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Water for agriculture and the environment: the ultimate trade-off

Henry Vaux Jr

Department of Agricultural and Resource Economics, University of California, Berkeley, CA 94720-5800, USA
E-mail: vaux@are.berkeley.edu

Abstract

Global population is projected to increase over year 2000 levels by 30% in 2025 and by 50% in 2050. Producing sufficient food to feed a more populous Earth will be a challenge requiring additional developed water supplies. Existing supplies are unevenly distributed around the planet. Some developing countries lack sufficient water to grow the food necessary to feed the growing population. With time, more countries will join that group. The strategies available to produce more food depend upon which sources are available. Two options open to all countries are improving the productivity of water in agriculture and importing virtual water in food. For some, the additional options of bringing more land into production or harvesting rainwater may also be available. All these measures reallocate water to agricultural uses from environmental uses. Such reallocations may impose potentially large losses in the form of environmental services and environmental amenities. Difficult water allocation decisions with enormous values at stake confront humanity. These decisions are confounded because they entail the protection of the global commons for which there is no successful experience to draw on.

Keywords: Agricultural water use; Blue water; Environmental amenities and services; Environmental water uses; Global water availability; Green water

1. Introduction

The first decade of the 21st century has witnessed a profusion of books and articles trumpeting the coming global water crises (e.g. Pearce, 2007; Speth, 2008; Sandford, 2009; McKibben, 2010; Solomon, 2010). Indeed, available evidence indicates that the first half of the 21st century will be characterized by intensifying water scarcity globally, regionally and locally. Arid and semi-arid regions will be particularly susceptible, but scarcity will also plague humid regions and require residents to manage water under pressures to which they have not previously been exposed. The fundamental causes most often cited for the intensifying scarcity lie with the fact that demands for water are expected to grow while supplies will shrink or remain static. Demand growth will be fueled by population growth and economic development while the status of supplies will be adversely affected by a number of factors

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including persistent groundwater mining, continuing declines in water quality and, in some locales, by climate change.

Most studies cite population growth as the principal driver of increases in the global demand for water. Although there are uncertainties surrounding future population levels, a number of centerline projections show that population is likely to grow by 30% between 2000 and 2025 and by 50% between 2000 and 2050 (Lutz *et al*., 2001; U.S. Bureau of the Census, 2006). If correct, these projections would mean that global population would increase by 3×10^9 during the first half of the century. Most of this growth will occur in developing countries where water supplies are already less than plentiful. In addition, economic development is likely to fuel increased demands for water both directly, as in the growth in water consuming industries, and indirectly, in the form of dietary and other life-style changes which tend to be more water consumptive. Economic development is also likely to be a significant driver of growth in the demand for water. The need to provide food for an additional 3×10^9 people represents a daunting task that will likely fuel derived demands for water from the agricultural sector.

In some countries and regions, existing water supplies are either inadequate or barely adequate to support existing levels of population. Population growth will increase the water stress experienced by these regions and countries. With time, more countries and regions will likely find their water supplies inadequate as their population numbers grow. Persistent groundwater overdraft, which is globally significant, cannot continue. The result will be declines in water availability from mined aquifers. In addition, water pollution from industrial, agricultural and domestic sources will likely continue to degrade water quality with the result that water available for high quality uses will decline. In short, the picture is almost inescapably one of growing demands matched by static or shrinking supplies. While new technology and wider adoption and implementation of existing technology may attenuate the impacts to some extent, there is every reason to expect that intensifying scarcity will result.

