness campaigns or through subsidising the retrofitting of houses with water saving devices). It is therefore that water utilities should preferably remain publicly owned. If privatised they should operate within a stringent and effective regulatory environment.

Increasing block tariff system

It should further be noted that any pricing policy aimed at influencing demand should consider the basic right of people to access of safe drinking water. Thus demand management through economic means should consider financial (full cost recovery) and equity criteria. The increasing block tariff pricing structure implies a cross-subsidy from rich to poor users. It is a good example of a satisfactory compromise between both criteria and is becoming increasingly adopted, especially in water scarce regions.

Tables 4.6 and 4.7 give the block tariffs used in various cities. The block tariff systems of Windhoek (Namibia), Gaborone (Botswana), and Hermanus (South Africa) are also presented in Figures 4.12. The block tariff structure of Harare (Zimbabwe) incorporates a fixed monthly charge (Figure 4.13).

Table 4.6: Water tariff structure in Western Jakarta, prices converted to US\$
(Adapted from Fournier et al., 2010; cited in UNEP, 2011)

Customer type	Volume of water used (m ³ /month/connection)		
	0-10 m ³	11-20 m ³	>20 m ³
Low-income Domestic	0.105	0.105	0.158
Middle-income Domestic	0.355	0.470	0.550
High-Income Domestic	0.490	0.600	0.745
Small Business	0.683	0.815	0.980
Non-Domestic	1.255	1.255	1.255

Table 4.7: Tariff systems for selected cities in Southern Africa

Windhoek 1997 (Macy 1999: xxiii)	
Consumption (m ³ /month/connection)	tariff (US\$/m ³)
0-8	0.44
8-15	0.62
15-36	0.76
36-45	1.00
45+	1.30

Bulawayo 1997 (Macy 1999: xviii)		
Consumption (m ³ /month/connection)	tariff	unit
fixed charge	1.29	US\$
0-18	0.17	US\$/m ³
18-30	0.36	US\$/m ³
30+	0.56	US\$/m ³

Gaborone (Macy 1999: 22-23)	
consumption (m ³ /month/connection)	tariff (US\$/m ³)
0-10	0.30
10-15	0.88
15-25	1.12
25+	1.54

Harare 1999		
Consumption (m ³ /month/connection)	tariff	unit
fixed charge	0.68	US\$
0-14	0.11	US\$/m ³
14-40	0.20	US\$/m ³
40-70	0.28	US\$/m ³
70-300	0.42	US\$/m ³
300+	0.50	US\$/m ³

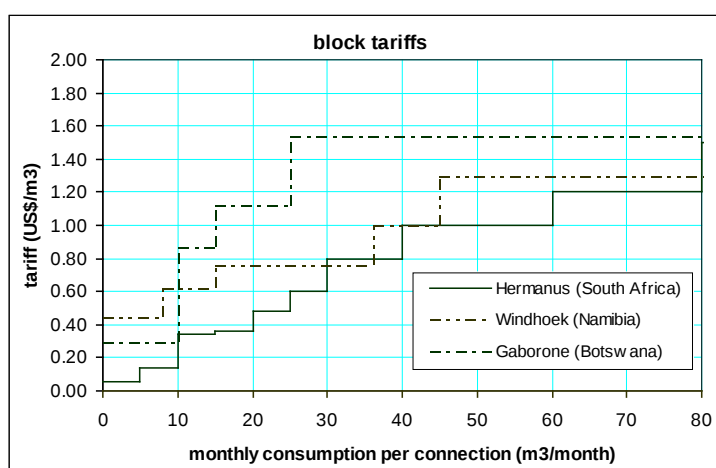


Figure 4.12: Block tariffs of Windhoek (Namibia), Gaborone (Botswana), and Hermanus (South Africa) (after Macy 1999)

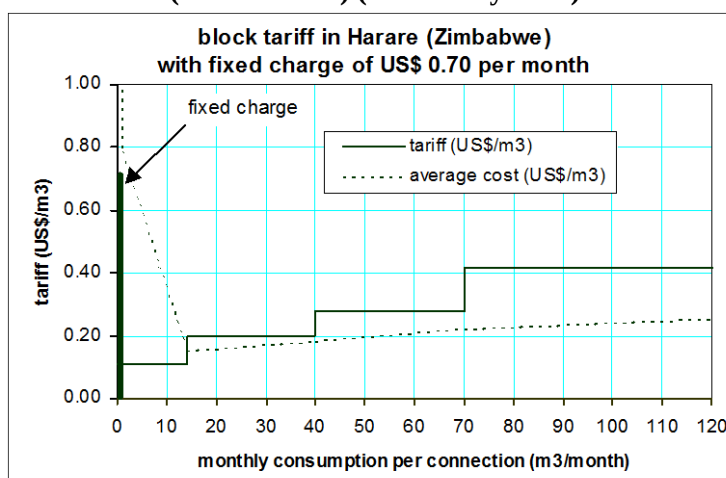


Figure 4.13: Block tariffs of Harare (Zimbabwe) and average water price

Defining the functions for each block

In order to find a satisfying compromise between *full cost recovery* and *equity*, each block should have a clearly defined purpose, from which block size and tariff can be derived. Below is an example of how the functions of four blocks could be defined:

First of all: check whether cost recovery is possible; i.e. check whether the average income is sufficient to purchase the amount of water that a person consumes on average (i.e. can 3%-5% of monthly per capita cash income purchase average per capita water consumption at (full) cost?). If so, (full) cost recovery is feasible; a block tariff system will ensure access of the poor to water, as follows:

(1) the poorest households have access to a lifeline amount of water and do not spend more than a certain percentage of their income on water;

(2) the ‘ideal’ per capita water consumption level is defined, which will ensure “well-being”; this “well-being” amount is e.g. twice the lifeline amount; all water consumed over and above the lifeline amount, but less than the well-being amount, is charged at the Full Cost of Water Supply (FCWS expressed in e.g. US\$/m³); meaning that the average price of water is still less than FCWS, so these households still receive subsidy;

(3) those households that use water over and above the well-being amount, but less than a certain upper limit (e.g. 4 times the lifeline amount) will pay the full cost of water over their entire use; this means that the tariff of the third block should off-set the implicit subsidy that these users receive in the first block;

(4) water use over and above the amount specified in the third block will be charged at a rate that will off-set the subsidy received by households falling within blocks 1 and 2, or at the long-run marginal cost.

The above functions of the tariff blocks would ensure full cost recovery *and* equity.

Box 4.8: Impact of upstream impoundments and water abstraction on an estuary; the case of the Incomati (Sengo et al., 2005; LeMarie et al., 2006; Van der Zaag and Carmo Vaz, 2003)

Water consumption of the Incomati river basin (shared by South Africa, Mozambique and Swaziland in South Africa) is very high: more than half of all groundwater and surface water resources is consumptively used for irrigation, industrial and domestic purposes (see figure 3.6 in section 3.2.3 above). Many reservoirs have been constructed to ensure that water is reliably available for these purposes. As a result, the flow regime of the Incomati river has been altered significantly (Figure 4.14). Small floods that would naturally occur every second year now occur only every fourth or fifth year. This is significant since such water pulses are required for the river to overtop the riverbanks and inundate the flood plain, which is a natural condition for maintaining and sustaining essential ecological services. Floods of similar magnitudes also and simultaneously flush the mouth of the estuary and deposit new sediments in the mangrove forests, where shrimps will breed, finding shelter and nutrients. The decreased fresh water pulses may be the cause of the decrease in healthy mangrove forests (Figure 4.15).

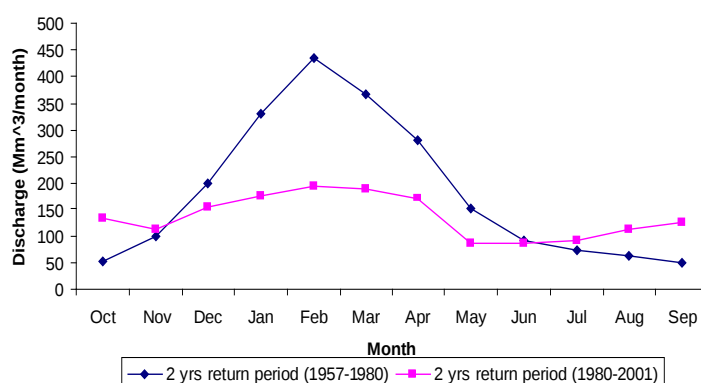


Figure 4.14: Return periods of monthly discharge, Chobela gauging station, Mozambique, for two periods (1957-1980 and 1980-2001)

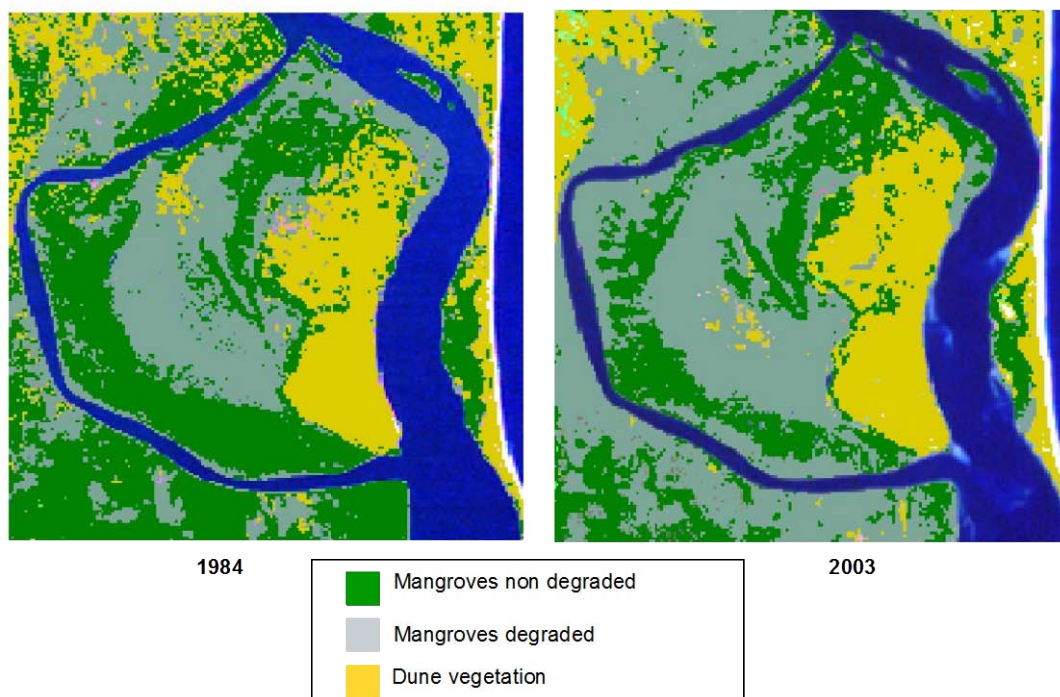


Figure 4.15: Change in area with non-degraded mangrove forests in Benguela island, Incomati estuary, 1984-2003

4.4 Environmental water requirements

The environment requires water. In principle, the environment requires the natural flow regime, undisturbed by human interference. Over-abstraction of water and the construction of large reservoirs has in some river basins significantly affected the ecology. In some basins this has damaged the ecosystems irreversibly, thereby significantly altering the processes of water generation. This is not a desirable situation.

Considering the environment a legitimate water user, however, poses a challenge: how much water must be reserved for the environment? The answer to this question is complex, as water for the environment should be specified spatially, temporally, and in terms of quality, so that a certain level of dynamism is assured by means of allocating water to the environment (see e.g. King and Brown (2010), and Poff et al. (2010)).

Ecosystems thrive on fluctuations in discharge through the year that would naturally occur. Many households live off resources generated by such ecosystems, such as fish, or require regular minor flooding of floodplains for recession agriculture. Floods also recharge groundwater, on which households may rely for their drinking water.

It has now been generally accepted that the environment is a ‘legitimate water user’. This is not merely a luxury, and a nice gesture to animal and plant-life. It is a survival strategy for us, human beings, and for generations to come, since water is the basis of life. We live in, and are part of, ecosystems and depend on them. Altering the natural system may even curtail its capacity to continue to generate fresh water.

In heavily committed river systems infrastructural works (such as dams) have not only decreased water remaining in the riverbeds; they have also attenuated the hydrograph. The base flow that would naturally occur is often not maintained, and regular small floods have been shut out (Box 4.8). As an example serves the Zambezi estuary: the presence of Cahora Bassa dam, and the manner in which the dam has been operated, caused a decrease in the economically important shrimp fisheries (Gammelsrod, 1996).

We need criteria that can assist policy-makers in making balanced decisions in which the immediate economic interests are weighed against the interest of the environment. These criteria should generate practical operational rules, related to, for instance:

- reservoir releases which accommodate the environment;
- water rights or permits, which contain conditionalities allowing water abstraction only if a certain specified flow is let through;
- water quality objectives and discharge permits;
- dam designs to allow for artificial floods and fish passes.

The main aim should be to maintain a certain fraction of the natural base flow (zero in ephemeral rivers!) and to re-create small flood events. Large floods will occur anyway, because even in heavily committed river systems all dams will fill and subsequently spill. Allocating water to the environment inevitably means that less water will be available for other uses (Figure 4.17).

A simple criterion and first “guestimate” of the minimum regime the environment requires is that the return period of certain discharge events should not be less than the return period of the natural regime squared (Symphorian et al., 2003). A small flood that would naturally occur every two years should at least occur once in four years; and a flood with a natural return period of 3 years at least once in 9 years. According to this criterion, large floods would hardly ever have to be simulated (e.g. a 10-year flood event only once in 100 years), but in practice these large floods will occur anyway, simply because even in heavily committed river systems all dams will fill, and subsequently spill. So no specific provisions have to be made for large floods. The main point is to re-create small flood events.

In river systems with low commitment levels (the fraction of the natural mean annual runoff that is withdrawn and consumed from the system), this criterion will nearly always be met, and hardly any additional water for the environment needs to be released. When commitments increase, however, water from dams will have to be released for the environment, decreasing the effective yield of dams, and significantly affecting the non-environmental water uses. Figure 4.16 shows that if commitment levels remain below 35%, environmental water requirements can easily be met and will require relatively little water to be released from dams.

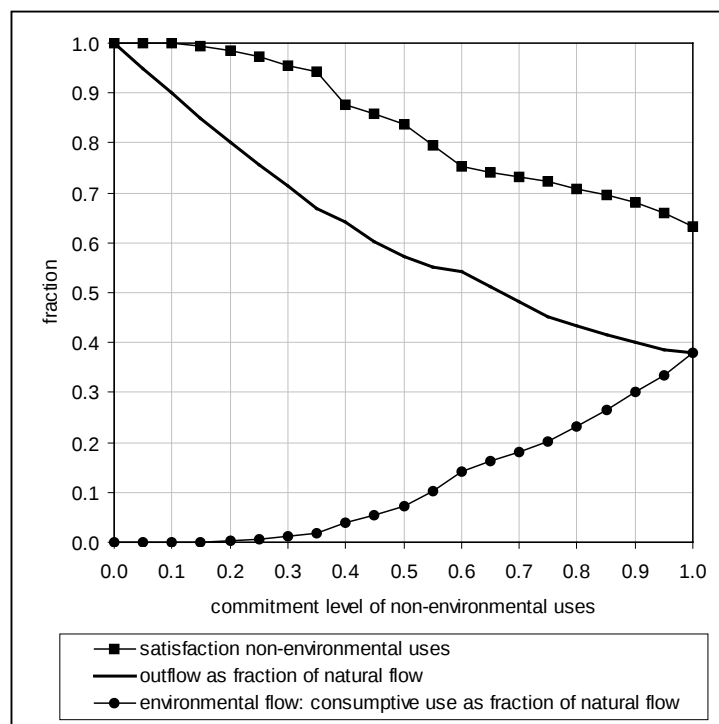


Figure 4.16: Effect of environmental water requirements on non-environmental water uses
 (data for a river with a coefficient of variation of annual flow of 68%)
 (Van der Zaag and Makurira, 2003)

There are several assessment procedures for determining environmental flows. The decision on which procedure to use is dependent on the sensitivity of the aquatic environment, the complexity of the decision to be made and the increased cost and difficulty of collecting large amounts of information. Procedures for determining environmental flow requirements fall into one of four basic categories:

1. Historical discharge method: the Tennant method;
2. Hydraulic method: the wetted perimeter method
3. Holistic method: the building block method
4. Habitat rating method: Instream Flow Incremental Methodology

Each method differs in its data requirements, procedures for selecting flow requirements, ecological assumptions and effects on river hydraulics.

Implementing environment flow requirements through changing the operation of reservoirs

To establish an environmental flow regime is one thing; to implement it is something else - and often requires that the operation of large reservoirs need to be adapted. In this section some preliminary ideas are given.

Upstream developments in a river system may affect and change the flow regime downstream. Basically three different situations may apply:

- 1) upstream reservoirs that store and divert water for consumptive uses (e.g. irrigation, large cities), which leads to a significant decrease in water flows downstream, “lowering” the hydrograph (Figure 4.17);
- 2) upstream reservoirs that are constructed for hydropower production and other developments that are largely non-consumptive, including flood protection and navigation; which “flatten” the hydrograph (Figure 4.18);
- 3) combinations of consumptive use and river regulation upstream.

