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# Towards water security: political determination and human adaptation crucial



Malin Falkenmark and Jan Lundqvist

*Although high-level attention has been drawn to the escalating world water problems, few changes are noticeable in terms of actual management of the water resource. Politicians continue to be misled by the apparent simplicity of water. The environment-oriented community tends to focus only on problems arising from man-induced side-effects, and most people tend to take water for granted. The double challenge of providing adequate water supplies and meeting increasing food requirements of expanding populations, in addition to already existing water management problems, requires special attention. In addition, the intensifying pollution of water systems will have to be dealt with. Considerable human adaptation to physical realities as well as ingenious action are needed.*

*There is a brief discussion of the risk of hydrocide, a condition of serious water-quality degradation where available water is no longer sufficient, or cannot be used for the purposes needed. However, the main focus of the paper is on water quantity issues, highlighting the confusion arising from different methods of assessing water scarcity. Levels of regional water scarcity predicaments are discussed in terms of distinct regional clusters. Attention is drawn to the limitations of dry climate regions to achieve food self sufficiency, and the emerging need in many areas to import food; related trade and price aspects are also discussed. A distinction is made between efficiency of use and efficiency of allocation.*

*The need for a global ethic regarding upstream–downstream water-sharing is stressed, especially in cases of consumptive (evaporative) use of water for cultivating crops, which may deplete river flows available to downstream users. In conclusion, four key concerns are highlighted that call for global consensus.* 

Despite the fundamental importance of water to human life, efforts to bring the increasing water scarcity[1] into the political debate have been largely unrewarded. Acknowledgement among users is also largely lacking, as people tend to take water for granted. At the political level, discussion of water-related problems is mostly limited to technical issues, e.g. water supply, irrigation, dams etc. As pointed out by Ivan Cheret, the father of the widely admired French system of river basin commissions, consumers as well as politicians tend to be completely misled by the apparent simplicity of the water issue, as "everybody uses it daily and it looks quite simple".

The UN Conference on Environment and Development (UNCED) in Rio de Janeiro (June, 1992) did not address the problems of water scarcity driven by explosive population expansion, especially in arid climate zones (Falkenmark, 1989). There seem to have been two main reasons for this. The first reason was the way the Conference looked upon environmental problems; and the second reason was that no attention was paid to population growth. To start with the latter, population growth was considered a separate issue, which was diverted to the subsequent Cairo Conference. Turning to the former, the Conference saw environmental problems as man-induced in the sense of being side-effects produced by human manipulations of land, water and atmosphere either for the harvesting of natural resources or for the disposal of waste products. However, the Conference did not address problematic environmental preconditions, linked to hydroclimate and soils, a condition that characterizes large parts of those regions of the world where most of the low income countries are situated and where populations are rapidly expanding (Falkenmark, 1991). The only water scarcity issue raised in Rio was 'desertification', which, in parallel with the side-effect notion, was seen as a soil degradation problem rather than one of water scarcity in the root zone ('green water' scarcity).

## Addressing the problem

### *Spreading degradation of land and water*

Neglecting problems does not make them go away,

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[1]The term water scarcity is used in this article to indicate a condition of insufficiency of water in usable condition in relation to demand for plant production and/or human activities.

however. Since the Rio Conference in 1992, the world population has grown by more than 80 million per year, a total addition of almost half a billion new world inhabitants, mostly in dry climate regions, with inherent difficulties in mobilizing additional water and in attaining self-sufficiency in food production.

Problems related to water pollution continue to escalate. Degradation of aquatic systems from pollution has begun to spread to groundwaters. Reversing this condition will take generations, because of the slow natural processes involved in water renewal. Antipollution legislation, although widely enacted, is difficult to implement without effective enforcement mechanisms.

Land degradation continues to spread. Water-logging and salinization encroach and disable agricultural lands at the same pace that new lands are being brought under cultivation. In spite of a large number of reports and a considerable amount of discussion since the Mar del Plata Conference in 1977 about what could be done to protect water resources, successful practical action is deplorably limited. The impression is that many politicians and opinion leaders have not yet properly understood the implications of expert warnings, and the urgency of action. A lack of attention, both among professionals and decision-makers, to the demand side has also contributed to the impending water crisis.

In one of its reports to the World Food Summit, FAO (1996) makes an assessment of the extent of human appropriation of the renewable global freshwater, based on data from Postel *et al.* (1996). Precipitation over land is seen as the overall freshwater availability and is partitioned into 'green water' (evaporating vertically), and 'blue water' (flowing more or less horizontally) (see Figure 1). FAO estimates that 54% of accessible blue water is already appropriated for direct and indirect human use, while 26% of available 'green water' is already appropriated for agriculture and forestry.

*Call for a freshwater revolution*

The incipient world water crisis has made the scientific community cry out for a "freshwater revolution" to bring high-level attention to the increasing constraints on human activities posed by the condition of the water resource (Milburn, 1996). A worldwide freshwater assessment,

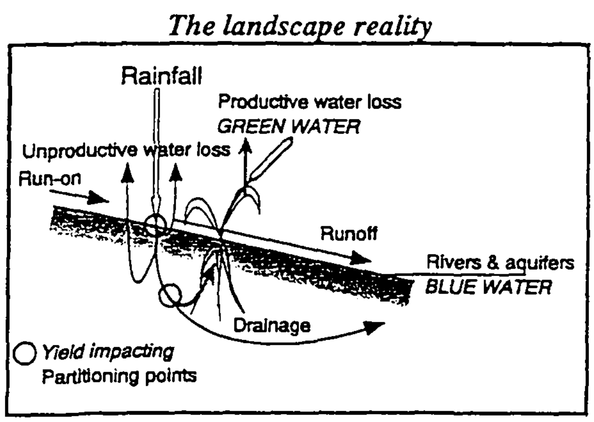


**Figure 1** The distinction between the 'green water' being released into the atmosphere as productive or non-productive water 'loss', and the 'blue water' recharging aquifers and rivers.

initiated in 1994 by the UN Commission for Sustainable Development (CSD), was recently presented to the UN General Assembly at its Special Session Five Years after Rio, in June 1997 (UN, 1997). Now convinced of the urgency of major shifts in the approach to water resources management, the General Assembly decided that the 1998 meeting of CSD will focus on "strategies for water resources".

Two months later, in August 1997, water experts, gathered at the Congress of the International Water Resources Association in Montreal to discuss water scarcity as a key factor in food security, expressed grave concerns about future global food security (IWRA, 1997).

The present article introduces a regional dimension to the discussion of the current water resources predicament. In particular, one key problem is addressed: how to secure enough water for the production of the additional food which will be required to feed the rapidly growing world population and, at the same time, meet the needs of other essential activities and functions in society, and of the natural environment. Food and biomass can only be produced if there is enough 'green water' for evapotranspiration, in connection with photosynthesis. Issues concerning allocation and use of blue water as well as a strategy to control demand, also need to be dealt with.

*Risk for serious water quality degradation*—hydrocide

In society as well as ecosystems, freshwater fulfils functions similar to those of the blood within the human body. Pollution of water systems, on which humanity depends, can be seen as analogous to blood-poisoning: a serious, even life-threatening condition. In an increasing number of sites, especially downstream locations, a situation threatens to develop where local water resources are no longer available in a usable condition. As water use intensifies and little or no efforts are mobilized to reduce or contain harmful effects on water quality, options for its use decline and reuse becomes impossible. Eventually, pollution loads will outstrip the self-purifying capacity of water systems. If no countermeasures are effected, anthropogenic assault will gradually lead to a situation where water is not only the source of life and human and ecosystem wellbeing, but also a source of disease, ecosystem disruption and societal disorder. Such a scenario may aptly be termed hydrocide (Lundqvist, 1998).

In Europe, more than 85% of groundwater lying beneath agricultural land exceeds the EU guidelines for nitrate concentration levels in drinking water (Stanners and Bourdeau, 1995). Nitrate levels are still rising both in groundwater and large rivers. Existing levels of phosphorus in surface waters are still high enough to cause eutrophication, in spite of improvements in wastewater treatment. The presence of pesticides in groundwater is of increasing concern, as these chemicals take a long time to break down in natural waters. The implication of this long time-lag is that even though the use of pesticides is declining in the European region, the situation will get worse before it can get better. Acidification of surface waters has been of public concern since the fish kills in Scandinavia in the early 1970s. Although overall acid deposition ($SO_2$ and $NO_x$) has decreased, critical loads are still exceeded in more sensitive regions of Northern Europe. In agricultural regions, nitrogen fertilizers may be a more important cause of acid deposition owing to the conversion of nitrates in the soil. Microbiological contamination is also causing increasing concern and many chemicals found in water, such as hormonally active compounds and persistent organic pollutants, are under scrutiny for possible health impacts (for an overview of the environmental challenges in Europe, see Stanners and Bourdeau, 1995).