The concept of water scarcity means simply that there is not enough water to support all of the various uses which we would wish to support. Scarcity requires that choices be made among competing uses. It means that some uses will be served more fully than others, some uses will not be served and some will be served with smaller quantities than would be ideal. In most parts of the world, the kinds of choices that have been made historically have not entailed very large apparent opportunity costs. In this paper the proposition is advanced that intensifying water scarcity will ultimately confront the world with trade-offs between environmental uses and agricultural uses of water that will likely have extremely high opportunity costs. Insufficient water to produce food to feed hundreds of millions of new souls will condemn many to starvation. Insufficient water to support environmental uses carries a high risk of environmental collapse with the loss of important ecosystem services, the growth of environmental instability and increases in the incidence of disease and pestilence. Resolution of such high-stake trade-offs and the associated conflicts is likely to be very difficult to resolve peacefully. This is especially so since there has been little experience historically with allocative decisions where the opportunity costs are as large as they are likely to be here.

2. The global water situation

Only a tiny proportion (0.6%) of the total global water resource is freshwater available for use. The vast majority of global water is found in the oceans (97.4%) and in polar ice and glaciers (2.0%). The total quantity of global freshwater available for human use has been estimated at about 475 million km^3

and much of this is inaccessible (Shiklomanov, 1997). Thus, the available resource is quite large but the portion of it that is readily and economically susceptible to use is tiny. The totality of freshwater available to support various consumptive and non-consumptive uses is commonly considered to be the sum of rainfall used to grow crops, accessible fresh groundwater resources and surface water. Falkenmark & Rockstrom (2004) partition this resource among green water and blue water, with green water originating as rainfall that is available as soil moisture and subsequently returned to the atmosphere, while blue water is what remains after evaporation as run-off and accessible groundwater. The estimates of available global blue water resources are highly uncertain but a frequently quoted value is 42,700 km^3 (Shiklomanov, 1997). This illustrates that the blue water resource upon which people have relied historically is but a tiny fraction of the total global freshwater resource.

The problem is further complicated by the uneven distribution of water across the surface of the Earth. Some regions, such as the Amazon Basin, have significant flows which are largely unutilized by humans but remain important for environmental purposes. Other regions have low levels of annual precipitation and are water deficient. The regions which experience the largest shortfall are the Middle East, large portions of Africa and Southeast Asia (Postel, 1997). Thus, when considered in the abstract, available freshwater supplies could appear sufficient to serve foreseeable demand. Yet, when the relatively minuscule volume of blue water, the accustomed source, and the uneven distribution of it are accounted for, it is little surprise that the deficiencies in regional and local water supplies are somewhat common.

The global demands for water can be summarized, albeit crudely, by referring to existing and anticipated population levels. Of course, there are other variables which determine water demand but the number of people who require water for domestic and industrial purposes, to grow their food and to provide important environmental services, is probably the single most important. At a minimum, the fact that global population is expected to grow from its 2000 level of 6.5×10^9 to over 8.0×10^9 by 2025, and to 9.5×10^9 by 2050 invites questions as to whether there will be sufficient water to support population increases of this magnitude. The concern becomes more urgent when it is recognized that nearly all of this growth will occur in developing countries, many of which had inadequate or barely adequate supplies to support population levels that prevailed in 2000.

The Falkenmark Stress Index provides at least a first approximation of the extent to which supplies are likely to be adequate now and in the future. The index is based on a classification which relies upon estimates of liquid water resources availability, which is defined as surface water flow plus groundwater recharge. 1,700 m^3 per capita per year of blue water is defined as the amount required for water self-sufficiency. Countries which have this quantity of water can produce the food needed to feed the population and provide the necessary services to sustain human and ecosystem health. Further, countries which have between 1,000 and 1,700 m^3 per capita per year are defined as being under water stress, while countries with less than 1,000 m^3 are said to suffer from chronic water scarcity (it should be noted that the term ‘scarcity’ is used here as a simple definition and differs from the customary economist’s definition in several ways). Although this index is arbitrary, it does permit reasonable approximations to be made of blue water availability for different countries, both now and in the future (Falkenmark & Rockstrom, 2004).

