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Water Policy Article

Water issues: the need for action at different levels

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Abstract. Fair fresh water distribution among humans and nature and among all sectors will be one of the main challenges of the 21st century. There is a complex interplay between the different water users, and clear systematics are needed for efficient decision making. Water uses can be divided into four sectors, (i) water for people, services and industries, (ii) water for agriculture, (iii) water for nature, and (iv) water for energy production. A number of water related issues are relevant for each sector, though not all with the same importance. The issues relate either to water quality, water quantity, (urban) water infrastructure and integrated water management, and socio-economics and institutional aspects. Depending on the sector and the issues, there is an appropriate level for actions. Responsibilities for providing water for people, services, and industries must be taken at the local level (communities, cities, districts). Water for nature and the provision of ecosystem services ask for a more regional, national, or even multinational decision-making structure. The demographic development of the coming 25 years will be a challenge for agriculture to satisfy the food needs of all humans. The adequate and just access to agricultural products needs to be internationally guaranteed. Decisions for all sectors and on all levels imply formidable economic challenges, which will accompany human societies for the next decennia.

Key words. Water uses; virtual water; urban water infrastructure; ecosystem services; economy of water uses; drinking water.

1. Introduction

Water is a basic need for life on Earth and is used for many purposes. In recent years awareness has risen that the "precious blue" is a finite and vulnerable resource and is likely to have a decisive impact on the future development of human societies. The total amount of renewable freshwater available from precipitation on the earth surface stayed roughly constant over the last hundred years, whereas the water use for human needs multiplied sixfold, mainly due to raising water demand for food production and industrial activities. Although the current total water use itself has not yet reached the limit of available freshwater resources, the uneven distribution of the resources has made increasing parts of the world enduring severe water scarcity. The increased use of water has also meant an increase in wastewater. A large portion of released wastewater is not properly treated or not treated at all, polluting water bodies and reducing their use as freshwater resources. The situation is particularly serious in developing countries.

Given the considerable variation of the natural freshwater supply (precipitation) in space and time, water-related issues and problems have been quite different from one region to the other. In the mostly water abundant regions of the industrialized North, quality of surface and groundwater has been the issue of major concern over the last decades. Water scarcity was a problem only for some

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specific areas and has largely been overcome by implementing big water engineering projects storing the water in large dams and transferring it over long distances. In developing countries, the most obvious and pressing water-related difficulties are the huge backlog of access to basic drinking water and sanitation services. The increasing water scarcity associated with rapid population growth and relevant development is imposing a looming threat to food production and security in many countries, particularly those in arid and semi-arid areas. The increasing competition among users and for different functions, only exacerbates the situation.

In the past, difficulties related to chronic water scarcity have been limited to arid regions where the precipitation is not sufficient to grow enough food for the local population (e. g., North Africa and Middle East). Until recently, the countries in these regions could partly "solve" the water scarcity problem by importing "virtual water" in the form of food products and/or by mining non-renewable groundwater resources (Yang and Zehnder, 2002). With the growing world population, the increase in industrial activities, and the change of consumption patterns, the total amount of freshwater required for human activities is fast approaching a magnitude that water scarcity is becoming a global issue (Rosegrant et al., 2002). This, on the one hand, will lead to a substantial increase in the water scarcity induced demand for food import worldwide. On the other hand, food insecurity and starvation may intensify for a growing number of people because many countries that are faced with looming threat of water scarcity in the coming years are poor and populous. For these countries, "virtual water" import may not be an affordable option to deal with water scarcity (Yang et al., 2003).

According to latest statistics, 1.1 billion people have still no access to safe drinking water and 2.4 billion live without adequate sanitation facilities (WHO, 2000). The situation, however, is seldom related directly to water scarcity but to factors such as the lack of political will and the financial ability to provide adequate facilities that are affordable for the users. Many of the fast growing urban and industrial areas in the developing world are facing water challenges similar to industrialized countries (protection of quality of surface- and groundwaters) without having the means to satisfy even the very basic water needs (access to adequate water and sanitation facilities). As a consequence, the ecological water problems in fast industrializing countries are increasing dramatically.

In view of the high complexity and the many interests and stakeholders involved, a systematic approach is required when addressing the water issues and challenges, and identifying the need for action. The water needs have to be defined according to their uses, quality requirements, economic sensitivities, and the volumetric necessities. The main international water issues are closely related to the different water uses and functions of water. For the discussion of the action to be taken, it is helpful to examine these topics separately. Against this background, we first present a review of the different functions of water needed by different users. This is followed by a comprehensive discussion on the main international issues related to water at present and through the year 2025. We will then define the actions to be taken and assign the responsibilities for these actions to the different organizational levels (local, regional, and global). At the end the economic implications of water problems and challenges for all organizational levels and individuals living in industrialized and developing countries are highlighted. For reference, the technical terms used are defined in a glossary at the end.

The examples used in the text are not exhaustive, they are chosen by us for illustrative purposes. Obviously, there is a great number of studies and publications related to the topics discussed in this paper. To reference all of them goes beyond the scope of this paper. However, we would like to mention here especially the work of Gleick (www.pacinst.org), Postel (www.worldwatch.org), and Falkenmark (www.siwi.org) as well as organisations such as the International Water Management Institute (www.iwmi.org), the International Food Policy Research Institute (www.ifpri.org), FAO and WMO who have published in recent years extensively on various aspects of global water issues. The Intergovernamental Panel on Climate Change (IPCC) does incresingly take into account water resources issues in its analysis (www.ipcc.ch). We also would like to refer to the World Water Vision process led by the World Water Council (Cosgrove and Rijsberman, 2000). Issues related to the global water and sanitaion crisis were the subject of large recent international conferences such as the 2nd World Water Forum in March 2000 (www.worldwaterforum.org), the International Conference on Freswater in June 2001 (www.water-2001.de) and the World Summit on Sustainable Development in August 2002 where countries commited themselves to halve the proportion of people who lack access to clean water and proper sanitation (www.johannisburgsummit.org).

2. Water Uses and Functions

The following discussion on the different uses and functions of water is in line with the division used by the World Water Council (WWC, 2000) when developing the "Long Term Vision for Water, Life, and Environment in the 21st Century". Four categories are defined: Water for People and Industries, Water for Food and Rural Development, Water for Nature, and Water for Energy Production.

2.1 Water for people, services, and industries

2.1.1 Water for the basic needs. Drinking water is a basic requirement. The daily need for a person is between 3 and 9 liter, depending on the climatic conditions (Table 1). As a consequence each person needs annually between 1 m^3 and 3 m^3 of highest quality water. This water has to be free of pathogenic organisms, harmful chemicals, low in inorganic salts, and should not contain odorous compounds. The detailed quality is defined by the World Health Organization in its Guidelines for Drinking-Water Quality (1993, 1998).

Basic to human needs is also water for the personal and domestic hygiene. The amount actually used today varies between 5 to 120 liters per person per day, depending on whether water availability is restricted and/or people are using water for flushing toilets. A minimum of 30–50 liters per day is considered to be satisfactory (WHO, 1996; Gleick, 1996) for keeping up a basic personal and domestic hygiene, for cooking, and for washing (Table 1). Gleick (1998) calls this amount of water, which includes drinking water, “basic water requirement” or BWR.

Access to safe drinking water is defined differently in various countries. In urban areas 50 meters are proven to be acceptable by most, for rural areas that distance can be up to 500 meters (WHO, 1996). There is no universally accepted definition of adequate water supply. The Global Water Supply and Sanitation Assessment 2000 Report (WHO, 2000) measures the state of water supply according to the technologies applied. Although this classification may not be entirely correct for all cases, it is helpful for a certain systematic discussion. The following technologies were considered “improved”: household connection, public stand pipe, borehole, protected dug well, protected spring and rainwater collection. “Not improved” are: unprotected wells, unprotected springs, vendor-provided water, and tanker truck provision of water. Because of potential limitations in quantity, supply of bottled water alone is also considered to be “not improved”.

2.1.2 Water for other household needs. Watering the garden, washing the car, filling the swimming pool, and flushing the water closet increases in OECD countries the annual per capita water needs by another 30 to 90 m^3 (calculated from the information given in Gleick 1993b and Levin et al., 2002; Table 1). From the functional point of view, this water does not have to fulfill the high quality requirements of drinking water. In developing countries, the needs of water for these purposes are currently lower than that in OECD countries, but increasing rapidly.

2.1.3 Water for services. Hospitals, restaurants, hotels, and other institutions with a high hygienic vulnerability use considerable amounts of water. The actual numbers vary from 8 m^3 per capita and year in Africa to 35 m^3 in Europe and 140 m^3 in North America (Gleick, 1993b; Raskin et al., 1995; WRI, 2002).

2.1.4 Water for Industries. When cooling water and energy generation is not accounted for, industries consume annually between 8 and 140 m^3 per capita (Table 1). This water is generally heavily polluted and must be treated before it can be re-used (Raskin et al., 1995; Postel et al., 1996; WRI, 2002).

