1 Comparing 20th-century trends in US and global agricultural water and land use

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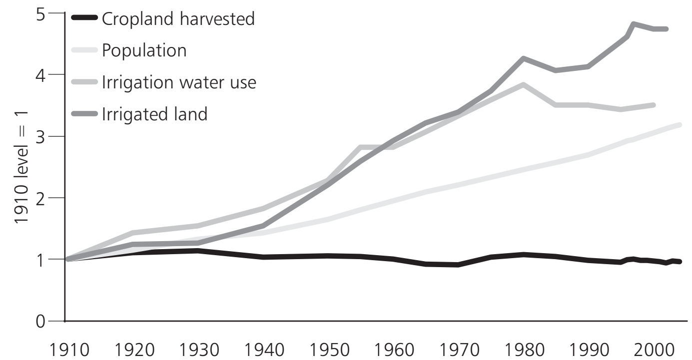
Nearly everywhere in the world where humans use land and water, they primarily use it for agriculture. The amount of land used per capita for agriculture has been in decline since the early 1900s. However, agricultural water use per capita only began to decline in the latter half of the 20th Century. One factor that helps explain these facts is that farmers (and farming communities) have traditionally had stronger property rights to their land than to their water. As a result, through much of the 20th Century, farmers had a greater incentive to improve the efficiency of land use than that of water use, and to substitute water for land (or irrigated land for dryland) in producing crops.

Land and water are the two most critical natural resource inputs for agriculture. Globally, agriculture accounts for 38 percent of land use, 66 percent of freshwater withdrawals, and 85 percent of freshwater consumption (FAO 2001; Shiklomanov 2000).

Agriculture inevitably has a significant impact on terrestrial and freshwater habitats, ecosystems, and biological diversity (Wilson 1992; Goklany 1998, 1999a; IUCN 2000). It is generally recognised that conversion of land to agricultural uses is the single most important threat to terrestrial biodiversity. According to the International Union for the Conservation of Nature, habitat loss and degradation – to which agriculture is a major contributor – affect 89 percent of

Figure 1.1 **US cropland and irrigation water use 1910–2004**



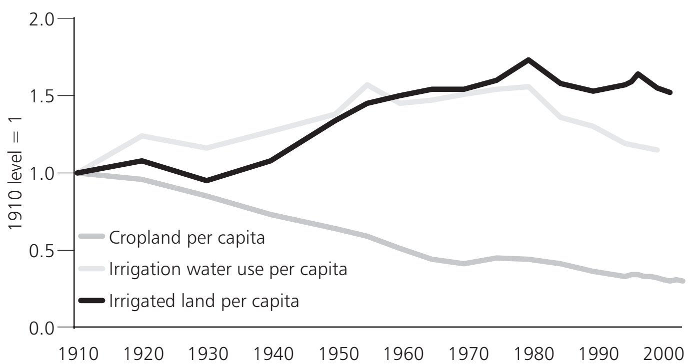
Sources:
Irrigated land: from 1910–1955, USBOC (1975, p. 433); from 1960–1995, USDA (2001), p. ix–7 (interpolated, as necessary); for 2000, Gollehon et al. (2003);
Irrigation water: USBOC (1975), p. 434; for 1950–2000, Solley et al. (1998) and Hutson et al. (2005);
Cropland: for 1910–1995, USDA (no date); for 1996–2004, USDA (2005) Agricultural Statistics 2005, p. ix–17.]
Population: Bureau of the Census (USBOC)
(1) 2000–2004: 'National and State Population Estimates: Annual Population Estimates 2000 to 2004,' at http://www.census.gov/popest/states/NST-ann-est.html visited August 14, 2005.
(2) 1900–1959: Historical National Population Estimates, 1900 to 1999 at http://www.census.gov/popest/archives/pre-1980/ visited August 14, 2005. (3) 1960–1999: Statistical Abstract 2004–2005

birds, 83 percent of mammals, and 91 percent of plants assessed by the organization to be 'threatened' (IUCN 2000).