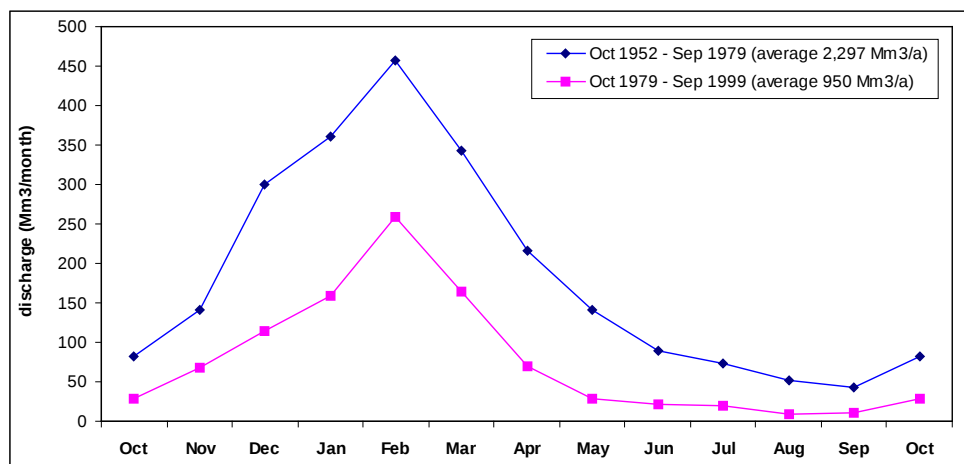


Figure 4.17: The modified flow regime of the Incomati at the border between South Africa and Mozambique, due to upstream consumptive use (mainly due to transfers out of the basin, irrigation, and commercial forest plantations). Source: Carmo Vaz and Van der Zaag (2003).

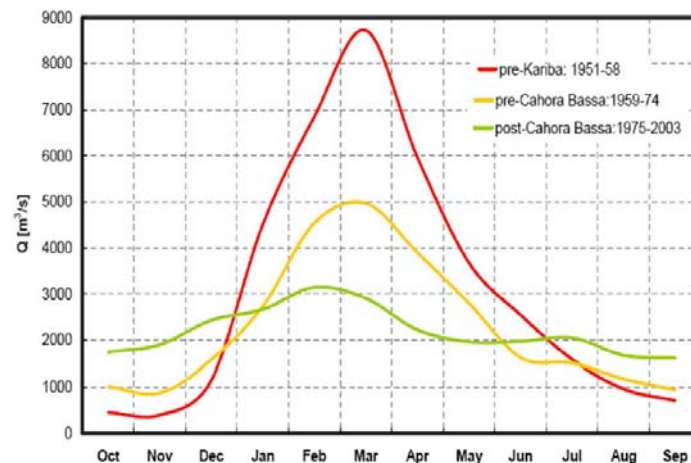


Figure 4.18: The modified flow regime of the Lower Zambezi river due to large hydropower developments upstream (notably Kariba dam (1958) and Cahora Bassa dam (1974)). Source: Beilfuss (2001); see also Ronco et al. (2010).

If the issue is to mitigate or minimise the negative impact of these upstream developments on downstream aquatic ecosystems etc., then these reservoirs should adapt their operations, and partially restore the natural flow regime. This would mean to consider the natural periods of high and low flows. Of course, also alterations of the water quality (in terms of temperature, sediment load, pollutants, etc.) need to be addressed, but this is not discussed here.

Generally, operating rules that attempt to restore the flow regime should focus on the high flow period and the low flow period.

During the low flow period, two conditions must be defined:

- ensure a certain minimum low flow;
- ensure a certain maximum low flow.

During the high flow period, one condition must be defined:

- ensure a certain minimum high flow (Figure 4.19).

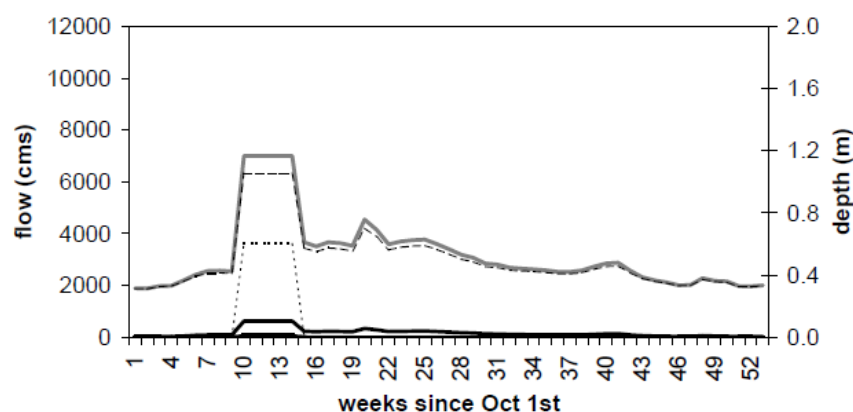


Figure 4.19: Example of a possible flow release for ecological purposes during the wet season – here flows into the Zambezi delta are simulated for a 4-week high flow event in December. Source: Beilfuss and Brown (2006).

Therefore, operating a reservoir to include environmental concerns requires these three conditions to be defined and adhered to (Figure 4.20, in which I have added these three conditions). What the precise values are of these minimum and maximum flows are, whether these will be fixed and identical for all years or dynamically established, e.g. as a function of climate fluctuations (e.g. will relatively dry and wet years be treated differently), for how long a period they have to be maintained, are all relevant questions. Answering these requires a good knowledge of the water resources-cum-aquatic ecosystem, and of the degree to which a society can and will afford to take ecological considerations into account.

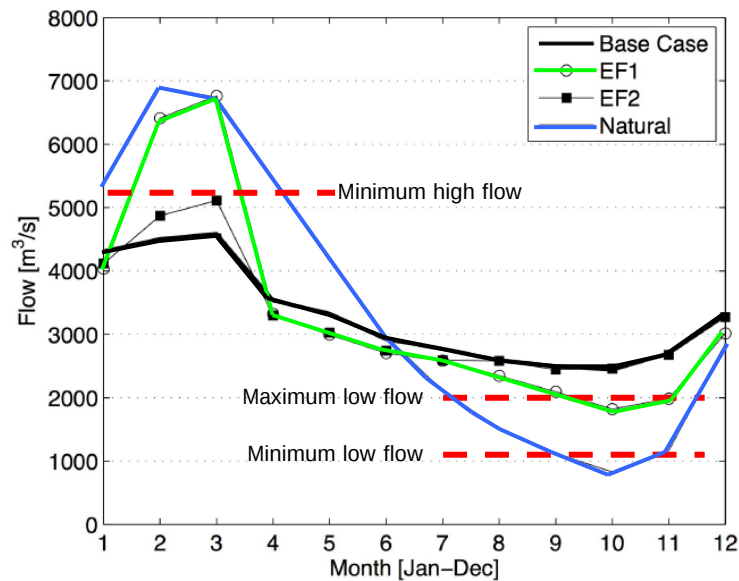


Figure 4.20: The natural and modified flow regime of the Lower Zambezi river, and a proposed amended flow regime to benefit the environment (EF1) by changing the operating rule of Cahora Bassa dam. Source: Adapted from Tilmant and Beevers (2010).

4.5 Water demand for agriculture

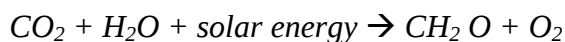
Agricultural production requires a lot of water, be it water directly from rainfall (rainfed agriculture), or from rivers and aquifers (irrigated), or both.

Irrigation is in many river system the main user of “blue” water. Often water use for irrigation accounts for at least 80% of total water use in a water resources system. For the proper planning and management of such a system it is therefore important to have adequate tools to reliably estimate the demand for irrigation water, the possible yield reductions due to water shortages, and the economic benefits of irrigation water.

The present subject belongs to the working area of specialists such as agriculturalists and irrigation engineers. However, it is important that water resources managers have a basic understanding of the subject matter, such that they can weigh the water demand from the agricultural sector vis-à-vis the demands for water from other sectors.

4.5.1 Yield response to water

Plant growth occurs through the process of photosynthesis (also known as CO₂ assimilation). Photosynthesis is the manufacture, in green plant leaves, of organic materials (carbohydrates, (CH₂ O)_n), through reduction of carbon dioxide (CO₂) from the air by means of solar energy (sunlight = short-wave radiation) in the presence of H₂O:



Photosynthesis itself uses a negligible amount of water. However, through transpiration of water through the stomata of plant leaves, nutrients flow from the plant roots through the stem to the leaves. Transpiration of water, thus, should not be considered a 'water loss'; it is essential for plant production.

Crops utilise a lot of water. The water utilization efficiency for harvested produce (*E_y*) range, for grain crops such as wheat, sorghum, maize and rice, between 0.6 and 1.6 kg harvested grain per m³ of water used. For tuber and root crops, such as potatoes, the water utilization efficiency is around 4-7 kg/m³. For fresh vegetables and fruits, such as fresh beans, tomatoes, water melon, this efficiency ranges from 1.5-12 kg/m³ (Table 4.8).

In a situation where nutrients are not in short supply, crop yield (*Y_c*) is a function of incoming shortwave radiation (*R_s*) and maximum evapotranspiration (*ET_m*), and inversely related to the moisture in the air (expressed as the difference between the saturation vapour pressure *e_a* and actual vaporation pressure *e_d*: *e_a-e_d*):

$$Y = f (R_s, ET_m, 1 / (e_a - e_d))$$

In this relationship, evapotranspiration is of greatest interest since this is the term which can be influenced by irrigation: more water available to the crop translates to more evapotranspiration and to higher yields, provided nutrients are not in short supply.

Relations between crop yield and evapotranspiration may be established from field experiments. The relationship found will always be site specific. Field experiments with maize in California and Israel found a linear relation between dry matter production (a specific measure of yield) and the evapotranspiration (Figure 4.21).

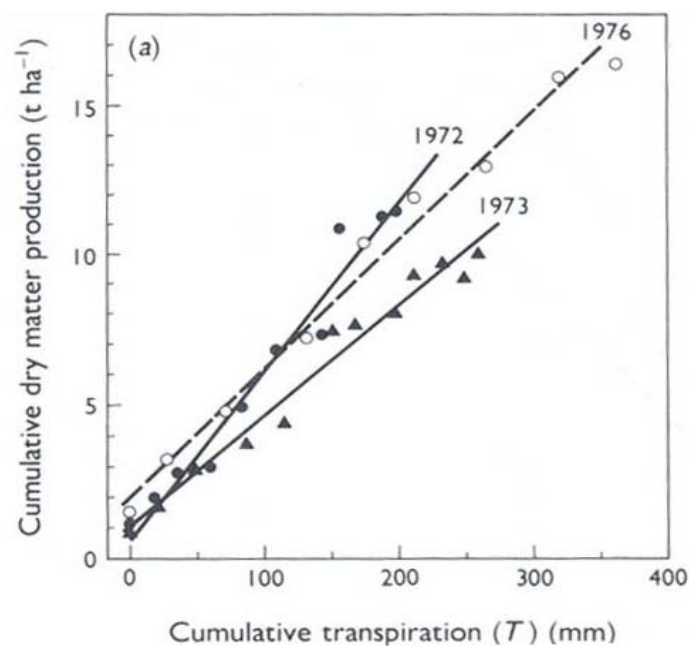


Figure 4.21: Relation between dry matter production and transpiration
(Source: Loomis and Connor, 1992)

Table 4.8: Good yields (Y_m) and water utilization efficiency (E_y) of selected crops (tropics and subtropics) (source: FAO, 1977: 6-7, table 2 and 88, table 39)

Crop	Yield (Y_m)		Water utilization efficiency for harvested yield (E_y)	
		ton/ha	kg/m ³	(% moisture)
Bananafruit		30-60	2.5-6	(70)
Bean: fresh	pod	6-8	1.5-2.0	(80-90)
dry	grain	1.5-2.5	0.3-0.6	(10)
Cabbage	head	40-60	12-20	(90-95)
Citrus	fruit	20-60	2-5	(70-85)
Cotton	seed cotton	3-4.5	0.4-0.6	(10)
Groundnut	nut	3-4.5	0.6-0.8	(15)
Maize	grain	6-10	0.8-1.6	(10-13)
Onion	bulb	35-45	8-10	(85-90)
Pea: fresh	pod	2-3	0.5-0.7	(70-80)
dry	grain	0.6-0.8	0.15-0.2	(12)
Pineapple	fruit	65-90	5-12	(85)
Potato	tuber	15-35	4-7	(70-75)
Rice	paddy	5-8	0.7-1.1	(15-20)
Sorghum	grain	3-5	0.6-1.0	(12-15)
Soybean	grain	2.5-3.5	0.4-0.7	(6-10)
Sugarcane	cane	100-150	5-8	(80)
	sugar	12-18	0.6-1.0	(0)
Sunflower	seed	2.5-3.5	0.3-0.5	(6-10)
Tobacco	leaf	2-2.5	0.4-0.6	(5-10)
Tomato	fruit	45-75	10-12	(80-90)
Water melon	fruit	25-35	5-8	(90)
Wheat	grain	4-6	0.8-1.0	(12-15)

4.5.2 Rainfed agriculture (Falkenmark and Rockström, 2004)

Rainfed agriculture is the source of the bulk of world food, and will continue to do so also in the foreseeable future. Irrigation plays a very important role, but it is worth remembering that worldwide only 20 % of the agricultural land is under irrigation, a figure that ranges between 2 – 5 % for countries in Sub-Sahara Africa. This means that over 95 % of the food producing land in Sub-Sahara Africa is rainfed. Moreover, the vast majority of smallholder farmers depend on rainfed agriculture. It is thus here we find the majority of the world's 1.1 billion farmers (of which 95 % live in developing countries). Their share of global agriculture is very large, amounting to 60 % of world currently practiced agriculture.

We know that population growth and present malnutrition will require at least of doubling of food production over the next 25 years. We also know that focus is required in both irrigated and rainfed agriculture in order to achieve this huge challenge – which is most urgent for Sub-Sahara Africa and South Asia where population growth is highest and present food deficits largest. And will there be enough water to produce all that additional food (Figure 4.22)?

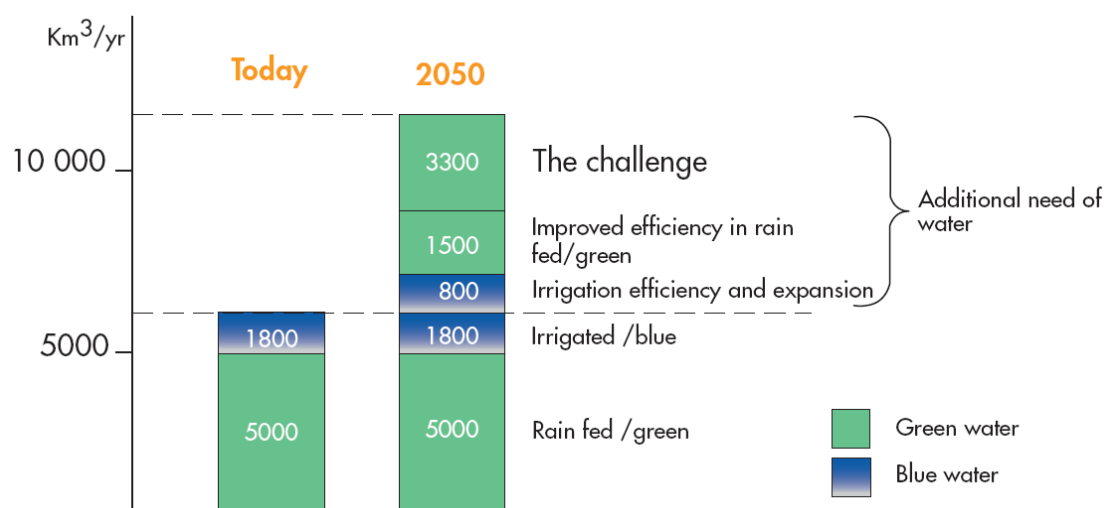


Figure 4.22: Current and future water use by rainfed and irrigated agriculture
(Source: SIWI, 2005)

Under rainfed conditions, crop growth is subject to the random variability of rainfall in space and time. In tropical regions, rainfall variability is particularly high, as a result of the erratic, high intensity characteristics of the rainfall. Also, as a rule of thumb, the variability of rainfall over time increases with decreasing annual and seasonal rainfall levels. This means, e.g., that a semi-arid location with 500 mm of annual rainfall may have an annual variability of 30 – 40 % (average departure from the mean)¹, while a wetter sub-humid savannah may have a variability of only 20 % (i.e., much more reliable rainfall between years). So, not only is rainfall lower – i.e., water more scarce – in drier areas – variability of rainfall also increases.

Rainfall variability is strongly related to crop yields in rainfed tropical agriculture, particularly in semi-arid and dry sub-humid areas (annual rainfall between 400 – 900

1. Normally expressed as the coefficient of variation (CV): CV = Standard Deviation/Average.

mm) where water is a major constraint in food production. The length of growing period ranges from 75-120 days in the semi-arid zone. Daily potential evapotranspiration levels are high, ranging from 5-8 mm day⁻¹.

Rainfall is highly erratic and most rain falls as intensive, often convective storms, with very high intensity and extreme spatial and temporal variability. The result is a very high risk for annual droughts and intra-seasonal dry spells. Statistically in a semi-arid region, severe crop reductions caused by a dry spell occur 1-2 out of 5 years, and total crop failure caused by annual droughts once every 10 years.

An agricultural drought occurs when the cumulative plant available soil water is significantly lower than cumulative crop water requirements, i.e., there is absolute water scarcity. A dry spell occurs as short periods of water stress, often only a couple of weeks long, during crop growth. Such short periods of water stress can have a serious effect on crop yields if occurring during water sensitive development stages like, e.g., during flowering. For example, in semi-arid locations in Kenya and Tanzania, there is a minimum probability of 0.2 – 0.3 for a dry spell to last more than 10 days at any time of the growing season of a crop, and a probability of 0.7 for such a dry spell to occur during the sensitive flowering stage (maize).

Any effort of improving land productivity in small holder farms in tropical drylands must take into account the entrepreneurial risks perceived by farmers trying to make their living from farming systems where crop failures occur four or five seasons in ten on average.

Crop yields in the semi-arid regions of Africa often are low, and in the order of 1 ton of grain per hectare. This compares dismally with the optimal yield of grain crops, for example 8-10 ton/ha for maize, and 3-5 ton/ha for sorghum and millet.

Such low yields experienced on-farm indicate the constraints facing smallholder farmers, both in terms of water scarcity and other inputs, such as soil fertility management, tillage, timing of operations etc.. However, because the yields at present are so low, there is a lot of scope to improve the productivity of rainfed farming, and the water utilisation efficiency, for instance through:

- alternative tillage techniques best suited for the local climatic and soil conditions, which conserve soil and water;
- appropriate fertilization; as water is not the only constraint in crop production, improved fertilization will result in higher production per mm of rain water
- the best possible choice of crops and crop varieties given local conditions; this includes the option of e.g. intercropping.