2.2 Water for agriculture

Besides drinking, hygiene and shelter, food is also an essential need of people. Food production needs much more water than is generally appreciated. During growth, the plant consumes water. Most of it is evapotranspired. For the production of about two kilograms of dry wheat plant material roughly 1 m^3 of water is needed under optimally controlled conditions with all nutrient supplied in sufficient amounts (Muller, 1974; Musick et al., 1994). Two kilograms of dry wheat plant contains approximately one kilogram of grains. Thus, based on grain weight, the water-use efficiency or water productivity is 1 kg m^{-3}. The water-use efficiency varies from plant to plant but is for other cereals on the average similar to wheat

Table 1. Water requirements for people, services, and industry[a]. Detailed information for each purpose is given in the text.

Purpose	Daily requirements liter per person	Annual requirements m^3 per person
Drinking water	3 – 9	1 – 3
Personal hygiene, sanitation services, and cooking	30 – 50	11 – 18
Other household needs	80 – 250	30 – 90
Services	20 – 400	8 – 140
Industries	20 – 400	8 – 140

[a] Data are partially calculated or taken from Gleick 1993b, 1996 and 1998; Levin et al., 2002; Raskin et al., 1995; WHO, 1996; and WRI, 2002.

(Postel, 1998; Rockström et al., 1999; Yang and Zehnder, 2002).

Taking wheat as a benchmark, one kilogram of wheat flour supplies about 3,500 kilocalories. Our body can, depending on the bread quality, extract from one kilogram of bread about 2,700 kilocalories. The global average daily supply by food was 2,500 kilocalories in 1992 (UNDP, 1996). For an average vegetarian diet, 260 m^3 of water per capita and year is needed. This number is true for optimal condition and zero loss. Assuming a pre-and postharvesting loss of totally 40%, the water needs rise to 360 m^3 (Zehnder, 1997).

The conversion ratio of plant material to meat ranges between 6% and 20%. This gives an average conversion factor of 0.1. As a consequence 10 times more water is needed for each kilocalorie from meat than from cereal. Under the stall-fed condition, to produce one kilogram of beef, about 5 m^3 of virtual water is needed (1 kg beef contains about 2000 kilocalories) (Zehnder, 1997). For pork and poultry, the ratios are 1:4 and 1:2, respectively (Cole et al., 2002). As a rule of thumb, a diet with 20% meat increases the individual annual food based water consumption to roughly 1,000 m^3 to 1,300 m^3 (FAO, 1994; Zehnder, 1997; Rockström et al., 1999).

In practice, however, the figure could be much higher. According to FAO, on average only 45 percent of the irrigation water is used by the crop. 15 percent is lost in the farm distribution system, the same percentage in the irrigation system and 25 percent in inefficient field applications (FAO, 1994). Depending on how the water is brought to the plant and the fertilizer applied, the water use efficiency in wheat production goes all the way from below 0.1 to 1.2 kg m^{-3} under rain fed and optimally irrigated situations, respectively (Musick et al., 1994; Smith, 2000). For rice similar variations could be observed (Ines et al., 2002). With water saving measures, including better management, application of water saving technologies and implementation of market-based incentives, water use in agriculture could be reduced substantially. Micro-irrigation, or similar efficient system could cut water use further (Postel, 1998; IWMI, 2000). In addition, reducing pre- and post-harvest losses could improve the yield of crop, increasing production of per unit water. Genetic engineering of plants may also reduce water consumption of some plants. The basic physiological needs by the plant will limit such a reduction, however. It has to be kept in mind, that all these measures will bring the water-use efficiency closer to 1 kg m^{-3}, but not much below this value, which can be regarded as optimally reachable yield. This yield is controlled by the physiology of the plant, i.e., this amount is needed for growth, for maintaining the internal water household in equilibrium, and allowing the biochemical and physiological processes to proceed properly. In summary, 1,000 to 1,300 m^3 per capita and year is the minimum for sufficient food production.

2.3 Water for nature

Water for people and water for agriculture are of obvious importance and have therefore in everyday policy and decision making priority. They both deal with an immediate need and basic question of survival. The needs of nature come only second or third in priority. Thus, they have been generally dealt with only when means and time allow it. Plundering natural ecosystems has commonly no immediate devastating effect, they come furtive and lingering until the point of disaster is reached. Then the action has to be taken at high costs. Overuse of natural resources has brought about the decline of many civilizations. Mesopotamian cultures have risen and fallen because of ecosystems' disturbance (Hillel, 1994), the Easter Island culture apparently disappeared because all life supporting ecosystems were much impaired.

Freshwater systems act as a source of water for people and for food production, and can be ecosystems by their own, e.g. lakes, rivers, wetlands, aquifers (Baron et al., 2002). Water quality is the key for both. Wetlands and aquifers, play an essential role in maintaining water quality by removing harmful microorganisms, chemical contaminants, high nutrients, and organic wastes. Surface water quality has improved in the United States and Western Europe during the past 20 years (Stanners and Bourdeau, 1995). Data on water quality in other regions are sparse, but water quality appears to be degraded in almost all regions with intensive agriculture, industrialization, and rapid urbanization. Pollution of rivers and lakes with nitrogen and phosphorus has a distinct effect on the ecosystem. At onset of fertilization, the effects seem to be positive, more primary production and better growth of fish. At a later stage, lakes become heavily eutrophic and deep waters anaerobic. As a consequence the reproduction of a number of fish species is hampered because their eggs are hatched in deeper waters. Eutrophic lakes can be brought to their "pristine" stage only with high investments in wastewater treatment and costly water management schemes. At the moment, there are no internationally accepted water quality standards for surface waters as we know it for drinking water.

Although, it is widely accepted that water must be reserved for ecosystems, there is little esteem when it comes down to decisions for their goods, functions, and services. In negotiations on the water distribution to the different sectors, ecosystems are often not seriously dealt with. Rockström et al. (1999) have compiled the existing literature and made a number of new calculations on the water vapor flows from ecosystems, crop lands, and other urban and rural systems (Table 2). The mean annual water needs per hectare can be considered the bottom line of water, which must be available to assure the function of that specific ecosystem. In reality it may be more, since water is also lost by direct evaporation from the soil surface, or it runs off or infiltrates into aquifers.

Table 2. Water needs by different biomes and their average global value of annual ecosystem services (taken and calculated from Rockström et al., 1999, and Costanza et al., 1997)

Biome	Vegetation subgrougs	Climatic zone	Land surface [a] 1000 km^2	Mean water vapor estimates km^3/yr	Mean water needs m^3/ha yr	Value of ecosystem services [b] US$/ha yr
Forest, woodlands	taiga	boreal	11,560	4,636	4,010	302
	predominantly coniferous	temperate	3,500	1,705	4,870	
	predominantly deciduous	temperate	8,500	6,199	7,250	
	woodland/woody savannah	temperate	5,200	2,165	4,160	
	forest dry/deciduous/seasonal	tropical/subtropical	7,400	5,857	7,910	2,007
	forest wet	tropical/subtropical	5,300	6,600	12,450	
	savannah/woodland, dry	tropical/subtropical	12,700	11,201	8,820	
	savannah/woodland, wet	tropical/subtropical	1,300	1,647	12,670	
Wetlands	bog	boreal	651	144	2,210	14,785
	bog	temperate	488	329	6,740	
	swamp	temperate	41	35	8,540	
	swamp	subtropical	16	18	11,250	
	swamp	tropical	508	841	16,560	
Grassland	cool grasland	mostly temperate	6,940	2,843	4,100	232
	mountainous grassland	temperate	650	426	6,550	
	warm and hot grassland	mostly tropical	17,300	10,356	5,970	
	mountainous grassland	tropical	650	390	6,000	
	dry shrubland	tropical	4,000	1,080	2,700	

[a] There is a difference between the estimates for temperate/borel and the tropical areas used for forests and woodlands by Rockström et al., (namely 24,080 km^2 and 26,700 km^2) and Costanza et al., (namely 29,550 km^2 and 19,000 km^2).

[b] Values given are the average for all sorts of temperate/boreal forest, all sorts of tropical forests, all sorts of wetlands, and all sorts of grass rangelands.

Ecosystems fulfil at least four different functions, namely, regulation functions, habitat functions, production and resource functions, and information functions (de Groot, 1992; IUCN, 2000). In practice, valuation of ecosystem assets is difficult since most services are not presently traded on markets and future social costs by current wrong decisions are difficult to be assessed by retro-extrapolation. Corporations usually are valued for acquisition or investment at the present discounted value of their future earnings. So, on this principle a watershed could be valued at the present discounted value of the flow of watershed services that it will provide in the future as was done by Guo et al. (2000). Such an approach may work for some cases. However, if services are included for which there is no market place it will fail (Heal, 2000). Thus, the impact of these reflections on decision making has been so far low, although the Dow Jones Global Sustainability Index (2002) has incorporated some of the ideas on ecosystem valuation and social costs into valuing large capitalized companies worldwide.