Similarly, water diversions for agricultural uses and the pollution generated by agricultural practices contribute significantly to the threats facing many freshwater species (IUCN 2000; Wilson 1992). Although robust information and data are lacking, it is estimated that about 20 percent of freshwater species are threatened, endangered, or extinct due to a variety of causes, including agricultural demand (IUCN 1999).

This chapter considers the trends in water and land use over the course of the past 100 years, in the US and globally, and the factors underlying these trends.

Figure 1.2 **US per capita cropland and irrigation water use 1910–2004**



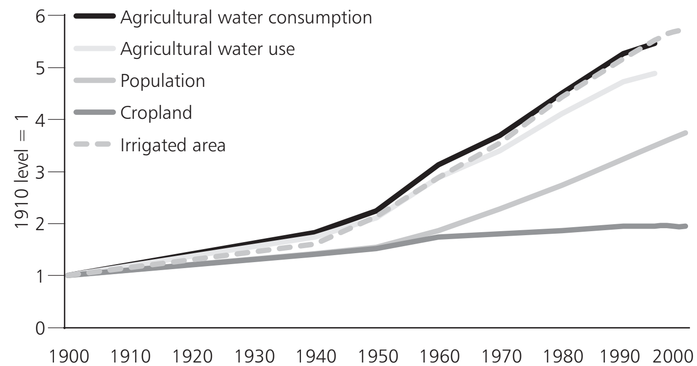
Sources: USBOC (1975, various years), Solley et al. (1998), Hutson et al. (2005), Gollehon et al. (2003), USDA (2001, 2005).

US trends: 1910 to 2004

In the US, agriculture currently accounts for one-third of surface water withdrawals, two-thirds of groundwater withdrawals, and 85 percent of consumptive water use (Solley et al. 1998). Meanwhile, harvested cropland accounts for 16 percent of US land area excluding Alaska (US Bureau of the Census 2006; US Department of Agriculture 2001a).[1]

Between 1910 and 2000, the US population increased by 205 percent. Despite the increase in demand for food, the amount of cropland harvested declined by 3 percent. However, as can be seen from Figure 1.1, total water withdrawn and used for irrigation increased by 251 percent (US Bureau of the Census, 1975; Solley et al. 1998; US Department of Agriculture 2001b, 2005a, 2005b; Gollehon et al. 2003; Hutson et al. 2005)). Meanwhile, the amount of irrigated land increased by 374 percent.[2] Over the same period, yields per unit of land increased substantially for

Figure 1.3 **Global cropland and irrigation water use 1900–2000**



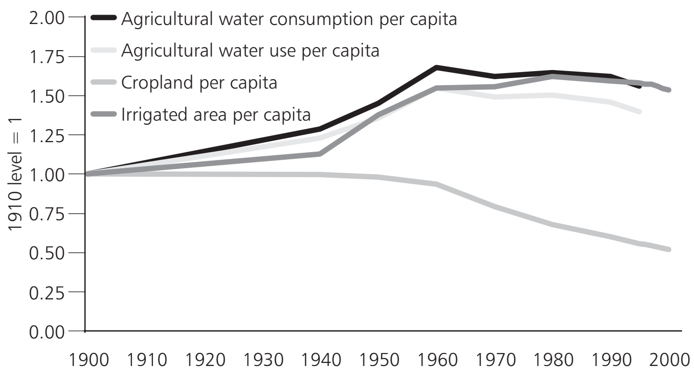
Sources: for water and irrigated land, Shiklomanov (2000); for population, McEvedy and Jones (1978) and FAO (2002); for cropland, Goklany (1999a) and FAO (2002). Since the FAO's data for cropland begins in 1961, cropland for 1960 is extrapolated using 1961 and 1962 data.

many of the major crops. For instance, corn (maize) and wheat yields increased by 391 and 208 percent, respectively (USDA 2000, 2005)

Figure 1.2 shows the contrast between trends in per-capita cropland, irrigation water use and irrigated land in the USA. In combination, figures 1.1 and 1.2 demonstrate that cropland per capita has declined at least since 1910, while aggregate cropland rose slightly until around 1930 and then fell very gradually. Although both aggregate and per capita levels of water use for irrigation have declined since around 1980, this followed substantial increases throughout most of the 20th century.

