



**20Years**  
*Into Our Common Future*

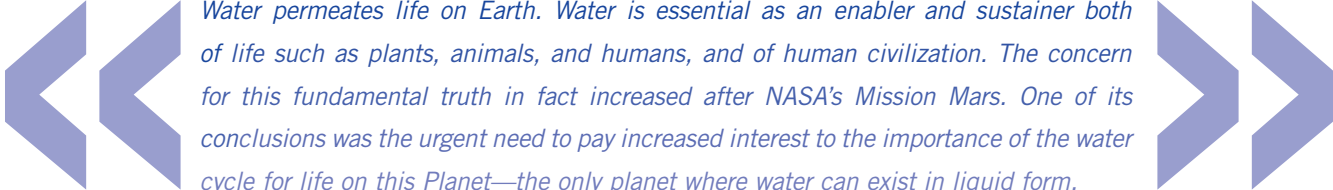
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# WATER

## AND SUSTAINABILITY

### A REAPPRAISAL

by Malin Falkenmark



*Water permeates life on Earth. Water is essential as an enabler and sustainer both of life such as plants, animals, and humans, and of human civilization. The concern for this fundamental truth in fact increased after NASA's Mission Mars. One of its conclusions was the urgent need to pay increased interest to the importance of the water cycle for life on this Planet—the only planet where water can exist in liquid form.*

INTERNATIONAL WATER RESOURCES  
ASSOCIATION STATEMENT, 1991

In 1987, the World Commission on Environment and Development (WCED) analyzed the environmental problems of the time. It presented as its core idea the concept of sustainable development, with the goal of meeting “the needs of the present without compromising the ability of future generations to meet their own needs.”<sup>1</sup> The committee’s guiding image of the world followed the mainstream idea at the time of environmental problems as pollution and land degradation. The committee paid no particular attention to crucial environmental resources such as water, nor did it examine fundamental environmental constraints that would influence the ability of future generations to meet their own needs.

By its May 1987 launch at a Nordic conference in Saltsjöbaden, Sweden, the report was subject to severe criticism. One year later, the Sixth World Congress of the International Water Resources Association (IWRA) on Water Resources held in Ottawa, Canada, issued a sharply worded statement that accused WCED of being blind to water issues:

*WCED in its report . . . tends to severely underestimate water-related problems involved. The report is indeed strongly misleading in that respect. In spite of the evident ambitions to cover the specific problems of each Third World region, the Commission pays no attention to the galloping and multidimensional water scarcity now developing in Africa. . . .*

*The fact that so many developing countries are situated in an arid and semiarid climate is thought provoking in itself. A report discussing sustainable world development without reference to the specific conditions of these arid and semiarid regions indeed lacks in credibility. . . .*

*[T]he Report as regards water resources is heavily biased towards present thinking in the temperate zone. . . .*

*Fundamental strategy changes are needed to address the massive sustainability problems in the realm of water.*<sup>2</sup>

The WCED report’s inattention to water is all the more remarkable considering it came in an era of growing awareness of the importance of water for socioeconomic development: 10 years earlier, the UN Water Conference in Mar del Plata started the movement.



Despite this, the WCED report treated water only as a casualty of other problems, and its central role in the life support system for biomass production and soil fertility was not understood. The severe water scarcity problems in the Sahel region vanished under the concepts of drylands and droughts. WCED’s fragmentary approach was characteristic of the time, when each branch of science looked only at pieces of the whole; rarely did scientists step back to see the larger picture. It demonstrated the deep chasm between engineers and environmentalists, two communities focusing on the same landscape from completely different angles.<sup>3</sup>

The overall dilemma now can be much more clearly seen, and the twentieth anniversary of the WCED report provides a much-needed opportunity to highlight the water-related problems that unfolded during the years since publication.

## UNCED and Agenda 21

The severe criticism of the WCED report resulted in quite a lot of attention to water at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992. In the lead up to the conference, IWRA submitted a second statement in 1991 that stressed the crucial role of water as an issue that bridged many of the issues being discussed in the preparations.<sup>4</sup> Statements about the water crisis continued to fall on deaf ears, however, although the preparatory meeting of the International Council of Scientific Unions (ICSU) had drawn attention to the fundamental importance of regional hydrological differences.<sup>5</sup> The drought and desertification chapter in Agenda 21, the UN’s sustainable development program unveiled at Rio, remained “dry”—desertification was discussed mainly as a land degradation problem.

The conceptual difficulties met in trying to analyze environment and development together were the result of science’s development through the millennia, according to Torsten Hägerstrand,<sup>6</sup> a highly respected Swedish scholar with early interest in interdisciplinary science. He recalled the stress on particles inherited from earlier generations of scientists: the universe had been seen as having a sort of grain structure, constructed of building blocks or particles. In other words, science had never properly conceptualized the interaction between human and natural phenomena in the reality of the everyday world. The consequence of the conceptual difficulties was that the tension between environment and develop-

ment was inadequately expressed and poorly understood.<sup>7</sup>

The poor conceptual framework around human interactions in the landscape sustained the dichotomy between natural resources and their handling and the more or less unavoidable environmental side effects produced by the landscape interventions required (pipelines, canals, well drilling, drainage, land clearing, and land cover change, for example).<sup>8</sup> The situation has isolated engineers and environmental proponents from each other.<sup>9</sup>

This dilemma in conceptualization became extremely unsatisfactory in a world approaching a dangerous situation (including energy crisis, ozone depletion, global warming, and scarcity of cropland) with a rapidly growing human population that is dependent on the productivity of landscapes, which are already full of symptoms of past mismanagement of land and water (floods, water scarcity, water pollution, and water-related land fertility degradation).