2.4 Water for energy production

Rivers were dammed for a number of reasons. Historically the most important was water supply for agriculture; remains of constructions are found back to 3000 BC in the Near East. Roughly 49% of the reservoirs are used to retain water for irrigation. Hydropower is used to perform mechanical work since the Greeks and Romans times. The discovery of electricity created new opportunities. Today about 11% of dams are used almost exclusively for electricity generation. Pure flood control dams make about 4%. Most of the rest serve multi purposes, such as water supply for people and agriculture, flood control, and electricity generation (WCD, 2000).

Dams serving multipurposes are economically more profitable. For irrigation alone, return of investment within 50 years is often difficult to achieve. A combination with electricity production and water supply for cities and industries allows to pay back investments earlier, and make the operation profitable. Ortolano and Kao Cushing (2000) have done a detailed study of such a multipurpose dam, the Grand Coulee Dam and the Columbia River Basin. Their calculations showed that irrigation pays less than 5% of the capital costs. The rest is earned primarily from electricity and a modest governmental subsidy for flood control.

Large dams currently produce about 19% of the world's electricity. While Europe and North America use more than half of their economically feasible hydroelectric resources, 60–80% of the potential in developing countries remains unexploited (Eberhard et al., 2000). The global reservoir capacity for hydropower is approximately 2,300 km^3 (WCD, 2000), or 390 m^3 per capita and year if all water in the reservoir would be replaced in one year. There is a growth potential of up to 2000 m^3 per capita and year when all capacities would be exploited. It is important to keep in mind that this water can be reused for irrigation and water supply. Thus, it should not be added up to the annual water requirement per capita. However, there is an annual evaporation loss from reservoirs of 27 m^3 per capita, which compares to 100 m^3 per capita from all lakes each year (Rockström et al., 1999).

3. Issues Related to Water Quality

3.1 Safe (drinking) water

In 2000 about one sixth (1.1 billion people) of the world's population had no access to improved water supply, in Asia (63%), Africa (28%), Latin America and the Caribbean (7%), and Europe (2%) (WHO, 2000). At any given time, about half of the population in the developing world is suffering from one or more of the six main diseases associated with water supply and sanitation. About 450 children below age 5 die every hour from waterborne diarrheal diseases. In developing countries about 36% of all death (39 million per year) are caused by waterborne infectious and parasitic diseases as compared to only 3.2% in industrialized countries (total death 11.4 million per year) (WHO, 1996).

In some delta areas (West Bengal, Bangladesh, Vietnam) arsenic is a major threat in drinking water. Knowledge about this threat is of recent origin (Nickson et al., 1998; Berg et al., 2001). It is estimated that in Bangladesh about 50 million people are affected and in West Bengal some 1 million. No quantitative information is yet available about Vietnam. The problem is also seen in some other areas (Mongolia, Mexico, Argentina, Chile, Ghana, Hungary), though to a much lesser extent.

In industrialized countries the microbial water quality is in general satisfying. Nonetheless, outbreaks of waterborne diseases are happening mostly due to accidents in water treatment or distribution systems. Here, the so-called (re)emerging pathogens play the major role: *Campylobacter*, pathogenic *Escherichia coli*, *Legionella pneumophila*, *Cryptosporidium parvum*, and *Calci* viruses. *Cryptosporidium parvum* was responsible for over 400,000 cases in Milwaukee, USA in 1993, and pathogenic *E. coli* (EHEC) for 2,300 cases in Walkerton, Canada in 2000 (Köster et al., 2002).

To estimate the cost of diseases, Murray (1994) developed a measure called disability-adjusted life years (DALYs). DALYs are the number of healthy years of life lost due to premature death or disability (Elbasha, 2000). It measures health by the degree of deprivation experienced by a person in being able to use one's own body for the daily obligations and enjoying leisure (Murray and Acharya, 1997). According to the estimate of Worldbank (1993), waterborne infectious diseases are by far the number one reason for DALY in developing countries and the number eight out of twelve in industrialized countries, the values are 293 million and 4.6 million, respectively. This means for developing countries and industrialized countries 79,490 and 5,610 DALYs per million of their population, respectively. These numbers are calculated based on the assumption that 80% of the infectious diseases are waterborne.

Linking DALYs to income loss on a global scale is not appropriate due to different income levels across countries. It could be done at a country or regional level. It is safe to suggest that the largest portion of the cost imposed by waterborne diseases is borne by those in the lower socioeconomic strata, and exactly those people can least afford the time of productivity loss by diseases.

3.2 Pollution by organic materials and nutrients

The introduction of the water closet and sewerage made an important contribution to improving domestic hygiene in the cities of Europe, North America, and Asia. But its introduction also generated large volumes of wastewater that were initially discharged untreated into the environment. This marked the beginning of the development of large-scale water pollution in Europe and North America in the middle of the 19th century. The hectic pace of urbanization and industrialization aggravated the problem.

Despite all efforts to remove all excess organic carbon from wastewater, not all aspects of pollution could be stopped. In the fifties of the 20th century the concept of the minimal nutrient was developed, reflecting *Liebig's law of the minimum*. Phosphate was identified as the trigger for surface water eutrophication (NAS, 1969 and Schindler, 1977). For the first time in pollution combat, engineers were seconded by chemists and biologists in identifying the causal agent. Chemical and biological methods have been introduced in the sixties to reduce the phosphorus in effluents of treatment systems. Phosphate bans in detergents were discussed in a number of countries and actually imposed in the seventies in some US states and 1986 in Switzerland. With the introduction of phosphorus replacements in the seventies and eighties, a main contributor to phosphate pollution was removed right at the source and additional bans were not deemed necessary.

The diversion of wastewater from many lakes, and the technological removal of phosphate showed already in the 1980s a positive effect. Severe algal blooms disappeared and many lakes in Europe and the US have a water quality even better than in the 1930s. Once it became clear that estuarine systems are not only phosphorus but probably at the same time also nitrogen limited, pressure was exerted from the coastal to the upstream regions to reduce their nitrogen pollution, i. e., also nitrate input had to be lowered. Both the Rhine Ministerial Conference and the North Sea Conference set effluents limits for treatment plants and for rivers leaving the countries for total nitrogen in 1990 (Stanners and Bourdeau, 1995). To obey these limits nitrification/denitrification steps had to be included into wastewater treatment.

Eutrophication has many negative effects on aquatic ecosystems. Perhaps the most obvious consequence is the increased growth of algae and aquatic weeds that interfere with use of the water for fisheries, recreation, industry, agriculture, and drinking (Carpenter et al., 1998). Oxygen shortage caused by senescence and decomposition of nuisance plants cause fish kills. Eutrophication causes the loss of habitats and is a factor of loss of aquatic biodiversity (Seehausen et al., 1997). Freshwater blooms of cyanobacteria release water soluble neuro- and heptatoxins when they die or are ingested. They can kill livestocks and may pose a serious health hazard to humans (Martin and Cooke, 1994).

3.3 Synthetic chemicals, heavy metals, and pharmaceuticals

400 million metric tons of synthetic chemicals are produced per year, 2,700 new compounds are registered at the EU since 1981, 30,000 compounds are produced in quantities above one ton, 3,300 chemicals are used in human medicine, etc. By looking at these numbers, it is not surprising that some chemicals find their way into the environment and eventually into water. In fact many of these chemicals are designed to be used in or to reach the environment. Pesticides are manufactured to be applied outside a containment and pharmaceuticals will eventually be excreted by the animal and human body through urine into wastewater.

A number of barely understood diseases could be linked to some synthetical chemicals (e. g., DDT to diseases in seals or weakening of eggshells in birds of prey; benzene to cancer), or heavy metals (e. g., mercury to Minamata Disease, arsenic to fatigue and cancer). Targeted measures have helped to eliminate many of these chemicals from the water environment through ban of application (DDT), change of production (benzene, mercury), or the use of alternative water sources (arsenic). These chemicals are because of their acute effects the best known. There are a number of compounds found in traces in aquatic systems that are suspected of harmful effects on individual members or communities of ecosystems, the so-called emerging contaminants, such as polybrominated diphenyl ethers generally used as flame retardents in furniture, textiles electronic appliencies, etc., fluorinated sulfonate detergents, methyl *tert*-butyl ether (MtBE), pharmaceuticals, including synthetic estrogens (Richardson, 2002; Schmidt et al., 2001; Trussell, 2001).

Absolute predictability for fate and effects of all old and new chemicals will be difficult to achieve. An impressive illustration of the surprises in store is the recent discovery that various chemicals and pharmaceuticals in daily use have an endocrine or hormone-like effect on fish, water snails, etc. even at extremely low concentrations in water. Whereas acute, accidental water pollution leads to death of animals exposed to it (e. g., fish dying because of liquid manure discharges, and catastrophes with cyanide and heavy metal pollution as has occurred recently in Romania and Hungary), certain chemicals lead to developmental abnormalities in the second or third generation at persistent very low concentrations (ng range). It is not yet possible to determine with certainty whether these effects are the first indications of much greater damage, or whether the extent of the damage is already fully evident.