Overall, between 1910 and 2000 irrigation water use per capita and irrigated land per capita increased 15 and 55 percent, respectively. By comparison, over the same period, cropland per capita declined by 68 percent. Figures 1.1 and 1.2 show that between 1910 and 1950, US irrigation water use grew more rapidly than irri-

Figure 1.4 **Global per capita cropland and irrigation water use 1900–2000**



Sources: Shiklomanov (2000); McEvedy and Jones (1978); Goklany (1999a); FAO (2002).

gated land, but this trend was reversed in the 1950s. Currently, irrigated land seems to be increasing at a faster rate than irrigated water use.

Global trends: 1900 to 2000

Figure 1.3 shows global trends in aggregate land and water use and consumption by agriculture between 1900 and 2000. It suggests that they are on paths similar to that of the United States, except not as far along. While the amount of land devoted to crops seems to be levelling off (Goklany 2001a), agricultural water use and consumption, and the area devoted to irrigated land, continue to increase, although much less rapidly now than in the past.

Moreover, during this period, total water use and consumption of water relative to population growth have both increased much more than the amount of cropland. Between 1900 and 1995, the global population increased by 249 percent, cropland increased 95 percent, and agricultural water use increased 388 percent. Agricultural water consumption and irrigated land area increased even faster – by 446 and 453 percent, respectively.[3]

Figure 1.4 provides the same information, but on a per capita basis. It shows that cropland per capita has declined since around the 1930s. Between 1900 and 1995, it fell by 44 percent. By contrast, per capita agricultural water use and consumption both peaked around 1960. Although they have declined since then, per-capita withdrawals, per-capita water consumption due to agriculture and per-capita irrigated land were higher in 1995 than in 1900 (by 40, 56, and 58 percent, respectively).

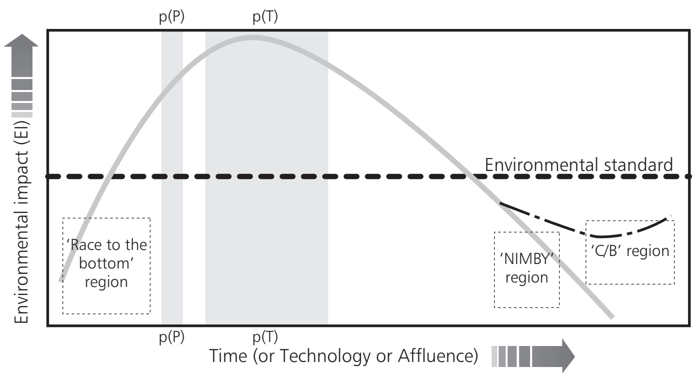
Just as for the US, Figures 1.3 and 1.4 show that global agricultural water withdrawals and consumption grew more rapidly than irrigated land in the first four decades of the 20th Century, but since then this trend has reversed. Since 1980, irrigated land has increased at a faster rate than either agricultural water withdrawals or consumption. Between 1980 and 1995, irrigated land area increased 25 percent, while water withdrawals and consumption increased by 19 and 21 percent, respectively.

The environmental transition hypothesis

What accounts for the large differences in the trends for agricultural water and land use in both the US and worldwide? Why has agricultural water use increased much more rapidly than land use? Why did increases in the efficiency of cropland use precede those of agricultural water use?

The trends displayed in Figures 1.1 through 1.4 are consistent with the “environmental transition hypothesis” (Goklany 1998; 1999b). This is depicted graphically in Figure 1.5: the y-axis indicates the environmental impact (EI) on a society as measured by a particular indicator (such as air quality), while the x-axis represents time (which is a proxy for the state of technological development). EI first increases, then it goes through an “environmental transition” (ET) after which it declines – at least until society determines that it is

Figure 1.5 **The environmental transition**



Note: p(P) = period of perception; p(T) = period of transition; NIMBY region = "not in my back yard" region (EI enters this region if benefits far exceed costs borne by beneficiaries); C/B region = EI enters this region if costs and benefits have to be more carefully balanced.
Source: Goklany (1999b).

'clean enough' (Goklany 1999b). Until that point, the trajectory for EI is shaped like an inverted-U.