In the developing world, major water-related problems include ground- and surface-water pollution resulting mainly from insufficient waste water treatment, lack of infrastructure to take care of sanitation and effluents from latrines, contamination from agricultural fertilizers/pesticides, and primary and secondary salinization of groundwater. A further explosion of pollution loads is expected in the near future in response to rapid industrial development in newly industrialized countries. As demonstrated by a recent study in South India, water pollution may be a significant consequence of successful industrial development, and control of and responsibility for this form of environmental degradation is often difficult to transfer to the polluters themselves (Blomqvist, 1996). Thus, pollution in the South is not only a poverty-related phenomenon, but can also be a result of rapid growth in the industrial and related sectors, such as transport.

Moreover, for the goal of universal supply of safe water and sanitation to be achieved by 2025, an additional 2.8 billion people have yet to be provided with safe domestic water, and an additional 5.4 billion people with safe sanitation (UN, 1995): tasks of almost unimaginable scope. The difference between the two figures may be taken as an indication of the degree of attention granted to the two related problems, and their relative orders of magnitude. By far the most concern has been devoted to the problem of water supply, while the attention given to water quality in connection with usage has been meagre. Thus, water quality degradation has been allowed to proceed almost unchecked.

## Water scarcity—a global outlook

### *Climate factors*

In arid regions, water is, by definition, scarce in relation to potential demand. Acceptance of this fact has been difficult to establish, possibly owing to the presence of large rivers that pass through many such regions, originating in precipitation-rich, humid highlands (e.g. the Nile, Zambesi, Euphrates, Tigris, Indus and Ganges Rivers, etc). The distinction between 'green' and 'blue' water indicated above may clarify the discussion of the complex problems relating to water management in arid regions. This means drawing attention to the fundamental role of freshwater in plant growth (where water constitutes one of the two main raw materials, with carbon dioxide). Vast quantities of 'green water' evaporates into the atmosphere when stomata open to absorb $CO_2$: the water loss being proportionate to the evaporative demand of the atmosphere. 'Green water' consumption of 4000 $m^3$ per ton of grain produced, sometimes considerably more, is not exceptional in tropical and

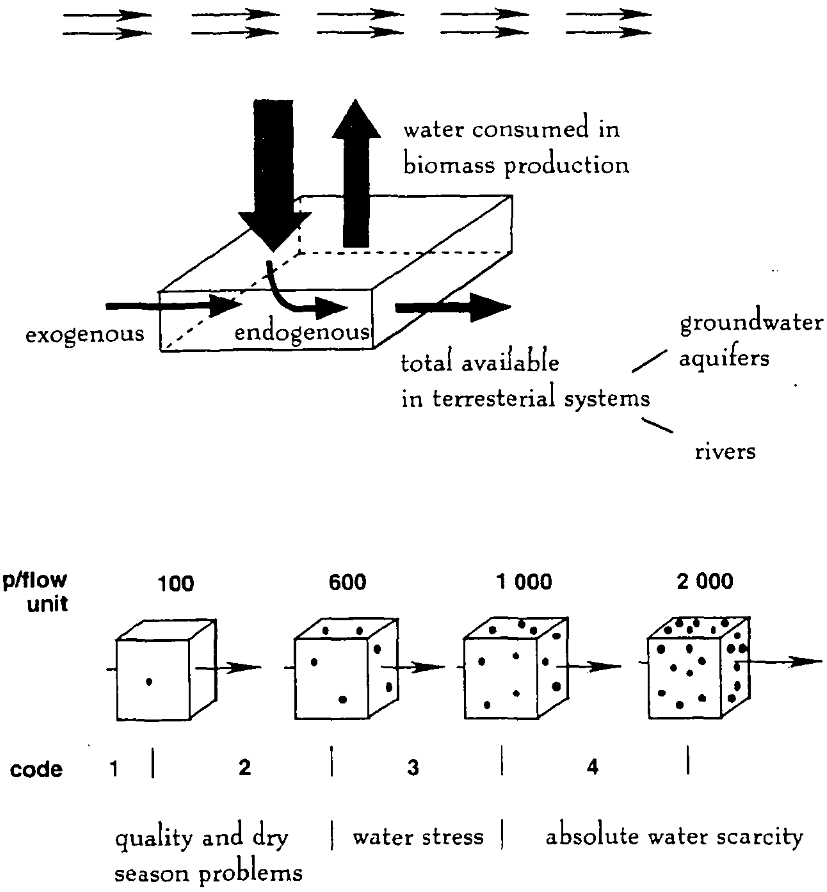


Figure 2 Demographic water scarcity. (a) Water availability and its two major components: exogenous, imported from upstream countries; and endogenous, run-off generated by rain within the country. (b) population pressure on available (blue) water.

sub-tropical regions. Arid regions typically suffer from 'green water' scarcity, which makes crop production dependent on the addition of 'blue water' through irrigation.

*Indicators of water-related environmental pressure*

The term 'water scarcity' may be applied in relation to five major categories of water use:

- *scarcity of water* for plant production, i.e. scarcity of 'green water', implying difficulties to meet current/future food needs through rain-fed agriculture alone:
- *demographic water scarcity*, i.e. demographic pressure on 'blue water' availability as an indicator of competition for water between individuals, sectors, and subbasins; political disputes and water pollution may be implicated;
- *technical water scarcity* refers to the withdrawal-to-availability ratio and indicates difficulty to meet increasing 'blue water' needs by further water resource development;
- *induced in-stream water scarcity*, which occurs when abstractions from natural streams and other water bodies increase and in-stream functions are affected; although it is difficult to determine exactly what constitutes an excessive withdrawal, it is obvious that functioning of aquatic ecosystems as well as estuaries are impaired at some stage;
- *use scarcity*, i.e. the limitation of options for the use of available water owing to degraded quality; even if water is available, pollution will reduce options for its use; moreover, the existence of polluted waters, as such, often constitutes a health hazard, providing a breeding ground for various harmful vectors.

*Terminology: water stress, water scarcity and water vulnerability*

A certain conceptual confusion affects the use of the above terminology. In different assessments made to quantify water scarcity implications, a variety of definitions are being used that describe water stress, water scarcity, and water vulnerability. Seemingly inconsistent assessments of the number of people that live in water-stressed regions or in regions that are expected to face water scarcity in the near future, tend to confuse politicians and erode expert credibility.

A large number of studies focus on demographic water scarcity (Falkenmark, 1994), a fairly objective parameter indicating long-term constraints on realistic expectations related to increased water demand linked to socio-economic development (Figure 2). Other studies focus on technical scarcity, highlighting an imbalance between user demand and capacity (financial and other) to make further water resources accessible. Various assumptions are made regarding food self-sufficiency, domestic and industrial water-use efficiency, efficient irrigation of total estimated irrigable land areas (Seckler *et al.*, 1997), unchanged per-capita-demand (UN, 1997), climate change (Kulshreshtha, 1993) etc. (Table 1 provides an overview).

*Five water predicament clusters*

Shiklomanov (1996) in a background report for the Comprehensive Assessment of the Freshwater Resources of the World (UN CSD, 1997), divides the world into 26 fairly homogenous regions for which water resources data is provided. Translating these data into categories of respectively demographic water scarcity, technical water scarcity and per-capita-use, show the world in terms of five main clusters (Figure 3) (Falkenmark, 1996). The five groups are characterized as follows.