Using this definition, Jury & Vaux (2007) showed that in 1995 some 18 countries were water scarce and 11 more were water stressed. The combined population of the 29 countries was over 450 million. In the year 2025, the number of water-scarce countries rises to 29 and the number of water-stressed countries rises to 19. The combined population of these 48 countries is estimated to be 2.9×10^9 persons. Thus, in 1995 the number of people affected by water insufficiency was relatively small. By 2025 it will be relatively large. It should be noted that these figures are disproportionately affected by the fact that India is expected to fall into the water-stressed category by 2025. Thus, both the number of countries and the affected population become more significant by 2025 than they were in 1995. It can be anticipated that these numbers will grow significantly between 2025 and 2050 (Jury & Vaux, 2007). These findings may be offset to an unknown extent by greater reliance on green water.

This analysis is admittedly arbitrary because the definitions of adequacy, stress and scarcity are all arbitrary. There is no necessary reason why the 1,700 m^3 per capita per year or the 1,000 m^3 per capita per year figures will remain constant or even indicative of adequacy, stress or scarcity over the coming years and decades. Nevertheless, there is corroborating evidence from a variety of sources that more countries and larger populations will be overtaken by water stress and scarcity in the future. The empirical work of Yang *et al.* (2003) shows that a threshold value of 1,700 m^3 per capita per year of blue water was reasonable during the period 1980–2000. Raskin *et al.* (1997) defined water stress in terms of the quantities withdrawn annually as a percentage of available annual supplies, with values of 40% or more indicating water stress. Seckler *et al.* (1998) used this index and estimates of projected increases in withdrawals by 2025 to rate countries according to the degree of water stress and scarcity. Though the specifics vary, all of these studies arrived at the same general conclusion that, over time, more countries and larger numbers of people will find themselves beset by water stress and water scarcity. More recently, Vorosmarty *et al.* (2010) have completed a study which concludes that 80% of the globe's population lives in areas where water supplies are not secure. The study conclusions are based on a snapshot of global and regional water supply and demand conditions in the first decade of the 21st century. While the study contains no systematic attempt to look ahead, the authors note that the implications of population growth and climate change for the world's water supply will likely pose daunting challenges.

Available water use data show that consumptive uses of water, which amounted to 2,100 km^3 in 1995, were dominated by agriculture which accounted for a little over 84% of all consumptive uses. Domestic and industrial uses accounted for approximately 6.5%, while reservoir losses accounted for a little over 9% (Jury & Vaux, 2007). As a practical matter, domestic and industrial uses tend to be the highest-valued uses and are therefore likely to have priority in an age in which water is extremely scarce. While some reduction may be possible through conservation and education programs, the likelihood is that domestic and industrial consumptive uses will grow modestly as a function of population growth over time. Simultaneously, reservoir evaporation losses are likely to remain quantitatively static in the absence of large programs of additional reservoir construction, which seem unlikely because of cost and environmental considerations. These conclusions are based on estimates of blue water availability and could be overstated if green water proves economically available to serve growing demands.

Projections of global consumptive water use through 2025 suggest that it might grow as much as 50%. That would still leave substantial supplies of water available for instream uses, of which environmental uses are undoubtedly the most important. Estimates of the quantities of water needed globally for ecosystem support are few and not especially reliable. Falkenmark & Rockstrom (2004) state that 30% of the unimpaired flow is the minimum that must be left in streams to protect ecosystem health. Postel *et al.* (1996) cite a figure of 34% of unimpaired flow as being necessary to sustain the functions of aquatic ecosystems. These authors suggested that water to meet direct human needs and ecosystem function could account for 70% of available run-off by 2025. These figures are significant on a global basis because they suggest that freshwater use will become a very substantial fraction of the available resource in the first decades of the 21st century. As noted above, global averages mask the fact that some locales and regions already suffer from deficiencies, while others will find themselves in this predicament during the first five decades of the 21st century.