3.4 Pollution by agricultural production

In agriculture the need to produce more food for a growing population has a direct link to the quality aspects of the aquatic environment. Three factors are of importance: increased soil erosion, chemical pollution (incl. increased salinity) by fertilizers and pesticides, and pollution from animal operations (Novotny, 1999). Excessive sediment loading as a consequence of erosion disconnects the rivers from groundwater interaction (fine sediment particle clog water carrying interstitial connections), destroys spawning areas (many fish need gravel), increases turbidity in the receiving waters and loss of storage capacity in reservoirs (high sedimentation rate). The annual nitrogen fertilization will augment from 87 million tons in 2000 to 135 million tons in the year 2020 approximately equaling the nitrogen input from natural sources (140 million tons per year). Phosphorus input will increase from 34.3 million tons in 2000 to 47.6 million tons in 2020. As food production increases, pesticide production becomes more important. It has gone from about one million ton per year in 1960 to 3.75 million tons in 2000, and will reach about 6.55 million tons in 2020 (Tilman et al., 2001). Some of the nitrogen and phosphorus becomes part of the food and is as such exported to other places. After digestion by humans or animals it is excreted with a high eutrophication potential. Run-offs from animal factories, feedlots and grazed pasture are now one of the main polluters with nitrogen and phosphorus. Since a few years it also became apparent that pharmaceuticals (antibiotics, growth hormons) from animal treatments find their way to the aquatic systems. The tradition in agriculture has been to maximize production and minimize the cost. Little attention was given to the impact on the environment and the services it provides to society. With a significant increase in agricultural production in the coming years, it is critical that agriculture practices are modified to minimize environmental impacts, though many such practices may increase the costs of production (Tilman, 1999).

4. Issues Related to Water Quantity

4.1 Water scarcity, food production, and ecosystems

The largest portion (71%) of the water withdrawn is used for agriculture (UN, 2000), which translates to 2,424 km^3 per year or on an annual per capita base of 404 m^3. If the total water needs (rain fed and irrigation) is taken into account, the annual per capita needs for cropland is between 1,000 m^3 and 1,300 m^3 as calculated in Section 2.2. The values suggested by FAO (1,150 m^3, 1994), Rockström et al., (1,180 m^3, 1999), and Zehnder (1,258 m^3, 1997) are within this range. Meat production is included in the figure because a large portion of it is produced under stall-fed conditions. In developed countries, about 70% of harvested crops are fed to livestock (NRC, 2000). Worldwide, grazing on grassland only accounts for a small amount and thus is not considered here.

As agriculture is the largest water user among all anthropic sectors, there is an intrinsic relationship between a country's renewable water resources and the capacity for food production. In water scarce countries, lack of water poses a persistent constraint to food production. An increasing amount of food has to be imported to substitute local water demand. Of the food imported, cereal grains have been the dominant commodities in terms of the quantity and importance for food security to the importing countries. Yang et al. (2003) applied modeling techniques to quantitatively articulate the relationship between a country's water resources and the need for cereal import. A per capita water threshold of 1500 m^3 yr^{-1} (all water needs included) was estimated, below which a country's cereal import is closely related to its renewable water resources. The volume is close to the water stress threshold of 1700 m^3 yr^{-1} suggested by Falkenmark and Widstrand (1992). Yang et al. (2003) found that the water threshold has dropped over the last 20 years, thanks to the improvement in water use efficiency, replacement of rain fed by irrigated areas, and perhaps also the increasing use in non-renewable fossil groundwater.

The annual available water gives a grand total which allows us to make estimates about the water situation in a given region. However, it is of importance when and at which rate water becomes available. The annual rain pattern, to a large extent, controls the type of agriculture which can be carried out (rainfed, irrigated, crops requiring high or low amounts of water, etc.) and the type of ecosystems which are able to proliferate. Humans have learned through building dams and reservoirs to overcome some of these limitations for basic water supply and crop production. Natural systems have low possibilities for such regulatory actions. Anthropogenic influence can drastically change the dynamics of water availability and influence spatial heterogeneity (Stanley et al., 1997). This is particularly true for river systems. In rivers with a regulated flow, the benthic communities (algae and macroinvertebrates) are characterized by lower diversity and density, as compared to homologous non-regulated rivers in the same zone. Similar effects have also been observed with fish communities. This seems to be the consequence of the absence of floods, which sporadically create landscape heterogeneity and thus more variations in habitats (Cazaubon and Giudicelli, 1999; Fausch et al., 2002). Sporadically high discharges increase also groundwater infiltration rate and the wetted perimeter of a river, a habitat for a specific flora and fauna. For example, cottonwood seedlings show a very specific requirement for appropriately timed high flows to create and saturate suitable floodplain sites and a gradual flow recession to permit seedlings survival (Mahoney and Rood, 1998). It is important that flow recession is slow enough for protecting the fauna from stranding and providing a longer period of high flows for vegetation seeding (Petts and Maddock, 1996; Baron et al., 2002).

4.2 Water situation at present and in the future

Estimates of the annual rainfall on the landmass of the Earth go between 99,000 km^3 and 119,000 km^3 (Gleick, 1993b). The rain is a natural and renewable resource. The local and global distribution of the water between the different user compartments is a point of debate. We have tried to summarize the current knowledge and estimates for the water need of each compartment (Table 3). The compartment "water for people and industries" represents the least, followed by "water for food production", "other systems", "river runoff", and "water for ecosystems". In total, the water needs of 118,552 km^3 add up to the amount of the maximum estimated annual rainfall.

The water needs were also extrapolated to 2025, assuming a world population of 8 billion as compared to 6 billion in 2000 (WRI, 2002). There are a number of compartments that do not allow flexibility while there are others which do. The basic supply of water for people and water needed for food production allows little elasticity and there is no substitution. The water use by ecosystems is a rough estimate and the values given may vary by approximately +/– 25 percent (Rockström and Gordon, 2001). We have used the mean values reported by these authors and made two assumptions for 2025. First, both the total volume of the water for ecosystems and the annual per capita needs for the ecosystems remain constant. The second assumption was made with the idea in mind that nature needs resources and spaces for its development and each human being requires a certain amount of ecosystem services as a physiological and psychological

Table 3. Global water needs for 2000 and 2025.

Water uses and fates	2000 [a]		2025 [a]			
	$km^3\ yr^{-1}$	$m^3\ cap^{-1}\ yr^{-1}$	$km^3\ yr^{-1}$		$m^3\ cap^{-1}\ yr^{-1}$	
Water for people						
Basic needs (drinking water & hygiene) [b]	110	18	146		18	
Hosehold activities	300	50	400		50	
Industry and services	930	155	1,240		155	
Total [c]	1,340	223	1,786		223	
Water for food production [d]	7,200	1,200	9,600		1,200	
Water for ecosystems [e]						
Forests & woodlands	40,010	6,668	40,010	53,344	5,002	6,668
Wetlands	1,367	228	1,367	1,824	171	228
Grassland	15,095	2,516	15,095	20,128	1,887	2,516
Total	56,472	9,412	56,472	75,296	7,060	9,412
Other systems						
Green areas in urban settlements [f]	100	17	200		25	
Upstream rural water use [g]	210	35	150		19	
Lake evaporation	600	100	600		75	
Evaporation from reservoirs [h]	160	27	320		40	
Tundra & desert	5,700	950	5,700		713	
Total	6,770	1,129	6,970		872	
River runoff [i]	46,770	7,795	43,486		5,436	
Total water uses and fates	118,552	19,759	118,314	137,138	14,791	17,143

[a] World population in 2000 and 2025 is 6 billion and 8 billion, respectively (WRI, 2002).
[b] Approximately 50 liters per day.
[c] This total reflects the water use of an average industrialized country in Europe.
[d] Falkenmark and Widstrand (1992) estimate 1,700 $m^3\ cap^{-1}\ yr^{-1}$ to be sufficient for both water for people and food production. Zehnder (1997) estimated with a diet of 20 percent meat and a daily caloric intake of 2500 kcal a water need of 1,258 $m^3\ cap^{-1}\ yr^{-1}$, FAO (1994) 1,150 $m^3\ cap^{-1}\ yr^{-1}$, Rockström et al. (1999) 1,180 $m^3\ cap^{-1}\ yr^{-1}$, and Yang et al. (2003) calculate a critical amount to be around 1500 $m^3\ cap^{-1}\ yr^{-1}$. This last number includes also the water for people fraction.
[e] Left column in the split field, total volume "water for ecosystems" remains constant, right column the per capita volume is kept constant.
[f] Assumed doubling of the area of urban settlements.
[g] Consequences of the reduction of rural population.
[h] Assumed doubling of the reservoir's surfaces and capacities.
[i] All the runoffs of Ganges/Brahmaputra, Indus, Mekong, Yangtze and Nile will be used upstream in 2025.

life support. Because of the demographic development, this would boost the water needs to 137,138 km^3, far beyond the current annual availability. The most flexible compartment is the river runoff. Rivers can be dammed and regulated to retain large parts of the water, which otherwise would flow into the oceans. However, this may have some drawbacks from the production point of view. The absence of river water input into the estuarial and coastal oceans will certainly have an effect on the quality and productivity (e.g., fish) of these ecosystems. In our runoff estimates for 2025, we took the extreme assumption that the waters of Ganges, Brahmaputra, Yangtze, Mekong, Indus and Nile will no longer flow into the oceans. The demographic development on the Indian subcontinent and Southeast Asia will put pressure on the waters of their rivers for agricultural purposes. Many long-time projections (e.g., Sigurdson, 1977) foresee for these regions a crucial water shortage. With the damming and water diversion projects in China, the flow in the Yangtze will be reduced, which can impose significant negative impacts on the riparian and estuarial ecosystems. Agricultural development in Ethiopia, the rapid growth of the population in Sudan and Egypt, and the construction of large irrigation projects in west of Lake Nasser (Southern Valley Development Project, or Toshka Project) will draw so much water from the Nile that there is nothing left to the Mediterranean (Egypt, 1999).