For some indicators, such as sanitation or safe water, the transition has historically occurred early on in a country's developmental history (Goklany 1995). Currently-available trend data might therefore start at a point after the transition has occurred. That is, the trend data may only indicate the downward slope. For other indicators, because the problem has yet to be addressed successfully, a transition may not be evident, in which case the country may still be on the upward slope of the ET.

Historical trends for a variety of environmental indicators in many of the world's wealthier countries follow a path stylistically shown in Figure 1.5. These include various indicators related to air quality for traditional air pollutants, such as lead, sulfur dioxide, particulate matter, and carbon monoxide (Goklany 1999b), as well as indicators of water quality, such as dissolved oxygen levels, lead, and DDT (Goklany 1994; 1998; European Environment Agency 1998).

However, data from relatively poorer countries often shows that their pollution levels are currently increasing – that is, they are on the ascendant part of the environmental transition curve (Goklany 1994). So what accounts for environmental transitions?

Human beings are on a continual quest to improve their quality of life, which is determined by numerous social, economic, and environmental factors (Goklany 1995; 1998; 1999b). The weight given to each determinant changes constantly along with a society's precise circumstances and perceptions at any given point in time.

Over time, people develop new and better technologies with which to satisfy their needs and wants. The improved technologies typically increase productivity and lead to increases in wealth. In the early stages of economic and technological development, society places a higher priority upon satisfying basic needs, such as food, water, shelter, and heat, than on other concerns. This is true even if this higher priority entails tolerating some environmental deterioration.

Fundamentally, in the early phases of economic development people place a higher priority on affluence, because it is a means of achieving all their basic needs and also provides the means to reduce the most significant risks to public health and safety, such as malnutrition, infectious and parasitic diseases, and child and maternal mortality.

Also, in these early stages, society may be unaware of the potential risks posed by any particular technology. However, as society becomes wealthier, it tackles the more significant problems and possibly gains more knowledge. Hence, the specific environmental problems represented by EI automatically rise higher on its priority list (even if EI does not become worse).

In addition, because economic activity frequently increases EI, people perceive improvements to environmental quality as a more important determinant of the overall quality of life. This stage is represented in Figure 1.5 as the period of perception or p(P) (Goklany 1999b). Prior to p(P) one should not expect society to require, or private parties to volunteer, to reduce EI, although reductions may occur as a result of secular improvements in technology or other reasons (Goklany 1995;1996).

For example, in the US, the period of perception for sulphur dioxide probably did not begin earlier than October 1948, when an air pollution episode in Donora, Pennsylvania, was associated with 18 excess deaths in a population of 14,000. Nevertheless, for reasons explained below, indoor sulphur dioxide levels began to improve before the 1940s (Goklany 1999b).

From p(P) onward, a democratic society will often translate its desire for a cleaner (or improved) environment into laws, either because improvements are not forthcoming voluntarily or rapidly enough, or because of sheer symbolism. In general, this means that a relatively wealthier society will have more demanding laws, and will be more able to bear the costs of those laws.

At the same time, with increasing affluence and ongoing improvements in technology, society is better able to improve its environmental quality. Affluence also liberates the resources required to engage in research and development targeted towards cleaner technologies. Likewise, affluence makes possible the widespread deployment of new, or existing but unused, technologies (especially if their up-front costs are higher) by individuals in a society. Consequently, EI undergoes a period of transition. Ultimately, greater affluence and technological change should result in a decline in EI (Goklany 1995; 1999b).

The timing, height, and width of an environmental transition for a specific indicator is unlikely to be the same for all countries. In general – all else being equal – the ETs for latecomers to industrialisation should occur at lower levels of affluence because they can learn and adapt technologies from countries that have already gone through the ET. Indeed, this seems to be the case worldwide. By comparison with relatively wealthier countries, many of today's poorer countries have started to address environmental issues (such as safe water and sanitation, and lead, sulfur dioxide, and other air pollutants) at much lower levels of economic development. Sometimes, these countries are actually cleaner (or better off) than

wealthier countries were at equivalent levels of economic development (Goklany 1995; 1999b; 2001a).