- *The group 'close to the ceiling'* (N. Africa, W. Asia, S. Asia) where water demands are approaching accessibility. A major shift in strategy will be required to maximize

**Table 1 Different assessments of water stress, water scarcity and water vulnerability**

| Reference | Water stress | Water scarcity | Water vulnerability |
|---|---|---|---|
| *Falkenmark* (1994)<br>*Demographic scarcity* | 600–1000 people per flow unit | Chronic water scarcity:<br>>1000 people per flow unit | — |
| *Kulshreshtha* (1993)<br>Combined demographic/technical scarcity for different scenarios by 2025 | > 500 people per flow unit:<br>40–60% ratio<br>100–500 people per flow unit:<br>60–80% ratio | < 500 people per flow unit:<br>> 80% ratio<br>> 500 people per flow unit:<br>> 60% ratio | Marginal vulnerability:<br>> 500 people per flow unit: < 40% ratio<br>100–500 people per flow unit: 40–60% ratio<br>< 100 people per flow unit: 60–80% ratio |
| *CFWA*<br>Technical scarcity for current demand | Low water stress: < 20% ratio<br>High water stress: > 20% ratio | — | Combination of high water stress and low coping capability |
| *Seckler et al.*, 1997<br>Technical scarcity for standardized demand by 2025 | — | Water scarcity groups:<br>Group I—incr. demand/ > 75% ratio<br>Group II—incr. demand/ < 75% ratio<br>Group III—incr. demand/freeing water<br>Group IV—freeing water | — |

the benefit from available water to accommodate the increased need for food resulting from population expansion. This group may need to seek alternatives to expanded water consumption. A reorientation of national economies towards increasing food imports balanced by exports of high-value, low water-intensity products could possibly be considered.

- *The group with exceptionally high levels of per capita use* (Central Asia/Kazakstan, the Caucasus Mountains, the US). Water saving policies might allow reduced water withdrawals, thereby allowing a reduction of river depletion and ecological problems.
- *The intermediate group* (Central and S. Europe, S.E. Asia, the northern part of the People's Republic of China and Mongolia). This group is experiencing moderate levels of demographic and technical scarcity; the situation may be manageable since comparatively limited changes are foreseen in population and water demand.
- *Poor, semi-arid regions with rapid population growth* (E., W. and S. Africa). Critical issues here include water mobilization difficulties; the need to intensify food production based on highly water-efficient crops; and infrastructure development to keep up with the population growth.
- *Relatively water-rich regions* (Scandinavia, Canada, Central Africa, large parts of S. America). This group includes industrialized countries focusing primarily on pollution abatement to reduce ecological problems. Regions in this group may be called upon to intensify agricultural exports to water-scarce regions. Developing countries (Central America, Central Africa) may also focus on the balance between forest protection and opening up of new land for agricultural development, and on infrastructural development to keep up with population growth.

*The two most extreme dry climate regions*

The two most extreme regions in terms of respectively technical scarcity and demographic scarcity are both arid, i.e. they both suffer from 'green water' scarcity which makes crop production dependent on the addition of 'blue water' to achieve root zone water security.

- *The North Africa/Middle East region.* This region is 'close to the ceiling' in terms of its very high number of people per flow unit of water, and already exceeds a sustainable ratio of withdrawals. More 'blue water' can hardly be made accessible. Socio-economic development in countries with rapid population expansion may call for strategies based on both high efficiency and a high value per unit in water use. The only viable long-term development option in water-starved regions may be found in exporting high value/low water-intensity goods and services and to import the necessary goods, notably food, which requires very large volumes of water in relation to its economic value. The pumping of fossil ground water, which is done in some of the countries in North Africa and Middle East is obviously not a sustainable resource management practice. When very large volumes of fossil groundwater are used for the production of low-value food articles, the strategy needs to be reviewed.
- *Arid portions of sub-Saharan Africa.* This region tends to remain poor with mainly rain-fed agriculture. The low population density has not stimulated the development of water storage traditions (tanks etc.), which are widespread in S. Asian cultures (Agarval and Narain, 1997). The region is in great need of secure year-round access to water. Local water courses are often ephemeral, carrying water only during a short period of the year. Most of its large rivers are international and water-use rights may have to be negotiated.

One of the difficulties experienced by countries in the North Africa/Middle East region is the political and social insecurity associated with dependence on food imports from other regions. Apart from perceived or real threats of an embargo on the trade of food items, there is also a considerable economic challenge to poor countries to develop income-generating exportable products. A heavy reliance on domestic food production in countries with increasing water scarcity constitutes, however, a significant problem. This is particularly the case for countries where the majority of skills and social networks are geared toward traditional agriculture, while industry and other income-generating activities are poorly developed. Such is, for instance, the case in Yemen, where the annual per capita water availability is one of the lowest in the region. The country's economy is predominantly rural with rain-fed agriculture as a major occupation. However, due to its extreme water scarcity, Yemen has neither water security nor food security (Appelgren, 1997). To be able to improve living conditions in this context is a daunting task. Among other things, it will require the development of a broader economic base, where non-agricultural activities must increase in relative importance.

The problems typical for arid regions of sub-Saharan Africa have been highlighted by the challenges encountered by efforts towards multi-national collaboration over the sharing and utilization of the large rivers in southern Africa. Solving the lingering disputes that loom in the region is an important task. Within the SADC region, there are fifteen major international water systems. Neither socio-economic development nor attending to ecosystem requirements can be dealt with single-handedly by any individual country. Both issues must be approached in an integrated manner through joint initiatives by several riparians acting in close collaboration. Some assistance may be needed from the international community (Pallet, 1997).

The Okavango River is but one example of this complex problem. During periods of drought, socio-economic development and efforts to eradicate poverty in Namibia are invariably related to water withdrawals from the Okavango River. The waters of the Okavango arise in the humid tropical parts of Angola and pass through the north-eastern part of Namibia. Downstream Botswana, however, wants the flow untouched to preserve the unique Okavango delta (Pallet, 1997; Ramberg, 1997).

## The global food security issue

*Food self-sufficiency in the semi-arid tropics?*

The rapid growth of the world population raises the issue of the global food economy. What parts of the world can produce a surplus of food? What parts can be self-sufficient?

And what regions do not possess enough water to be self-sufficient in food production? The cluster diagram in Figure 3 allows an approximate idea of the overall situation by comparing water availability with water requirements. In a summary calculation, FAO estimates that for a diet of 2700 kcal per person per day (2300 vegetable, 400 animal-based) some 1600 $m^3$ per person per year of water in the root-zone is needed to allow self-sufficient food production (W. Klohn, Food and Agricultural Organization, Rome, personal communication, 1996). In humid climates, enough water is provided from 'green water'; but in arid climates required water has to be provided by 'blue water' (irrigation). In semi-arid climates, maybe some 50% of the necessary humidity can be provided from 'green water', while the remaining 50% has to be provided from 'blue water'. Clearly, irrigated agriculture, whether consisting of small-scale collection of run-off or large-scale irrigation, has to compete for 'blue water' with households, industry and in-stream water requirements.

If, as assumed by Seckler *et al.* (1997), some 200 $m^3$ per person per year are required for households and industry (a fairly water-efficient situation), the per-capita water need for semi-arid regions would be of the order of 1000 $m^3$ per person per year altogether [1600/2 + 200]. The 1000 $m^3$ per person per year line in Figure 3, thus becomes the dividing line between two zones. Countries on the right-hand side of the diagram would need to mobilize more 'blue water' to feed their current population at the targeted nutritional level. Any growth in population would aggravate current difficulties. If population density exceeds water availability beyond the 1000-people-per-flow-unit level, food self-sufficiency would be impossible since more than 100% of the total available 'blue water' would be consumed. Two types of constraints may be foreseen: one is that the required change may be too rapid given the particular society's ability to adjust; another is that the required mobilization level might be unrealistically high. A recent study (Falkenmark, 1997) indicates that by 2025, more than half of the world's population may be living in regions affected by water constraints that jeopardize food self-sufficiency.

The diagram in Figure 3 also suggests that the global bread basket will be found in the humid and subhumid regions in the bottom left corner of the figure. The diagram also shows that certain regions use excessive amounts of water. If water-use efficiency is improved by avoiding unproductive evaporation losses as well as seepage and the associated problem of waterlogging, certain savings might be accomplished. The water thus 'freed' could be made available for downstream uses (the US, the Caucasus Mountains, Central Asia/Kazachstan). The same would, of course, apply to many countries engaging in water-inefficient irrigation, although this is not evident from the cluster diagram, which only shows regional tendencies.

*Transfer of food*

Today, about one billion people in the world lack access to sufficient food. It now appears, as indicated above, that by 2025 half of the world's population may live in water scarce regions, where food self-sufficiency will be extremely difficult to achieve. A substantial food gap seems unavoidable in these regions. Food may, therefore, have to be transferred from surplus areas to deficit areas through trade and other food-regulating mechanisms (IWRA, 1997).