Such measures may translate into higher production, offsetting the need to create new irrigation schemes, and thus freeing water and monetary resources.

Rainfed agriculture is the world's largest managed land use and will continue to constitute the major source of food for a growing world population. Nowhere is this more true than for sub-Saharan Africa. On-farm rainfed yields in savannahs (often denoted as dry lands) are low, often in the order of 0.5 – 2 t/ha, as a result of frequent dry spells, occurrence of drought, and low plant water uptake capacity related to soil fertility deficits, poor tillage, timing, weeding, and crop varieties etc. Water is thus not

the only factor determining low yield levels in rainfed agriculture, even in “dry” areas. But, water is the only random factor, which due to poor distribution of rainfall affects farmers’ willingness to invest in improvements of other components, such as soil nutrient management (which buy fertilisers if the investment most likely is lost due to dry spells). Investing in water management such as supplemental irrigation in rainfed farming systems is therefore not only a way of increasing yield thanks to better water availability of the crop, but also a way of giving incentive to better soil nutrient management, for example.

For engineers, small scale water management may seem very simple, with few construction and design challenges. In reality this is not the case. The intricacy of runoff dynamics at small catchment scale, design of storage facilities, spill ways, techniques to seal and avoid evaporation, scheduling of supplemental irrigation (as one has to cater for rainfall occurrence) are challenging also at the small scale.

4.6 Water demand for hydropower

Hydropower is a technique for converting the pressure energy and the kinetic energy of water into electrical energy. This conversion is achieved by passing a flow of water through a *turbine*, which is essentially a water wheel or *runner* with vanes, buckets, or blades rotated about an axis. The rotation drives an electrical generator which either produces electrical energy or drives other machinery. The conduit used to carry flow from the upstream source of supply in the *forebay* to the turbine is known as the *penstock*, and water is carried away from the turbine via the *draft tube* to the *railrace* where the flow rejoins the stream channel on which the installation is located. The turbines therefore operate under a net head, H , given by the difference in elevation between the *headwater* in the forebay and the *tailwater* at the exit from the draft tube minus the hydraulic losses in the penstock and draft tube.

Hydropower is, in principle, a benign source of energy that, unlike thermal power sources dependent upon the combustion of fossil fuels, uses renewable resources, i.e. the flow of a river under a given head difference.

The power produced P (N m s^{-1} or W (Watt)) is a function of discharge Q ($\text{m}^3 \text{s}^{-1}$) of the fluid, its density concentration ρ (kg m^{-3}), the gravitational acceleration g (9.81 m s^{-2}), the available head H (m), and efficiency factors:

$$P = e_t e_g \rho g Q H \quad (4.12)$$

where e_t , e_g are the efficiencies of the turbines and the generators respectively.

$$\text{Check of units: } \frac{\text{kg}}{\text{m}^3} * \frac{\text{m}}{\text{s}^2} * \frac{\text{m}^3}{\text{s}} * \text{m} = \text{kg} * \frac{\text{m}^2}{\text{s}^3} = (\text{kg} * \frac{\text{m}}{\text{s}^2}) * \frac{\text{m}}{\text{s}} = \text{N m s}^{-1}$$

Generated energy E (N m or W s) during time T (s):

$$E = P T = e_t e_g \rho g Q H T \quad (4.13)$$

Normally, the generated energy is expressed in kWh, by dividing equation 4.13 by 3.6×10^6 . Rearranging equation 4.12 gives:

$$Q = \frac{P}{e_t e_g \rho g H} \quad (4.14)$$

Using this equation the water use for hydropower requirements can be calculated (see Box 4.9 and 4.10).

Box 4.9: Estimating the minimum instream flow requirement for a hydropower facility (HR Wallingford, 2001)

Kafue hydropower plant in Zambia has six 150 MW turbines each with an efficiency of 90%. To produce sufficient electricity to meet the base load requirements a minimum of three of these turbines are required to be in operation. The effective head difference for the plant is 400 m.

The minimum instream flow requirement can be calculated as follows:

Minimum power requirement: $P = 3 \times 150 \times 10^6 = 450 \times 10^6$ W

Minimum instream flow requirement: $Q = \frac{P}{e_t \rho g H} = \frac{450 \times 10^6}{0.90 \times 1,000 \times 9.81 \times 400} = 127 \text{ m}^3/\text{s}$

Box 4.10: Estimating electricity generation of Kariba (Zimconsult, 1995; Soils Incorporated, 2000; ZERO, 1999)

Kariba hydropower plant has six 117.5 MW turbines on the south bank and four 153.5 MW turbines on the north bank, giving a total capacity of 1,320 MW. Assume that the efficiency of the turbines is 90%, and that of the generators is 95%.

Kariba Dam has a total capacity to store $180.6 \times 10^9 \text{ m}^3$ of water; of which only the water stored above 475.50 m above sea level can be used for electricity generation. The so-called live storage is $64.8 \times 10^9 \text{ m}^3$. Average available head for power generation is approximately 110 metres.

The discharge required through the turbines to generate their full potential is therefore:

$$Q = \frac{P}{e_t e_g \rho g H} = \frac{1,320 \times 10^6}{0.90 \times 0.95 \times 1,000 \times 9.81 \times 110} = 1,430 \text{ m}^3/\text{s}$$

The discharge through the turbines does not normally exceed $1,000 \text{ m}^3/\text{s}$, which would generate some 920 MW.

Using up the entire live storage would take $64.8 \times 10^6 \text{ s} = 18 \times 10^3 \text{ hrs} = 750 \text{ days}$, and would generate 20,300 GWh of electricity. Taking lake evaporation into account ($8.7 \times 10^9 \text{ m}^3/\text{annum}$; thus $17.4 \times 10^9 \text{ m}^3$ during two years) would still generate 14,850 GWh.

For comparison: in 1996 Zimbabwe consumed in total 11,500 GWh of electricity (of which 2,125 GWh was generated by Kariba south bank turbines) (Zero, 1999).

4.7 Exercises

- 4.1 Assuming that the rate of growth of a certain city (as a proportion of its current population) is 5 per cent per annum.
- 4.1a How many years will it take for the city to grow by 30 per cent from its present level?
- 4.2 Over the last 5 years, the population level of a certain area has gone from 120,000 to 150,000, and seems to follow an exponential pattern.
- 4.2a If the same pattern of growth continues, what will be the population after another 5 years?
- 4.2b How long will it take under the same conditions to reach a population level of 200,000?
- 4.3 Assume the city's population to have doubled over the last 20 years.
- 4.3a What was the average annual growth rate of that city?
- Assume further that in the next 5 years city population increases with the same growth rate, while average per capita water consumption increases 2% annually.
- 4.3b What will be the city's gross water use 5 years from now?
- 4.4 Given are the block tariff systems of Windhoek and Harare urban water supplies (see Table 4.7 above).
- 4.4a Calculate the total water bill (US\$/month) and the average cost of water (in US\$/m³) for households in both cities that consume 1, 10, 50 and 100 m³/month.
- 4.5 Develop a block tariff system that is equitable and efficient consisting of only three blocks. Define the function of each block, and indicate how the volume and price of each can be established.
- 4.6 Population growth and demand management
A town had the following population in 1990 and 1995:
- | year | city population |
|------|-----------------|
| 1990 | 10,000 |
| 1995 | 12,000 |
- It has been established that the population grew exponentially during this period.
- 4.6a What is the average annual growth rate of the population of this town during the period under consideration?
- 4.6b Make a projection of the town population in the year 2000.
- The town has a source of water supply of 600×10^3 m³/annum. Total net water use in the town was measured in 1990 and in 1995, and, expressed in per capita terms, was 100 l/cap/day for both years. Unaccounted-for-water was estimated to be 20% of total water use in both years. The water price remained constant between 1990 and 1995.
- 4.6c What is the projected water use of the town in the year 2000?
- 4.6d Given the answer in c), mention four water resource strategies which the town could consider?

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Chapter 5

Water allocation: some general considerations

Pieter van der Zaag

The purpose of the allocation of water to different users is to match or balance the demand for water with its availability. There are various ways how to allocate water. The challenge is to find an optimal allocation that, firstly, adheres to laid-down legal and other regulations, and secondly, satisfies the water demand of all users as much as possible. Or, in the words of Malin Falkenmark and Carl Folke,

The challenge is to cope with the whole gamut of different considerations needed: water needs, land use needs, terrestrial ecosystems and the goods and services that they provide, and the aquatic ecosystems and their goods and services. Management also involves the linking of upstream and downstream activities in the catchment, and the ethics involved. Reconciliation of conflicts of interest with a solidarity-based balancing of human livelihood interests is to be achieved against unavoidable environmental consequences, defined as hydrosolidarity. (Falkenmark and Folke, 2002, p. 4)

Water allocation is not an issue when water availability far surpasses the demand. In such situations all demands can be satisfied, and in fact there is no need for a regulated allocation of water. In many catchment areas and parts of river basins, however, water availability is frequently less than the demand for it. It is then necessary to find a suitable allocation of the scarce water.

Water allocation is not only concerned with the physical allocation of water. More broadly it is about satisfying conflicting interests depending on water. These may be functions derived from water such as navigation (navigability, minimum water levels), hydropower (head difference), environment (a water regime of water level fluctuation), recreation (availability of water but non-consumptive), etc. These functions are only to a certain extent consumptive, but can be conflictive in their timing and spatial distribution. Also flood protection is a function of the water resources system that is related to the water resources. Flood protection through the construction of storage dams can have a positive impact on water availability for other functions (e.g. hydropower), but can have negative impacts on others (e.g. on the environment).

5.1 Balancing demand and supply

Finding a suitable allocation key for water can be quite complex, since a large number of parameters have to be considered, both on the supply- and the demand-side.

Supply

- The generation of water in a catchment area naturally fluctuates, both within years and between years.
- Water occurs in different forms, which often have different uses. Special reference is made to rainfall and its use as "green water" in agriculture. Green water cannot be allocated in the same way as "blue" water occurring in rivers and aquifers. Yet, dryland agriculture and other types of land use do influence the partitioning of rainfall into groundwater recharge, surface runoff and soil moisture (i.e. evaporation and transpiration), and hence their availability.

Demand

- The demand for water fluctuates, but normally much less than its generation. For many types of uses, water demand increases when water availability decreases, such as during the dry season.
- Many water uses are (partially) consumptive, meaning that the water abstracted will not return to the water system in the form of "blue water"; consumptive water use typically converts blue or green water into water vapour, which in this form cannot be allocated to other users.
- Water uses that are non-consumptive allow others to use the water afterwards. Recreational water uses are a typical example. However, some non-consumptive uses alter the time when this water becomes available for other users. A typical example is water used for the generation of hydropower: electricity is needed also during the wet season, and thus water has to be released from dams for this purpose, when demand for it from other sectors may be low. As a result, this water used for electricity generation is unavailable to these potential uses when they need it. The environment is another (partially) non-consumptive user of water; its requirements are frequently out of sync with the needs of other users. (That is precisely why these environmental water requirements are now increasingly being recognised.)
- Many uses of water generate return flows, which, in principle, are available for other uses. However, return flows normally have a lower quality than the water originally abstracted. This may severely limit their re-use. Sometimes the quality of return flows is a hazard to public health and the environment.
- Different types of water use require different levels of assurance. For arable (non-perennial) irrigated crops, levels of assurance of 80% (i.e. a chance of failure in one out of five years) may be acceptable. For urban water supply assurance levels of 96% or higher are the norm (failing in one out of 25 years).

The legal framework

In many countries water is considered a public good. Here the water is owned by the citizens of a country, and the government manages this public good on their behalf. Laws and regulations will therefore provide the rules pertaining to the use of this public resource.

Box 5.1: From a public to a private good

In countries where water is considered a public good, water allocation may be viewed as the process of converting a public good into a private one. An irrigator, for instance, will apply the water to his/her privately owned crop. The crop will consume a large part of the water, converting it into water vapour and increasing its yield. The irrigator derives direct and private benefit from using a public good, but in so doing s/he denies another person the opportunity to use that water and deriving similar private benefits.

Balancing supply and demand must be done within the established legal framework. A country's water law and subsidiary government regulations will prescribe many aspects of water allocation. Amongst these are:

- The law will prescribe the types of water use that are regulated and therefore require some kind of permit, concession, right etc.; and the types of water use that are not regulated and do not require permission. The use of water for primary purposes often does not require a permit or water right, just as the direct use of rainwater.
- A water permit or water right typically defines which water (groundwater, surface water) can be diverted, where (point of abstraction), and for which purpose (e.g. irrigation of x ha of land). A permit or right specifies certain conditions under which water use is permitted. A typical condition is that the permit or right is limited in that it does not permit the use of water that infringes on similar rights of others. Another condition frequently specified is that the water should be used beneficially and not be wasted, and that return flows should adhere to certain quality standards.
- The law often stipulates the hierarchy of different types of water use; distinguishing between, for instance, primary use, environmental use, industrial use, agricultural use, water for hydropower etc. In most countries water use for primary purposes has priority over any other type of water use. Some countries also specify a hierarchy of the remaining uses, whereby the most important economic use in that country normally receives a high priority of use. In other countries all uses of water other than for primary (and sometimes environmental) purposes have equal standing. In times of water shortage the amount of water allocated to all non-primary uses will be decreased proportionally, so that all these user share the shortage equally.

The law may provide more detailed stipulations with a direct bearing on the allocation of water. The law may stipulate, for instance, that the allocation of water should be equitable. In some countries, in contrast, the law directs that junior rights may not affect senior rights.

In most cases, however, the legal framework does not provide a detailed "recipe" of how the water should be allocated. The water manager will therefore have to interpret the more general principles as laid down in the law, and translate these into operational rules for day-today allocation decisions. In many countries the water manager may not even do this without consulting all relevant stakeholders.

Box 5.2 provides an example of two different water allocation systems. The first is the allocation system based on “prior appropriation”, also known as the “prior date system”, which was the allocation system for non-primary water in Zimbabwe prior to 1999. The second allocation system is known as the proportional system, which has now replaced the prior date system in Zimbabwe.

Box 5.2: Water allocation principles in Zimbabwe

As in many other Southern Africa countries, Zimbabwe has recently restructured the water sector and has enacted a new Water Act. This box briefly outlines the allocation principles enshrined in the now defunct 1976 Water Act before considering those outlined in the new 1998 Water Act.

Under the 1976 Water Act use of water for primary requirements did not need a right. All other uses, except the abstraction of groundwater, required a water right. The allocation of these righted waters was based on the prior appropriation doctrine, also known as the prior date system. The granting of water rights was the exclusive function of the Administrative Court sitting as the Water Court. The right would only be granted if water was available and if it could be ascertained that the water would be put to beneficial use. The right granted was dependent on the date on which application for the right was made. The date determined the applicant's priority in the use of the water applied for. This meant that holders of senior rights could satisfy their rights without having to consider junior rights ('first in time, first in right'). The priority date thus defined the right holder's place in the “water queue”. Water rights were 'real' rights registered under the title of the property to which they related and were granted in perpetuity.

In December 1998 a new Water Act was adopted. The new Act introduces a number of important innovations. Water is to be managed on a catchment basis. The overall mandate for management is placed upon the newly established Catchment Councils made up of all stakeholders. All existing water rights have to be converted to water permits that are valid for a limited period of time (twenty years). The prior date system upon which these rights were based (first in time, first in right) was abolished.

From now on it is the Catchment Councils who issue water permits. They do so with regard for the need to achieve an equitable distribution of the available water resources; the needs of each applicant; and the likely economic and social benefits of the proposed use. The Councils have power to revise, reallocate or reapportion the permits in order to ensure the equitable distribution and use of the available water.

The 1998 Water Act does not precisely prescribe the new allocation system that should replace the prior date system. However, a proportional allocation system has been adopted that replaces the prior date system. The proportional allocation system has been defined 'as the apportionment of either underground or surface water according to proportions of permitted volumes of abstraction for direct use or storage of a single permit over the total volume of all permits within a realistic sphere of influence' (DWD, 2000).

The value of water

The various uses of water in the different sectors of an economy add value to these sectors. Some sectors may use little water but contribute significantly to the gross national product (GNP) of an economy. Other sectors may use a lot of water but contribute relatively little to that economy. Table 2.1 (chapter 2) gives the contribution of the various sectors of the Namibian economy to its Gross National Product, and the amount of water each sector uses. Industry and commerce uses less than 3% of all water used in Namibia, but contribute 42% to the Namibian economy. In contrast, irrigated agriculture uses 43% of all water used, but contributes only 3% to the economy.

Care should be taken to interpret the above data. For instance, it is well known that the agricultural sector typically has a high multiplier effect in the economy, since many activities in other sectors of the economy depend on agricultural output, or provide important input services (Rogers, 1998). The "real" value added by water may thus be underestimated by the type of data given in the table.

Box 5.3 provides some data on the added value of (irrigation) water for the production of maize in Zimbabwe.

Box 5.3: The value of water for maize in Zimbabwe (see also Figure 5.1)

For selected plots in Nyanyadzi irrigation scheme, Pazvakawambwa and van der Zaag (2000) found that one additional m^3 of water (irrigation + rainfall) supplied to the maize crop (rainfed with supplementary irrigation) gave an added yield of $1.5 \text{ kg of maize m}^{-3}$ ($r^2 = 0.81$). Assuming a maize price of $0.10 \text{ US\$ kg}^{-1}$, it follows that the marginal value of water (rainfall + irrigation) is $0.15 \text{ US\$ m}^{-3}$.