One area where it was particularly urgent to proceed was in the linkages between land use and water functions.<sup>10</sup> In Agenda 21, land use issues were addressed separately from water issues—to facilitate rational discussions between UNCED delegates, complex issues had to be addressed in a reductionist manner.<sup>11</sup> The chosen approach, however, neglected linkages between even deeply integrated issues.

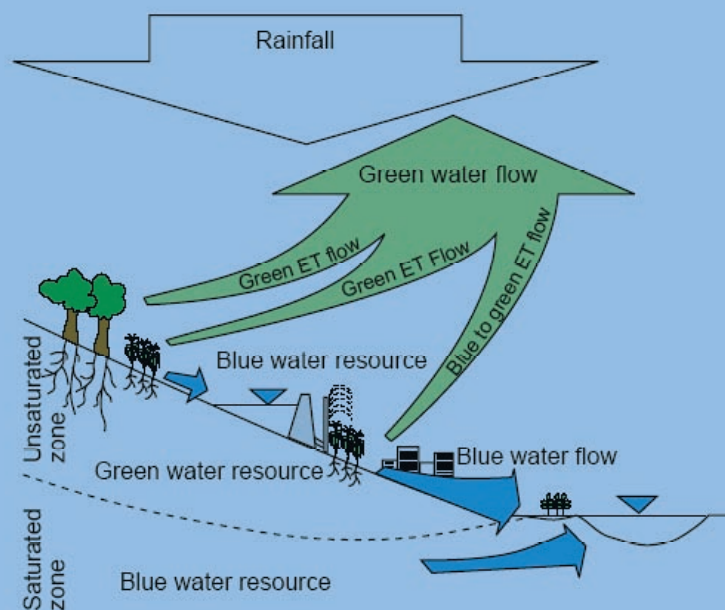
A conceptual breakthrough that allowed an integrated land-water approach came at a UN Food and Agriculture Organization seminar in January 1993,<sup>12</sup> when the concept of green water was proposed for soil moisture (see Figure 1 at right). According to this concept, rainfall constitutes the basic water resource and is partitioned between “green” water, which is consumed by vegetation, and “blue” water, which constitutes water in rivers and aquifers, accessible for societal use. Thus, green water is important to terres-

trial ecosystems. It is involved in (rainfed) plant production and, therefore, in the production of food, fuelwood, biofuels, timber, and forests. Because changes in plant cover alter the partitioning between green and blue water resources, this plant cover change is a key phenomenon in deforestation and reforestation.<sup>13</sup> Blue water, on the other hand, is the base for the household, municipality, industry, and irrigated agriculture water supply; a carrier of solutes and silt through the water systems; and the habitat for aquatic ecosystems.

Incorporating the concept of green water into the bigger picture made it possible to understand not only the

water implications of land cover change, but also the water scarcity problems of rainfed agriculture in the semiarid regions of sub-Saharan Africa and South Asia. These problems had earlier tended to hide behind concepts like the “hunger gap”<sup>14</sup> and “droughts and desertification.” Since many of the problems in the semiarid tropics in sub-Saharan Africa are linked to the water in the soil, this conceptualization resulted in renewed efforts to come to grips with the food production challenges and drought problems in that zone.<sup>15</sup> It opened the possibility to address the “drought and desertification” problem from the perspective of the water’s presence rather its absence.<sup>16</sup>

**Figure 1. Green and blue water**



NOTE: Incoming rainfall generates two types of water resources: green water in the soil, consumed in plant production and returning to the atmosphere as a vapor flow; and the blue water in rivers and aquifers, accessible for human use, including irrigation (by which blue water is transformed into green water). ET=evapotranspiration.

## Rising Demands on an Overappropriated Resource

Warnings regarding the foreseeable increase in water requirements to feed a growing world population had been brought up already by the Swedish Delegation at the UN Conference on Population 1974<sup>17</sup> and were highlighted again at the UN Water Conference in Mar del Plata and in publications such as the book *Water for a Starving World*.<sup>18</sup>

This type of analysis continued in a study of the foreseeable difficulties of African countries to be food self-sufficient.<sup>19</sup> The blue water perspective of global food production was further discussed at a 1996 meeting, "Land Resources: On the Edge of the Malthusian Precipice?" held by the Royal Society in London, where interregional blue water differences were distinguished<sup>20</sup> (see Figure 2 at right). In demand-driven water scarcity, there is a high usage compared to the availability of water, whereas in population-driven water scarcity (also known as water crowding), many people are dependent on finite water supplies.