5. Issues Related to (Urban) Water Infrastructure and Integrated Water Management

5.1 Water infrastructure and investment

By and large, the functions of urban water infrastructure include production and distribution of water for people, collection and treatment of wastewater, and drainage of stormwater. The production of water for people ranges from withdrawal of water from a source to sophisticated treatment technologies. The ways of the production depends on the quality of the source and the finances available. Taking into account the distribution system, the technical efficiency of urban water supply is often low. Up to 65 percent of the bulk water supply in cities never reaches the users, and thus considered "unaccounted-for water" (UFW). UFW is as low as 8 percent in Singapore and less than 20 percent in most well managed cities. Tokyo was able to cut its water leakage from 22 to 10.2 percent between 1960 and 1992. In the United Kingdom, as much as 25 percent is lost to UFW (WRI, 1996). In Damaskus the figure is 65 percent and in Casablanca 33 percent (ADB, 1994). In China, it is estimated that over 35 percent of the water in the urban systems is lost to UFW (South China Weekend, 2001).

There are two major causes of UFW, physical and commercial. Leaks to groundwater are the former and illegal connections, malfunctioning meters, incorrect meter reading, and faulty billings belong to the latter. Capital investment, operation and maintenance were done in the past by the municipal sector. With the increasing financial constraints on the one hand and rising demand for water supply on the other, it has become more and more difficult for this sector to support these activities alone. There is a trend that the private sector is taking over some of the tasks, by services (e.g., Santiago de Chile), management contracts (e.g., Amman), lease (e.g., Senegal), operation transfer (Sydney), concession (Buenos Aires) or divestiture (England) (Saghir et al., 2000). Generating sufficient revenue to finance the utilities will only be possible through a combination of increased tariffs, improved billing systems, and a reduction of leakage losses.

The life span of the urban infrastructure is between 50 and 80 years. This requires an annual renewal rate of 1.3 to 2 percent. Only few cities in Europe invest sufficiently. Amsterdam and Zurich run at 1.7 percent, Vienna at 1.2, Munich at 0.8, and London at 0.1 percent. Since most cities in industrialized countries have not replaced their water infrastructure at a sufficiently high pace, many cities and agglomerations will have to do so in the coming 20 to 30 years. Failing urban water infrastructure has recently been cited by the American Society of Civil Engineers as a major national issue that will take many billions of dollars to address (ASCE, 2002).

5.2 Integrated catchment, river basin, and groundwater management

Most impairments of water resources and the health of aquatic systems are the direct results of local and regional human activities, such as water consumption, waste production, construction of buildings and transport systems, and the engineering of rivers (Baron et al., 2002). Large-scale effects, crucial in air pollution and climate change, play a relatively lesser role at this scale. Many water problems are either "home-made" or are the result of upstream activities. The awareness of inhabitants and local stakeholders to water issues is generally high on a watershed scale. People care for the state of their local water resources, and the quality of their drinking water supply, and may be willing to support more sustainable water management. Moreover, the effects of personal actions to reduce water use and water pollution, and improve water management strategies and policies, tend to be most visible at a watershed level. A watershed focus therefore facilitates individual involvement and responsibility of water users, a prerequisite for successful water policy planning and implementation.

In an international multi-watershed case study, Wagner et al. (2002) found that an effective governance of water management has to focus on a watershed scale and must integrate all relevant aspects such as hydrology, ecology, urban water management, agriculture, and waste management. The design and implementation of integrated management measures are fostered by decentralization of decision-making and democracy. With new policies on groundwater protection and water pollution control of 1994 and the "Clean Water Action Plan" of 1998, both the United States and Japan have been focussing the legislation on a watershed scale. In its "Water Framework Directive", the European Union is for the first time trying to apply such a watershed approach in international legislation (EU, 2001; Holzwarth, 2002).

One of the most successful handling of a watershed may be the River Rhine Basin. With a drainage basin of 252,000 km^2, it is the most important navigable artery in Western Europe, almost 40 million people live in the basin, and about 20% of the world's chemical industries are concentrated here. The river had once been severely polluted during the 19th century and the early 20th century in association with the industrialization and subsequent population growth along its banks. Apart from serving as a source of water for people and energy, it was the major water-way for moving goods, and played a strategic and recreational role. In the late 1950s and 1960 the Rhine was Western Europe's open sewer (Zehnder, 1993). The quality of the water has drastically improved in the 1980s and 1990s. Despite the achievement, the goals set in the Action Programme Rhine for the year 2000 have not been reached entirely. The salmon has not yet become indigenous and the Rhine is not yet a balanced ecosystem that does not further endanger the North Sea.

6. Socio-economics and Institutional Aspects of Water Issues

According to the classic economic theory, the marginal benefit from use of a resource should be equal across sectors (uses) in order to maximize returns of investment. In other words, the benefit from using one additional unit of the resource in one sector should be the same as it is in another sector. If not, the market would benefit by allocating more of the resource to the sector where profits, or returns, are higher. However, allocation of water to different sectors may not be viewed purely from an economic point of view in a portfolio of investment projects. This is because water is a special resource. Besides being an economic good, it is also a social and public good and should even become a human right. This human right should comprise the 30 to 50 liters of high quality water (Table 1) or the "basic water requirements" as coined by Gleick (1998). Water has not been specifically included in the U.N. Declaration of Human rights, but it should have been. Gleick (1999) made a detailed and thoughtful plea for the Human Right to Water. The EU has enforced this view in its Water Framework Directives, which were put into effect in December 2000 (Dirksen, 2002). Just at the time when we got this paper back from review, the United Nations Committee on Economic, Cultural and Social Rights took the unprecedented step on November 27, 2002, of agreeing on a General Comment on water as a human right, saying, "Water is fundamental for life and health. The human right to water is indispensable for leading a healthy life in human dignity. It is a pre-requisite to the realization of all other human rights" (World Water Council, 2002).

The following characteristics distinguish water from other goods. (i) Water is indispensable for human survival, without substitution. We cannot decide not to drink water as we could for buying a car. (ii) Water is essential to produce food. Although we can decide individually what kind of food we purchase or grow, the basic caloric needs for survival have to be met (approx. 2500 kcal per day). (iii) Water is essential for nature. Humans are part of nature and as such have to share the resource. One thing should not be forgotten: nature will do well without humans, the contrary is very unlikely. (iv) Water systems are large, multifunctional and require high investments. Because of its social good nature, the private sector is reluctant to take the risk of investment. And because of the characteristics of (i) and (ii), water availability becomes easily a political issue and governmental interference in the immediate interest of the people against the longer term vision of investors are often likely. (v) Water assets are extremely durable, and maintenance can be neglected far longer than most industrial infrastructures. An 80 years investment horizon is difficult to deal with in the current market situation. (vi) Water and sanitation have a natural monopoly. The considerable investment costs prevent cost-effective competing services for customers. (vii) Water is very costly to transport, thus water markets for large quantities have been forced to remain as long as possible local.

Given the above characteristics, water has to be considered a social as well as an economic good. In most societies water is also strongly associated with spiritual values. It is not surprising that the international debate about water and its fair allocation among users has always been quite emotional, especially if water as a basic need is in competition with commercial interests. In his thoughtful analysis of the market mechanisms for managing water, Jaeger (2001) concludes that there is no single best solution available to deal with global water challenges of the coming decades. He further postulates a patient search for the "second best solution" despite the fact that promises of a "general theory of second best solution," have failed to materialize so far (Lipsey and Lancaster 1956, Srinivasan 1996). A clear distinction between the different functions of water is required to conduct the water debate on a more rational basis.