Yields were also correlated with net total irrigation water (I_{net} in mm). The following mathematical relationship was found:

$$Y = 1,450 + 19 * I_{\text{net}} \quad (\text{correlation coefficient } r^2 = 0.71)$$

The constant of $1,450 \text{ kg ha}^{-1}$ indicates the yields obtainable for a rainfed crop without irrigation. The marginal productivity of net summer supplementary irrigation water was $19 \text{ kg ha}^{-1} \text{ mm}^{-1}$, or 1.9 kg m^{-3} . This means that 1 m^3 of supplementary irrigation water will produce an additional 1.9 kg of maize, which is valued at $\text{US\$ } 0.19$. The marginal value of supplementary irrigation for maize in Nyanyadzi is therefore $0.19 \text{ US\$ m}^{-3}$.

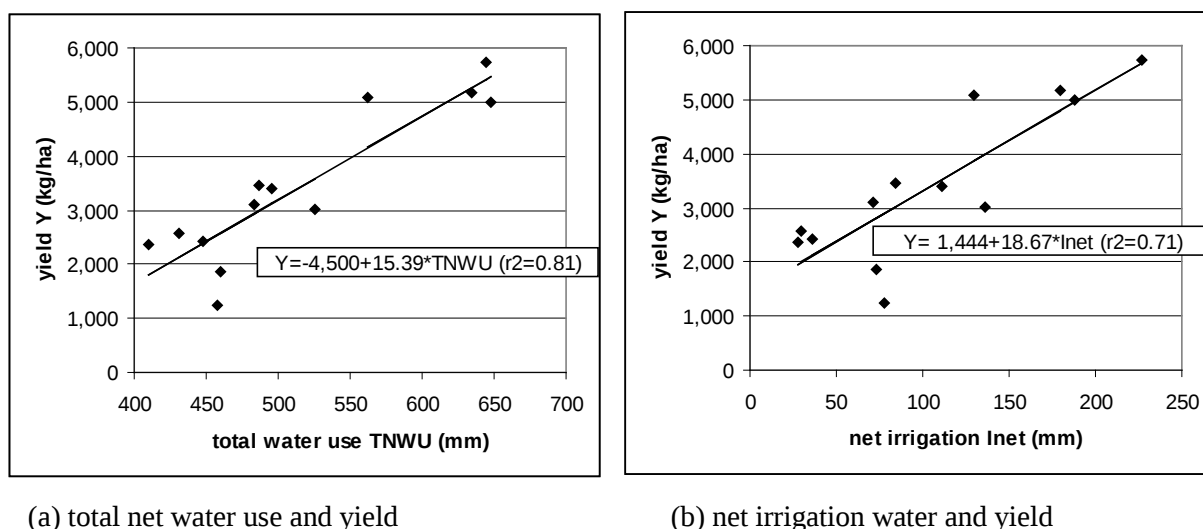


Figure 5.1: Relationship between water use and yield for maize, Nyanyadzi, Zimbabwe

The added value of some uses of water is very difficult, if not impossible, to measure. Consider for instance the domestic use of water: how to quantify the value of an adequate water supply to this sector?

The damage to an economy by water shortage may be immense. It is well known, for instance, that a positive correlation exists between the Zimbabwe stock exchange index and rainfall in Zimbabwe. The drought of 1991/92 had a huge negative impact on the Zimbabwean economy (see Box 2.1 in chapter 2). Conversely, floods, though often

beneficial, can sometimes be devastating (Box 5.4).

Box 5.4: The floods of February 2000 (Brito, 2002)

Heavy rains, which started in early February 2000, flooded parts of Mozambique's southern provinces. The Save, Limpopo, Incomati and Umbeluzi rivers, which have their head-waters in Zimbabwe, Botswana, South Africa and Swaziland, reached their highest-ever recorded levels in early March, and many riparian communities were submerged for weeks. 699 people died, 95 disappeared, and one million people required some form of emergency assistance.

Large sections of the major road connecting Maputo to the north were demolished. Bridges along the Limpopo flood plain and the railroad were damaged. About 20,000 cattle drowned and 140,000 hectares of crops were destroyed, with the largest irrigation scheme in the country (25,000 ha, along the Limpopo) seriously damaged. Health centres as well as water supply and sanitation infrastructure in many towns and villages suffered extensive damage, exposing one million people to water-borne diseases such as cholera, malaria and diarrhoea.

The destruction caused by the floods is estimated at US\$ 600 million. Mozambique's economic growth went down from 10% in 1999 to 2% in 2000.

Scales and boundary conditions

Any allocation decision potentially has third party effects: it may affect those not immediately involved in the allocation process, either beneficially or detrimentally. A special case, and a very important one, is where downstream users are affected that are located outside the jurisdiction of a given water allocation institution.

An allocation process that does not encompass the entire river basin runs the risk of being affected by upstream uses and in turn impacting on downstream uses. Since most river basins are simply too large in extent, and often shared by more than one country, the water allocation processes is normally fragmented into catchment areas which form part of the larger basin. In such cases the allocation process must include boundary conditions; i.e. a specification of water requirements at the inlet and at the outlet of the catchment area under consideration. Even a most downstream catchment area, with its downstream boundary being an estuary, will have to set such boundary conditions so as to minimise salt intrusion, and/or ensure the health of the estuary for environmental, social and/or economic purposes (e.g. for mangrove forests and prawn fisheries).

Boundary conditions are especially important in river basins that are shared by more than one country. If an upstream water allocation institution does not consider the requirements of the downstream country, it may even affect the bilateral relations of the two neighbouring countries.

It would be advisable to formalise such boundary conditions in writing and to get them endorsed by all water allocation institutions involved; in a similar manner as how claims of individual water users are formalised in water permits or rights.

The water allocation process should ideally consider both the detailed allocation decisions between individual water users at the local level, as well as the "big picture" allocation decisions covering the entire river basin. Obviously, these different spatial scales require different levels of accuracy and specificity. But they are both required, since decisions at these different spatial scales affect each other. In practice, the

decision-making process has been iterative, with an initial focus on the smaller spatial scales, especially in heavily committed parts of a basin. With the steadily increasing pressures on our water resources, the interconnectedness between the various parts of the basin have become apparent in many river systems. This has inevitably led to widening the scope of the water allocation process also to the largest spatial scale.

It should be noted that an obligation to surrender a certain amount of water to a downstream area or country does not necessarily imply that all this water is "lost" by the upstream catchment. If this catchment also has to provide for instream environmental water requirements within its area of jurisdiction, the water that has to be surrendered to a downstream area could first serve these environmental requirements (or at least the non-consumptive part of it).

The question remains: how much water should an upstream catchment area leave in the river for downstream users? There is no general answer to this question, and should be subject to agreements with the stakeholders involved (between sub-catchment areas along one tributary or between riparian states). The UN Convention on the Law of the Non-navigational Uses of international Watercourses gives guidance with respect to the parameters to be considered, but their relative weight should be agreed upon in any specific case (see section 5.3 below).

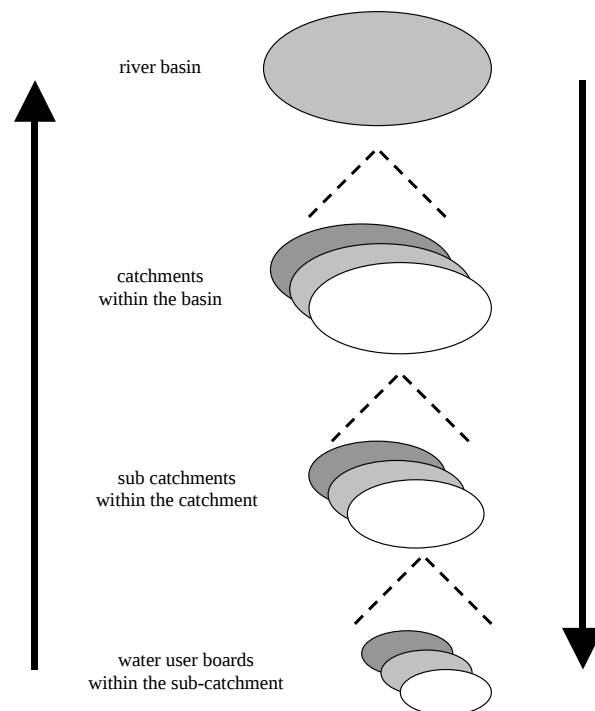


Figure 5.2: Water use and water development plans at various levels in a basin

5.2 Issues in water allocation

In this section some important issues directly related to water allocation are briefly discussed. These issues typically cannot be solved overnight. Any actor involved in water allocation, however, must be aware of them. These issues are: key allocation concepts, uncertainty, efficiency and equity

(a) Defining key concepts

Key concepts used in a country's water allocation system must be very precisely and clearly defined, and be known and understood by the water users. Such key concepts may include: the ownership of water, water use, primary use, equity, efficiency, and the precise rights and obligations conferred with a water permit.

A particularly important issue is the definition of water use, since this basically defines the point where water converts from a public to a private good. Lack of clarity about where exactly this conversion occurs will create confusion, which will directly impact on the effectiveness of the water allocation process. For instance, if a permit holder has lawfully stored water in his/her dam, has this water already been used and hence is owned by the permit holder, or not yet?

Box 5.5: Water use

The South African Water Act defines water use as taking and storing water, activities which reduce stream flow, waste discharges and disposals, controlled activities (declared activities which impact detrimentally on a water resource), altering a watercourse, removing underground water for certain purposes, and recreation.

(b) Uncertainty

Generally speaking, if a user does not know how much water he or she is entitled to, and how much water is likely to be available at a future time, he or she tends to over-use or hoard water often at considerable losses.

The allocation of water over different uses should therefore aim to effectively deal with uncertainty and increase the predictability of water available to the various uses. Increased predictability is an important condition that will allow users to use water more efficiently. Even a better understanding of how *unpredictable* water availability is will improve a user's ability to deal with this.

Two types of uncertainty may be distinguished: physical uncertainty and institutional uncertainty.

Physical uncertainty

Physical uncertainty does not so much refer to the stochastic nature of hydrological processes (which is normally quite well understood), but more to the impact of human activities on the hydrological cycle. At the global level, human-induced climate change is a possibility and may have wide-ranging effects, but the specific effects are not yet well understood. At a smaller spatial scale, the effects of land use change on the

availability of blue water are difficult to predict. Will a more efficient use of soil moisture for rainfed crop production indeed translate into decreased blue water flows? A bit more straightforward is the link between groundwater and surface water abstraction; but still it is difficult to predict the precise effect of groundwater abstraction in a given location on the surface water availability somewhere downstream.

The physical uncertainties mentioned here must be acknowledged. If a proper understanding of such processes is lacking, in the first instance conservative estimates should be made on possible impacts of certain interventions. The water management agency should then put in place a programme of data collection meant to gradually improve the understanding of these dynamic processes.

Institutional uncertainty

A different type of uncertainty is created by the institutions that are involved in water allocation. If the manner in which such institutions allocate water is unknown to the users or ill-understood by them, or seen as haphazard, then users may distrust the allocation process. They will receive the wrong (perverse) incentives to, for instance, overstate their water requirements, hoard water or even over-use it.

The institutional system of water allocation should therefore be predictable to users. All users should know the principles and procedures guiding the allocation of water. Moreover, the allocation process must treat all users in the same way. It must also be transparent, and information on permits granted or permits refused must be freely accessible, not only to all water users, but to the wider public as well. A fair and transparent allocation process will enhance the individual users' trust in the process, and will increase their confidence in the worth of their permits/rights to use water. Trust in the allocation process will enhance users willingness to invest in water related infrastructure, and desist from "free-rider behaviour" in times of water scarcity.

(c) Efficiency and equity

It could be argued that Postel's three *Es* (Equity, Efficiency and Ecological integrity) should form the pillars of any water management activity. Since water allocation is a major water management activity, following this line of argument the three *Es* should also inform water allocation decisions. Suppose now that the environmental/ecological water requirements are adequately taken care of, by assigning to the environment rights to sufficient water with an acceptable ecological regime. Then two *Es* remain, i.e. equity and efficiency.

Some people believe that there is a trade-off between the principles of equity and efficiency; i.e. a more efficient allocation system may ignore certain issues of equity, and vice versa, a more equitable allocation system may be less efficient. This is not necessarily true for all situations. Here some tentative definitions are given, and some implications for water allocation briefly explored.

Equity

Equity can be defined as affording everyone a fair and equal opportunity in the utilisation of the resource according to one's needs. Equitable access does not necessarily mean access to equal quantities but rather equal opportunity to access water

(WRMS, 1999). Equity deals with the distribution of wealth or resources among sectors or individuals of society.

Efficiency

Different definitions of efficiency can be used, depending on one's objective. The reason why efficiency is important is that water is a finite and often scarce resource. Generally, efficiency measures how much one can do with one unit of water. Economic efficiency would then measure the benefits derived from a unit volume of water used. Water use efficiency measures the amount of water actually consumed for a given use.

At a more abstract level, efficiency can also indicate to what extent the ensemble of technical, legal, institutional, economic and other measures induce efficient use of the scarce water. For instance, certain legal and institutional arrangements may enhance people's willingness to privately invest in water infrastructure, or induce them to waste less water, or pollute less. This will eventually lead to increased water use efficiency as well as increased economic efficiency.

This wider definition of efficiency calls for pricing arrangements that ensure cost recovery of water services. This will not only give the correct signal to water users, namely that water is valuable and should not be wasted, but will also lead to the sustainability of infrastructure and institutions. The wider definition of efficiency also calls for suitable legal arrangements that provide users with sufficient security of water tenure, such that they are willing to invest in water-related infrastructure.

[Note: We prefer this wider definition above a narrow economic interpretation. Such an interpretation usually states that the marginal benefit from the use of the resource should be equal across use sectors; if not, society would benefit more by allocating more water to the sector where the benefits will be highest (the so-called Pareto optimum). In our view, such a Pareto optimum is not likely to exist, since different uses of water require different levels of assurances. See below.]

Trade-offs

The principle of economic efficiency is often translated into proper pricing of water services. This may obviously jeopardise the equity principle, in that poorer households may not be able to buy such a service. The fact that poorer households are thus denied access to a basic amount of water may however be extremely costly to society, in terms of disease, ill health etc. From a societal perspective it may therefore be highly efficient to provide all households with a very cheap (subsidised) lifeline quantity of water, and to make up the financial shortfall through cross-subsidies. In this manner win-win combinations of efficiency and equity in water allocation systems may be achieved.

(d) Water losses

Reducing water losses often has a high priority in attempting to balance demand with supply. However, water losses should always be carefully and precisely defined. This is because it depends on the scale and the boundaries whether water is considered a loss or not. At the global scale no water is ever lost.

In many situations, and especially in irrigated agriculture, a reduction of water losses may not free up all the "saved" water. Even "real" water losses, such as when water is released from a dam through the river bed for a downstream user, may provide an important service; namely recharge of aquifers, water for the environment etc. Once such services are recognised and formalised into permits (or in a "Reserve", as done in South Africa), the water manager may sometimes be able to find interesting win-win solutions. In other cases, of course, this may not be possible.

Analysing water losses should therefore always:

- clarify the scale and boundaries at which the analysis is done;
- consider both the consumptive and non-consumptive parts of the water use;
- consider any other type of use (including the environment) that may benefit from the water "lost".

(e) Water allocation between sectors (Savenije and Van der Zaag, 2002)

As was noted earlier, some types of water use add more value than others. The classic case is the different values attained in the agricultural and urban sectors: the value attained in urban sectors is typically an order of magnitude higher than in agriculture (Briscoe, 1996).² If water is currently used in the agricultural sector, the opportunity cost, i.e. the value of the best alternative use, may be 10 times higher, subject of course of "location and the hydraulic connections possible between users" (Briscoe, 1996). Thus a shift towards the higher value use is often promoted.

Whereas the opportunity cost of water for domestic water use may be highest, the moment availability is higher than demand, the opportunity cost of the water will fall to the next best type of use. It is just not possible to consume all the water at the highest value use. The proper opportunity cost for irrigation water may therefore be only half, or less, than the best alternative use (Rogers et al., 1997).

Even then, we should realise that water for irrigation requires a lower level of assurance of supply than, for instance, water for urban and industrial use: the same storage dam supplying irrigation water at 80 % reliability (failing one in five years), yields much less water for urban water supplied at 96 % reliability (failing one in 25 years). Figure 5.3 demonstrates this for a river system in Zimbabwe with a hydrological regime typical for many other rivers in semi-arid environments. Here the dam yielding a certain flow at 80% reliability can only provide between 50% and 65% of that flow at 96% reliability, depending on the level of flow regulation, as defined by the reservoir constant (the ratio of reservoir volume to mean annual runoff).

2. However, in economies with many industries depending on the agricultural sector, the multiplier effect of agricultural production is high, and therefore the value added by water may be under-estimated when only using farm-gate prices of agricultural produce (Rogers, 1998).

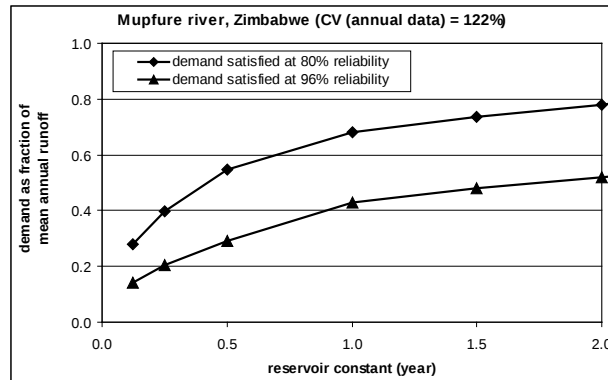


Figure 5.3: Comparing the yield of a reservoir at 80% and 96% reliability

The effective opportunity cost of water used for irrigation should therefore again be decreased. The resulting opportunity cost is thus only a fraction of what some neo-classical economists claim it to be.

Figure 5.4 illustrates the variation of supply and demand in an imaginary case. It shows that, in general, primary (domestic) and industrial demands, with the highest ability and willingness to pay, require a high reliability of supply, which is normally achieved through relatively large storage provision. Also environmental demands are not the most demanding on the resource. Agricultural water requirements tend to be much higher, fluctuate strongly but also accept a lower reliability of supply.