Countries that cannot be self-sufficient in food production, face the necessity of importing food from other countries or regions. In a general sense, transfer of food, either through ordinary trade agreements or other means, from relatively water-rich regions to water-deficient regions seems more practical and feasible than the transfer of water. The main argument for food imports rather than international water transfers to produce the equivalent food domestically, is that such large transfers of water would be virtually unmanageable and extremely expensive. The water, thus "embedded in food", has been referred to as "virtual water" (Allan, 1995). This concept is relevant in view of the great difficulties of many countries to mobilize

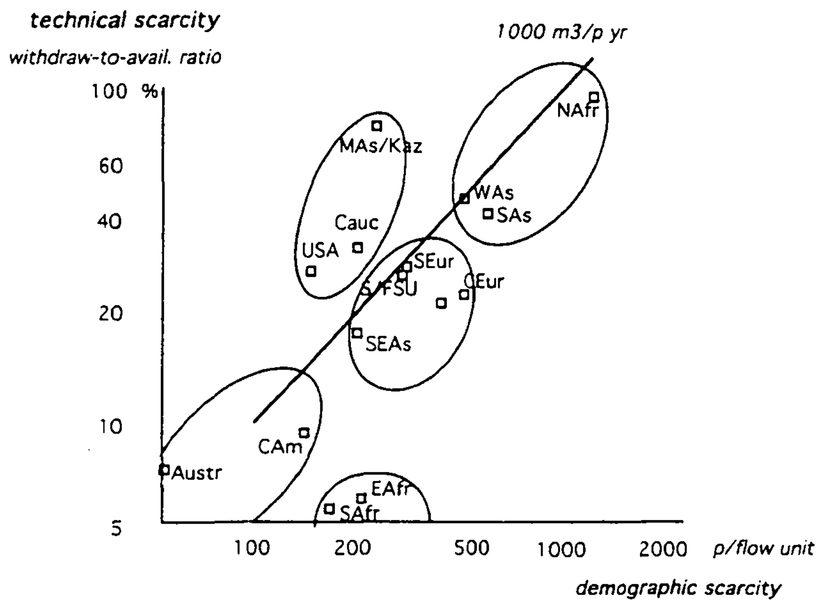


**Figure 3** Global differences between regions with different characteristics in terms of demographic (horizontal axis) and technical water scarcity (vertical axis). Five different clusters are shown including the total 1994 population. Data from Shiklomanov (1996).

sufficient water domestically to attain national food self-sufficiency. The concept also captures the tendency among countries with rising purchasing power and undergoing structural transformation of their economies, to import an increasing share of their food requirement.

Moves towards a more rational adjustment to water scarcity and the development of strategies for water-intensive products to be traded on the international market are, however, hampered for various reasons. For many countries in the South, the combination of weak economic and political systems and increasing import requirements of food is a major and most problematic dilemma. Logistic problems, and sudden drops in domestic food production are other complicating factors that hinder the development of viable international food transfers. In view of the considerable time delays to be expected in a possible adaptation of world trade and major market changes, it is urgent for the global community to assess the implications of this fundamental dilemma. An analysis by McCalla (1994) of future global food export volumes shows a gap between the assessment of optimists and that of pessimists: the former indicate a doubling while the latter suggest a quadrupling of the present export volume during the next 30 years.

### *Extra food produced where and for whom?*

Authoritative sources, such as the FAO and IIMI, assume that the major portion, or up to 80%, of the required increase in food production will come from irrigated agriculture (FAO, 1996). The World Bank/UNDP, in a study completed some years ago, estimated that there is considerable scope for expanding the acreage under irrigation by about 110 million ha, most of which might be in Asia (World Bank/UNDP, 1990). Apart from expanding acreage, the potential for increasing output from land currently under irrigation, is believed to be significant (FAO, 1996). There are, however, a number of barriers to the realization of this potential, at least in the short term. Also, available information is contradictory. In terms of expanding acreage, Africa has a potential of about 46 million ha while the actual acreage under irrigation is about 12 million ha. Latin America has a potential of about 20 million ha while Asia is believed to have a much larger potential (FAO, 1996). However, the experience of irrigation in Africa is quite disappointing (Moris, 1987) and the motivation to invest huge sums in Latin America seems to be lacking. For the time being, there are no signs of large-scale irrigation projects coming forward on any of the continents. Moreover, as pointed out by David Seckler, General Director of IIMI, among others, the world is currently loosing as much irrigation acreage through waterlogging and salinization as it is gaining from new schemes. Irrigation development has slowed down considerably compared to the situation during the 1960s and 1970s (Postel, 1997). Competition for water is increasing in highly irrigated countries like India and the People's Republic of China; and other countries in Asia have seen the rise of increased environmental awareness and protests against the resettlement brought about by expanded irrigation works. All these factors suggest that the rate of irrigation expansion will continue to be low for the foreseeable future.

The most desirable development in irrigated agriculture seems to be a combination of two activities:

- *improved management* through, for instance, better timing of water deliveries in relation to season, upgrading of structures, lining of canals, etc; and
- *introduction of appropriate technologies* such as water-efficient sub-surface and above-surface pipes and sprinklers, which require only modest investments but could save considerable amounts of water, at least in many Asian countries (Sivanappan et al., 1987; Sivanappan, 1987).

Introduction and use of water-saving technologies often requires energy inputs and/or more labour, apart from investments. Supply of electricity to pumpsets has, however, been a problem in many areas. Irregular supply is one of the bottlenecks, but there are also other worries, such as, how to finance the supply of electricity and how to minimize risks and effects of overpumping. In South India, for instance, strong farmer lobbies in combination with populistic political strategies have brought about a situation where electricity to pumpsets is provided free of charge. One of the results of this policy has been that there is no incentive to save water or to grow the most suitable crops. The struggle for free electricity was quite fierce with many clashes between farmers and the authorities. Several people were detained and even killed (Djurfelt, 1996).

Irrespective of technical solutions, it is evident that the economics of water use for irrigated agriculture have been distorted by enormous subsidies. Data from different countries indicate subsidies of 50–90% of costs (Tolba, 1994). The heavy burden of these subsidies on budgets is evidently one of the factors that impedes the building of new irrigation schemes as well as the maintenance and operation of existing ones. Also, subsidies counteract incentives to grow water-efficient crops. As illustrated in Figure 4, one of the most favoured crops in South India and many other water-short areas, paddy rice, gives a relatively small return to the farmer in terms of income per volume of water required. Paddy rice is, however, a major crop regardless of water availability and since farmers do not pay for volume of water used, that calculation is of little relevance to them.

### *Physical and economic constraints on food production*

Two very different considerations are relevant to the discussion of food production and food security: one being the quantities that can be produced, the other being the question of economic return.

One decisive factor determining food security is the physical limitation on the quantities that can be produced under given water and environmental conditions. Apart from climate-related difficulties to secure enough water, which exist in many parts of the arid and semi-arid regions of the world, it should also be mentioned here that fewer and fewer countries have the opportunity or the capability to develop more water.

The other important factor is economic return, that is, demand: there is little reason for a farmer to produce food that no one can afford to pay for or that no one wants to buy. Hence, while some are concerned about the potential to increase production from a resource point of view, others point to the lack of economic incentives for farmers to increase production, and to the very uneven distribution of purchasing power among consumers, which limits fair access to food available on the market.