### Basin Closure

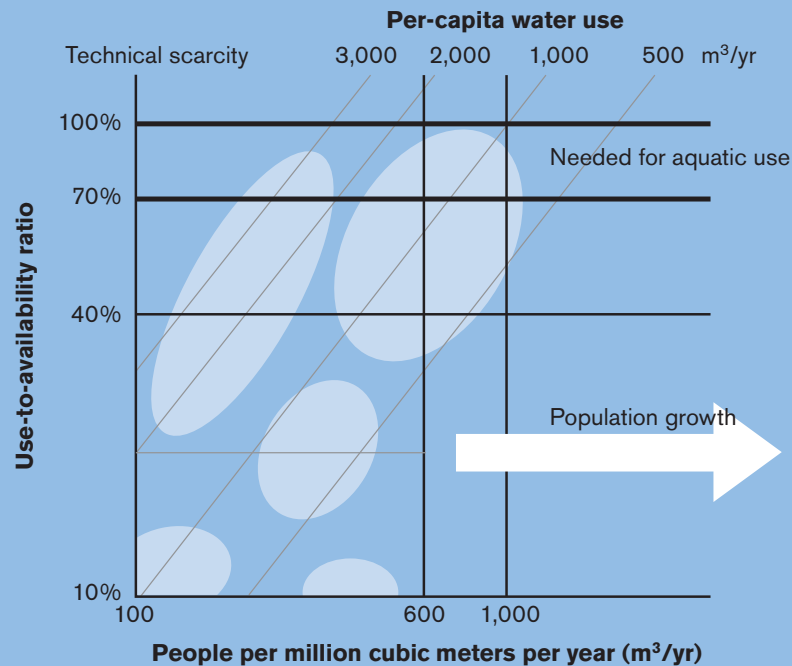
During the 1990s, an additional difficulty emerged in terms of the consequence in the semiarid regions of the irrigation-based "Green Revolution" that made countries like India become self-sufficient in food production. Since the irrigation water taken up by the plants had been consumed during the photosynthesis process, that part did not return to the river system. Therefore, the multiregional river depletion phenomenon developed.<sup>21</sup> Two cases have been discussed internationally: the extensive lowering of the Aral Sea and its massive ecological consequences, and the drying up of the downstream part of the Yellow River, where one could walk

across the river seven months a year in 1997. But the river depletion phenomenon is widespread, covering 15 percent of the continental land area<sup>22</sup> (see Figure 3 on page 9).

The International Water Management Institute (IWMI) has introduced the concept of basin closure for this phenomenon.<sup>23</sup> In the river basins concerned, all water is already being put to use, so that further water requirements can only be met by reallocation between users and uses. The fact that this phenomenon is expanding in a period when population

growth is continuing in the low latitude countries, and hunger alleviation is a goal, agreed upon by all state leaders at the Millennium Summit 2000, suggests a very serious dilemma. It has now been estimated that by 2000, 1.4 billion people were living in closed river basins (as defined by a rough proxy of more than 70 percent use to availability). Out of these, 1.1 billion lived in basins where chronic water shortage was already severe. Another 180 million lived in closed basins where severe water shortage was approaching (more than 600 people per unit of river

**Figure 2. Fundamental regional differences in terms of water resources predicament, 1990**



NOTE: Elliptic fields symbolize five contrasting situations (right to left): dry climate regions with high water crowding and high use-to-availability ratio (northern Africa, western and southern Asia); tropical savanna regions with low use-to-availability ratio and moderate water crowding (sub-Saharan Africa); regions moderate in water crowding and use-to-availability ratio (Central and South Europe, southern part of former Soviet Union, Southeast Asia, and northern China/Mongolia); temperate-zone regions with high use-to-availability ratio and moderate water crowding (United States, Central Asia); and water-rich regions with low use-to-availability ratio and low water crowding.

flow in million cubic meters in annual recharge).<sup>24</sup>

### Groundwater Overexploitation

In addition to the river depletion problem, a groundwater shortage has developed in the same regions. Groundwater use in agriculture has grown exponentially in scale and intensity over recent decades.<sup>25</sup> As the competition for surface water has increased and posed constraints on farmers, many have turned to groundwater—the hidden, much more reliable water resource that already exists under their own land. The availability of water in aquifers is theoretically much more stable than that of surface water, which is delivered in irrigation schemes where those in the top end of the canal system easily get more water than do the farmers at the tail end. With a well of his own, the

farmer is no longer dependent on such an inequitable system.