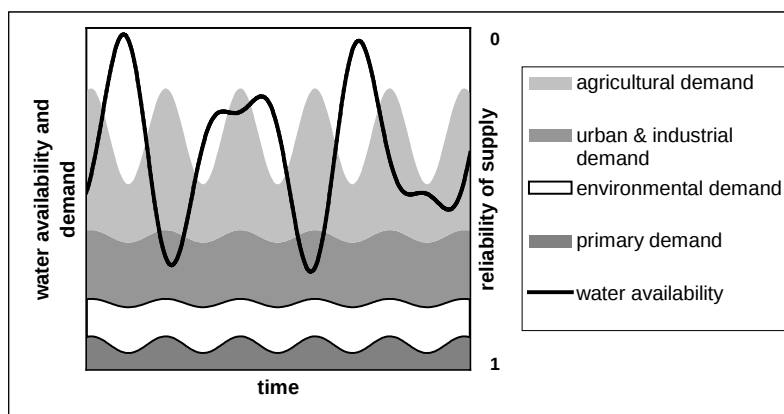


Figure 5.4: Variation of water availability and demand, and reliability of supply

The emerging picture, then, is fairly straightforward and common sense: the sectors with highest value water uses should have access to water. In many countries these sectors require only 20-50% of average water availability, and these demands can easily be satisfied in all but the driest years. In most years much more water will be available, and this water should be used beneficially, for instance for irrigation. There is therefore no need for *permanent* transfers from agriculture to other sectors, except in the most heavily committed catchment areas of the world. What is needed is a legal and institutional context that allows *temporary* transfers of water between agriculture and urban areas in extremely dry years. No market is required to cater for such exceptional situations. A simple legal provision would suffice, through which irrigators would be forced to surrender stored water for the benefit of urban centres against fair compensation of (all) benefits forgone.

In those heavily committed catchment areas where permanent transfers of water out of the agricultural sector are required, normally voluntarily negotiated solutions can be agreed, provided the laws allow this to happen. Rosegrant and Gazmuri (1996: 276-77) report a case of a factory financing the construction of a water-saving drip irrigation system for an irrigation scheme, thereby obtaining the right to use the water thus saved.

(f) Do higher value uses of water need to have priority over lower value uses?

Do higher value uses of water need to have priority over lower value uses? No, not necessarily. Higher value uses (such as urban water use) often have the potential to mobilise sufficient financial resources to secure a reliable supply. Higher value uses often require higher levels of reliability, meaning larger dams, and hence much larger investments, compared with lower value uses (e.g. irrigation). Often, the higher value uses are able to mobilise even these higher investment requirements. In such cases, it is not necessary to give higher value uses priority over lower value uses. The obvious economic advantage to society of not giving priority to various non-primary uses, is, that sectors have to fend for themselves, and will not, in all but the most extreme droughts, damage each other. As observed earlier, in extreme cases of drought, transfers between sectors will have to be against fair compensation.

5.3 Water allocation in international river basins

(Savenije and Van der Zaag 2000)

Principles underpinning the sharing of transboundary waters evolved quite separately from national water allocation systems. With the “Helsinki rules on the uses of the waters of international rivers” the ILA in 1966 codified the principle that “Each basin State is entitled, within its territory, to a reasonable and equitable share in the beneficial uses of the waters of an international drainage basin.” There was insufficient support within the United Nations to adopt the Helsinki Rules as UN law. This was because many countries with well-developed water systems wanted their current water uses explicitly defended. To counter-balance the equity principle, the obligation not to cause significant harm was formulated. The General Assembly of the United Nations eventually adopted the “Convention on the Law of the Non-navigational Uses of International Watercourses” in May 1997, in which the “no harm” principle appears in Article 7, and the equity principle in Article 5.

The question is frequently asked: which comes first, the right to equitable and reasonable use or the obligation not to cause significant harm? Those riparian states with a stake in the status quo tend to stress the importance of the latter principle (which appears to recognise established uses however inequitable these may be), while those riparians who lagged behind in water development tend to use the former principle to claim waters already used by ‘more developed’ riparians. The differential application of both principles should, however, be considered a false dilemma. Both principles apply concurrently and represent, as it were, two sides of the same coin. They convey the basic tenet that riparians have rights and duties in the uses of water resources, in line with the second principle of the Rio Declaration:

“States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and development policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.” (UNCED, 1992: 9)

Both principles imply that also downstream countries would need to seek a declaration of no-objection from upstream riparian countries when planning large-scale water development projects. In this context the current World Bank policy that only require upstream countries to seek a declaration of no-objection from downstream riparians (Subedi, 2003) is inadequate. Some authors have argued that the principle of equity is key to water allocation (Wouters, 1997; Wolf, 1999), which was also the premise of the 1966 Helsinki Rules (McCaffrey 1993). The principle of reasonable and equitable use (Article 5 of the UN Convention), however, is defined in general terms. To establish what is an ‘equitable share’, the UN Convention in Article 6 directs riparian countries to consider a wide variety of aspects (Box 5.6).

Box 5.6: Article 6 of the UN Convention: Factors relevant to equitable and reasonable utilization (UN, 1997)

1. Utilization of an international watercourse in an equitable and reasonable manner within the meaning of article 5 requires taking into account all relevant factors and circumstances, including:
 - (a) Geographic, hydrographic, hydrological, climatic, ecological and other factors of a natural character;
 - (b) The social and economic needs of the watercourse States concerned;
 - (c) The population dependent on the watercourse in each watercourse State;
 - (d) The effects of the use or uses of the watercourses in one watercourse State on other watercourse States;
 - (e) Existing and potential uses of the watercourse;
 - (f) Conservation, protection, development and economy of use of the water resources of the watercourse and the costs of measures taken to that effect;
 - (g) The availability of alternatives, of comparable value, to a particular planned or existing use.
2. In the application of article 5 or paragraph 1 of this article, watercourse States concerned shall, when the need arises, enter into consultations in a spirit of cooperation.
3. The weight to be given to each factor is to be determined by its importance in comparison with that of other relevant factors. In determining what is a reasonable and equitable use, all relevant factors are to be considered together and a conclusion reached on the basis of the whole.

Van der Zaag et al. (2002) attempt to define measurable criteria on the basis of which water resources can be allocated to the riparian countries in an equitable manner. Such measurable criteria may facilitate negotiations between riparian countries that are in conflict over the issue. A key parameter for establishing an equitable share is the number of people living in the various parts of the basin. In addition, not only the availability of “blue” water should be considered, but also the availability of “green” water. Two important variables were identified over which the riparian countries could reach consensus:

1. the value of green water relative to blue water;
2. the fraction of reserved water, which is defined as the basic entitlement of each riparian country.

5.4 Conclusion

There is not one single best way to balance water demand with water availability. This balancing act is region, country, basin and catchment-specific. It is also clear that the balancing act will often involve a process of decision-making where difficult compromises have to be made. Another course module (water resources analysis and planning) provides tools to assist with these decision processes. In all cases, the water allocation process requires a sound quantitative understanding of both water availability and water demand. This will be further elaborated in other course modules.

5.5 Exercise

- 5.1 In a similar but more detailed manner as Pallett (see Chapter 2), Lange (1997) calculated the contribution of water by sector to the economy of Namibia:

Economic contribution of water by Sector in Namibia, 1993

Sector	Value added 10 ⁶ N\$/yr	Water use 10 ⁶ m ³ /yr
Agriculture		
Commercial agriculture	405	111.4
Communal agriculture	176	34.8
Mining		
Diamond mining	609	13.6
Other mining	253	8.1
Manufacturing		
Fish processing	316	0.7
Other manufacturing	340	4.3
Services		
Hotels/Restaurants (Tourism)	129	1.1
Transportation	245	0.8
Other services	2,433	3.3
Households		
Rural	n.a.	10.0
Urban	n.a.	34.7
Government	n.a.	2.3

- 5.1a On the basis of the data provided, define an appropriate indicator for the “value added” by water.
- 5.1b Calculate for each sector this indicator.
- 5.1c Compare the sectors. What do you observe?
- 5.1d Should Namibia decrease water use in certain sectors and allocate it to other sectors?
- 5.1e What would be required to effectuate such re-allocation?

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Chapter 6

Water governance

Pieter van der Zaag

6.1 Introduction

Water governance is receiving more and more attention, as the lack of good governance is often blamed for much of the identified water problems in the world. The water governance concept is extremely pliable and means different things to different people. The World Bank (1992: 3) definition may be the most straightforward:

Governance is the manner in which power is exercised in the management of a country's economic and social resources for development.

Box 6.1 summarises the position of the UN World Water Development Report (UN/WWAP, 2003) concerning water governance.

Box 6.1: Water governance (UN/WWAP, 2003, pp. 371-372)

The notion of water governance and its meanings are still evolving and there is no agreed definition. Its ethical implications and political dimensions are all under discussion. Different people use the notion differently, relating it to different cultural contexts. Some may see governance as essentially preoccupied with questions of financial accountability and administrative efficiency. Others may focus on broader political concerns related to democracy, human rights and participatory processes. There are those who look at governance with a focus on the relationship between the political-administrative and the ecological systems. Other approaches see governance entirely in terms of management, and the operation and maintenance of infrastructure and services.

The United Nations Development Programme (UNDP) defines governance as the exercise of economic, political and administrative authority to manage a country's affairs at all levels. It comprises the mechanisms, processes and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations and mediate their differences.

In this particular context, governance refers essentially to the manner in which power and authority are exercised and distributed in society, how decisions are made and to what extent citizens can participate in decision-making processes. As such, it relates to the broader social system of governing, as opposed to the narrower perspective of government as the main decision-making political entity.

Governance of water is perceived in its broadest sense as comprising all social, political and economic organizations and institutions, and their relationships, insofar as these are related to water development and management. Governance is concerned with how institutions rule and how regulations affect political action and the prospect of solving given societal problems, such as efficient and equitable allocation of water resources. The rules may be formal (codified and legally adopted) or informal (traditionally, locally agreed and non-codified). Sound and effective water governance systems are crucial to pursuing various sustainable water development and management goals.

Ineffective water management, and the failure to implement water demand management measures, is often blamed on the “lack of political will”, or on ineffective forms of governance. As the Global Water Partnership’s Framework for Action (GWP, 2000) stated:

the water crisis is often a crisis of governance.

The 2000 Hague Ministerial Declaration reinforced this view and called for

good governance, so that the involvement of the public and the interests of all stakeholders are included in the management of water resources. (Rogers and Hall, 2003)

Those involved in water management often prefer to shy away from the sensitive issues surrounding governance, and rather focus on solving tangible problems. But in so doing, we may fail to address underlying, and persisting, weaknesses.

Before venturing into opportunities for strengthening good governance, it is important to acknowledge why there is this strong link between politics and water management. It is easy to call for “creating an enabling environment” (Rogers and Hall 2003, p.7) or “raising political will to overcome obstacles to change” (p.37). But the deafening silence that often follows shows that we often don’t know how to improve it.

The main purpose of this chapter, then, is to explore the link between politics and water, between governance and water management; and from there to consider institutional options that improve governance and facilitate and promote the implementation of measures consistent with integrated water resources management. The chapter starts at a fundamental level by considering *needs*. Thereafter, *interests* are examined. Needs and interests form the bedrock of any system of governance, which seeks to balance the needs and interests of a constituency or community. This balancing act can only be accomplished through a feedback mechanism called “*accountability*”. Why is accountability often problematic in water management? From here, the step towards *institutions* is small: which mechanisms of accountability do water institutions have? How can these be strengthened?

Without accountability, water institutions will be weak. Weak institutions will not be able to develop and implement strategies that are consistent with achieving equitable, efficient and sustainable use of the finite water resource.

6.2 Needs

“Needs are necessities, the things that are essential for survival, such as food, water, shelter and clothing. Needs, unlike wants, are not absolutely unlimited. For example, it is possible to calculate the basic needs which have to be met if a person or household is to survive” (Mohr et al., 2000: 8).

Water is a vital, life-giving resource, without which people would not survive. Clearly then, water is a basic need, and access must be ensured. It is widely accepted that governments have the duty to ensure that people have access to sufficient clean water.

The South African Constitution, for example, states the following (cited in Bond, 2001):

everyone has the right to an environment that is not harmful to their health or well-being... everyone has the right to have access to healthcare services, including reproductive health care; sufficient food and water; and social security...

Providing such a vital resource to people is an important responsibility, and quite sensitive: What if supply fails? What if the quality of the water is unacceptable? Hundreds of people may suffer, fall ill or even die.

Generally, governments have invested significant resources to ensure access to sufficient water of acceptable standards. For urban water supply, high assurance levels of supply often require large storage reservoirs, and expensive treatment works are built to ensure quality. For irrigation the main challenge is to control and store the large volumes required to grow crops.

Such water infrastructure is never an end in itself. It is intended to serve certain purposes, namely satisfying the demand for water for a certain constituency, for instance a community of irrigators, or residents of a city, or, at the level of the river basin, to satisfy the different demands as much as possible, taking into account the needs and rights of the various user communities.

This is all pretty obvious. But why do governments assume such an important role in water provision, compared to providing other basic needs, such as food, shelter and clothing?

This may be explained by the nature of water. Unlike food and fibre, water is a fugitive resource, meaning that you have to capture it or lose it. In semi-arid countries capturing water normally requires large investments, which are beyond the scope of any individual water user. Economies of scale then dictate that a higher level institution, such as a local authority or a government department, takes charge of this. In so doing, that institution becomes a monopolist.

6.3 Interests

All people have interests. All people have a direct interest in having access to sufficient water of acceptable quality. User groups may be more or less successful in claiming and accessing the resource. Some well organised users may employ legal and institutional means to get the water service they want. Others may use the force of political or physical power, and in the process marginalise others.

Water allocation decisions are in a sense value-generation decisions as they influence the relative power/affluence/etc. accruing to users; since the more powerful segments of society have the highest capacity to make themselves heard, the 'squeaky wheel' strategy will probably thus serve to further concentrate power and exacerbate social inequality. (Burrill, 1997)

Since water institutions (whether public or private) are natural monopolists, it is possible that the management activities might not be in the best interest of either the users or the water system.

Those in charge of a water system may find themselves in situations where they have conflicting interests. For example, professionalism may point to increasing the water tariff if insufficient funds for essential maintenance are generated. However, this may be politically unacceptable. So what should we do? Do we follow our professional judgement or will we compromise that judgement and bend under political pressure?

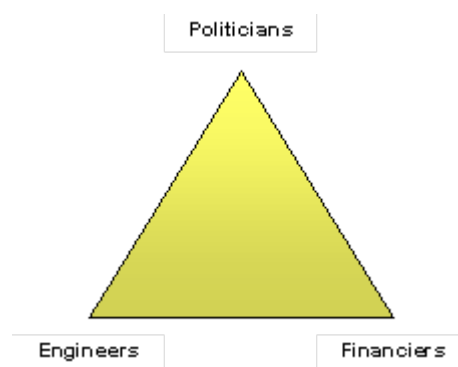
Those in charge of water systems may be tempted to “loosen” their link with the customers. A typical indicator of this is when water service providers fail to regularly inform customers about the state of the water system and withhold crucial information, for instance about new projects that are deemed necessary, or rather their alternatives (e.g. water demand measures). Instead they may prefer to strengthen ties with other actors (Box 6.2).

Box 6.2: Water coalitions in Mutare, Zimbabwe (Gumbo and Van der Zaag, 2002)

Since water is finite, different uses and users compete for it, and it easily obtains a value. Since water is a vital, life giving resource without which we cannot survive, it may obtain an incalculable value, even a political one. Controlling water may thus become a political rallying point. Since water is fugitive, it often requires sophisticated and costly engineering infrastructure to harness it. Taken together these three attributes of water may facilitate the emergence of powerful coalitions between engineers, financiers and politicians.

Engineering firms will be more than willing to apply their knowledge and skills to ambitious water projects, and they may tend to favour the larger supply-oriented projects as it would generate more work. To financiers, a monopolistic water supply system for a city is normally an attractive investment opportunity, since the city's residents will always need water. Politicians, finally, are likely to initiate water projects as this will portray them as the provider of a life-giving resource that enhances health, security and prosperity.

Such coalitions, then, may opt for supply-oriented measures.



For effective adoption of water demand management it is essential to acknowledge this political dimension. As a strategy it is suggested that: (a) stakeholders should be better informed about alternative solutions to water problems; (b) a new generation of engineers trained in integrated water resources management is needed with the skills to carefully study the problem definition before rushing to solutions; and (c) financiers should be made aware of the relevance and economic rationale of demand management solutions.

6.4 Accountability

Users actively evaluate the water services using various indicators, for example the reliability and timeliness of supply, the water quality, the cost of water, etc. The intended beneficiaries have a way of communicating with those operating the water network, and provide feedback about their satisfaction or dissatisfaction of system performance. Often the link between service providers and users is institutionalised, defining the rights and duties of both types of actors. Service providers may or may not be accountable to the user groups they are supposed to serve. Conversely, users may or may not respond to signals given by the service provider to improve the beneficial use of water.

Often the water service provider is the local authority with the municipal officials accountable to the councillors who in turn are accountable to the electorate. The lines of accountability and communication are theoretical relatively simple, officials – councillors – electorate. With the changes in the service delivery models (commercialised utilities, privatisation), lines of accountability may become blurred.

The communication link between users and service providers is often weak in water systems, and yet it is this link that provides essential feedback about the quality of the service provided and the state of the network. This communication link provides a feedback loop (one of the few mechanisms) through which service providers can be held accountable to their customers. And in so doing, find a balance between needs and interests.

In case of a weak service provider – customer link, excesses may result, which may ignite a strong response, as was the case in the Bolivian city of Cochabamba (Box 6.3).

Feedback loops may therefore be considered a weak link of water systems. Why this is so must be related to two issues:

1. One explanation is water-related, namely that suitable alternative sources of water are absent, or that these are insufficient or unfit. Customers of a water system therefore cannot withdraw from it, and have no other option than to accept the sub-optimal service they receive. Operators, then, are monopolists, and can thus continue with the manner in which they do their work.
2. A second explanation is social, namely that the relationship between operators and users is problematic. Ideally, water users should play the role of customers, whereas operators should play the role of serving them. In many water systems these roles are reversed: water users see themselves and are seen by the operators as passive recipients or subjects, while those operating the system are “in charge”, direct, and command.