6.1 Water as a social good

As stated by Gleick (1999) the access to a minimum of 30–50 liters of high quality of water per day and capita (roughly 11–18 m^3 per year, Table 1) at an affordable price should be a human right. Governments have the responsibility to ensure this basic requirement to be met for all. This is now enforced by the General Comment of the United Nations Committee on Cultural and Social Rights (World Water Council, 2002) and means that the 145 countries which have ratified the International Covenant on Economic, Social and Cultural Rights as appendix to the UN Human Rights Document (UN, 2002) must progessively ensure that everyone has access to safe and secure drinking water and sanitation facilities – equitably and without discrimination. However, this does not imply that the (drinking) water has to be supplied free of charge. In any case, the system has to be designed and operated in such a way that the costs for operation and maintenance can be covered by the users. This is not only important for reasons of financial sustainability, but also because an appreciation of water only gets up when it costs something and care of the water supply infrastructure will be taken when water has a price. The price may be regulated within acceptable economic boundaries. Subsidies for the initial investments might be necessary and justified.

A common argument for low water price is that the poor cannot afford a real market price. This argument is only intuitive at best. In many places, because of lack of a tap in their houses or in the neighborhoods, the poor have to buy water from the street vendor. Thus, they are already paying market prices, which are often higher than those asked by utilities. From the 7.9 million inhabitants of Jakarta, for instance, only 14 percent receive water directly from the municipal system, 32 percent have to buy water from street vendors at a price between US$ 1.50 and 5.20 per m^3, depending on the distance from the public tap (Serageldin, 1995). The ratio between prices charged by vendors and public utilities ranges between 4 and 100. A similar situation is also seen in many other places. In Cali, Columbia, the ratio is 10, Guayaquil, Ecuador, 20, Port-au-Prince, Haiti, 17–100, Karachi, Pakistan, 28–83 and Istanbul, Turkey, 10 (Bhatia and Falkenmark, 1993). These facts leave us with a perverse situation. In almost all poor countries, the low water price and the heavy subsidy in urban water supply, albeit unintentionally, are mainly in favor of the rich. In other words, the rich who can afford the high water price have been the main beneficiaries of the low water price. To change this situation, urban water price has to be increased and the subsidy system improved to target the poor. One possible mechanism is the “block tariff ”, a system whereby the per-unit cost of services increases as more is consumed. In Cape Town the first 6,000 liters per household and month are free with a progressive price increase for all additional water consumed (McDonald, 2002).

6.2 Water as an economic good

Water for irrigation purposes, industrial use and partly also for household needs and services is an economic good. Its price and quality should be demand driven, i. e., supply and demand will control price. As a matter of principle, users should pay the full costs for water being used in excess of 50 liters per capita per day. Currently, however, this is not the case in most countries. Because the distribution of tap water is supply driven, most of the water and/or the distribution systems are subsidized (perhaps except for the industrial supply) using the public task as argument to deliver at any moment and at any place sufficient water. Distribution networks are designed to deliver much more water than the basic needs. Progressive prices, therefore, should be made in such a way that the basic needs are affordable for everyone and other uses being covered by market mechanisms.

Industrial water use is a good example for water as an economic good. By imposing effluent charges, industrial water use drops drastically. After introducing charges in São Paulo, Brazil, water use in manufacturing declined between 42 and 62 percent, depending on the industry within two years (1980–82). Similar results were obtained in the United States. In 1980 the industrial water consumption was 200 million m^3 as compared to 130 million m^3 in 1990 (Serageldin, 1995). Water conservation measures need investments. So far, it has been generally paid back faster than originally anticipated. A study in San Jose, California, showed that the period of return of investment is between three and twelve months (Postel, 1992).

Historically, the water sectors (water for basic needs, water for irrigation, industrial water supply) have developed independently with their own rules, economic incentives, subsidy mechanisms, and political power structure. Nowadays, privatization in industrial water supply is widely implemented. In many cases larger companies run their own water supply. There are also a number of private operations for water services in larger agglomerations in developing countries (Mexico City, Buenos Aires, Lima, Manila, Paris, etc.). Water for ecosystems was generally neglected and until recently freshwater ecosystems had no powerful advocates. In our free market societies, water for ecosystems reminds no currency value.

6.3 Privatization of public water supply

International aid agencies like the World Bank and some water organizations like the World Water Council are pushing for privatization of the public water sector. Gleick et al. (2002) have critically analyzed the privatization efforts. Their conclusion is that privatization of public water services has not proven to be the panacea expected. In contrary, there is a tendency towards public institutions and public private partnerships. The main issue here is the increase of efficiency of water services. Whether this is done by the private or public sector, or a combination of both, depends on the historical development of the sector, the cultural environment, and the possibilities for the implementation of good governance. A critical evaluation needs to be done case by case. The household centered approach developed in the Bellagio Principles (Schertenleib, 2001) would rather be hindered than stimulated by large scale privatization.

7. Actions to Be Taken at Different Levels

Given the variation in the nature and complexity of the issues and the jurisdiction of different institutions and organizations, the water and water-related problems have to be approached at different levels. Issues such as to guarantee the supply of basic water requirements, the economic allocation of water for other human purposes, the more efficient use of water by all users and the protection of water resources from pollution have to be solved primarily at the local level. The problem that needs to be dealt with mainly at the regional level, is the fair allocation of the water recourses among the different requirements and user segments in a catchment and watershed. The questions of how to supply enough food for the increasing world population with limited and unevenly distributed freshwater resources have to be addressed mainly at the global level.

7.1 Responsibilities at the local level

The responsibility of local authorities is to provide sufficient water of highest quality for the basic water requirements (BWR), i.e., 50 liter per person and day. There are different ways by which this water reaches the households, tap in house, a local central tap, or reservoir, etc. In addition to the guaranteed quality control, the access to water should not take excessive time of family members, mainly women and children, and this water must be affordable. A certain amount of subsidies or other support to the poor by the local, regional or central government is desirable. Supplying this amount of water should be the number one priority for all governments and international organizations.

Water for other household purposes, industry and services is an economic good. This makes up approximately 200 to 230 liters per person and day. Provision of sufficient water for these activities is not a question of survival but rather one of development. The infrastructural implementation is second in priority. It is fair to make the consumers pay for the full service. Whether it is delivered through the distribution network for drinking water or by a separate system depends on the local situations. As an economic good, its delivery basically could but must not necessarily be privatized. It is the responsibility of locals to create this market, though an initial help in investments from (supra)-governmental organizations is acceptable.

The annual provision of water for people, services and industry, i.e., 220 to 250 m^3 per person, is the bottom line for each nation. Above this level, countries may have choices to invest in either agriculture or the preservation of ecosystems, or a combination of both. Such choices, however, are no longer available in a growing number of countries. The demographic development in many countries has dried up their renewable water resources. For example, with the annually renewable freshwater of 309 m^3, Israel is at the edge of the limit to provide sufficient water to meet the basic needs of people. In Libya, where water resources are merely 100 m^3, the limit has far been surpassed (Yang and Zehnder, 2002). This is one of the reasons that Libya has chosen for the “Great Man-Made River” project (Gijspers and Loucks, 1999).

7.2 Responsibilities at the regional level

From the numbers presented in Table 3, it is apparent that the only sector with quite some flexibility in the hydrological part is the river runoff. However, many of the large rivers flow through areas that are, from a climatic point of view, not suitable for food production (e.g., Yenisei and Lena in Siberia). The former Soviet Union had plans to divert the Siberian streams to Central Asia to attain a higher agricultural production. A sustainable irrigation management was not part of the plans and questions of how this diversion is affecting global climate was not a concern at that time. Colorado and Yellow River fall dry at their mouth during part of the year because of upstream water diversions into agriculture and cities. Five and less percent of the Nile discharge reach the Mediterranean after construction of the Aswan High Dam. With increasing water use efficiency in the coming years, Egypt plans to bring this “loss” to zero (Egypt, 1999; Hamza, 1999). Other rivers will certainly follow. In the coming twenty-five years, about 10 to 15 percent of the river runoff may be diverted. Initiatives and decisions on integrated management in large river basins are of regional, national or multinational responsibility, as already executed in many large basins, like Rhine, Mekong, Nile, etc.

A remaining question is who should be responsible for the waters for ecosystems, in particular as tropical and subtropical forests are consuming a large portion (Table 2). The ongoing debate on the value of ecosystems is a first step to the answer. More information is needed about how much and what kind of ecosystem we would like to preserve, what functions have to be protected, and how those who may profit from ecosystem destruction should be indemnified. The industrialized countries have destroyed most of their natural ecosystems and they now teach the developing countries not to make the same mistakes. There is little common understanding in these “discussions”. Finding solutions of how industrialized countries may provide economic incentives for the protection and sustainable management of larger ecosystems for those countries, which still do have such intact systems is a challenge in its own. A regional or national will combined with a more global commitment to tackle this issue seriously could pave the road to the better. Keeping the existing ecosystems intact from the point of view of water quantity, at least for the coming 25 years, is a viable option (Table 3). However, it should be kept in mind that some unavoidable impacts from global change may influence a number of assumptions made here (Gleick, 2001; Baron et al., 2002).