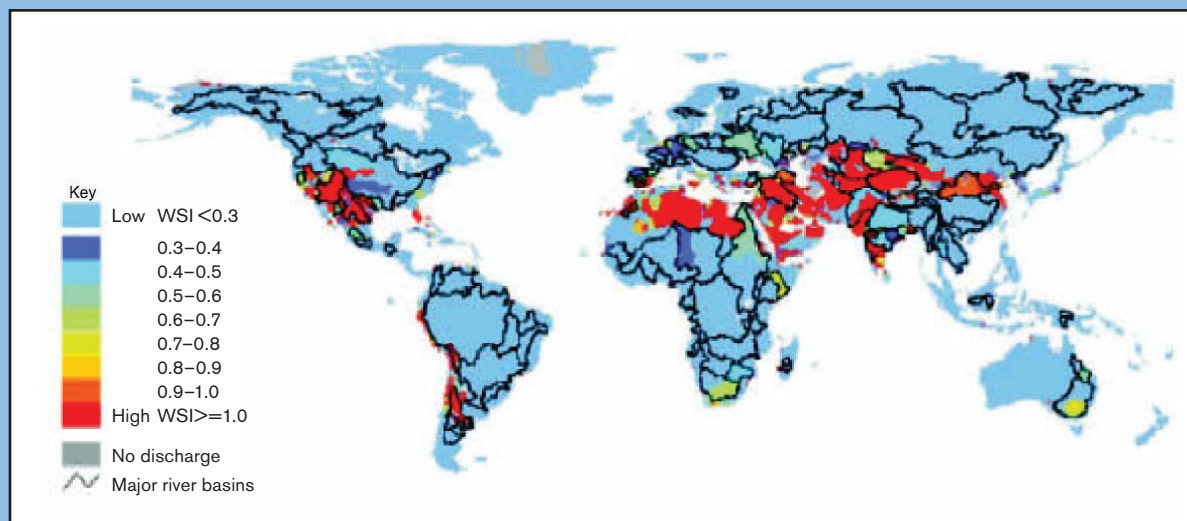
All over Asia, the history of well irrigation goes back for millennia. Globally, water withdrawals have grown from roughly 100–150 cubic kilometers (km<sup>3</sup>) per year in 1950 to almost 1,000 km<sup>3</sup> per year in 2000. Most of this growth is concentrated in agriculture and often facilitated by cheap, subsidized pump electricity. Water policy scholar Sandra Postel has suggested that roughly 10 percent of the world's food production may in fact depend on a yearly overdraft of groundwater.<sup>26</sup> IWMI senior advisor Tushaar Shah and colleagues report that there are 19 million wells in India, 500,000 in Pakistan's Punjab province, and 3.3 million in the North China Plain.<sup>27</sup> In some areas in India—North Gujarat, Tamil Nadu, and southern Rajasthan—the bubble is about to burst. Although many farmers seek

relief through rainwater harvesting to get more water to their crops, farmer suicides are in fact increasing in number as family economies are destroyed by loans to deepen their wells that cannot be repaid after bad years.<sup>28</sup>

### The Threat of “Hydrocide”

The prevailing focus on water management has been to secure water supply for different sectors in society. Comparatively little concern has been devoted to what happens to water after use. Disposal of wastewater, which is untreated in many parts of the world, has resulted in considerable negative impacts on aquatic ecosystems.<sup>29</sup> A rapid industrial growth in semiarid regions (where the dilution effect is limited during the dry season) is particularly problematic because relatively large volumes of water are required,

Figure 3. Map of environmental water stress



NOTE: More than 70 percent of available water is being withdrawn. WSI=Water Stress Index.

SOURCE: V. Smakhtin, C. Revenga, and P. Döll, *Taking into Account Environmental Requirements in Global-Scale Water Resources Assessments: Comprehensive Assessment of Water Management in Agriculture*, Research Report 2 (Colombo, Sri Lanka: International Water Management Institute, 2004).

and the volume of effluents is correspondingly large.

Thus, besides the river and groundwater depletion dilemmas, the world now stands in front of the problem of expanding water pollution. Environmental impacts of water pollution are predicted to increase in most transboundary water regions studied by the Global International Waters Assessment (GIWA).<sup>30</sup> If this development is allowed to continue unabated, the world is threatened by a “hydrocide,” a circumstance in which the water accessible in rivers is no longer fit for use. The Millennium Ecosystem Assessment reported that the Living Planet Index, which compares biodiversity loss in different types of ecosystems, indicates that aquatic ecosystems are the type of ecosystem that has suffered the largest loss of biodiversity; in a mere 30 years, aquatic ecosystems have lost 50 percent of their biodiversity.<sup>31</sup>

### No Environmental Sustainability in View

The base for the sustainability concept introduced by WCED is evidently the biophysical production capacity of the planet, or what we may more specifically refer to as environmental sustainability. In the Millennium Project, this environmental sustainability was understood as equivalent to “non-undermining of the life support system.”<sup>32</sup>

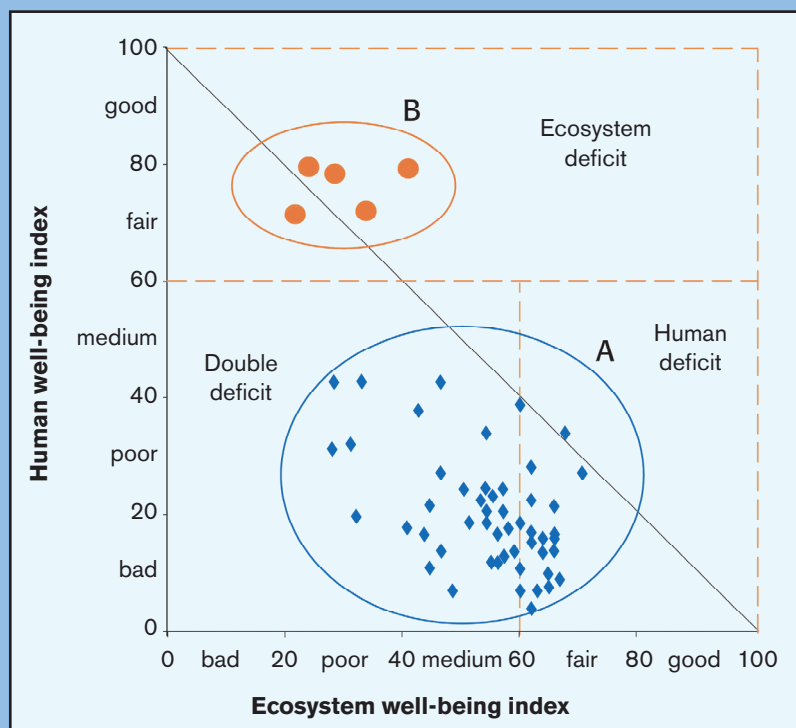
It has been difficult to give the sustainability concept a precise meaning. Even in 1982, Mustafa Tolba, director general of United Nations Environment Programme (UNEP) stressed that it is essential to relate development to the limitations and opportunities created by the natural resource base to all human activities.<sup>33</sup> In a critical assessment,<sup>34</sup> Cecilia Tortajada, vice president of the Third World Centre for Water Management, points out that after 15 years of rhetoric, it is still not known how sustainability can be measured, analyzed, judged, or implemented.