Box 6.3: Water war in Cochabamba, Bolivia (Lobina, 2000)

In September 1999, the Bolivian government awarded a 40-year concession for the water and sanitation system of Cochabamba, a city with 500,000 inhabitants, to Aguas del Tunari.

Aguas del Tunari is a consortium led by International Water Limited. Aguas del Tunari increased water tariffs sharply in December 1999, provoking popular protests. The tariffs hit the people of Cochabamba where the minimum wage is less than US\$ 100 per month. The average water bill is estimated to equal 22% of the monthly pay of a self-employed man and 27% of that of a woman.

Led by La Coordinadora de Defensa del Agua y la Vida (The Co-ordinator for the Defence of Water and Life), an alliance including the trade union representing minimum-wage factory workers, peasant farmers, environmentalists and youth, protests broke out in January. After protesters shut the city down for four days, the government promised it would reverse the rate increases.

As the situation remained unchanged, La Coordinadora called for a peaceful march to take place in February. The demonstrators were confronted with tear gas and more than 1,000 police and soldiers. The toll of the clashes was two young people blinded and 175 injured. Following the upheaval, the government and Aguas del Tunari pledged to reduce and freeze the tariffs until November this year when they would start a new round of negotiations. As the population identified the foreign-owned consortium as the cause of the hikes, La Coordinadora called for the cancellation of the concession and the return of the water system to the public sector.

Exasperated by the government's failure to fulfil these requests, even more violent clashes exploded in April as peasants protesting against a law threatening popular control of rural water systems joined the angry Cochabambinos. In a clampdown to regain control of the situation, protest leaders were arrested and confined while President Hugo Banzer declared a state of siege in the whole country, restricting civil liberties. This time, the tear gas came together with not just rubber bullets but live ammunition. On 8 April, a 17 year-old boy was shot in the head and died. Bolivian television showed an army captain firing into the crowd of protesters from behind police lines.

Only then did the government agree to revoke the concession to Aguas del Tunari, free the civic leaders arrested, reform the national water law which would affect farmers and compensate the families of the victims. Subsequently, the protests eased in Cochabamba and the rest of Bolivia.

But what caused the rate increases which ignited the water war in Cochabamba? The answer is: the cost of the Misicuni Project. The Misicuni Project involves the construction of a dam, construction and operation of a hydroelectric power station and digging of a tunnel to bring water from the river Misicuni to Cochabamba through a mountain. Not only did the Cochabambinos have to pay in advance to cover the cost of a massive and probably unnecessary engineering project, they also had to guarantee abundant profits to operators reluctant to run any real risk. In fact, the concession agreement provided for a guaranteed 15 per cent real return. All the burden was on the people of Cochabamba.

As suggested by Bolivian Times, the generosity was most likely due to political connections. The local partner in Aguas del Tunari, ICE Ingenieros, is owned by one of the most affluent and influential men in Bolivia. His company is also a partner in the Misicuni tunnel consortium.

Recently, the government of Bolivia handed over the management of city's water supply system, including its US\$ 35 million debt, to community organisations, coordinated by the secretary of the town's trade union federation. Will this organisation succeed, and transform from a protest movement to effective management? (Hazelton et al. 2002)

The challenge is to find ways to clarify the roles of water users and operators, and reinforce the feedback links between them.

This will require efforts from *both* groups of actors. Water users need indeed start seeing themselves as customers, being able to articulate their needs and demand an adequate service. At the same time they need to be responsible customers, and fulfil their duties accordingly, for instance by paying bills promptly and reporting bursts and faults without delay. Operators should see it as their main task to satisfy the customers' needs. There needs to be a reward structure that reinforces this customer focus.

Seen in this light, accountability is the key characteristic of “governance”. To demonstrate this, we quote part of the definition used by the United Nations Development Programme (quoted in Rogers and Hall (2003), p. 7):

Governance comprises the mechanisms, processes and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations and mediate their differences.

It is important to note that governance is not only about the government as the main decision-making political entity. It is a much broader concept. Governance is about how different groups of people relate to each other in society, in terms of needs, rights and duties or obligations.

Without good governance there is no accountability. Without accountability, water institutions will be weak. Weak institutions will not be able to develop and implement strategies that are consistent with the equitable, efficient and sustainable use of the finite water resource. Good governance is therefore a prerequisite for integrated water resources management.

6.5 Water governance institutions in Southern Africa

During the last 10 years a significant revolution in water governance has been set in motion in most SADC countries (Southern Africa). Many SADC countries have adopted new water policies and/or enacted new legislation, as well as overhauled the institutional structure of water management.³ It is important to note two salient features that are common to all these country reforms, namely:

1. water management is now based on hydrological units, each with appropriate institutions;
2. water users and their representatives have a formal role in decision-making concerning water management.

As a consequence of these reforms, most SADC countries are now overhauling their water sectors. The major overhaul involves a fundamental change in water governance, from the inherited “predict and provide” mode of water management, where well-trained water engineers took charge of decision-making, to a much more inclusive

3. This is true for the following countries: Lesotho (1999), Malawi (2001), Mozambique (1995), Namibia (2000), South Africa (1998), Swaziland (2003), Tanzania (2002), Zambia (1994) and Zimbabwe (1998).

process of decision-making in which water users have a formal say. This implies a major change of the water management culture in all countries.

Such a change is not easy and not automatic. Changing the policies, laws and institutions is a necessary, but not a sufficient, condition to institute the required change of water governance, and, importantly, a change in practice of all actors involved in water management, be they water engineers, industrialists, urban and rural water consumers, small-and medium-scale entrepreneurs, small-scale irrigators, large-scale commercial farmers, and even rainfed producers.

One of the major challenges that are faced is the manner in which water users that hitherto had been left out of the decision-making process, will now articulate their needs and insights and bring them to the decision-making tables, for instance the water user board/water point committee, subcatchment council, catchment forum and river basin commission. This “vertical” chain, which involves the articulation of voice upward, report back downward, and holding representatives accountable to their constituencies, is notoriously fragile in a continent where the relationship between citizens and their representatives has been marred by the colonial, as well as the post-colonial, experience (Mamdani, 1996).

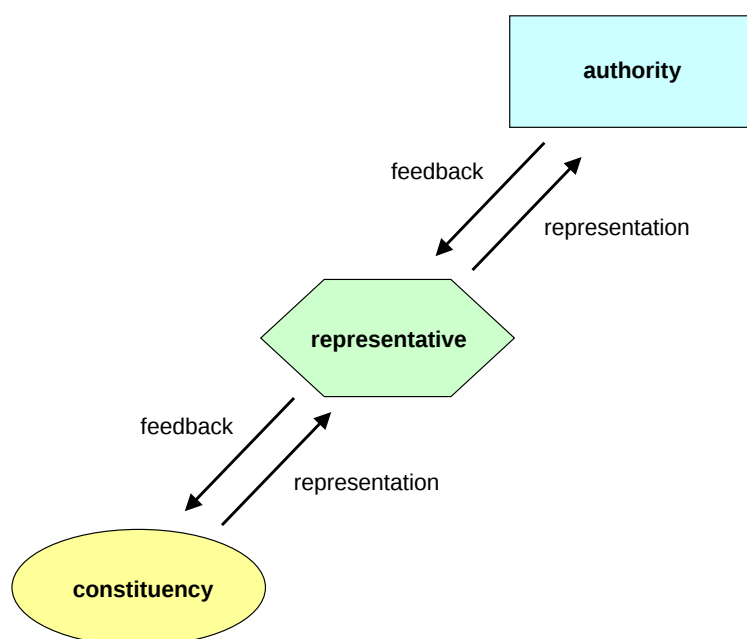


Figure 6.1: Vertical chains of representation and feedback

Here we are back at the subject dealt with in the previous section: effective institutions should have strong links between water users and water managers, at the local level (e.g. water user board, irrigation boards, water utility, local authority) but also higher up (catchment areas). One way of reinforcing such links is through greater public participation in the management of water. In this manner the communication and accountability lines gets institutionalised. Water managers and service providers get to hear first hand the needs and interest of the users and users get to understand the obligations and constraints of the service provider.

Strengthening these vertical links is a challenge, but feasible. There is a growing number of positive experiences, such as in some Catchment Councils in Zimbabwe, and some water utilities in South Africa. However there are many pitfalls and challenges remaining (Box 6.4).

Box 6.4: The user pays, Zimbabwe (Sithole, 2000)

Throughout southern Africa, the new managerial regimes treat water as an economic good and vests ownership in the state. On this basis the state has established regimes to charge for non-primary use of water. However, the approach in customary practice and law, throughout the region, is that water is treated as a god-given resource that all are entitled to use. The statutory law approach raises two issues at the local level – firstly, the state's title to water and secondly its authority to charge for it.

In Zimbabwe, for example, the Act vests title in the state and it requires all users to apply for a permit to use water other than for primary purposes. Difference around this was evident in the consultative meetings for the establishment of the new catchment councils under the new Water Act. Interestingly, communal land stakeholders in the Mazoe catchment area accept that there are circumstances under which payment might be justified, for example where a level of personal control is evident. They observed that the “person who impounds the water is the one who makes the river dry.” Thus it is acceptable that water stored in dams, but not that sourced from small weirs, boreholes and pools, should be paid for.

One participant stated, “this water that you want permits for, who is making it, who is its owner?” – essentially rejecting the notion that we control water that is flowing. In rejecting this, the moderator replied, “water is water, no distinction is made about source. It is use that will determine whether water is paid for.”

In what seems to be a veiled rejection of the state's right to charge, the chiefs in Nyadiri sub-catchment stated, “most people did not know about permits; the meeting was the first time they were being told about such issues or indeed being asked to get involved. As far as water is concerned most people follow the ways of their forefathers and are not aware that this or that use is illegal.” The chief added, “our concern is for our tiny gardens”, a use that is excluded from Zimbabwe's legal definition of primary use. For such water use a permit is required and an annual fee needs to be paid.

The remainder of this section highlights three such pitfalls, related to (a) the differential “voice” users have (some have a louder voice than others); (b) institutional shortcuts, such as the privatisation of “weak” water utilities, and (c) technological fixes for social challenges, such as the pre-paid water meter.

(a) The loud voice of the privileged

When most of the water is allocated, “new” water can be found within existing allocations through water demand management. Care needs then to be taken that the “new” water will not flow to where the money is and is not allocated by “adopting the ‘squeaky wheel management strategy, whereby the users that make the most noise get the most water. This strategy will certainly not result in an optimal distribution of resources” (Burrill, 1997). See Box 6.5.

Box 6.5: The user pays, South Africa (source: <http://www.icij.org/dtaweb/water>)

Ronnie Kasrils got the first hint that his government's cost recovery policy was not working in 1999 during a visit to a village in the former homeland of Transkei. Kasrils, once a committed communist and soldier in the African National Congress' armed wing, had just become the minister of Water Affairs and Forestry.

His department was coordinating a project in the village of Lutsheko in which each resident was contributing 10R (\$1) a month to receive basic water service. While touring the village, according to press reports at the time, he came upon a woman digging in a riverbed.

"You don't have to do this anymore — we have this project now."

"I have to," she replied. "I haven't got 10 Rand."

In February 2000, Kasrils issued a new policy, giving six cubic meters per month of free water to every household in the country..

(b) Institutional shortcuts

It should be noted that there is no short-cut or quick-fix for a situation where the link between water users and providers is weak. Privatising a water utility cannot be a substitute for an ineffective public water provider that maintains a weak link with its consumers. This is because a privatised service provider needs a strong public regulator, which defends the interest of the public. And this was missing in the first place.

There is no institutional shortcut for a lack of accountability. First get accountability sorted out, and then consider privatisation as one of possible institutional options; not the other way round.

(c) Technological fixes for social challenges

Pre-paid meters have been proposed for supplying low-income households with water. This appears to be an expensive technological fix for a social issue that the water provider finds difficult to resolve, namely to force people to pay their bills, when they are unable and/or unwilling to do so (Box 6.6).

Box 6.6: The pre-paid meter, South Africa (ICIJ, 2003)

The prepaid meters are "the most insidious device," said McDonald, who co-directs the Municipal Services Project, a research centre based at University of the Witwatersrand in South Africa and at Queens University in Kingston, Ontario. "People won't buy what they need — they'll buy what they can afford. So people are simply cutting themselves off rather than having the state come in and do it."

6.6 Conclusion

Control without consensus is hard, if not impossible, to reach. The basic premise should be: those who have an interest in the water resource and benefit from it have the duty to contribute to its management and upkeep (in money and/or in kind) and have the concomitant right to participate in decision-making. This leads to the maxim of the water boards in The Netherlands: interest - taxation – representation.

This chapter has argued that IWRM requires good water governance and effective institutions. Institutions are effective if there are strong links between users and managers, between customers and providers. This essentially promotes accountability. Accountability is needed to find a satisfactory balance between the needs and interests of all actors involved. Such strong institutions will be able to develop and implement strategies that are consistent with the equitable, efficient and sustainable use of the finite water resource.

To strengthen the link between users and managers, both must cooperate. The new water architecture that is emerging in many regions of the world poses important new institutional opportunities to implement IWRM. For integrated water resources management to be implemented successfully, there has to be a clear and consistent message coming from national departments, catchment level institutions and water utilities, as well as an active voice by the users, and consistent listening, and learning, by these institutions (cf. Stakhiv, 2003).

This all sounds very optimistic. However, reality is much more complex. One of the problems with the “governance” concept is that it is extremely pliable and that it may mean different things to different people. The current attention for “governance” is linked to decentralisation processes and neo-liberal reforms such as trade liberalization, deregulation and privatisation that started in the 1980s (Nuyten, 2004: 104). Governance is frequently linked to administrative and institutional reforms within the public sector, and the shifting role of government in development processes: from state-led development towards the strengthening of both civil society and the ‘invisible hand’ of the market. This sounds all very nice, but may blur the highly political content of such reforms (Shore and Wright 1997: 8). The danger is that decentralised democratisation may lead to “decentralised despotism” (Mamdani, 1996; Bond and Zandamela, 2000). In the context of water governance this may mean that the newly established catchment institutions will be dominated and “captured” by local elites (see also Waalewijn et al. 2005).

Governance is a concept that has been exported by states with relatively strong economies to states with relatively weak economies. Recent water reforms in Southern Africa have seen that establishment of new catchment institutions in which water user representatives have a voice. Central government has delegated certain powers to such institutions, justified by the “subsidiarity” principle. At the same time it also shifted the burden of financing water management to these more localised levels.

Delegating executive powers to more localised levels may lead to local bosses capturing the new platforms created by central government and use them for their private interests. Governments must therefore enhance their regulatory powers at central level such that constitutional rights and duties, as well as transboundary obligations, are upheld and respected. Effective monitoring and regulation is notoriously difficult for weak states. And here is the catch: it is often because governments were weak that they decided to decentralise water management in the first place.

6.7 Exercise

Chart the water flows and “accountability flows” for a case of a water system you are familiar with. Alternatively, use the case described in Box 6.7.

Explore the following questions: Is accountability effective? If so, why? If not, why not? Can accountability be improved?