Other factors can also affect the timing of an environmental transition in a country, and the level of affluence at which it occurs. First, they depend on the precise indicator used to characterize environmental impact, and how closely it is tied to the perceived quality of life. This helps explain why in the US, for example, the transitions occurred earlier for indoor air pollution than for outdoor air quality, and for sulphur dioxide and particulate matter (pollutants most directly related to the killer air pollution episodes of the 1940s and 1950s) than for less powerful pollutants such as nitrogen oxides and ozone (Goklany 1999b). Similarly, we see that worldwide, countries address the lack of safe water and poor sanitation ahead of other forms of water pollution.

Second, the timing, height, and width of an environmental transition also depends upon government responsiveness to the perceived needs and desires of the general public. Thus democracies are more likely to see earlier transitions. In addition, the relative political power of the sectors which contribute environmental impacts can affect the timing, height and width of the transition, because that determines their success in affecting the stringency of laws directed at their contribution to EI.

Environmental transitions are also affected by the country's natural resource endowment. A country endowed with abundant natural gas and hydropower is less likely to burn coal while a country with large and easily accessible reserves of coal will be less eager to switch to cleaner fuels. Similarly, the period of perception for water use is more likely to be delayed for a country with plenty of water, for instance.

Finally, the extent of a transition will depend on the fiscal resources and human capital available and devoted to bringing about the environmental transition. The costlier or more difficult it is to bring about a transition, the more likely it will be delayed, the period of transition may be longer, and the height at which the transition occurs will be greater.

This helps to explain why relatively poorer countries are still on the upward slope for many pollutants even though wealthier countries have gone past their transitions. It also helps to explain why greenhouse gas emissions, for example, continue to increase globally (Goklany 1999b).

A superficially similar result is obtained by plotting environmental impacts against affluence (GDP per capita) using cross-country data for a range of pollutants. In this case, the inverted-U shaped curve has been called an “Environmental Kuznets Curve” (EKC) after the Nobel prize winning economist Simon Kuznets.

However there are significant differences between the ET and the EKC. In the former, the environmental indicator is plotted for one country (or region) at a time, and the x-axis represents time, which is a good proxy for both affluence and technological development, at least for the past two centuries (Goklany 1999a; 1999b). However, in the EKC, the data are generally plotted for a set of countries, and the x-axis represents only affluence.[4]

With respect to water resources, one measure of environmental impact could be the irrigation water withdrawn or consumed. Similarly, cropland use could serve as a measure of the human impact on the land (Goklany 1996). However, the amount of irrigated land does not fit neatly as a measure of environmental impact solely for either land or water, although it might help to explain some of the trends in land and water use.

US situation

Figures 1.1 and 1.2 show that for the US, aggregate as well as per capita irrigation water use have gone beyond their environmental transitions (or peaks). Aggregate cropland is close to, and perhaps also past the transition while cropland per capita is clearly past its environmental transition. These figures also indicate that although aggregate cropland has stayed more or less static for the 20th Century, the increase in the productivity of agricultural land use substantially exceeds the increase in water use productivity.

One possible reason as to why the decline in cropland per capita commenced earlier than agricultural water use per capita might be that cropland, in contrast to water, has mainly been privately owned. While there are several reasons why this has traditionally been the case (e.g., water supplies are uncertain and variable, not all its uses are rival, and water use can result in externalities),[5] private property rights over land provide the owner with powerful incentives to maximize long term productivity per unit of land (this is discussed further below). These incentives are weaker where private property rights are either absent, poorly delineated, or difficult to enforce – as has been the case with water in the US.

If US agricultural technology had been frozen at 1910 levels – i.e. if cropland per capita had stayed at 1910 levels – then to produce the same output as achieved in 2004, US farmers would have had to utilise 1,007 million acres rather than the 305 million acres that were actually harvested that year.[6] That’s more than four times the total amount of land and habitat under special protection in the US in 1999 – including National Parks, National Wildlife Refuges, and National Wilderness Areas. Quite possibly, the increase in land productivity averted a potential catastrophe for US wildlife and perhaps even biodiversity more generally.