In another assessment, Morris Miller, former executive director of the World Bank, finds the concept flawed, unhelpful, and damaging, claiming that the biggest mistake was the inclination of WCED to slide over the difficult tradeoffs between environment and development in the real world.

The need for such tradeoffs stands out clearly from sustainable development consultant Robert Prescott-Allen’s overview of the relation between human well-being and environmental stress in different coun-

tries.<sup>35</sup> The sustainability diagram in Figure 4 (below) shows the relation, for a set of both developing and developed countries, between a human well-being index (HWI) and an ecosystem well-being index (EWI), both going from 0 to 100 percent. EWI was assessed from country data of air and water pollution and other environmental indicators. The diagram distinguishes among situations with human deficit (human well-being less than 60 percent), ecosystem deficit (human well-being more than 60 percent; ecosystem

**Figure 4. The relationship between human well-being and ecosystem well-being**



A = a set of poor developing countries  
B = a set of highly industrialized countries

SOURCE: Based on data from R. Prescott-Allen, *The Wellbeing of Nations: A Country-by-Country Index of Quality of Life and the Environment* (Washington, DC: Island Press, 2001).

well-being less than 60 percent) or double deficit (both human and ecosystem well-being less than 60 percent).

Environmental sustainability was defined in terms of the ratio between the ecosystem stress index (100 - EWI = ecosystem stress index) and the human well-being index, and should amount to at least a factor 4. As shown by the relative positions in Figure 4, the best cases correspond to a quotient of only around one. No country in the world is even close to environmental sustainability (value 4). In addition, Will Steffen, former executive director of the International Geosphere-Biosphere Programme, in his invitation to a recent lecture at the Royal Swedish Academy of Sciences,<sup>36</sup> stated that nearly every significant global sustainability indicator has stalled or gone backward during the past two decades.

## Future Challenges and Hurdles

As though these established environmental difficulties were not enough, the world still finds itself in a state of rapid change, manifested not only as population growth, urbanization, rising food expectations, and water quality deterioration, but also as responses to peak oil scenarios (in which finite oil resources can only decline from a particular point in time until their eventual depletion) and climate change. In a situation of widespread river basin closures, the changes involved in human responses demand additional water for replacing fossil fuels with biofuels and for mitigating foreseen climate change by so-called carbon sequestration.

### Food Production

The green-blue approach to water discussed earlier allows a broader view of the water requirements as a whole, irrespective of whether met by naturally infil-



trated rainfall or after adding irrigation water.<sup>37</sup> In two recent Swedish studies, the water requirements for food were analyzed as they related to potential green and blue water sources by which these requirements might be met. They were based on different assumptions regarding food requirements for self-sufficiency. One study focused on how to meet the longer-term Millennium Development Goal of hunger alleviation in 92 developing countries.<sup>38</sup> It was based on future calorie levels as foreseen by the Food and Agricultural Organization for the developing world by 2030 (3,000 kilocalories per person per day), assuming that 20 percent of these calories would be from animal protein (as seen in Figure 5a on page 12). The other study focused on global-scale implications of food-preference changes as driven by rising incomes<sup>39</sup> (as seen in Figure 5b on page 13).

Both studies analyzed the available water sources that would have to be relied on to meet those water requirements, assuming that naturally infiltrated soil moisture (green water) as well as liquid (blue) water could be used. In both studies, the researchers paid attention to realistic possibilities to improve water productivity, reducing losses. The studies also analyzed the additional land require-

ments (horizontal expansion of agricultural lands) needed to achieve self-sufficient food production. The basic conclusions drawn were that, given realistic improvements of water productivity, horizontal expansion of cropland will be unavoidable and must continue at the same order of magnitude as it presently does. The future water scarcity dilemma will be reflected in expanding food trade needs.

### Biofuels

Many global scenarios suggest a huge growth in the use of biomass for energy with dedicated bioenergy plantations to replace fossil fuels. A common denominator in previous assessments has been a failure to consider water constraints as well as opportunities in different regions.<sup>40</sup> Since bioenergy is a considerable water user, increasing its share substantially will be a huge challenge.<sup>41</sup> Already, the biofuels production in projections from world energy planners represents additional water requirements of the same order of magnitude as agriculture.<sup>42</sup>

A pertinent question, then, is whether an increased demand for bioenergy will be compatible with an increasing demand for food, or if competition over scarce water resources will stiffen dramatically. It will be important for developing countries, especially China and India, to maintain a delicate balance between food, fodder, water, and energy security. A pro-poor bio-power strategy, if adopted in the semiarid tropics, might be a win-win proposition: ethanol from sweet sorghum and biodiesel from non-edible oil trees grown on wastelands would not compromise food production or use cultivated lands.