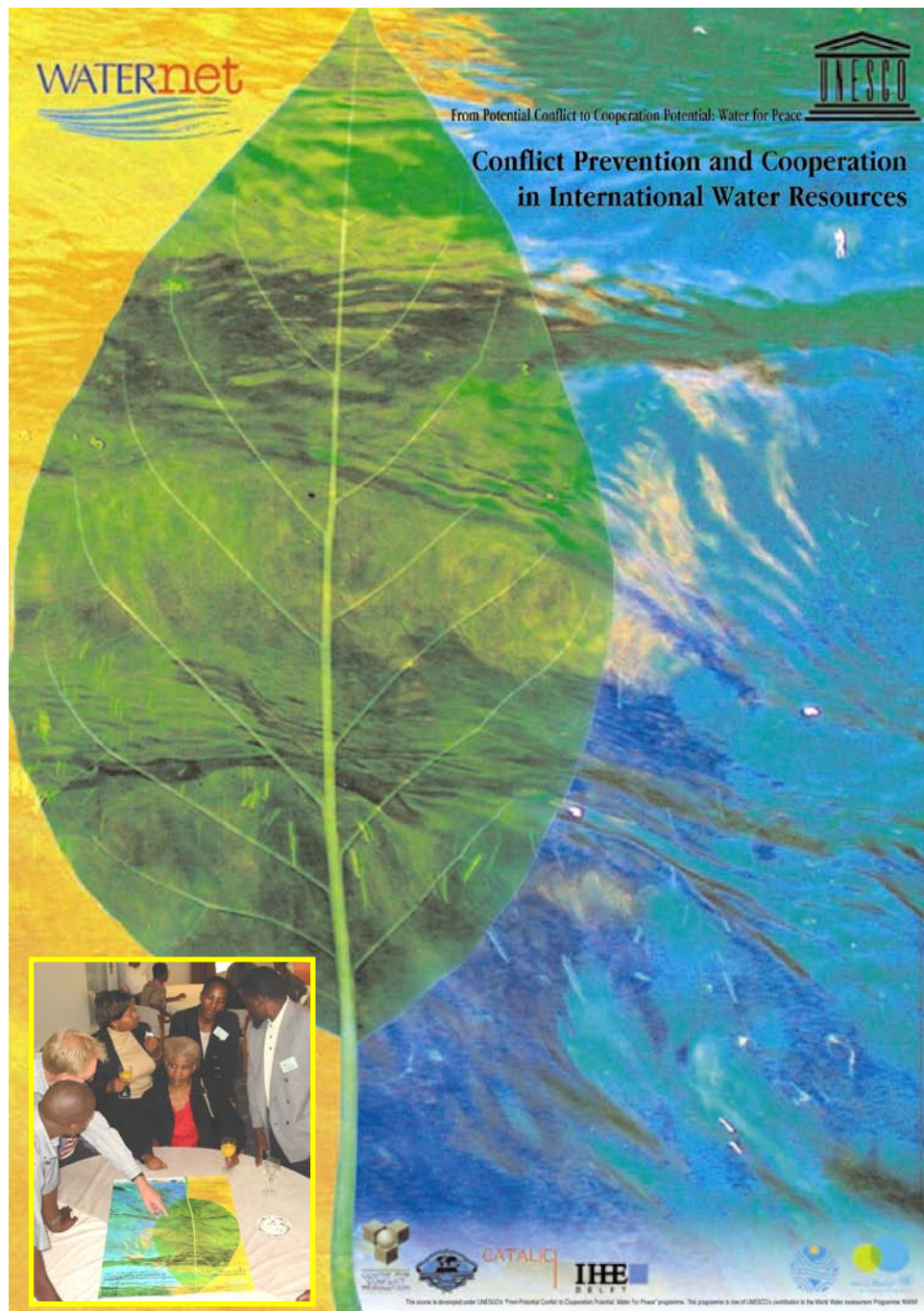
Box 6.7: Irrigation furrows in eastern Zimbabwe (Bolding et al., 1996)

In a communal area in eastern Zimbabwe, farmers have long built and used irrigation furrows, but never bothered to apply for formal water rights. Some 20 furrows exist that irrigate some 50 hectares. Two furrows stand out in size: one has a length of 1,200 metres and irrigates 15 hectares; the other is comprised of a main furrow that bifurcates into two subsidiary furrows with a total length of 1,600 metres, irrigating 10 hectares. The first mentioned furrow was built around 1900 and extended in 1932. The second was built around 1945. Irrigation in this communal area may be characterised as follows:

1. No formal water rights exist, but there is a strong sense of a historical user right to river water for irrigation.
2. The furrows are simple and straightforward earthen constructions that are adequately laid out, nicely meandering along the hill slopes.
3. The furrow intakes at the river are not permanent structures and are made of locally available materials such as rocks and sticks. They all leak and have to be rebuilt every year. There is a taboo on making the intakes in the river from concrete.
4. The furrows do not divert all water from the river. One woman irrigator explained: “the Chief doesn't allow us to take all the water”. The deputy chief later confirmed this: “We can't take all the water at the intake because it may kill the water creatures”.
5. The furrows regularly experience head- and tail-problems; i.e. irrigators located near the intake of a particular furrow may find it easier to access water than those with plots at the tail end. This situation sometimes causes open conflict – however this is often avoided by the simple fact that tail-enders initiate repair and maintenance activities along a furrow, and thus increase the flow available to them.
6. Water allocation is based not on a formal ‘Agritex system’ but on a ‘cultural’ system, as an irrigator once put it. People say: “Along a furrow people just share the water”. One farmer explained canal organisation thus: “We work together to construct the furrow, every year we reconstruct it in April. We are from the same village. Nobody is in charge of distribution. We give each other chances.” In case of conflicts, the traditional village leaders mediate.

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Chapter 7

Emerging issues in water management

Pieter van der Zaag

In this final chapter a number emerging issues in water management are re-visited. These have been grouped under four headings:

- Upstream-downstream linkages
- Water scarcity, food security and virtual water
- Critical institutional issues.
- The role of hydraulic infrastructure

The section on “Upstream-downstream linkages” deals with the fundamental asymmetrical relationship between up- and downstream users; which has important ramifications for management. The section on water scarcity deals with the largest water consumer, crop production, how rainfall can be more efficiently used and how the uneven water distribution can be resolved by means of the trade in “virtual water”. The subsequent section raises some critical institutional issues. Finally, also the contentious role of hydraulic infrastructure in development is briefly discussed.

7.1 Upstream-downstream linkages

In water resources, there are important dimensions to consider when thinking about the upstream and downstream linkages, and how to manage these in a beneficial manner. The first is that claims to water flow in the opposite direction then the water itself. The second is that as water naturally flows only in one direction, downhill, there is a fundamental asymmetry when we consider different users within one watershed or catchment.

7.1.1 Claims to water flow in the opposite direction of the water

As water flows downhill to the user, the water user looks expectantly in the upstream direction. So whereas water flows downhill, claims for water, and water entitlements flow in the upstream direction, towards the source of water.

Whereas hydrology is mainly concerned with understanding the process of water generation, water resources management is concerned with balancing water use and water demand with water availability. Water resources models therefore always model flows in two directions: water flows in the one direction and water demands in the opposite direction. This point is briefly elaborated here.

The most basic form of a water system only considers its inputs and outputs (Figure 7.1; cf. figure 3.5). This model describes the behaviour of the water system in terms of inputs and outputs: what happens with the output if the input is changed?



Figure 7.1: Input- Output model

Simple input-output models may be inadequate because water infrastructure has been created to honour a certain water requirement or demand. This means that the output of the water network is not only related to the input, but also how the network is being operated in order to satisfy the required downstream output. What is needed is to add a feedback loop, which flows in the reverse direction as the water. This feedback loop essentially models the demand for water (Figure 7.2).

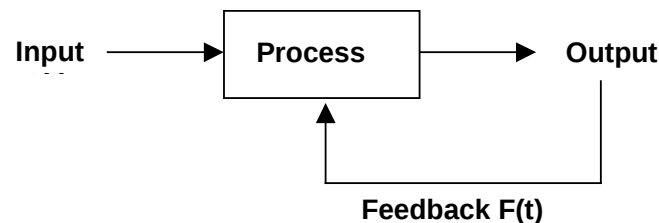


Figure 7.2: Input-Output-Feedback model

Feedback loops may take different forms. It may be physical or non-physical. A simple example of a physical feedback loop is a toilet cistern with a floating valve: when the cistern is emptied, the valve opens and demands water from the network. If the network has sufficient water, water will immediately flow into the cistern until filled, when the valve automatically closes. If the system does not contain sufficient water, the cistern's demand for water will remain until such time that the water network again has sufficient water to satisfy this demand.

An example of a non-physical feedback-loop is a request from an irrigator to a dam operator to open the sluice gate. Depending on the institutional reality (does the irrigator have a legitimate claim on water, i.e. does he or she have a water permit, did he or she pay the annual fee, can the irrigator show he or she will use the water beneficially, is the amount requested reasonable, etc.) and the operational rules (is the dam full or empty, are new inflows into the dam expected, must other requests also be considered, do some requests have priority over others etc.), the demand will be satisfied either in full, or partially, or not.

Even a physical feedback may have an institutional dimension: if the household with the toilet cistern did not pay its water bill, the water authority may physically disconnect the cistern from the supply network.

A system's understanding of the operation of a human-made water infrastructure can therefore never be limited to physical water flows alone. Such a system will be a hybrid system, containing physical and non-physical parameters. Such a hybrid system will contain interfaces, where the physical and the non-physical dimensions meet (Box 7.1).

Box 7.1: A hybrid water system

Consider a local authority supplying water to its residents, and collecting revenue for the services provided. In some situations, two systems may be distinguished:

1. the water supply service consisting of e.g. the works department, the physical water network and the water consumers;
2. the revenue collection system, consisting of the Treasury department, which produces bills that are sent to the ratepayers, who pay their bills.

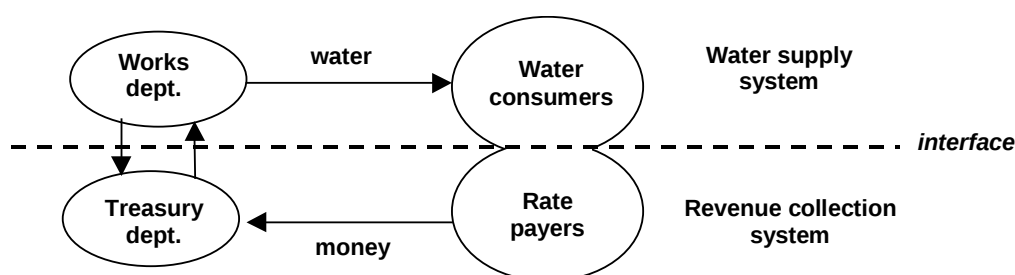


Figure 7.3: A water supply system, a revenue collection system and their interfaces

The interfaces between both systems are clear: the water consumers are the same actors as the ratepayers, and the Treasury and Works departments are part of the same local authority. Moreover, the Treasury needs to know from the Works department how much water should be billed to whom. The Works department, in turn, requires money from the Treasury to operate its water supply system. In cases where these interfaces are not clearly defined, the water supply system may become unsustainable. There is therefore need to consider both the revenue collection and the water supply system as being, in actual fact, sub-systems of one water services system.

7.1.2 Dealing with the asymmetry of upstream and downstream users

Downstream users of “blue” water rely on soil and water managers upstream, who first of all influence the two partitioning points (see chapter 3) and hence the manner in which rainfall is converted into blue and green water (e.g. through crop husbandry, soil management etc.) and subsequently use all the green water for biomass production and part of the blue water for other purposes. In so doing they (largely unilaterally) determine the availability of blue water to downstream users.

In many situations, the physical link that connects the downstream user with the upstream user (through gravity flow) is not reciprocated by an institutional link.

For example, if it is true that through diligent soil husbandry, storm flows and erosion can be reduced and more rainfall water infiltrates to the saturated zone, becomes groundwater and will appear as (valuable) base-flow in the river downstream, why cannot those who helped to generate this water be considered the owner of it; and those who want to use it lease it from them? This is the case with the current initiatives for the Payment for Environmental (or Ecological) Services, known as PES (De Groot et al., 2002; Smith et al., 2006), and more specifically, the idea of establishing “Green Water Credits” proposed by ISRIC, and tested in the Tana River in Kenya (Grieg-Gran et al., 2006).

In so doing, an institutional link reciprocates the physical water link, and upstream users receive an incentive to good soil conservation and husbandry. The most difficult part of this strategy is to attribute certain soil management activities to specific quantities of blue water generated. This is not trivial, as an increase in ground water (“deep-blue” water”) may be accompanied by a decrease in surface water flows in the form of storm flows (“light blue” water).

The sharing of international waters between riparian countries is in principle not different from the above situation; especially if such waters are shared between upstream and downstream countries. Water use in the downstream country does not affect water availability in the upstream country, but consumptive water use upstream does diminish water availability in the downstream country.

Countries will tend to achieve the highest *individual* benefits in negotiating shared water resources. International rules have put limits to the manner in which countries may utilise the international water resources occurring within their territories.

Because of the asymmetrical situation in river basins, whereby downstream uses do not impact upstream users but upstream users do cause downstream impacts, the reasonable and equitable allocation of water without causing significant harm, as prescribed by the 1997 UN Convention on the Law of the Non-Navigational Uses of International Watercourses, will always imply that upstream countries will have to forego some of the potential water benefits. A key question is whether upstream countries are willing to indeed accept this. If the negotiations would focus on formulating the strategy for the entire basin that achieves the highest total benefits, then countries that agree to forego certain developments for the benefit of other countries can be compensated by them (cf. Sadoff and Grey, 2002; Van der Zaag et al., 2002). This is tested in UNESCO-IHE’s research programme “*In Search of Sustainable Catchments and Basin-wide Solidarities; Transboundary Water Management of the Blue Nile River Basin*” (see the website <http://www.unesco-ihe.org/Blue-Nile-Hydrosolidarity>).

7.2 Water scarcity, food security and virtual water

At the global scale, one can hardly say that there is water shortage. The problem with water shortage is related to the temporal and spatial distribution: it is not always available at the right place at the right time.

Statistics on fresh water availability, such as provided by Gleick (1993), Gardner-

Outlaw and Engelman (1997) and the UN World Water Development Report of 2003 give a serious indication of a looming water crisis. Although there are indeed reasons for concern, many authors tend to neglect the most abundant and locally available resource in their water resources statistics, namely rainfall! About 60% of the world food production is provided by green water. The potential for increased food production of green water is large, particularly through

- soil husbandry and soil and water harvesting techniques;
- supplementing (erratic) rainfall with supplementary irrigation during the wet season.

7.2.1 Scope for improving rainfed agriculture (Rockström, et al., 2003)

The challenge of doubling food production over the next 25 years in order to keep pace with population growth requires increased attention to water productivity and rainwater management, simply making the best use of the local water balance. Even in water scarcity prone tropical agro-ecosystems, there is no hydrological limitation to doubling or in many instances even quadrupling staple food crop yields in rainfed small-holder agriculture. There are several appropriate technologies and methodologies at hand to enable a development towards improved soil and water productivity.

Interestingly, even when focusing on water productivity in semi-arid rainfed farming systems (where water is a major limiting factor for crop growth), other factors than water are shown to be at least as (if not even more) critical limiting factors for productivity improvements. The experiences on water harvesting for supplemental irrigation in Burkina Faso and Kenya clearly show that soil fertility management plays an as important role as water management. Similarly, for *in situ* water harvesting using conservation tillage in Tanzania, addressing water conservation only (through ripping and sub-soiling) resulted in similar yields and water productivity as addressing soil fertility alone (in conventionally ploughed systems). The only win-win opportunity in these examples arises when soil fertility and water are managed simultaneously, as shown in water harvesting experiments in Burkina Faso, where isolated management of water or soil fertility resulted 1.5 - 2 times higher yield compared to the traditional practice, while integrated soil nutrient and water management resulted in a factor 3 times higher yield.

However, these biophysical facts play only a limited role in decision-making at farm level. Farmers' investment decisions are strongly influenced by their risk perceptions. Risk of reduced or no return on invested capital in rainfed semi-arid farming is directly related to the unreliable rainfall distribution. Managing water, especially by developing appropriate tools to bridge recurrent dry spells (e.g. through small-scale water harvesting), may be the most sustainable entry point for farming systems improvement. This form of upgrading rainfed farming may be the incentive required to stimulate further investment (capital, labour). All evidence suggests that if crop water access is secured investments in soil fertility, crop, and timing of operations, will pay-off in terms of substantially increased soil and water productivity.

Reducing risk for crop failures by adding a component of supplemental irrigation implies the development of blended farming systems including components of both rainfed and irrigated agriculture. The time may be ripe to abandon the sectoral

distinction between irrigated and rainfed agriculture. The implications of such a reform would be substantial. Professionally there is still a divide between irrigation engineers dealing with irrigation management and agronomists dealing with rainfed agriculture. Irrigation and rainfed agriculture generally fall under different ministries (irrigation under “blue” water resources ministries and rainfed agriculture under “green” ministries of agriculture, natural resources or environment). Integrating the two may result in interesting management and technological advances in the grey zone between the purely blue and purely “green” food producing sectors.

Such improvements of rainfed farming systems enhance their resilience to cope with climate shocks to a fundamentally higher level. It will lift the livelihoods that rely on these farming systems, out of the so-called “poverty trap” (see Figure 7.4). This will bring livelihoods at a higher level of well-being. It also represents a “no regret” policy for climate change adaptation.

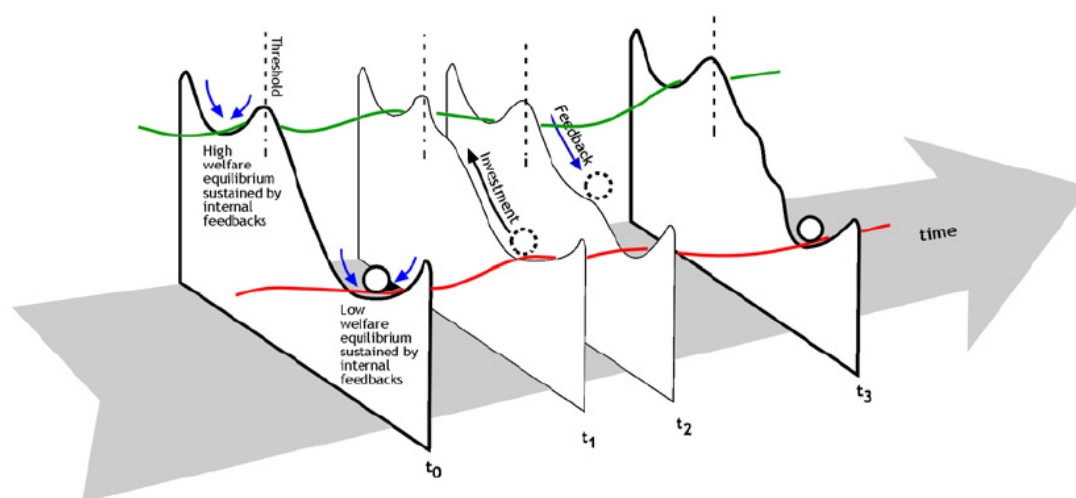


Figure 7.4. The poverty trap of rainfed farming communities in semi-arid Africa
(Enfors and Gordon, 2008)

7.2.2 Food self sufficiency or food security

In terms of water resources availability, the most critical issue is the amount required for food production. Unlike other essential commodities, such as oil and gas however, water is a relatively bulky substance relative to its value, making it relatively expensive to transport over large distances. We can, however, transport water easily in its “virtual” form. This is what water scarce countries are already doing.

A kilogram of grain, grown under favourable climatic conditions, rainfed, corresponds with about 1 to 3 m³, or 1,000-2,000 kg of water. This is a concentration by three orders of magnitude! Importing grain instead of trying to grow it oneself, implies importing water in a condensed, “virtual”, form (Table 7.1). Note that one hamburger, containing 150 grams of meat, requires 2,400 litres of water to produce it!

Table 7.1: Virtual water contents of some food products (m³/kg)

Potatoes	0.5	Milk	1.0
Maize	0.9	Chicken meat	3.9
Wheat	1.3	Eggs	3.3
Wheat	1.3	Goat meat	4.0
Sugar	1.5	Beef	15.5

Source: www.waterfootprint.org

The virtual water concept, which was coined by Professor Tony Allan (Allan, 1993, 1994), expresses a commodity in terms of the amount of water required to produce it. The virtual water concept creates insight into better distribution of water, both within countries and within regions. One could consider growing certain low value crops in regions where rainfall and water are abundant and where soils are favourable. This, indeed, requires a conducive and reliable regional and international market and political stability.