By contrast, water use per capita increased between 1910 and 2000, possibly because water use is more dependent on political muscle and machinations than on economics. Once access to water has been secured, in the absence of the ability to sell excess water or transfer it to other users for compensation, there are limited incentives to increase the efficiency of water used in agricultural activities.

However, even where *de facto* water “rights” are not fully transferable, there is an incentive to optimise water use within such constraints. One method to optimise water use is to improve irrigation efficiency which, in turn, would allow more land to be irrigated.

In the early part of the 20th Century, farmers and the agricultural sector had established a more-or-less free reign over water in the US. However, throughout the 20th Century, the demographic and economic power of the agricultural sector declined, while that of urban, suburban, and environmental interests – interests with broad overlap in membership – increased:

- In 1899–1903, agriculture contributed 18.9 percent of US national income and employed 36.9 percent of the working population.
- By 1948–1953, agriculture contributed 7.2 percent of national income and employed 10.6 percent.
- In 1970, agriculture accounted for 3.1 percent of national income and employed 4.3 percent of the working population. (US Bureau of the Census 1975).

At the same time, the percentage of the population living in rural areas declined from 60 percent in 1900, to 41 percent in 1950, and 26 percent in 1970 (US Bureau of the Census, 1975). Also by 1970, the demand for water and the costs of tapping new sources of water had increased for all sectors.

Thus, politics and economics came together in a way that enabled the urban-suburban environmental groups frequently to challenge agriculture's claims to water. Though not all of these challenges were fully successful, by the 1980s they had served to reduce the amount of water diverted to agriculture, as well as irrigation water use per capita (Solley et al. 1998; Postel 1999). The agricultural sector responded to increased water scarcity by increasing the efficiency of irrigation and expanding the amount of land under irrigation.

This helps explain both the decline in the amount of irrigation water applied per acre of land – from about 2.5 acre-feet in 1980 to 2.1 acre-feet in 1995 (Solley et al. 1998) – and the rapid increase in irrigated land during this period, even as irrigation water use declined.

Global situation

Figure 1.3 shows that globally, aggregate cropland seems to be levelling off – i.e. approaching an environmental transition (Goklany 2001a). But there is still an increase in aggregate water use and consumption as well as in irrigated land use (albeit less rapid than previously). Moreover, except for cropland, they have all increased at a faster rate than population.

On a per-capita basis, however, cropland and irrigation water use and consumption have all passed their environmental transitions. But these levels have not yet dropped off as much as the levels for the US.

Despite the pressures which agriculture has brought to bear on global biological resources, those pressures could have been much worse if global agricultural productivity, and therefore yields, had been frozen at a certain point in time (for instance, at 1961 levels). This would be equivalent to freezing technology, and its penetration, at 1961 levels. In that case, in order to produce as much food as was actually produced in 1998, agricultural land area would have had to more-than double to at least 26.3 billion acres, compared to the actual 1998 level of 12.2 billion acres (Goklany 2001b).

Thus, agricultural land area would have needed to increase from its current 38 percent to 82 percent of global land area (FAO 2001; Goklany 2001b). Cropland would also have had to more than double, from 3.7 to 7.9 billion acres. In effect, an additional area equivalent to the size of South America-minus-Chile would have been ploughed-under to achieve the 1998 level of food production. Thus, by increasing productivity in land, we forestalled further increases in threats to terrestrial habitats and biodiversity.

However, these improvements were not matched by similar increases in efficiencies of irrigation water use. Not surprisingly, some analysts now believe that the major resource constraint for being able to satisfy future global demand for food is likely to be water rather than land, as Malthus and others had traditionally believed (FAO 1996; Postel et al. 1996; Pimentel et al. 1997; Postel 2000).

Property rights – and their absence

Whether considering the US or the global situation, water use efficiency has lagged behind improvements in cropland efficiency for similar reasons. Namely, in most areas of the world farmers possess some property rights to their land but often not to water; nor is water generally treated as an economic commodity.

In fact, the tremendous increase in irrigation in the US (Gleick 1998) and worldwide during the past few centuries (L'Vovich et al. 1990; Goklany 1998) could be viewed – at least in part – as the substitution of often-subsidized water for land. This provides evidence for Terry Anderson's statement that when water is cheaper than dirt, it will be treated that way (Anderson 1995).