7.3 Responsibilities at the global level

The cherished principle of national food self-sufficiency has often hindered an innovative discussion on where the food for people should be produced. Nevertheless, importing food (virtual water) to compensate local water shortages has long been opted for in countries where the resources are lacking. In some countries, local food production has been only a small fraction of the total food consumed. Israel imports over 13 times more cereal than it produces. In Libya the ratio is 10, Algeria 2, Morocco and Egypt 0.6 (Yang and Zehnder, 2002). The number of countries with not enough water to produce locally needed food has been increasing in association with the rapid population growth. As a result, the volume of food import induced by water scarcity is expected to amplify more than twofold by 2030 (Yang et al., 2003). On the supply side, however, there are only five main net food exporters, USA, Canada, Australia, France, and Argentina which together provide 95 percent of import needs of soybean, 70 percent of cereals, and 40 percent of animal products (Zehnder, 2002). Basically, a small number of producers has to provide a large number of consumers for food, a situation we know from the oil and other commodities. Water for agriculture is thus only partially a local and national question. For a growing number of countries, the question of food for people has to be solved at the global level. An effective system for such a transaction requires a minimal guarantee of free food trade with no political strings attached. Currently, we are far from this situation. Part of the food market is strongly politically influenced. A newly to be created international agency may play a role of an independent global food broker.

8. Economic Implications and Challenges

8.1 Water for people, services, and industries: implications and challenges

Large amounts of investments in the water sector are required in the future. We are fully aware that other future tasks such as schools, hospitals, public transport, energy supply, roads and other communication systems might represent economically even a higher burden for societies. However, without safeguarding the standards and the supply for drinking water, sanitation and food, people are not able to lead a productive and healthy life, help themselves and become a positive economic factor by consuming goods and creating wealth. Hence, the issues of basic water requirements (Table 1) and a functioning global food market must have the prime priority. Without detailed explanations and braking the challenges down to what it may mean for individuals in a developing or industrialized country, there is an inherent danger of frustration on the side of the receiver of the message, dealing with global numbers only.

The World Water Council (Cosgrove and Rijsberman, 2000) estimated that for municipal water and sanitation infrastructures, investments of nearly US$1.8 trillion will be needed in the coming 25 years (Table 4). They assume that the required investment into industrial water management will be in the same order of magnitude adding up to a total of roughly $ 3.6 trillion. Neither of these numbers includes the cost for the replacement of existing systems which are generally aging and neglected. These estimates are based on the assumption that future water supply and environmental sanitation services in industrialized as well as developing countries will use conventional approaches, which are characterized by a high degree of centralization and capital intensity and little participation and direct contribution by the users.

The Vision 21 report (WSSCC, 1999) came to the conclusion that the required investment costs for adequate water supply and sanitation in developing countries can be considerably lower, if more appropriate approaches and technologies will be applied in combination with higher participation and direct contribution by the users. By these assumptions, the required investments for basic level water supply and sanitation services is estimated to be “only” US$ 225 billion over the next 25 years, in addition to the costs borne directly by households and communities (Table 4). Installations and services for basic water supply and sanitation in poor countries can be economically feasible if locally adapted technologies requiring small investments are being implemented step by step with the participation of all stakeholders and under the supervision of local authorities. The importance of applying a people-centred approach, involving all stakeholders in all phases of a project, considering human waste a resource and trying to solve the problems as close as possible to the place were they occur has been recognized by the Water Supply and Sanitation Collaborative Council. Its members have endorsed a series of principles, which make up the Bellagio statement on sustainable environmental sanitation (Schertenleib, 2001). It has also been recognized that local co-operatives play an important role as provider of basic services and that small investment per project reduces the danger for deviation of funds. In contrast, many large projects in countries like Italy, Russia, and many others, failed because a large amount of money involved led to appropriation of considerable sums by some organizations for own interests. For smaller projects (typically below US$ 100,000) run by local communities, the chance for such illegal transactions can be reduced. Meanwhile, good governance of the local authorities is also a prerequisite. Smaller projects are usually implemented and managed at a local or regional level with little intervention by central governmental agencies or organizations, which are difficult to control by the local stakeholders and investors.

The industrialized countries are faced in the coming years with enormous investments into their urban sanitation infrastructure. In the European Union alone, it is estimated that US$ 150–215 billion is needed to achieve sewerage compliance by 2010. In the United States, the Water Environment Federation estimates that US$ 325 billion will be required over the next 20 years for pollution control, with US$ 200 billion for treating sanitary sewer overflows (Cosgrove and Rijsberman, 2000). In most urban areas, the existing infrastructure is in poor state and outdated. The insufficient maintenance in the past will force many cities to almost totally replace their

Table 4. Global investment requirements in the water sector. In these numbers, operation and maintenance are not included.

	Total investments for the period 2000–2025 in trillion US$	Mean annual investment in billion US$	Annual costs per capita concerned in US$
Urban water supply and sanitation:			
– new installations for water supply and sanitation services in developing countries			
a) based on conventional approach	1.80[a]	72	20[b]
b) external costs for basic level services	0.225[c]	9	2–3[d]
– adaptation and renewal in industrialized countries (all functions)	10.00[e]	400	388[f]
Industrial water supply and wastewater treatment infrastructure	1.80[g]	72	nr[h]
Agriculture, irrigation and water storage	0.55[i]	22	nr
Ecosystem protection	0.59[j]	24	18[k]

[a] From Cosgrove and Rijsberman (2000).

[b] Assuming service for 3.5 billion people, 2 billion who already lack sufficient water supply and sanitation and 1.5 billion who will be born in the coming 25 years in the developing countries.

[c] From Vision 21 Report (WSSCC, 2000); in addition to the costs borne directly by households and communities.

[d] Assuming basic water supply services for additional 3.1 billion people and basic sanitation services for additional 4.9 billion.

[e] Based on estimates in Western Europe and the USA that the entire water infrastructure (supply, removal, and treatment) has to be replaced in the coming 20–30 years (this paper).

[f] Estimated from an average of 1,338 million people living in industrialized countries between 2000 and 2025, of which on an average 76.8 percent live in urban areas (WRI, 2002).

[g] Cosgrove and Rijsberman (2000).

[h] Not relevant, because paid either by the sector, or in the worst case by subsidies.

[i] Cosgrove and Rijsberman (2000), includes increase in storage and replacement and building irrigation systems.

[j] Since ecosystem protection results in a high return of investment (section 8.3), it is assumed that 5 percent of the total investments in industrialized countries and industry (11.8 trillion US$) would be a good approximation for the means necessary for developing and implementing additional protecting and management measures.

[k] Assuming that the industrialized countries are coming up for this money.

water and sewerage infrastructure in the coming 25 years to prevent unnecessary risks.

The annual replacement costs go from US$ 2.7 billion for Ontario, Canada (AMO, 2001), to US$ 4 billion for Switzerland (Lehmann, 1994), and US$ 23 billion for the USA (WIN, 2001; AWWA, 2001; Levin et al., 2002) about equally distributed between drinking water and wastewater infrastructure (sewers, waste water treatment plants, and storm-water control). This means per year additionally US$ 233 for each individual in Ontario, US$ 260 for each citizen in the USA, and US$ 570 for each person in Switzerland. For Switzerland with its 7 million inhabitants this would add up to a total cost in 25 years of US$ 100 billion, economically quite a burden even for such a rich country. Taking the different sophistication of the water infrastructure (treatment plants, sewers, distribution network, etc.) into account, the industrialized countries would have to invest in total about US$ 10 trillion over the next 25 years to assure safe drinking water and proper sanitation (Table 4). WIN (2001) and Lehmann (1994) estimate that household water bills must between double and quadruple in the coming years to come up for the entire infrastructure bill. If this were to happen, at least a third of the population in the USA would face economic hardship, using EPA's conventional criterion for hardship (WIN, 2001). At such high investments, the questioning about the adequacy of the conventional urban water management system is certainly also required in industrialized countries. Full-cost pricing for water supply and sanitation services covering more than the basic needs will give the proper economic incentives to develop systems with increased focus on conservation, recycling and reuse of resources, such as water and nutrients, as well as on minimizing waste produced by households, trade, and industry.

8.2 Water for agriculture: implications and challenges

The required investments for water development for producing enough food in the next 25 years is estimated to be $ 550 billion (Cosgrove and Rijsberman, 2000). However, the past two decades have seen a worldwide trend of decline in investments in irrigation infrastructure, agricultural research, technology extension, and overall rural development. The fall of such investments has been particularly large in poor countries where an increase in food production is needed the most (Rijsberman, 2002;

Rosegrant, 2002; Huang et al., 2002). In the developed world, although many governments have been generous in spending billions of dollars each year to provide subsidies to their farmers, they have been rather reluctant in investing into agricultural research and development (IFPRI, 2002; FAO, 2002). Even the World Bank has reduced its lending for agricultural and rural development over the last 20 years (Thompson, 2002). The problem has only drawn attention in recent years and there has appeared a sign of amelioration in some countries, such as China (Huang et al., 2002).