3. Water supplies for agriculture

Most evidence suggests that the combination of population growth and economic development drives significant growth in agriculture and agricultural water use. In general, food water requirements are calculated by estimating crop evapotranspiration requirements, assuming current levels of water productivity based on an assumed daily caloric demand per capita and the number of people in the population. Falkenmark & Rockstrom (2010) summarize four studies, each of which use slightly different assumptions regarding the role of income in diet, improvements in water productivity, allowances for global climate change and the time span of the analyses. The study of 92 developing countries by Lundquist *et al*. (2007) shows that, with income-driven diets, an additional 5,200 km^3/yr will be needed by 2050 by the sector. Other studies show that lesser amounts of additional water will be needed for agriculture but, in absolute terms, the quantities needed will be substantial (Rockstrom *et al*., 2007, 2008).

In order to understand the possibilities for meeting shortfalls of this magnitude in the global agricultural sector, it is necessary to understand the crucial distinction between green water and blue water. As mentioned earlier, precipitation can be divided between blue water, which is ground and surface water available for withdrawal and storage; and green water, which is stored in the soil profile and available to support plant evapotranspiration (Falkenmark & Rockstrom, 2006). The significance of this distinction lies with the fact that a significant proportion of precipitation is available as green water to support crop plant growth. Indeed, even where agriculture is routinely irrigated (with blue water) some portion of the water utilized by the crop plant is green water derived directly from precipitation and stored in the soil profile. The potential supply of agricultural water cannot be estimated accurately unless both green and blue water are accounted for. Furthermore, the manipulation of green water to reduce unproductive evaporative losses from the soil surface and the acquisition of additional green water through the conversion of new lands to agriculture, are both methods of accommodating water shortage and must similarly be accounted for.

Falkenmark & Rockstrom (2010) identify four means for augmenting water supplies to levels needed when food water requirements exceed the production capacity of present croplands and permanent pasture:

(i) *Acquire additional green water.* This entails the simple expansion of production to lands that are currently not cropped or in pasture. By increasing the extent of production, the green water from the lands brought into production is effectively converted from environmental uses to the support of agriculture;

(ii) *Harvest rainwater from adjacent lands for use as supplementary irrigation.* This option is the one that has been most intensively practiced historically. It entails capturing and storing blue water in times and places where it is plentiful for use at times and in places where it is not. Rainwater harvesting, in which precipitation that would otherwise be lost irrecoverably is captured though new and innovative techniques, also qualifies.

(iii) *Increase water/crop productivity.* The productivity of water in agriculture can be increased in a variety of ways. Improvements in on-farm water management which minimize or eliminate losses of irrecoverable percolation and run-off, minimizing the extent to which green and blue water are lost to non-productive evaporation from the soil surface, and conservation tillage, are among the methods through which water/crop productivity can be increased.

(iv) *Importing 'virtual' water.* Countries that lack water for agricultural purposes can acquire supplies of 'virtual' water by importing foodstuffs from exporting countries. Virtual water is defined as the water required to grow imported foodstuffs. It can be counted in the water budgets of the importing countries because it is water that those countries do not have to find in order to feed their populations. When virtual water (imported food) is used to satisfy a water-short country's food needs, the effect is to export some of the water scarcity of the importing country to the exporting country. It is simply a way of trading in water without actually having to move water by itself. The latter task is difficult and unlikely to be profitable because water is bulky, heavy and, by itself, usually low-valued.

The mix of these four options that will be employed will be country- and location-specific. Rockstrom *et al.* (2008) conducted a country-level analysis of existing and projected agricultural water availability. Each country was categorized according to four 'water shortage domains'. These domains are listed in Table 1 together with examples of countries that are projected to reside in those domains by 2050. All countries, no matter which domain they fall into, will have the options of responding to agricultural water scarcity by improving water productivity or importing food virtual water. Those short only of green water have the additional option of developing additional blue water by harvesting precipitation from adjacent lands to provide supplementary irrigation. Those short only of blue water have the additional option of expanding agriculture to previously uncultivated lands, thereby increasing the supply of green water.