Property rights include long-term tenure to land, the right to trade, and the right to profits from selling products and improving productivity (Goklany and Sprague 1991; IPCC 1991; Taylor 1997). Farmers would not invest – i.e. risk – their time, money, and effort to increase productivity and efficiency without such rights, especially the right to retain profits from such investments. Property rights therefore provide an incentive for the farmer to engage in long term sustainable practices.

A good example of the beneficial effects of property rights comes from the improvements in agricultural productivity in China in the early 1980s, and the subsequent slowdown in improving yields in that country (Prosterman et al. 1996). In the early 1980s, Chinese farmers were given rights to a portion of their produce. The annual rate of increase in agricultural productivity soared. However, it declined again when it became clear that these rights were not equivalent to long term tenure, and farmers held back further investments in "their" plots.

Property rights are one important aspect of "economic freedom." Indeed, Norton (1998) has argued convincingly that economic freedom serves as an aggregate measure for the deference given by a country to property rights, since it includes components for the security given to property rights under law, as well as components which would diminish those rights indirectly

through inflation or through limitations on the freedom to trade or exchange.

Not surprisingly, Gwartney et al. (1998) find that increases in cereal yields are proportional to the degree of economic freedom in countries. Norton also finds that deforestation rates decline when property rights are increased. These two sets of results – increased yields and lowered deforestation – support the notion that stronger property rights result in higher agricultural productivity, which leads to greater land conservation (Goklany and Sprague 1991; IPCC 1991; Goklany 1998; 1999a).

On the other hand, the absence of property rights for water simply encourages waste and reduces incentives to adopt existing or develop new technologies to enable conservation, re-use or recycling. To make matters worse, most societies subsidise water – particularly in agriculture – on the basis that water is vital for humanity (Anderson 1995; Pimentel et al. 1997). Such subsidies perversely reduce the incentive to utilise water more efficiently, or to conserve – and predictably, water conservation technologies remain under-utilized and under-developed.

Yet another perverse consequence of water subsidies is that in many urban areas in the developing world, the poor pay more for water than do the middle and upper classes that are connected to subsidized municipal water systems (Serageldin 1995). Ironically, many in these subsidized groups are happy enough to pay larger sums for bottled or canned soft drinks even when they are not needed to quench their thirst.

If institutions and policies are modified so that private entities are able to hold well-defined and transferable rights to water, this would form the basis for water markets. Water trading would occur, the price of water in specific contexts would reflect demand and scarcity, and 'virtual' water would be freed up. It might then be possible to replicate for water the almost universal historical experience with land, in which use has progressively has become more efficient.

The success of such policies and approaches has been demonstrated in cultures as diverse as the US, Chile, Jordan, India, Pakistan, and Indonesia (Anderson 1995; Rosegrant et al., 1995; Serageldin, 1995; Easter et al., 1998).

For example, in Chile, efficiency of water use was increased through water trading. Between 1976 and 1992, it improved from 22 to 26 percent, effectively expanding irrigated area by a similar amount (Rosegrant et al. 1995; see also Southgate and Figueroa, this volume, Chapter 3). The experience in India and Pakistan shows that gains in efficiency can be obtained even where markets are based on informal and imperfect property rights (Saleth 1998; Meinzen-Dicks 1998).

The environmental benefits of property rights

The environmental benefits of well defined, readily enforceable and easily transferable property rights are evident in other arenas besides water. For example, with respect to air pollution, the initial major improvements in air quality were experienced in the first half of the 20th Century when households and businesses began to switch from coal- and wood-burning stoves and fireplaces to oil and gas, while others adopted more efficient combustion equipment and practices (Goklany 1996; 1999b).

By and large, homeowners and businesses undertook these measures voluntarily because they were cleaning up their own private property. They were confident that investments in more efficient, cleaner fuel delivery would result in direct benefits by reducing smoke, dust, and grit to themselves, their families, and, in the case of businesses, for their employees and customers. No less important was the fact that the development of new, more efficient technology reduced their fuel costs. Thus, by virtue of the institution of property rights, they had an economic as well as an environmental incentive to clean up and to use resources more efficiently.