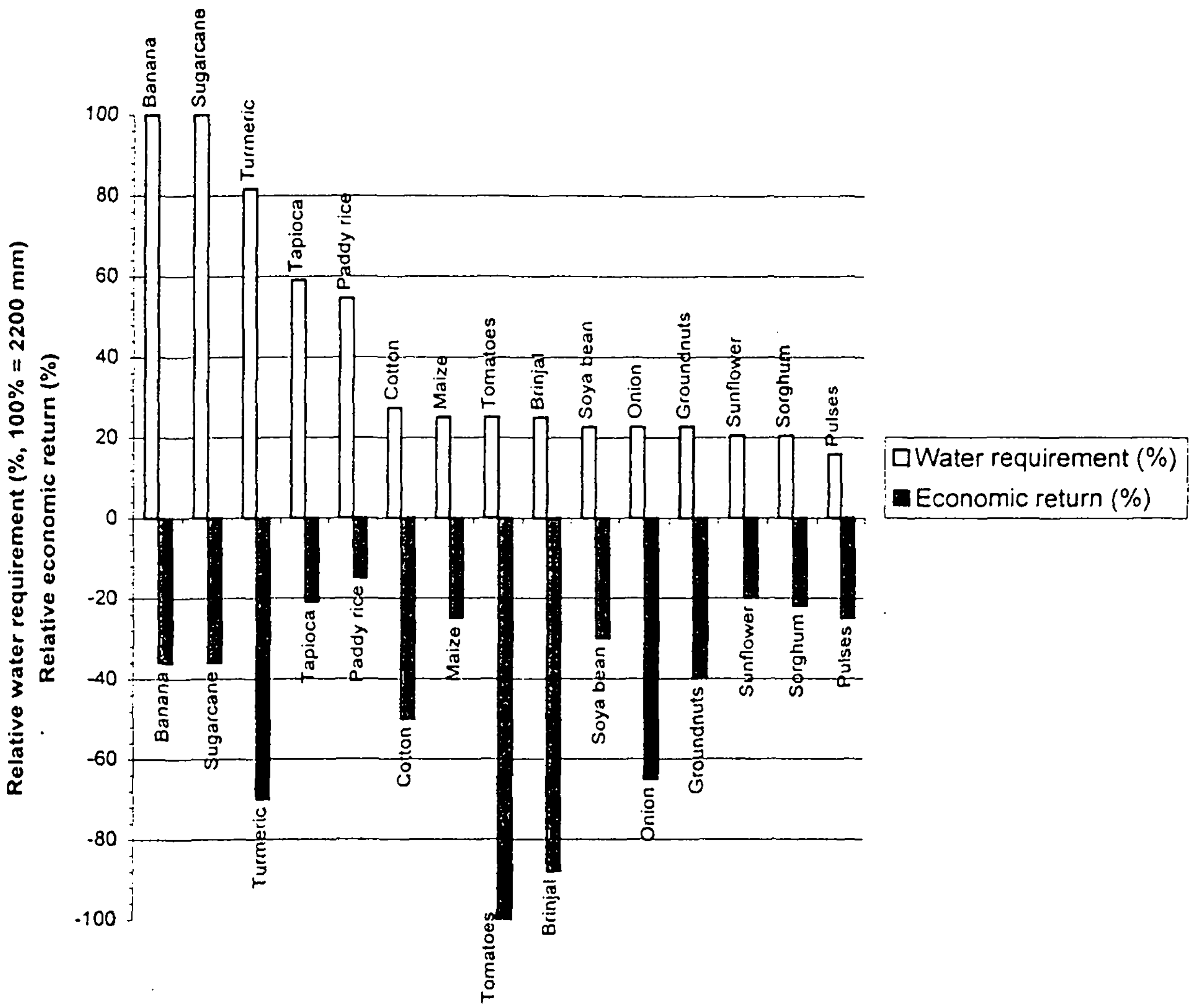


**Figure 4** Differences in crop water requirements (top part of figure) and the relative economic return per unit of water for the farmer (lower part of figure). Diagram based on information from Tamil Nadu Agricultural University, Coimbatore.

The argument based on water scarcity is a most valid concern, especially in relation to arid and semi-arid climates as discussed above. As far as economic incentives, it is quite plausible that farmers would increase output in some proportion to growing demand. If poverty were reduced so that those who, today, are barred from access to food, would have increased purchasing power, both the level of food production and the composition of the food being produced and traded, etc., would most likely be different from the prevailing situation today. "We do know what was actually produced certainly was possible, but we do not know how much more could have been produced if there were economic incentives for expanding output" (Sen, 1994, p. 58). Although economic incentives obviously exert an important influence on the level and orientation of production, many other circumstances might also be effective. Threats of food deficits, which do occur in rural areas, ought to be as good an incentive to increase production as the possibility of selling.

Purchasing power and access to markets are not distributed equitably. A widening gap in income level or purchasing power between nations, and also within nations, is evident in compilations such as the Human Development Report (UNDP, 1997). About 1.3 billion people have less than $1 per day to spend. At the same time, there is a tendency for the volume of aid and investment flowing into the most needy countries to stagnate in real terms (UNDP, 1997). Large parts of the world in arid or semi-arid climate regions, face the challenging combination of rapid population growth and a poor and vulnerable resource base. Although the majority of the poor are found in Asia, the most serious poverty problems exist in Africa. It is assumed that by the turn of the century, 50% of the population in Africa will be living under conditions of poverty (UNDP, 1997).

Other regions are experiencing a significant industrial expansion and structural change in their economies, particularly in Asia. In some parts of the Asian region there is both a rapid population growth and a dynamic industrial development. This development has resulted in considerably increased pollution (OECD, 1995), as well as a boost to purchasing power followed by increases in food imports, etc.

Rising levels of prosperity in parts of the South are expected to affect economic structures with increasing focus on industrial and urban activities. This development may also lead to changes in food habits. Developments in the People's Republic of China illustrate that a growing proportion of food needs will be met by imports, and that the country has both the economic capability and political will to become a major buyer of grain and other food stuffs on the international market (Brown, 1995). Similarly, current changes in food habits in Japan indicate that a sharp increase may be foreseen in animal-based consumption as a result of wealth and purchasing power. In the period 1960–1990, the average rice consumption in Japan fell by 40%, while meat consumption increased by 360%. (The figures are deceptive since meat consumption increased from a very low absolute level).

Uneven economic development and accompanying structural changes imply that incentives for increased food production may be strongly detrimental to the poorer population strata, as they tend to stimulate the production of luxury foods and animal fodder rather than grain for human consumption. Growing imports to large countries are also likely to raise general price levels. The long-standing tendency for food prices to fall relative to other commodities (Sen, 1994) may be reversed. It should also be borne in mind that consumer prices for many food articles are heavily distorted by subsidies in most countries owing to quotas and other regulations. Eventually, the rising costs of production and adjustments to improved farm-gate prices, will also raise consumer prices.

The combination of difficult environmental preconditions and weak economies is becoming more pronounced in certain parts of the world in view of demographic trends and changes in per-capita income. The widening gap between the 'haves' and the 'have nots' partly reflects differences in environmental, 'non-negotiable', preconditions and partly a variation in the degree of success of human ingenuity and effort to utilize the resource base. However, it is perhaps most often a sign of a rapid population increase where the consequent increase in demands cannot realistically be met through external support.

## Climbing the accessibility ladder

*Problems in mobilizing additional water*

Through empirical observations in Europe, it is usually argued that a country may, with comparative ease, utilize up to 15–20% of the total available 'blue water'. If a larger portion is to be captured, the technological and institutional arrangements have to be increasingly more complex and advanced (Figure 5). History provides many examples of so-called hydraulic civilizations that highlight the tremendous potential of advanced waterworks. However, these societies also illustrate the need for sophisticated political and