In the Middle East and North African (MENA) countries a water deficit already exists. This deficit is however not balanced by hydrological and water resources systems. It is the economic systems that achieve water security for the economies of the region (Allan, 1994). “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 Middle East and North Africa’s people in the 1990s lies in the soil profiles (green water) of temperate humid environments in North America, South America and Europe” (Allan, 1997).

Given the above, present thinking moves in the direction of food security, whereby arid countries focus on generating sufficient income to allow them to import the food they require.

On the basis of the virtual water concept, and borrowing ideas from the ecological footprint concept, Arjen Hoekstra developed the water footprint concept (see e.g. Hoekstra and Chapagain, 2007; see also www.waterfootprint.org).

7.3 Critical institutional issues

The growing complexity of water management induces a need for management at the lowest appropriate level (also known as the ‘subsidiary principle’), resulting in central government *delegating* functions to the decentralised organisational (regulatory) and operational levels. In general, the organisational (or regulatory) level may have a mandate over a river basin, while at the operational level concessions may have been delegated to sub-catchment areas or to user groups (municipalities, irrigation districts).

Thus in managing the resource, a functional differentiation is made between constitutional and policy making issues (related to property rights, security, arbitration), regulatory and organisational issues (regulation, supervision, planning, conflict management), and operational issues (water provision etc.) (World Bank, 1993).

These issues will then be handled at three different levels (Jaspers, 2003):

- Constitutional/policy-making level: the activities being governed by conventions of international organisation, bilateral or multilateral treaties and agreements, the national constitution, national legislation or national policy plans.
- Regulatory and organisational level: activities at this level are defined by (federal) state regulation, ministerial regulation, regulation or plan of functional public body (national water authority, (sub) catchment authority), provincial regulation or plan.
- Operational level: activities being governed by subcatchment-, district-, town regulations, byelaws of semi-public or private water users organisations etc.

The most important issue in dealing with water resources is to ensure an institutional structure that can coordinate activities in different fields that all have a bearing on water. *Linking structures* are crucial.

Through a process of vertical and horizontal coordination it is possible to integrate different aspects of the water issue at different levels. Linking can be facilitated if a country's water is managed following hydrological boundaries (river basins, which may be subdivided into catchment areas and sub-catchments).

Once agreement exists over what type of functions and decisions can best be made at what level, a next policy option is that of privatisation. Operational functions often involve the provision of specific services in water sub-sectors, such as irrigation and drainage, water supply and sanitation, and energy. The production function may, in principle, be privatised; but only if the nature of the good (or service) is fit for it, and if government's regulatory capacity is strong enough to prevent monopoly formation or other market failures.

7.3.1 Role of the private sector in water management

Privatisation is fashionable. Worldwide there is a discussion on-going about the way in which the private and public sectors should divide their tasks. What is the role of government and which role can the private sector play? In this respect one speaks of public-private partnerships (PPPs). It is clear that in IWRM the role of the central government should remain important in policy making, legislation, strategic planning, establishment of the appropriate legal and institutional framework, capacity building and the supervision and regulation of decentralised and privatised institutions in water resources management (such as water supply utilities, irrigation boards, catchment authorities etc.). Governments are increasingly realising that they should *not* privatise the resource itself.

Essential in the discussion about privatisation is a clear separation of policy-making, regulatory and operational functions. The government needs to be strong in order to effectively regulate decentralised water management bodies and (semi-privatised/commercialised or fully privatised) service providers; who are often (if not always) monopolists. The largest misunderstanding in the privatisation debate is that privatisation is needed to make an inefficient government more effective. In contrast, privatising public services requires a sharp, well-equipped and highly qualified government.

However, it is also recognised that the private sector can potentially shoulder the huge investments that are required to improve water services, especially water supply and sanitation. This requires that these services will be priced at full cost recovery.

7.3.2 Pricing of water

Financial and economic arrangements are complex issues. The maxim ‘water is an economic good and should be priced according to the principle of opportunity costs’, as well as the ‘users pays and polluter pays’ principles carry within them a danger, especially in countries lacking sufficient resources and with a skewed distribution of wealth. In such countries the ‘user pays’ principle may boil down to ‘who can pay is allowed to use or pollute water’.

Because of historically grown inequities in society, this may result in a large group of the population having limited access to water resources. This may create severe social problems, and may be considered unconstitutional, as it may violate a first order principle (equity). Savenije and Van der Zaag (2002) point out that the maxim “water as an economic good” does not necessarily imply water pricing, but that it primarily means that choices and decisions on the most desirable allocation and use of water should be taken on the basis of economic analysis. These decisions should be based on an economic trade-off analysis, balancing societal costs, benefits, advantages and disadvantages.

Water pricing, however, may be necessary to achieve financial sustainability and ensure that water systems remain efficient. A balance needs to be found between water pricing on the one hand, and the social requirement of sufficient access to clean water, on the other.

Instruments that may assist in achieving a balance between efficiency and equity include:

- recovery of real costs by functional (catchment) agencies;
- financial independence (and accountability) of implementing agencies;
- water pricing by means of increasing block tariffs, and other forms of cross-subsidies.

7.3.3 Public participation in international rivers

The newly established catchment or basin management institutions throughout the world all have a strong component of stakeholder participation. Such water management bodies, including water user boards, should be stimulated to establish contacts across borders. This will enhance mutual understanding, and will allow them to give practical form to the bilateral and trilateral agreements reached between States. Water users should be aware of international impacts of their water using activities and be able to influence international river basin management through their catchment institutions.

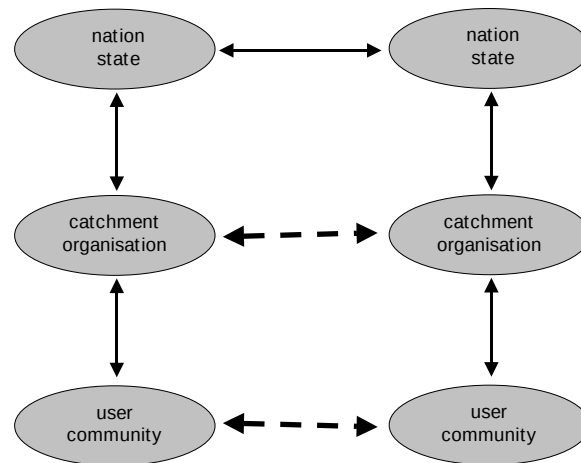


Figure 7.5: Missing links in international water agreements

Two major challenges exist: the first is to improve and strengthen the two-way vertical communication channels between State and user levels within country, by means of effective catchment organisations. The second challenge is to foster (horizontal) linkages between catchment organisations across national borders (Figure 7.5). Strengthening these vertical and horizontal linkages will deepen, and give a more practical meaning to, the existing bilateral and multilateral agreements between States on shared watercourses.

7.3.4 The challenge of institutional coordination: administrative and hydrological units

Before anything else, IWRM is an institutional challenge. It requires institutional capacity to integrate. Such capacity is in short supply. There may be competition over it. Many countries developed, over the years, integrative capacity, typically at the district level. This is where the various government departments such as health, education, agriculture, transport and water participate in implementing multi-sector rural development programmes. In contrast, the new water architecture that is emerging in many countries appears to create a parallel structure, alongside but separate from the existing administrative structures, entirely defined by hydrological boundaries. This may lead to misunderstandings, to competition and even to un-coordinated development. This obviously is a waste of valuable institutional resources (Van der Zaag, 2005).

It could be argued that the new water organisations should primarily serve as consultative bodies (sometimes called "multi-stakeholder platforms" or "catchment forums") that ensure that developments throughout the catchment are consistent; but that they should not necessarily have executive functions. In many countries it is the districts that will continue to play the executive role and implement water and other integrated rural development projects. It is also at this level that the agronomist and the water manager should work closely together in watershed management and soil and water conservation projects; important fields that many water managers have neglected in the past. Also, the institutions should be much more strongly based on existing customary practices (Mohamed-Katerere and Van der Zaag, 2003). Ignoring or overriding existing traditional management structures is another waste of institutional

resources.

In short, we have to be very pragmatic when it comes to designing appropriate water management institutions. In the same vein, the IWRM/Water Efficiency Plans that are currently being formulated must be pragmatic and practical instruments, that indicate how the available financial, institutional and human resources will be used to achieve tangible results.

7.4 The role of hydraulic infrastructure

A major problem in many river basins of the world is the extreme low levels of water access and use. Large sections of the population lack access to sufficient water for both domestic and commercial purposes. As a result they run health risks, they are food insecure and they are poor in terms of income. The few hydraulic works that exist are inadequate to honour the demands of the majority population. In fact, the existing hardware cannot control the water resource, i.e. store sufficient water for the dry season and dry years, protect the flood plain against floods, deliver sufficient water of sufficient quality and reliably to the urban and rural population and provide irrigation water to farmers.

Societies that lack sufficient capacity to store water typically find themselves at the whims of the climate, their economies being heavily influenced by floods and droughts. This point has recently been argued by experts from the World Bank (Grey and Sadoff, 2007), illustrated by the case of Ethiopia (Figure 7.6).

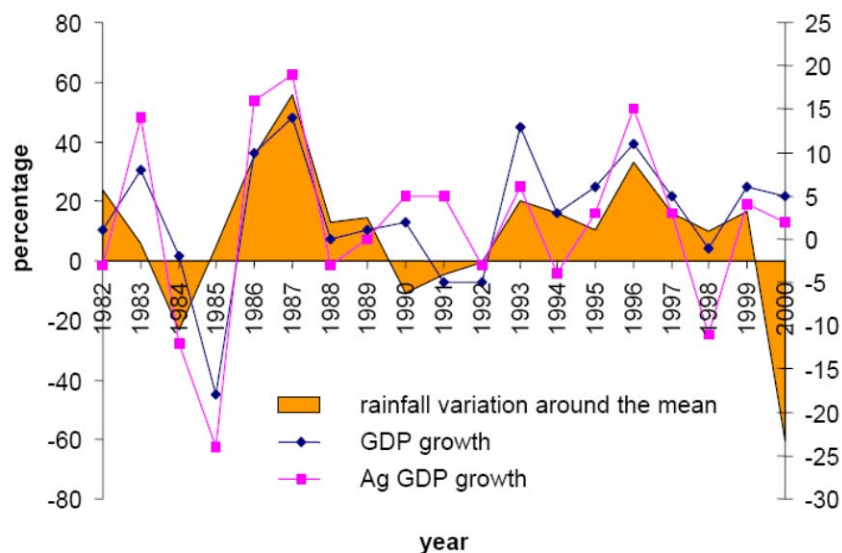


Figure 7.6: Relationship between rainfall, Gross Domestic Product (GDP) and Agricultural GDP in Ethiopia, 1982-2000
(Source: Grey and Sadoff, 2007: 558)

The development of new large hydraulic infrastructure is therefore sometimes inevitable for meeting the water demands of an increasing population in a growing economy. However, all possible alternatives should be carefully considered, including the possibilities of demand management measures (Gumbo and Van der Zaag, 2002). The new trend of accepting the need for further infrastructure development in the water sector is strongly supported by the new World Bank water resources strategy (World Bank, 2004) and follows the scepticism of the 1990s and the cautious approach advocated by the World Commission on Dams (WCD, 2000).

Many river basins in the world do need more hydraulic infrastructure that harness the water resources and channel it to those in need of it (Figure 7.7). Improved access to water is an important precondition for achieving security and prosperity. However, it is unclear whether such storage capacity should be centralised in the form of conventional large reservoirs, or de-centralised and distributed; for example in the farmers' fields (e.g. storing rainwater in the soil of non-tilled or ripped fields or fields that are ploughed along the contour or on terraced fields, and "harvesting" runoff water by storing it in small farm ponds), and at the scale of the micro-watershed and village (tanks, micro-dams and aquifers). The policy choice between developing centralised and distributed water storage is an important one, and requires critical analysis. This is because institutional complexity increases more than proportionally with increased physical scales (Gupta and Van der Zaag, 2008). Designing and building large reservoirs is a relatively modest challenge compared with developing the institutional capacity to manage them in accordance with IWRM principles (Van der Zaag and Gupta, 2008).

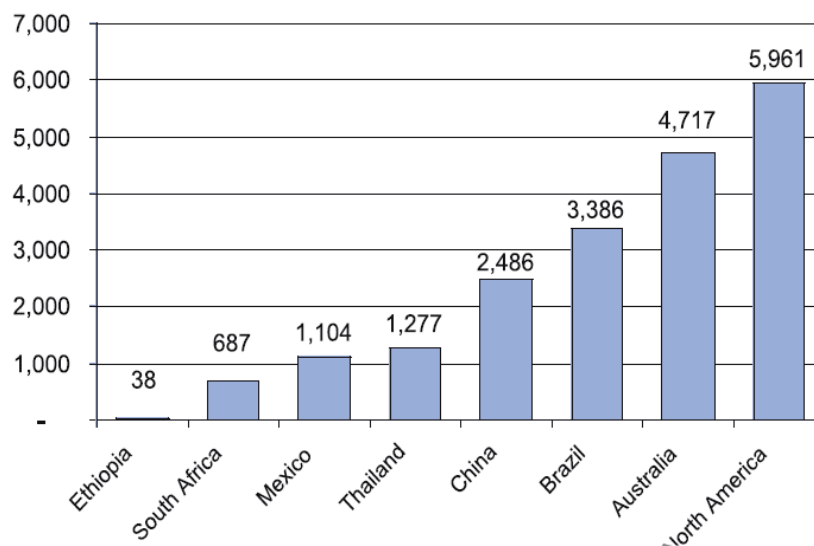


Figure 7.7: Reservoir storage capacity in m³ per person, 2003
(Source: Grey and Sadoff, 2007: 554)

Our concern is that upscaling institutional resources may prove problematic. It is suggested that the larger the hydraulic works (or the larger the spatial scale and command area of that works), the more difficult it will be to achieve a water use that is efficient, equitable and environmentally sustainable. The larger the “command area” of a hydraulic structure, the larger the economic interests involved and hence the political interests, and the more people with diverse interests will be affected, and thus more complex the allocation decisions will be. Such decisions will require adequate institutional arrangements and governance practices; but these only slowly develop over time.

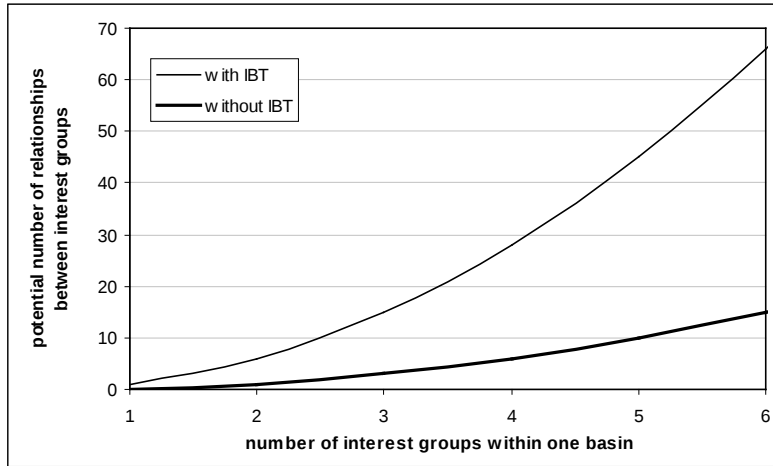


Figure 7.8: The increased institutional complexity with interbasin transfers
(Source: Gupta and Van der Zaag, 2008)

Institutional complexity is *not* linearly related to spatial scale. This has been illustrated for the case of interbasin water transfers (Figure 7.8). A *doubling* of spatial scale, as a result of an interbasin transfer, may result in a *quadrupling* of institutional complexity. This is the case if we assume as a proxy for institutional complexity the number of bilateral relationships n_b that can be established between actors having different interests. If within one river basin there are four different interest groups (e.g. domestic water, irrigation, hydropower, environmental water), in total 6 different bilateral coalitions or conflicts can be formed. In mathematical form:

$$n_b = \binom{4}{2} = \frac{4!}{2! \times 2!} = \frac{4 \times 3 \times 2 \times 1}{(2 \times 1) \times (2 \times 1)} = 6$$

Interconnecting two river basins would then give rise to a proliferation of coalitions and/or conflicts, as now eight different interest groups may potentially establish as many as 28 conflicting or converging bilateral relationships:

$$n_{2b} = \binom{8}{2} = \frac{8!}{6! \times 2!} = 28$$

If the institutional capacity has anything to do with the potential number of bilateral conflicting and converging interests, then interbasin transfers give rise to a quadrupling of institutional complexity (with increasing n , the quotient of n_{2b} and n_b converges to a

factor 4). So whereas from a technical perspective an interbasin transfer scheme may be feasible, it may be more problematic to equip the institutions with the required institutional qualities and capacities to reconcile the competing interests that the transfer will evoke.

Hydraulic infrastructure not only has a spatial dimension (command area / area of influence). It also has a temporal dimension. The larger the hydraulic infrastructure the larger the temporal scale. This is so because large hydraulic works have a design life that is much longer than the policies that allow them to be built. The values and priorities of a society tend to change significantly over a period of 40 to 50 years, the typical design life of a large hydraulic infrastructural project but in practice they last much longer. Yet these large hydraulic works influence how we utilise our water resources. This point has been made by Biswas and Tortajada (2003) with reference to the Spanish National Hydrological Plan.

Large infrastructural works represent large previous investments (sunk costs) that “frame” the decision variables by freezing the feasible technical solutions (Janssen and Scheffer, 2004). Alternative solutions may be discarded solely on the grounds that they do not require the services of the prior investments.

In conclusion, the need for an increase in capacity to store water in many countries located in semi-arid and arid climatic zones is evident. However, this also raises some important questions:

- Will such storage capacity be large-scale and centralised or distributed and decentralised?
- How will the required capital investments be financed?
- Does sufficient capacity exist to manage and govern such hydraulic infrastructure in ways that are consistent with IWRM principles?

7.5 References

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