The economics of response to water shortage will also be an important determinant of the feasibility of different responses. Water harvesting, expansion of agriculture and the making of improvements in water/crop productivity will all be costly. The feasibility of employing any of these options will be critically determined by their costs and whether they represent attractive economic investments, as well as by affordability. Thus, for example, the residents and governments of the poorest of countries may not have access to the resources necessary to invest in any of these water-augmenting strategies. The ability to import food is also critically determined by economics. Poor countries that generate little foreign exchange may have difficulty importing sufficient foodstuffs to feed their people. External aid would help to solve the problem but would create unwanted dependencies in some instances.

Table 1. Projected water shortage combinations in 2050.

	Green water short (<1,300 m^3/person/year)	Green water available (>1,300 m^3/person/year)
Blue water short (<1,000 m^3/person/year)	Iran, Pakistan, Jordan, India, Ethiopia, China, Egypt	Kyrgystan, Czech Republic, Lesotho, South Africa
Blue water available (>1,000 m^3/person/year)	Japan, Bangladesh, Nigeria, North Korea, South Korea, Togo	Zimbabwe, Ghana, Angola, Chad, Botswana, Kenya, Mali, Namibia, Sudan, South Africa

Source: Rockstrom *et al.* (2008).

Several important conclusions emerge from this analysis. First, there seems little doubt that the combination of population and economic growth will lead to a shortage of agricultural water in the coming decades. Unless new supplies are developed–be they green water, blue water or virtual water–there is a very high probability that future production of food and fiber will be insufficient to feed a more populous world. Should this occur, starvation will likely ensue on a large scale. Second, global figures have only very general meaning because there is so much variability in water supply and water use around the world. The country level analyses suggest that a band of countries including those of North Africa, the Middle East, India and China will be severely deficient and will likely have to import food to feed their populations. The presence of India and China in this group should be of particular concern because of the sheer size of their populations. Countries within this band whose populations are growing rapidly will be particularly susceptible to widespread starvation unless additional water can be found for agriculture. Finally, the analysis suggests that the countries of sub-Saharan Africa may be in a better position to solve their water problems than previously thought. However, what happens in this portion of Africa will depend crucially on economic growth, or the lack thereof. Where extreme poverty persists, it may be very difficult to solve regional water problems, even where feasible physical solutions exist.

4. Water for the environment

It is important to recognize that there is really no such thing as unallocated water. Water is and always has been fully allocated among uses, domestic, industrial, agricultural and environmental. For example, at the dawn of civilization, water was almost fully allocated to environmental purposes. The subsequent 'development' of water was in this sense nothing more than reallocating water away from environmental uses to some other use. In another parlance, environmental uses of water have always been 'the suppliers of last resort'. Since the beginning of human existence on Earth, water to support consumptive human needs has always been reallocated away from environmental uses. During early recorded human history human uses were so small as to have had a negligible effect on flows or on the environment. Beginning sometime in the last ten millennia, human uses began to grow and that growth has accelerated very rapidly during the last two centuries. It was only during the latter half of the 20th century that it came to be understood that continued growth in the consumptive uses of water, and the associated depletions of water for the environment, has very detrimental effects on the environment. Species extinction, the loss of biodiversity, infestations of pest species and the loss of environmental amenities were, and still are, among the symptoms (Solomon, 2010).

In recent years, there has been some recognition that further diversions of environmental water for consumptive uses may result in very significant and costly damages, not just in terms of lost environmental amenities but in terms of lost or degraded environmental services. This has led some to conclude that an appropriate response would entail a shift from environmental water uses to agricultural water uses as the suppliers of last resort (Vaux, 2004). This proposition needs to be evaluated in light of the evidence presented in the preceding section which suggests that the prospect of widespread starvation is very real in the absence of additional allocations of water to agriculture. An evaluation of the stakes associated with further depletion of water to support the environment focuses on the consequences of losses in environmental water to support agriculture and specifically on the implications for environmental services.