The ability of property owners to capture the economic benefits associated with greater efficiency also provided much of the

impetus behind the secular improvements in technology which helped to reduce emissions per unit of GDP for sulfur dioxide (SO_2), volatile organic compounds (VOCs), and nitrogen oxide (NO_x) pollutants. These improvements occurred long before any of those substances were generally recognized to be environmental problems or, for that matter, before the US federal government became involved in air pollution control (Goklany 1999b).

SO_2 was not perceived to be a public health problem until after several ‘killer smog’ episodes – including well-known events in Donora, Pennsylvania in 1948, and London in December, 1952. Yet SO2 emissions per unit of GDP have been declining since the early 1920s in the US while London’s outdoor sulphur dioxide concentrations peaked in the late 1890s (Elsom 1995; Brimblecombe 2004).

Similarly, emissions of VOCs and NOx per unit of GNP have been dropping across the US since the 1930s – decades before these substances were either implicated (in the 1950s) as being responsible for the formation of photochemical smog, or recognized (in the late 1960s and early 1970s) to be nationwide air quality problems (Goklany 1999b). Likewise, CO_2 emissions per unit of GDP in the U.S. have been declining at the rate of 1.3 percent per year for the past century and a half – long before global warming registered on the public consciousness in the late 1980s.

Summary and conclusions

Currently, agricultural land use and water use constitute some of the primary pressures on terrestrial and freshwater habitats, ecosystems and biodiversity, both in the USA and globally. These pressures would be much worse but for the increased productivity of land in agriculture during the 20th Century.

This leads to one of the most interesting conundrums concerning natural resource use. Although, decade-upon-decade, agricultural productivity per unit of land in the US and worldwide has increased spectacularly, these increases have not been matched by parallel improvements in productivity per unit of water.

It seems that water has been systematically substituted for land in order to boost productivity. As a result, the availability of water in the 21st Century could become the major impediment to resolving the dilemma inherent in satisfying global food and fibre needs while conserving habitat and maintaining biodiversity.

The differences in the trends for agricultural land and water use can, partly at least, be explained by the almost universal difference in the institutional arrangements for the use and management of these two critical natural resources. The widespread institution of clearly defined and readily enforceable and transferable property rights over agricultural land has provided the incentives and capital that have enabled enhanced efficiencies.

If similarly well-defined and readily enforceable and transferable property rights were to be instituted for water, it seems likely that entrepreneurs operating within the market would likewise increase the efficiency of use of water for agriculture – thereby helping solve the food/biodiversity dilemma by enabling both to be provided in ample amounts.

Notes

1. Farms account for about half of the land area outside of Alaska (which has very little agricultural potential), about one-third of which is harvested each year.
2. However, a word of caution is needed regarding these data. Figure 1.1 is interpolated from data provided in the periodic Censuses of Agriculture gathered until 1997 by the Department of Commerce (US Bureau of the Census 1975; US Department of Agriculture 2001b). The Census of Agriculture – which was gathered by the US Department of Agriculture for the first time in 1997 – shows a very rapid increase since the early 1990s in the amount of irrigated land. However, another data set collected by the US Geological Survey (Solley et al. 1998) shows a much smaller increase. A comparison of estimates made by the Census of Agriculture (interpolated) and those of the USGS show that the latter's figures are consistently higher by 10 to 25 percent.

3. The amount of irrigated land tracks relatively closely with agricultural water consumption because the two sets of data are related and come from the same source (i.e., Shiklomanov 2000).
4. In fact, I have elsewhere demonstrated that a set of single-country inverted-U-shaped ETs does not necessarily result in an inverted-U-shaped cross-country EI verses affluence curve; instead, it could be N- or even U-shaped (Goklany 1999b).
5. See for example Livingston (1998).
6. This calculation is based on three relatively optimistic assumptions: First, sufficient new cropland would be available, but this is unlikely since the total amount of potential cropland in the US is estimated to be only 647 million acres (Goklany 2001a, based on NRCS 2001). Second, the additional cropland would be just as productive as existing cropland. Third, the productivity of existing cropland would be maintained without any new technologies.

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