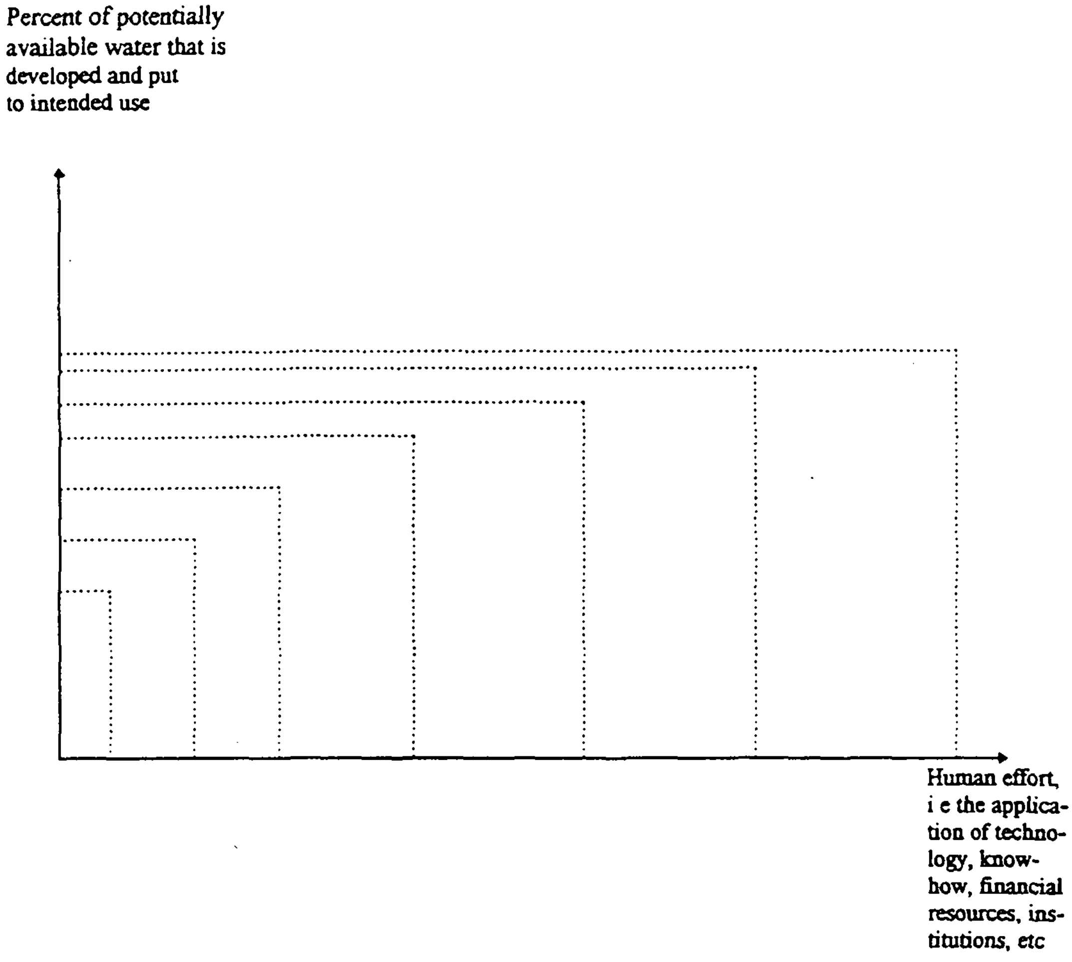


**Figure 5** The diagram implies that, in order to mobilize additional amounts of potentially available water resources, an exponential increase in human effort is required. In addition to the effort required to mobilize water for intended use(s), an equal increase is likely to be required to avoid, mitigate and remedy degradation of water quality associated with intensified use, and the effects of water degradation on the surrounding landscape.

institutional arrangements. They also raise the issues of the role of social and political order and the possibilities for a democratic system. The vagaries of nature may, thus, be converted to supreme human and cultural achievements, albeit not without concerted effort and considerable cost. Unless management is kept at a high level on a continuous basis, gains may be lost and serious reversals of fortune occur. The general lack of O and M in water resources management mirrors a widespread disregard for the need for continuous effort to make water development structures operate on a sustainable basis. Efforts required are usually not of the 'once-and-for-all' type. Water reservoirs, conveyance systems etc. require sustained high-level input in terms of maintenance and surveillance, without which nature is apt to take back what humans have acquired from her.

Another serious consideration is the need to balance the benefits from human interventions, i.e. the desired outcome, with possible negative associated impacts. While some negative impacts can be predicted, others arrive as 'surprises'. It could, thus, be asserted that it is necessary, and potentially of great benefit, to utilize 'non-negotiable' forces of nature. However, it should also be recognized that such efforts require an exponential increase in technological and human resources inputs and financial outlays in relation to the desired mobilization level (percentage of available water made accessible) (see Figure 5).

*Stages in water-management approaches in response to growing demand*

Given the magnitude and complexity of the looming water crisis, new water policies must reflect the fact that no policy can be implemented solely by professionals and official agencies. The involvement of users and affected interest groups is important for a variety of reasons. Firstly, prevailing systems of centrally controlled management have, for the most part, not been able to solve existing problems but, on the contrary, have led to widespread policy failure. Secondly, user involvement is also needed in order to spread responsibility. So far, users have often escaped responsibilities which rightfully might have been linked to their enjoyment of water services, such as financial responsibility, treatment of waste water, and the awareness of efficiency of use. Thirdly, unrealistic expectations of existing water resources can best be modified if management is carried out in a transparent manner and as a joint effort.

The viability of an administrative model that concentrates all responsibility for water management, including development, supply and waste-water treatment, to the public sector and at the central national level, is currently under scrutiny. Evidence suggests that antagonism between government authorities and water users often results in poor management, expensive solutions, and a generally sub-optimal situation. It is imperative that water users, and notably water polluters, assume a considerably more pro-active role and are able to take direct responsibility for water management. A real and functioning partnership between the various stakeholders holds great promise for enhanced opportunities for improved management and better stewardship of scarce and vulnerable water resources (Lundqvist and Sandström, 1997).

Policy must involve contributions from a wide range of stakeholders: suppliers, formal and informal institutions, public and private organizations, NGOs, and users. The main role of government is to facilitate this type of

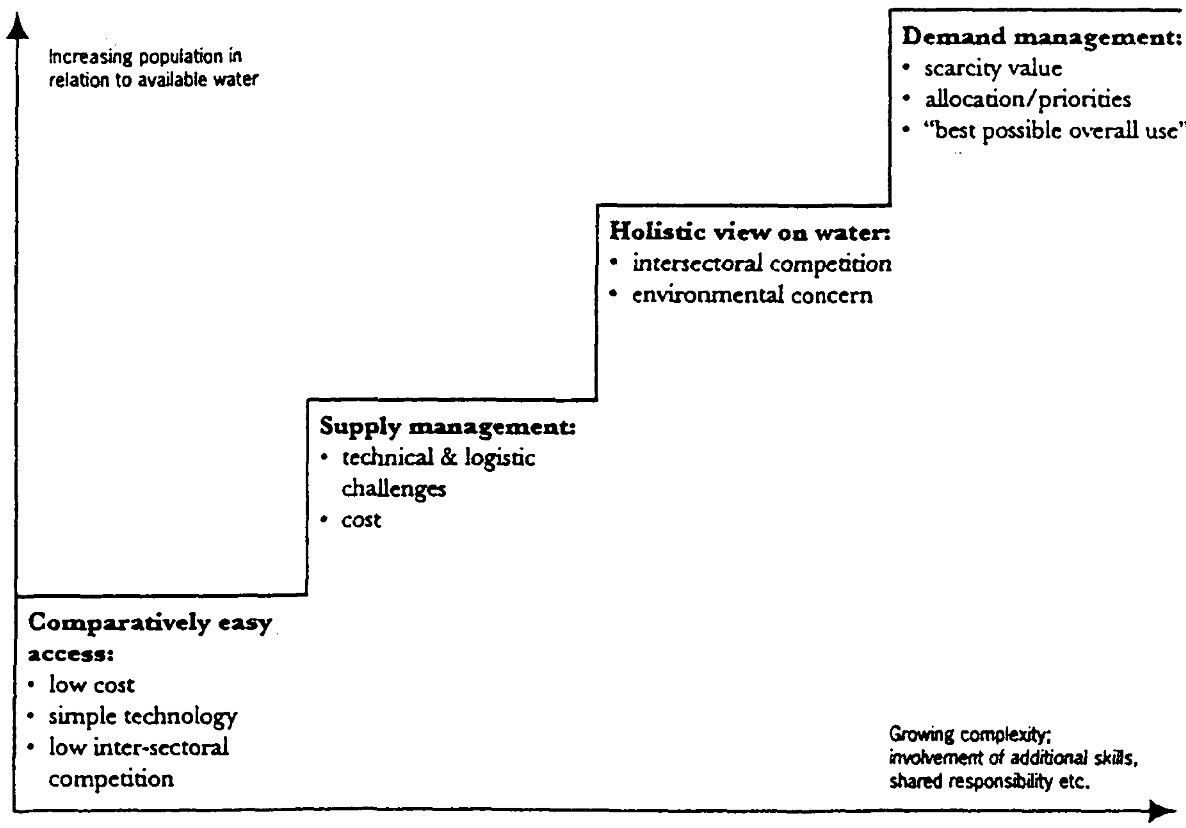


Figure 6 Stages in water-management approaches in response to growing demand.

partnership-based management, as well as providing efficient inter-sectoral coordination, transparent procedures, enforcement of rules and regulations, and performing similar tasks that cannot be accomplished by other agents.

Shifts in perception and awareness, and implementation and revision of policy are naturally consequences of changes in the character and severity of existing problems. Figure 6 attempts to summarize the stages of this process in a schematic way as progressive steps in water resources management which may be seen as logical and rational responses to growing needs and demands for limited and vulnerable water resources. The steps in the diagram indicate higher levels of management sophistication. Higher steps incorporate the elements of lower steps. This means that 'demand management' will include elements of 'supply management' and, of course, what is termed a 'holistic view on water'.

*The potential and limitations of demand management*

Regions where continuous policy failure has brought about a situation that appears to be nearing a water crisis, show certain common characteristics. These include escalating expenditure to maintain and expand water infrastructure, poor financial autonomy of the water sector and growing competition between user groups.