### Coping with "Drought and Desertification"

In Agenda 21, the problems of the semiarid tropics in Africa were discussed

under the banner of “droughts and desertification.” Securing safe livelihood conditions in the tropical semiarid region with savannah ecosystems and reducing the risk of outmigration will be of fundamental importance for humanity’s future in general. While inhabited drylands are generally much wetter than one might expect, large rain variability often causes periods of water deficiency.<sup>43</sup> Clear distinctions are needed for differentiating long-term climate change, meteorological drought, and agricultural drought caused by dry spells and/or land degradation.<sup>44</sup> This means combating desertification by

moving attention from reducing degradation to water resource management in savannahs.

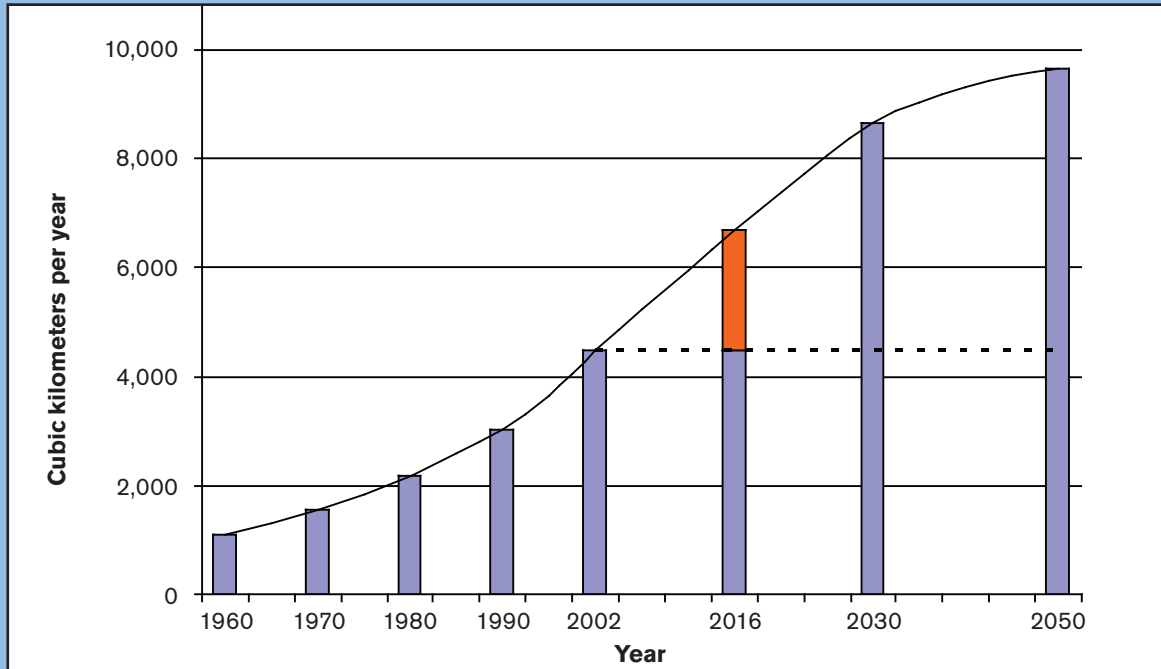
### **Climate Change and Its Water-Mediated Impacts**

Climate change is the single main issue that, although discussed in the WCED report, had received almost no attention in policy circles 20 years ago. Last year, according to the Intergovernmental Panel on Climate Change, scientific evidence indicates that “[w]arming of the climate system is unequivocal” and that it will

have an impact on the processes of the water cycle.<sup>45</sup> There is also observational evidence from all continents that natural systems are being affected. It is very unlikely that the observed changes are the result of natural variability only. Recent warming is already affecting terrestrial biological systems.

Many effects that climate change has on economies, human health, hunger, and diseases are mediated or transferred by temperature-driven alterations of the water cycle. These alterations are proceeding along two parallel branches: On one hand, the water cycle is speeding up and gla-

**Figure 5a. Projected water requirements for food production for 92 developing countries to reach MDG goal 2015 and to reach full diet by 2030**



NOTE: These projections assume 3,000 kilocalories per person per day with 20 percent animal protein and today’s water productivity.

SOURCE: Stockholm Environment Institute (SEI), *Water Energy and Sanitation: Attaining the Millennium Development Goals* (Stockholm: SEI, 2005).

ciers are melting faster, influencing human livelihoods and ecosystems. On the other hand, the warming-generated volumetric expansion of the oceans is causing sea-level rise in coastal regions, which influences coastal settlements and islands.

Thus, water plays a very central role in all the changes of the Earth system and in the impacts of climate change in the various sectors of activity. This century, annual runoff and water availability are projected to increase at high latitudes by 10–30 percent but decrease by 10–30 percent at mid-latitudes and in the dry tropics. Drought-affected areas will

likely increase in extent. Poor communities will be especially vulnerable because they are more dependent on climate-sensitive resources.