Desalination of seawater has been used in some oil-rich countries in the past decades to alleviate water scarcity. Can desalination become a source of water for food production in the future? The answer is probably no. The economy of desalination is directly tied to the availability and cost of energy. Currently the energy used by desalination plants range from 1.7 to 20 kWh per m^3 of water (Burns, 2002), with an energy cost of about US$ 1.0 to 1.5 (Postel, 1996). Given such a cost of water, food produced from this water would become exorbitantly expensive. If the energy has to be supplied by fossil fuels, efforts for more sustainability are at stake. Therefore, desalination will be limited to extremely water-poor and energy-rich regions for mainly drinking and household uses (Gleick, 1993a).

Low water price has been widely considered a root-cause of poor water use efficiency in irrigation. However, the price of water for irrigation is difficult to rise to the level that can recover the cost of its supply. This is partly because the increased water price would be added to the price of food. In the best case, a few cents per kg of bread may be added. But it could reach more than US$ 1 in water scarce countries if the irrigation water were from desalination, economically unacceptable for the public. The political sensitivity and psychological sentiment attached make the increase in water and food prices unpalatable almost in every country in the world, especially the poor countries. Although drinking water supply and agriculture may draw from the same resource, it is difficult to adjust the irrigation price to allow free market mechanisms. Linking the need of agriculture for water economically with other water use sectors and including the management of water for nature are certainly a challenge and must be reflected in the context of the local and country's water situation at large.

The problems, however, go far beyond the lack of investments and inadequate cost recovery of water supply. As estimated by IWMI (2002), under a business-as-usual scenario, at least 12–17 percent more water is needed by 2020 than that has been used now for irrigation to meet the food demand, which will be some 40 percent more of the current production. But the reality is that this amount of water is simply not available. Therefore, a paradigmatic change is necessary in dealing with the global challenge in water and agriculture. Researchers, policy makers and public and private sectors have to work together in the search of the ways to increase global food production required with the same amount of water used in agriculture today or even 10–20 percent less of that amount (Rijsberman, 2002).

In a growing number of countries, water scarcity and the increasing water demand from urban areas have led to a continuous transfer of water out of agriculture (Rosegrant et al., 2002). For these countries, producing enough food locally by expanding irrigation has become economically and environmentally impossible. As a consequence, the future food security in these countries lies in their ability to import food as well as the availability of a sufficient and accessible food supply at the international market.

Hence, while the question of how and where to raise and allocate the huge finances required for water development and improving water productivity needs to be addressed, an innovative vision on the future distribution in the global food production and trade is equally essential. Up to now mainly oil rich and well-developed countries have relied on the food produced elsewhere to meet a principal portion of the demand. The food import in most other countries is relatively small in comparison to their domestic production (FAO, 2002). In the near future, however, the situation will change. A growing number of economically less fortunate countries will have to substantially increase their import because of the lack of water to produce food locally. This will have a significant impact on the international food economy and trade regime and more importantly, food security (Yang et al., 2003; Rosegrant et al., 2002).

Most of the poor countries are already enduring huge debts and trade deficits (World Bank, 2002). The increased demand for food import will add further financial burdens on these countries and enlarge the trade gaps. This could increase the political and economic vulnerability of the poor countries and their people. The difficulty in penetrating the agricultural markets of industrialized countries and the fact that there are only a few countries with potential for increasing food production and export have made the situation more precarious. Without clear ideas of how these growing challenges can be handled in the future global food trade regime, food insecurity induced by inherent water shortage or political incapabilities could become intensified. To avoid this consequence, in the international context, food institutions must be improved and strengthened to ensure the participation of all countries. This specifically global issue requires an international consensus. Unfortunately, consensus and synergy in dealing with these problems are far from being built amongst the international community, particularly between the food importers (mostly poor countries) and exporters (mostly developed countries).

The currently practiced food aid system, though helpful in mitigating the immediate misery, has not been capable of preventing a large scale of hunger in the past. It will also be very unlikely in the future. To this end, WTO should be entrusted a more active role in providing an arena for constructive negotiations and consensus building. Protectionism, isolationism, and unilateralism will not solve the problems but only exacerbate them.

8.3 Water for nature: implications and challenges

There is an ongoing debate about the monetary value of freshwater ecosystems, wetlands, and water for terrestrial ecosystems. A landmark for synthesizing knowledge on the monetary benefits of services of ecosystems on a global scale was the paper from Costanza and co-workers (1997). They estimated the annual value of all the ecosystem services on Earth to be on an average US$ 33 trillion, this is 1.8 times the current global GNP (gross national product). They reasoned that if ecosystem services would be paid for, in terms of their value contribution to the global economy, the global price system would be very different from what it is today. The price of commodities using ecosystem services directly or indirectly would be much higher. The estimated annual value of water quality improvement provided by wetlands along a 5.5 km stretch of the Alchovy River in Georgia, USA are US$ 3 million (Lerner and Poole, 1999). The replacement cost of the water that would be lost if thirteen of Venezuela's National Parks that provide critical protection for urban water supplies were deforested would be between US$ 103 and 206 million (Reid, 2001). Guo et al. (2000) calculated the value of the ecosystem service in water flow regulation of a forested region in the Yangtze watershed. By taking canopy interception, litter absorption, and soil/groundwater conservation into account, they came to the conclusion that these services are currently only 0.42 times the annual income from forestry. However, when the Three Gorges Hydroelectric Power Plant will run, these services increase to 2.2 times the annual income from forestry. This is because the forested region retains water in the wet season when the surplus water has to bypass power generation and releases it during the dry season, thus allowing a higher electricity production. The economic importance of flood plains goes from US$ 24–51 ha^{-1} yr^{-1} for a Sahelian flood plain to US$ 7,500 ha^{-1} yr^{-1} for floodplain land in Illinois (Tockner and Stanford, 2002).

Many local authorities start taking active watershed management approaches. New York City began investing between US$ 1 to 1.5 billion in protecting the Catskill watershed by buying land and subsidizing the construction of better sewage treatment in the upper watershed. The expected gain for New York City is that they will not have to invest US$ 6 to 8 billion, plus running costs of US$ 300 million annually on a filtration plant to provide cleaner water to the metropolitan area (Chichilnisky and Heal, 1998). Other cities in the US made similar experiences. It is estimated that for every US$ invested in watershed protection, US$ 7.50 to nearly US$ 200 could be saved from investing into new water treatment facilities (Reid, 2001). The growing awareness of the role and value of watersheds, led to the watershed approach for protecting drinking water supplies of excess nitrate from agriculture in Central Illinois (Demissie and Keefer, 1998). Protecting ecosystems and actively manage their integrity leads us to a paradoxical situation where a good with no accountable market value assures a high return of investment.

9. Concluding Remark

Mankind is faced with unprecedented challenges imposed by water scarcity, pollution, and ecosystem degradation. The tasks to combat these challenges are formidable. Huge investments are required to halt the current situation from deteriorating and more are needed to improve the well-being of people and the nature in the future. Given the financial constraints in many countries, particularly in developing countries, it is very difficult, if not impossible, to solve all the water related problems at the same time. By breaking down the functions of water_uses and their essentiality to the well-being of people, this paper develops the most urgent tasks and proposes a way of assigning responsibilities and accountabilities to different levels of governments and organizations. Such an approach makes the intricate water problems become more tangible. This enables policy markers at different levels to prioritize tasks in the formulation of water policies and to take actions accordingly.

Glossary

In the water literature, a number of definitions are used to describe the type of water that is dealt with. In this article, we use the following definitions:

Annually available water is the amount of water, which is delivered on an annual base by atmospheric precipitation and inflowing rivers, leaving enough water for those down-stream. In a strict sense this represents the water resource that can be used on an annual base without violating the concept of sustainability. Water availability may vary yearly and also between different regions within a country. For the simplicity we use the average water availability and treat a country as a unity. The reason for the latter is that numbers are available on a country base and water transfer is politically easier to carry through within a country. Local actions also take place generally within country's boundaries. We are fully aware that this approach is imperfect and a simplification, but it does not distort the message.

Renewable water resources are conventionally defined as the sum of the mean annual surface runoff and groundwater recharge. This water is called by Falkenmark (1995) *blue water*.

Green water, a term coined by Falkenmark (1995) for the fraction of water that is evapotranspirated (water vapor flow), or with other words the water supply for all non-irrigated vegetation. In this paper, green water is defined as the cumulative flux of water vapor as evapotranspiration. This is the wider definition presently adopted by the FAO (FAO, 1997; Rockström and Falkenmark, 2000).

Water use efficiency or *water productivity*, is the mass of crop produced (or its economic value) per applied water volume (Musik et al., 1994).

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