A new perspective is gradually being established on the conditions under which water is being provided to users, as illustrated in Figure 6. In many regions, the prevailing management of water resources has resulted in waste, abuse and low efficiency and productivity. Significant expenditure has been incurred by governments and donors while financial rates of recovery have been very low. This, in turn, has had negative long-term consequences for national or local budgets. Subsidies to the water sector are substantial and the financial autonomy for the water sector is much lower than that of other infrastructure sectors (Serageldin, 1995). The subsidies to the irrigation sector are often commented upon (see above): "irrigation projects are some of the most heavily subsidized economic activities in the world. In some cases, subsidies to irrigation covered 90% of the total operation and maintenance costs" (Tolba, 1994, p. 52).

Concern over the escalating financial problems of water development, waste-water treatment, etc. has become noticeable and was expressed, for instance, in Agenda 21 and at some of the preparatory meetings for the UNCED Summit (see, e.g. ICWE, 1992). There is broad consensus regarding the need to review policies relating to subsidies (UN(CSD), 1997). It is also to be noted that the ambition of most countries in this regard is to try to introduce a system whereby the water users in irrigation schemes would cover operation and maintenance cost, i.e. a fraction of the overall costs. In terms of drinking water supplies, the picture is much more complex and it is difficult to identify any specific trend.

In response to prevailing water-management problems, there has been a shift away from supply management towards seeking new opportunities in demand management. To an increasing extent, countries have already harnessed most of their readily accessible water resources, and their financial resources to construct additional facilities are severely restricted. Under these circumstances, it is necessary to look at the demand side to analyze water usage patterns and determine if amounts requested by some users can be reduced while at the same time keeping water accessible for worthwhile purposes. There is, of course, no blueprint for what is a worthwhile use. This must be determined through a political process. However, it is reasonable to state that the most worthwhile use can only be achieved if water policy addresses the three 'Es': efficiency, equity and ecological soundness (Lundqvist and Sandström, 1997).

The objectives of demand management can be related to two major concerns. One is to reduce the amount of water used in relation to benefits. The second concern, which is receiving much less attention in the general debate, is to achieve enhanced financial autonomy for the water sector. As noted above, the financial autonomy of the water sector is much weaker than that of other infrastructure sectors, or about 28% (cf. Serageldin, 1995).

Demand management is often a relevant strategy in situations where there is inefficiency or low productivity, e.g. in conjunction with irrigation, and/or where water services are heavily subsidized. In countries or regions where the main water source is natural precipitation, where irrigation facilities are few and water mainly supplied through public standposts, demand management would be useful mainly to improve the financial autonomy of the water sector.

*Efficiency of use versus efficiency of allocation*

Water-use efficiency refers to the accomplishment of a specific task without using more water than necessary. One interpretation of water-use efficiency refers to the amount of water that reaches its intended use relative to the total amount withdrawn. Calculations of efficiency are, however, quite complicated. As discussed above, large amounts of water are lost through evaporation, e.g. in crop production as well as along the water's flow through the landscape, especially when the source is distant from the site of use. A considerable portion of water in streams, canals, reservoirs, etc. seeps through the adjoining soil, adding to soil moisture and groundwater in the vicinity, and replenishes local aquifers.

There is also another kind of efficiency of increasing importance. As water becomes more scarce in a society, decisions are needed regarding its allocation. What sectors, activities, or regions should be provided with water on a priority basis? The question of 'efficiency of allocation' addresses how water should be allocated among social strata, sectors, activities and regions in order to achieve optimal results (Lundqvist and Gleick, 1997).

The two kinds of efficiency are, to some extent, interlinked, as shown in Figure 7, but they pose entirely different types of management challenges. It is quite conceivable to improve efficiency within a single sector or activity, such as agriculture, without achieving a high overall efficiency. If large volumes of water are allocated to a sector producing a low-value output, the total amount of value generated will be low. This is the case even if water-use efficiency is high in that sector. An illuminating example is presented by Hillel Shuval from Israel: "While 70% of the nation's water resources are devoted to agriculture, only 3–5% of the GDP is generated by farming" (Shuval, 1997). The ratio is remarkable in view of the very efficient water-use in the

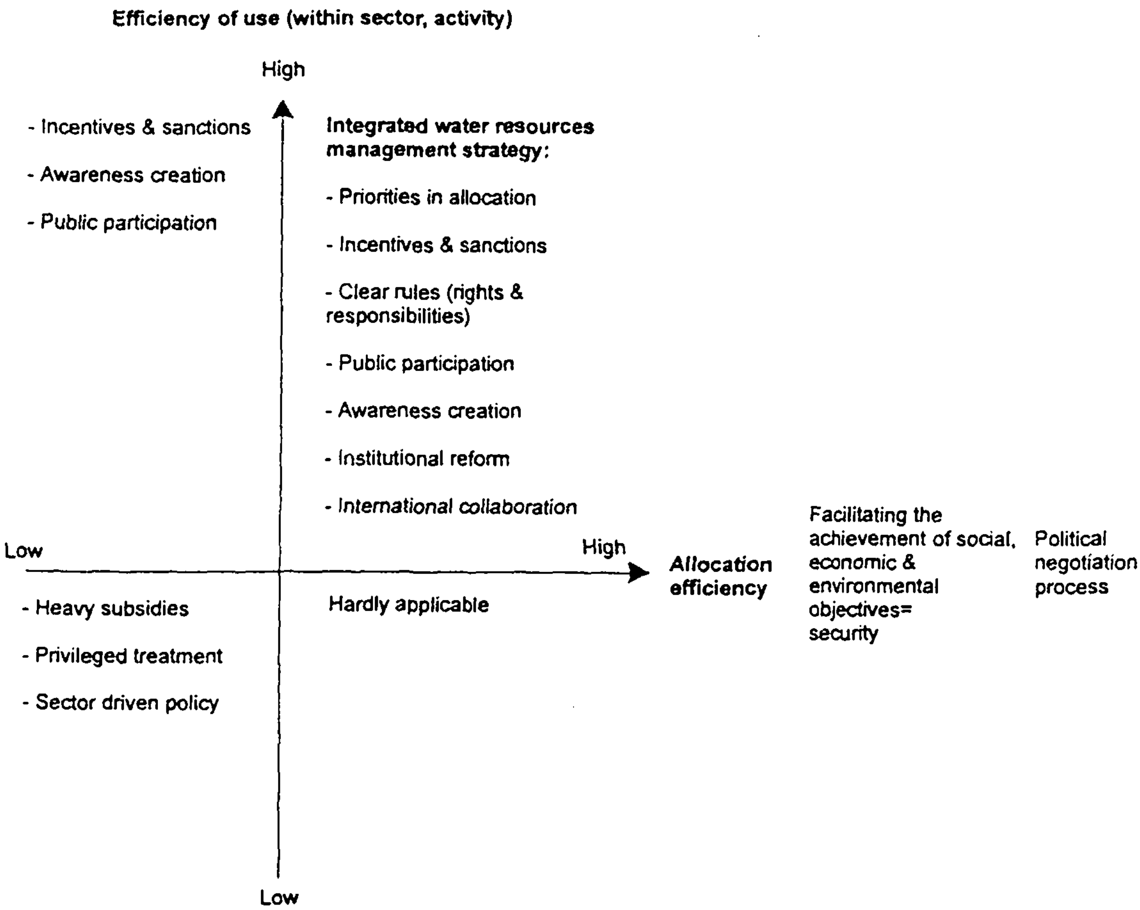


**Figure 7** A schematic representation of within-sector efficiency (vertical axis) and allocation efficiency (horizontal axis) and the policy elements associated with degrees of efficiency.

Israeli agriculture. In other words, it is possible to produce low-value items very efficiently. "If allocative efficiency is not achieved, it is possible, and even common, to be doing the wrong thing extremely efficiently. It would be much more useful to be doing the right thing, that is with efficiently allocated water, a little badly" (Allan, 1995).

The worst situation combines low water-use efficiency within a sector and low allocation efficiency, as characterized in the lower left part of the graph in Figure 7. This situation is typically a result of heavy subsidies, privileged treatment of certain sectors, i.e. where allocations are made without any attempt to control performance, and compartmentalized policy and planning, where sectors and activities are not coordinated. Many countries that have decided to allocate a large share of their accessible water to irrigated agriculture now find themselves in that corner. For most countries, it seems comparatively easy to improve efficiency within a sector or activity, i.e. movement along the vertical axis in Figure 7. To go from a low to a high allocation efficiency, i.e. along the horizontal axis is much more demanding.