Since most climate change impacts will be hitting society through altered water-related phenomena, water will have to play a crucial role in the adaptation efforts of the various socioeconomic sectors, in terms of managing altered water availability (blue as well as green), altered water demands, and increased water variability. Increased rain variability is noted in many areas and seen as one of the signs of ongoing climate change. Learn-

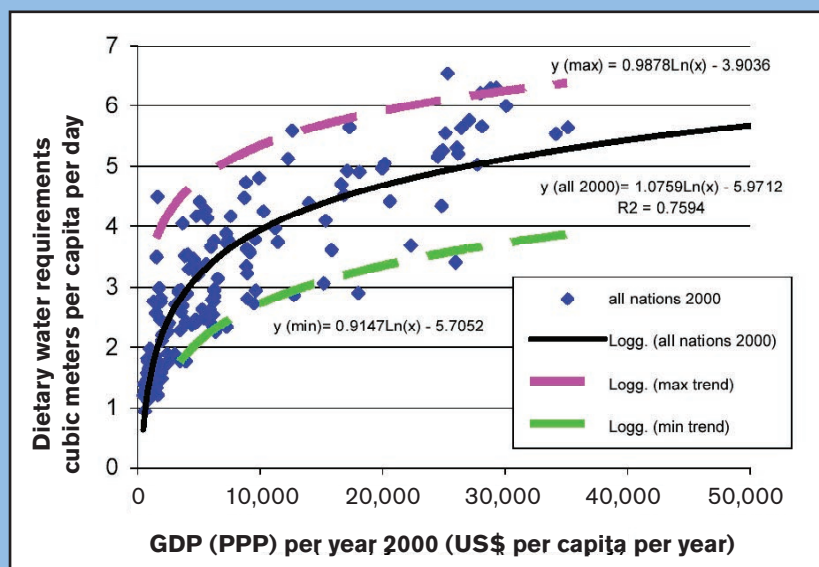
ing to cope with climate variability will therefore constitute a no-regret, win-win policy—especially learning to better cope with droughts and dry spells in the savannah regions, of critical importance for the future as hotspots of poverty and hunger. Many countries in these regions are also undergoing rapid population growth and altered preferences involving rising water demands. Improved ability to cope with water variability will in fact be a key to successful adaptation to the unavoidable impacts of climate change.

## Making Development Sustainable

Heedless of the need for a sustainable approach to development, the world continues its rapid globalization-driven change to improve living conditions. Huge water demands emerge from the parallel efforts to eradicate world hunger, feed the growing population, and replace fossil fuels with biofuels, which is in direct competition with food production.<sup>46</sup> Water pollution is expected to continue to escalate despite the serious health effects that have been observed in connection with bacterial pollution and hazardous chemicals that influence human fertility.

A relevant question is how to change this dangerous path to the future. It is high time to start living up to the goal of leaving our children and grandchildren a life-support system on which they can base their lives. How, and in what way, might water be involved? The fact that water has so many parallel functions in the living world (health, socioeconomic development, energy production, biomass production, carrier function of silt and solutes, and habitat, to name a few) might become an advantage, especially as the water that flows through a catchment or river basin acts as a water integrator.<sup>47</sup> Ecosystems are living parts of the physical environment, building up the life-

**Figure 5b. Projected water requirements for food production globally, assuming today's relation between income and diet**



SOURCE: J. Lundqvist et al., "Water Pressures and Increases in Food and Bioenergy Demand Implications of Economic Growth and Options for Decoupling," in *Scenarios on Economic Growth and Resource Demand: Background Report to the Swedish Environmental Advisory Council*, memorandum 2007:1.

support system for all living creatures. Since water is the “blood-stream” of the biosphere, water might serve as an entry point to better ecosystem management.

### “Good Governance”

Problems arise when we attempt to translate the scientifically based version of the ecosystem approach into policy-making.<sup>48</sup> There has been a slow realization that science may best influence decisionmaking if it acts within a sanctioned discourse, as mental models are not easily changed. Most of what can be realistically achieved within the decisionmaker community is to operate around the lowest-common denominator of the two opposing worldviews. This means that what is termed “good ecosystem governance” will have to proceed within “comfort zones”—where action is seen as realistic and, most likely, incremental.

### Land Use Change and Blue-Green Water Responses

Humans have long modified the land they live on and the water they use. Food production, timber harvesting, energy production, water supply, and wastewater disposal, for instance, have been used to drive socioeconomic development. Since the time of the 1972 United Nations Conference on the Human Environment in Stockholm, Sweden, efforts to achieve environmental sustainability have gone on with depressingly modest results.

A number of conclusions emerge from the intimate interactions between the landscape matrix and the water passing through that landscape.<sup>49</sup> Land must therefore be seen as having three dimensions, since the processes taking place in the soil and underground are fundamental for the functioning of the landscape system. A particular landscape is directly linked to neighboring landscapes through water flows above and below

the ground surface. Therefore, it must be analyzed as a component of the catchment or river basin of which it is a part. Although much attention is currently paid to expected climate change and its serious effects to human life—mediated by its influence on the water cycle—it has been suggested that the impacts of land use change may in fact rival or exceed those of climate change.<sup>50</sup> It will therefore be essential to integrate land and water resources management.