The Millennium Ecosystem Assessment redefined the concept of ecosystem services and classified those services in a way that makes their importance more readily apparent. Classification of the services is divided into four categories (Table 2). Provisioning services are the goods produced by natural and cultivated ecosystems, such as freshwater and food. The regulating services are the benefits from ecosystem processes, including the regulation of surface flows and water purification. Cultural services constitute non-material benefits provided by the environment which include amenities, spiritual values and recreational values. Many of these cultural services are difficult, if not impossible, to value in economic terms. Finally, supporting services are based on fundamental ecosystem functions and provide the support for all of the other services. The most important of these is the support of biodiversity (Millennium Ecosystem Assessment, 2005).

Although there is no conclusive work on the economic value of ecosystem services, existing evidence suggests that those values may be very large. The study most cited is that of Costanza *et al*. (1997) which estimates the value of all ecosystem services at US$33 $\times 10^{12}$ annually, almost twice the global gross domestic product (at the time) of US$18 $\times 10^{12}$. The estimated value of freshwater ecosystems is disproportionately high when considered in the context of all terrestrial and freshwater ecosystems together. Freshwater systems account for 2.4% of all freshwater and terrestrial systems, yet account for 40% of the value. It has been well documented that when the capacity of the environment to deliver ecosystem services is impaired, such services have to be provided by artificial means, and these are almost always expensive and inferior to what was provided at no cost by the environment. Stated differently, the least-cost alternative to most environmental services entails very high costs and inferior results (Tilman *et al*., 1994; Daily *et al*. 1997).

The value of environmental services lost over the last two millennia is not always apparent, and there is an understandable temptation to discount the magnitude and extent of such losses in the future based on past experience. There are several reasons for believing that past experience with the environment is not a guide to the future. The first of these is related to the loss of biodiversity. There is substantial evidence pointing to the fact that biodiversity is central to the provision of ecosystem services (Tilman *et al*., 1994; Heywood & Bastge, 1995; Millennium Ecosystem Assessment, 2005). Additionally, there is incontrovertible evidence that biodiversity has been lost in many ecosystems and that such losses continue at unparalleled rates. Thus, the symptomology of ecosystem degradation is clear, even if the consequences (in the form of diminished ecosystem services) are not always as readily recognizable.

A second reason for concern is that environmental damages may be relatively modest until some threshold in the dimensions of biodiversity is reached. Beyond that threshold, ecosystem services are likely to be significantly impaired. Such thresholds have been observed in some instances but

Table 2. Ecosystem services.

Provisioning	Regulating	Cultural	Support
Food	Climate regulation	Spiritual	Soil formation
Fresh water	Disease regulation	Inspirational	Soil conservation
Woodfuel	Flood regulation	Aesthetic	Nutrient cycling
Timber	Water purification	Educational	Primary production
Fiber		Recreational	Support biodiversity
Biochemicals			
Gene resources			

Source: Millennium Ecosystem Assessment (2005).

generalized knowledge of them is lacking. Aquatic ecologists and others have cited casual evidence that such thresholds exist in riverine systems around the point where flows are reduced in the range of 30–35% of unimpaired flows (Postel *et al.*, 1996; Falkenmark & Rockstrom, 2004). There are a number of rivers globally for which this threshold has already been crossed but, for the vast majority, the threshold has not yet been breached. This suggests that wholesale loss of ecosystem services is not yet widespread, although it may well be in prospect. This raises the very real possibility that continuing growth in diversions and declines in water quality will entail high risks of crossing threshold flow values, leading to very significant disruptions in the provision of ecosystem services.

A third reason for concern is that dryland ecosystems tend to be especially sensitive to the loss of biodiversity and thus especially susceptible to deterioration in ecosystem services. Safriel & Adeel (2008) note that the transformation of relatively undisturbed ecosystems into cultivated ecosystems tends to occur in drylands because most of the arable land outside drylands is already under cultivation. Such transformations invariably reduce biodiversity and render the lands involved susceptible to salinization, irrespective of whether they are dry farmed or irrigated. Finally, with such lands, the point of irreversibility is reached quickly with the result that biodiversity may be lost forever. Safriel (2010) cites the Dust Bowl of the United States in the 1930s, and a similar environmental degradation and resultant loss of services in the Sahel region of Africa in the 1970s, as examples. In addition, he provides a case study from the Hula Valley of Israel which details the causes and consequences of the loss of biodiversity.