In countries or areas with insufficient water to satisfy all potential needs and demands, choices must be made and priorities set. These are difficult tasks which can be addressed either through the political and administrative system, through the market, or through a combination of these two main systems. Discussions of use and allocation efficiency issues are gradually coming to reflect a more positive attitude towards the market as a mechanism. However, it is important to remember that markets cannot function properly in the absence of clear rules and regulations, i.e. it needs a strong political and administrative system (Kemper, 1996). Moreover, information and transparency are also crucial for market transactions to function smoothly. In many countries, neither of these preconditions are well developed. A dual strategy, where both market mechanisms and regulatory measures are promoted, should, therefore, be a realistic and viable approach.

It is also important to note that political action and planning now entails tasks which traditionally have not been much practised in most countries. Instead of only addressing the conventional top-down technical and administrative issues, water managers and planners are now required to also include other tasks in their agenda, usually associated with efforts to create an enabling environment. Accordingly, officials need to become true civil servants, seeking public participation in public work, stimulating community discussions about allocation and priorities, and generally induce more democratic decision-making. Both governments and NGOs now have far better means of communication at their disposal to perform these tasks compared to earlier times, with the help of information technologies (IT) including simple computer systems and other user-friendly technologies and applications.

Allocation criteria need to incorporate social and environmental concerns as well as political guidelines and objectives. If water allocation is guided solely by market forces and purely economic considerations, uses representing the highest monetary value would be promoted to the detriment of other purposes. Some groups, typically farmers and farm workers, would lose traditionally held allocations, which would reduce their economic base.

Generally, re-allocations require that the economy and the political system are able to provide alternative livelihoods for those affected, compensate third parties affected by market transactions, and arbitrate between conflicting claims for allocations.

## Summary and conclusions

Recent warnings emerging from the scientific community have resulted in a new perspective on the apparent simplicity of the water issue, and the tendency to concentrate only on 'blue water'. Grave concerns recently expressed regarding the looming water and food crises throughout the world make it urgent to emphasize a set of issues that have, so far, received no or insufficient attention in mainstream water resources discussions.

*Attention to escalating water pollution*

Considerable attention has been paid to supplying water to households in the developing world, but much less to its actual use and disposal. The introduction of viable and acceptable sanitation is crucial for expected health benefits to be realized, and must be attended to most urgently. Moreover, in the Third World, attention is seldom paid to the effects on water quality from its use in support of industrial development. There are already examples of local water resources being so severely polluted that they can no longer be used for water supply purposes. At the same time, experience from Europe suggests that the extent and severity of water pollution may in many cases be underestimated, particularly in the case of groundwater pollution. Realistic guidelines for anti-pollution measures are, therefore, needed, especially in poor countries, before it is too late to prevent serious, widespread and, on a human time scale, non-reversible groundwater pollution.

*Attention to both green and blue water in addressing biomass production*

The distinction in the local water balance between 'green water' (evaporating vertically) and 'blue water' (flowing semi-horizontally) has recently generated a new interest in the amount of water consumed in plant production, especially in tropical and sub-tropical dry climates where as much as 1000 $m^3$ per ton of biomass is released into the atmosphere. According to this calculation, some 4000 $m^3$ of water is required per ton of grain produced. More attention needs to be paid to the complementarity between the water consumed in plant production and the rainwater surplus recharging aquifers and rivers and available to meet the water needs of society.

In view of this complementarity between the 'green' and 'blue' water, it is essential that land and water resources are managed in an integrated manner. Increased consumptive (evaporative) use upstream to produce more biomass will reduce the water available to people living downstream. Some regions have already seen reductions in river flows. The Kariba dam on the Zambesi river has not been spilling since 1982 (Howard, 1994). The giant hydropower plant in the downstream portion of the Pangani river (Tanzania) can no longer produce its targeted quota of energy as the amounts of water reaching that stretch of the river are insufficient (Luhumbika *et al.*, 1994). In fact, it is difficult to determine whether the observed flow depletion merely reflects a succession of dry years, or whether major land-use changes are the cause. In any case, upstream–downstream problems will complicate water management in semi-arid regions in view of the struggle to achieve socio-economic development and an acceptable reduction of poverty. The fact that food self-sufficiency is often a central national objective further complicates the situation.

*Conceptual confusion over the term 'water scarcity'*

The interpretation of the concept of water scarcity varies considerably. To some, it simply denotes a situation where demand, including basic human needs, exceeds supply. The gap can be due to technological shortcomings, lack of purchasing power and/or lack of conducive institutions. In the more hydrologically oriented literature, water scarcity is discussed from other perspectives. A widely used index is demographic water scarcity, based on the number of individuals per flow unit of water. This is often also an index of dispute proneness, as well as proneness to water pollution. The recent UN Freshwater Assessment (UN(CSD), 1997) focuses on technical water scarcity, an index based on the withdrawal-to-availability ratio, and indicates a country's or region's position on the accessibility ladder. This index gives an indication of the complexity and the difficulty to mobilize an even greater portion of the total water availability to meet rising demand.

Both of these indices relate to 'blue water' scarcity. If 'green water' scarcity is added to this set, some of the difficulties experienced by the UN Freshwater Assessment (UN(CSD), 1997) in pinpointing the problems of sub-Saharan Africa may be overcome. The fact that green water scarcity introduces problems for rain-fed food production may contribute to development problems in the dry-climate tropics and subtropics, where many of the low-income countries tend to be concentrated (Falkenmark, 1991).

*Attention to regional differences in terms of food self-sufficiency prospects*

From the hydrological point of view, the world may be divided into five main clusters in terms of demographic as opposed to technical water scarcity. Food self-sufficiency problems vary considerably between the different clusters. The semi-arid regions are most vulnerable. The fact that possibilities are limited for mobilizing necessary amounts of 'blue water' to compensate for 'green water' deficiencies for food production suggests that, by 2025, regions hosting more than half the world population will become import dependent. In view of the scale of the world trade and market changes that this implies, it is urgent for the global community to assess the consequences.

*Distinction between use efficiency and allocation efficiency*

In countries with a high level of technical water scarcity and rising water demands, choices must be made and priorities set. Attention needs to be paid to efficiency of water use, so that unnecessary waste and leakages can be avoided; attention also needs to be paid to efficiency of allocation to ensure that limited water resources are used for the most worthwhile purposes, from the economic and ecological as well as social perspectives.

There is also an increasing need for equitable allocation of water within a river basin. Water allocation needs to be based on participation and joint decisions by local stake-holders. Upstream–downstream water-sharing data can be built into basin-wide water use profiles. For this purpose, it may be useful to distinguish three water-use categories:

- *Consumptive* (evaporative) water use, reducing downstream availability; occurs wherever water evaporates into the atmosphere as part of the plant production process, or is exported out of the basin by water transfers;
- *Polluting* water uses, sending a polluted return flow back to the river, reducing downstream uses; and
- *In situ* water use for hydropower production and navigation, but also for quality-sensitive aquatic ecosystems; protection of ecosystem services downstream in rivers may involve constraints on upstream water-use both in terms of quantity and quality; in addition to the use of water, an assessment of direct water loss through evaporation from moist surfaces needs to be incorporated.

An integrated approach to land and water use will clearly be essential in future water-resources management, encompassing all water-dependent as well as water-impacting sectors and activities within a basin, with proper attention to the difference between consumptive, polluting and quality-dependent in-situ uses.

### *Four emerging key concerns for global consensus-building*

Given the life-supporting implications of the issues raised in this paper, it is now becoming urgent to build global consensus to facilitate action in four main areas.

- Realistic guidelines, capable of being implemented, are needed for realizing anti-pollution measures.
- Guidelines are needed for participatory approaches to water allocation at the local community scale, to be incorporated within a framework of basin-wide upstream/downstream responsibilities.
- Interregional solidarity is needed, facilitating global food security through food trade from water-abundant to water-deficient regions.
- An overall water ethics is needed, defining principles that may assist countries upstream as well as downstream to maximize joint benefits from the waters passing through a shared river: for biomass production, for socio-economic production, and for in-stream use, including the protection of crucial ecological services of aquatic ecosystems.

These issues are extremely challenging and will demand a truly cooperative approach from the present generation of world leaders. It is essential to realize that, even if the world community might prefer not to address some of these issues, the problems they represent will not go away.

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