### Protecting Ecosystems: Why? What? How?

From a hydrological perspective, there are two fundamental categories of ecosystems: land-based and water-based systems.<sup>51</sup> The former may be located in recharge areas in a catchment (such as forests, savannahs, and grasslands) or in discharge areas (such as springs, ground-water-fed wetlands, and meadows), or they may be inundation-dependent (such as with flood plains). The habitat of aquatic ecosystems is water in rivers, lakes, and deltas. Aquatic ecosystems are particularly vulnerable since their habitats are affected by a whole gamut of human activities upstream, a fact that may well explain why aquatic ecosystems,



as already mentioned, were identified as the type that has suffered the largest biodiversity loss—50 percent—in the last 30 years.

There have been massive advocacy efforts in recent decades to explain why ecosystems must be protected. The advocacy usually refers to biological and hydrological functions. When analyzing what to protect, ecologists highlight the crucial ecosystem functions in the natural landscape. These include bird and insect habitats; primary production of food, timber, and biofuels; safe habitats for fish; and ecosystem resilience—the insurance against collapse. However, the water manager needs more specific information to determine which biological landscape components are the crucial ones upon which to focus.

How, then, can crucial ecosystems be protected?<sup>52</sup> This question may be clarified through diagnostic analysis:<sup>53</sup> identifying major ecological issues in a catchment, the root causes of ecosystem degradation, and the causal chains involved. This analysis has to identify the water determinants—that is, the characteristics of certain water elements forming the basis of a particular ecosystem. Such determinants will have to be secured through adequate water management, water quality protection, or land-cover protection and by incorporating into Integrated Land and Water Resources Management (ILWRM) water-dependent land use and ecosystem functions of particular relevance for human benefits. This calls for adequate attention to hydrologic-ecological linkages and dependencies such as between a forest and groundwater recharge, made possible by its root system, or between a grazed floodplain and the periodical inundations underlying the grass production. Some of the land and water modifications are, fortunately, avoidable and can be minimized, whereas others are unavoidable and have to be addressed by trade-offs, based on stakeholder negotiations.

## Taking Sustainable Development Seriously

As discussed, a number of severe problems unfolded in the 1990s. First, widespread river depletion emerged in the wake of the irrigation-based Green Revolution. By 2000, 1.4 billion people were living in closed river basins, and large-scale groundwater overexploitation developed in several of the world's breadbaskets, where irrigated agriculture has become a bubble ready to burst. In addition, water pollution and large-scale losses of biodiversity in aquatic ecosystems continue, and land use changes are generating unexpected effects on water resources.

Global forces such as population growth, which will be raising water-related demands, may exacerbate these already severe problems. If these demands are not met, risks for social instability will be introduced. Overall, population growth will have a greater impact on the future environmental situation than climate change. Secondly, human rights awareness groups will be calling for safe water, hunger alleviation, and food security.

The need to take sustainable development seriously, for the sake of our children and grandchildren, calls attention to three perspectives in terms of knowledge-based policy development:

- Pollution must be stopped to secure usable raw water sources and protect biodiversity of aquatic ecosystems, in the long term moving toward a water pollution veto.

- Awareness of depletive water use involved in plant production is essential, therefore water resources planning and management approaches need to incorporate green water resources (soil moisture) and green water use (evaporation).

- Groundwater has to be incorporated into water resources planning and management because of its link to river flow.

Regarding the sustainable meeting of rising demands (which are driven by

ongoing climate and social system processes), water is involved in two ways.

On one hand, environmental sustainability—demanding water pollution abatement, depletive use awareness, aquifer protection, and biodiversity protection—has water as a shared determinant. Water functions as an entry point to these kinds of environmental issues. ILWRM developed into a catchment-based water-balancing tool. Moreover, water pollution abatement must occur to protect our ability to use water as a raw source and as ecosystem habitats.

On the other hand, there is the human dimension, which includes social sustainability, meeting the Millennium Development Goals in terms of improved quality of life for poor populations, adequate food supply, safe water, and meeting needs of biofuels and carbon sequestration. Once again, water may be a useful entry point, ensuring a proper balancing and tradeoff striking against water availability. Projections of food water requirements by 2050 suggest a need for major food trade expansion from water-rich to water-short countries, since almost 40 percent of the world population will at that time be living in countries unable to produce enough food for self-sufficiency (including, for example, China, India, Iran, Pakistan, Bangladesh, and Ethiopia).

Since population growth will tend to dominate over the impacts of climate change on the global water scarcity situation, it is fundamental to reach a fertility level of two children per woman as rapidly as possible. This will call for major education and health campaigns in countries where fertility remains on a level of more than three or four children per woman. To this end, sterilization—male or female—might be made status for two-children families. For any chance of success reaching environmental sustainability, we must avoid the IPCC's high population projection of 15 billion by 2100 and instead aim for a stabi-

lized medium projection by 2050 of 9 to 10 billion.

Together, these four actions—population stabilization, seriously intended pollution abatement, water-based balancing of green and blue water requirements for social and environmental purposes, and preparedness for mega-scale food trade expansion from water-rich to water-short countries—will form the building blocks to a responsible approach to sustainability.

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This article draws heavily on almost 40 years of articles authored or co-authored by Falkenmark (see Notes) and to recent discussions with a colleague from IWRA's Committee on Water Strategies for the 21st Century, Professor Luis da Cunha, Lisbon, Portugal.

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