These concerns extend to all countries which must develop additional sources of water for agriculture. They include countries which will expand agriculture in response to increases in the demand for agricultural exports (virtual water) and they extend especially to the countries identified in Table 1 which occupy arid and semi-arid lands. Safriel (2010) states that what is at stake is not just the question of how much water should be allocated to the environment at the expense of people. The issue is, rather:

> *'… how much water can be allocated for driving current trends of global population and economic growth without degrading and reducing ecosystem services to the point that these cease to support these trends [and] bring about the mutual collapse of both people and nature.'*

The crucial point here is that water allocated to the environment is critical in supporting the production of environmental services. These services include not only the provisioning of water and the purification of water but the provisioning of food itself. It is ironic that failure to supply adequate water for environmental services could itself result in a decline in the capacity of the environment to provide food and to support modern cultivation practices (Kirschenmann, 2010). Failure to provide environmental water could itself lead to a reduction in global food supplies.

The evidence is clear and mounting that beyond some point the loss of water to support environmental purposes will lead to the loss of crucial environmental services and amenities. That point may be very near and the losses may be very large. Environmental services are frequently thought of in terms of air and water purification, which are very important. Ecosystem collapse will lead to even more devastating consequences, among which are an increased frequency and incidence of pestilence and human disease, the loss of environmental stability, a reduction in the capacity of the environment to support crop production, the maintenance of adequate quantities of clean air and water, and the very real and substantial values associated with maintenance of a diverse gene pool. In the face of such losses, it is hard to imagine how a minimal quality of human life could be sustained. The loss of life itself could be quite large. The evidence points to a situations in which we ignore the condition of our environment at our own peril. To state it differently, the continued reallocation of water away from environmental support toward agriculture and other consumptive uses will likely threaten to reduce the carrying capacity of the Earth itself.

5. Concluding comments

The evidence and views of experts summarized in this paper suggests that the allocation of water between agriculture and the environment is a significant issue globally, nationally and locally and can no longer be taken for granted. The stakes on both sides of the issue are enormous. On the one hand, failure to find ways to produce more food will likely lead to starvation of a significant number of humans. On the other hand, continued allocation of water from environmental purposes to agriculture in order to support continued population and economic growth runs the very real risk of incurring very costly losses in environmental services which themselves could lead to major reductions in the quality of life, or even to death, for substantial numbers of humans.

There are no paths to the resolution of the problem that are both simple and obvious. Clearly, efforts to improve the productivity of water, both green water and blue water, in agriculture hold some promise of increasing food production without allocations of additional water from environmental uses. It also appears that the widening gaps between rich and poor work against solutions by ensuring that poverty-stricken people will have very limited options to cope with water stress. Anything that could be done to narrow this gap and make additional resources available to the poor would help. Such resources would allow those who are currently poverty-stricken to engage in trade for food and to develop water-saving techniques for growing their own.

It also seems clear that the modification of human behavior through the adoption of new ethical norms and the guidance of enlightened religions could help significantly. Certainly, anything that can be done to reduce population growth will limit the extent to which the problem grows worse in the future. Yet, both this issue and the income distribution issue raise disturbing questions about the feasibility of managing the global commons in an enlightened and effective way. Decisions about population growth are frequently individual decisions and sometimes national decisions. Decisions about economic growth are almost always national decisions. These decisions are made by political leaders who frequently have little incentive to account for the implications of their actions for the carrying capacity of the planet. In a classical sense, the impacts of each of these decisions are tiny but taken collectively they are enormous and have brought us to the point where we may set in motion irreversible trends which will outstrip the world's water resources. In the absence of global action, this may be only one of many manifestations of global overreach.

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