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The Economic Costs of Ecological Deficits

(part 2 of 3)

Assessing the Food Prospect

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Throughout most of human existence, the scale of economic activity was small relative to the size of the earth's ecosystem. But over the last century this has changed. In 1900, global economic output totaled $2.4 trillion. In 2001, it was $46 trillion, an expansion of 19-fold. The world economy is now so large that its growth in the year 2000, a single year, exceeded that of the entire nineteenth century.[1]

The growth in population and in individual incomes, the two elements of this phenomenal growth, have both escalated over the last half-century. Population went from 2.5 billion at mid-century to 6.1 billion in 2001. Those of us born before 1950 are members of the first generation to witness a doubling of world population during our lifetimes. Stated otherwise, the growth in world population since 1950 is greater than that during the preceding 4 million years since our early ancestors first stood upright.[2]

Individual income climbed from $2,582 in 1950 to $7,454 in 2001, nearly tripling. Despite the extraordinary growth in the global economy over the last half-century, 1.2 billion people, one fifth of humanity, still live in abject poverty. The average income in the 20 richest countries is 37 times that of the poorest 20 countries.[3]

Since 1950, the growth in individual incomes has accounted for slightly over half of the economic expansion. Between 1950 and 2001, population grew by 146 percent and individual incomes by 188 percent. Population growth has come to a halt in 32 countries. In these nations, births and deaths are essentially in balance. Scores more want to stabilize their populations. No country, however, has stabilized individual consumption, however high it may already be.[4]

Although the global economy expanded nearly sevenfold from 1950 to 2001, the earth's ecosystem did not expand. The amount of water produced by the hydrological cycle is essentially the same today as it was in 1950. The capacity of oceanic fisheries to supply fish has not increased. Nor has the capacity of rangelands to support livestock or that of forests to supply wood for fuel, lumber, and paper. The earth's capacity to fix carbon is not increasing and may have decreased. Its capacity to absorb waste has not changed.

While the capacities of the earth's natural systems have not increased—and in many cases have diminished—the demands being placed on them have risen dramatically. World water use has tripled since 1950. The oceanic fish catch has expanded nearly fivefold. The pressures on forests to supply fuel, lumber, and paper have multiplied severalfold. Paper use has increased sixfold. Pressures on rangelands have intensified as the demand for beef and mutton has nearly tripled since 1950.[5]

In much of the world, the demands placed on natural systems have become excessive, leading to their deterioration and, in some locations, their collapse. The relationship between the global economy and the earth's ecosystems is an increasingly stressed one. Many of the stresses, including expanding deserts and increasingly frequent dust storms, rising temperature, falling water tables, eroding soils, collapsing fisheries, melting glaciers, and rising seas directly affect the food prospect.

These signs of stress, these trends of deterioration, are in large measure the result of market failures. The market has many strengths, but it also has some weaknesses that were not evident when the human enterprise was much smaller.

The market economy has brought a wealth to the world that our ancestors could not even have imagined. It allocates resources among competing uses, it balances supply and demand, and it facilitates the specialization that underpins the productivity of modern economies. But as the economy expands, the market's weaknesses are beginning to surface. Three stand out: its lack of respect for the sustainable-yield thresholds of natural systems, its inability to value nature's services properly, and its failure to incorporate the indirect costs of providing goods and services into their prices.

Soil: Surplus to Deficit

In some ways, the most fundamental ecological deficit the world faces is the loss of soil through wind and water erosion. This loss of an invaluable natural capital asset and the associated loss of land productivity are spreading as pressure on the land intensifies.

Soil erosion is not only widespread, but it is not reversible in any meaningful human time frame. Once nutrient-rich topsoil is lost, the capacity of the land to store the nutrients and the water that plants need to sustain growth is greatly diminished.

Soil scientists have assessed the risk of human-induced desertification—land that is losing its productivity as a result of human activity—and the number of people affected by it. Using four categories of risk of desertification—low, moderate, high, and very high—

they estimate that 11.9 million square kilometers are at very high risk. (See Table 1–3.) They argue that the land in the very high risk category should be the focus of policymakers because if measures are not taken to protect it soon, its productivity may be lost forever.[6]

The researchers call each of these categories a "desertification tension zone," and they are particularly concerned with the very high risk zone both because this area could turn to desert so quickly and because 1.4 billion people live there. For many of these people, their land is their livelihood.[7]

The Sahelian region of Africa, the broad band that stretches across the continent between the Sahara and the rainforest to the south, is one of the areas in serious trouble, slowly turning into desert. U.N. Secretary-General Kofi Annan reports that unless the desertification of this region is halted, within the next 20 years some 60 million people will be leaving the region—refugees from the desert.[8]

Table 1–3. *Land at Risk of Human-Induced Desertification*

Degree of Risk	Area at Risk (million square kilometers)
Low risk	7.1
Moderate risk	8.6
High risk	15.6
Very high risk	11.9
Total	49.2

Source: Hari Eswaran, Paul Reich, and Fred Beinroth, "Global Desertification Tension Zones," in D. E. Stott, R. H. Mohtar, and G. C. Steinhardt (eds.), *Sustaining the Global Farm* (2001), pp. 24–28.

Soil erosion is not new. What is new is the rate of erosion. New soil forms when the weathering of rock exceeds losses from erosion. Throughout most of the earth's geological history, the result was a gradual, long-term buildup of soil that could support vegetation. The vegetation in turn reduced erosion and facilitated the accumulation of topsoil. At some recent point in history, probably within the last century or two, this relationship was reversed—with soil losses from wind and water erosion exceeding new soil formation. The world now is running a soil deficit, one that is measured in billions of tons per year and that is reducing the earth's productivity. In China, as noted earlier, and in scores of other countries, the loss of soil is draining the land of its productivity.

In some areas, such as the flat fertile plains of Western Europe and the rice paddies of Asia, soils are stable. In others, including arid and semiarid regions, such as the Great Plains of the United States, most of Africa, Central Asia, and parts of northwestern China, land is vulnerable to wind erosion. Wherever there is sloping land, water erosion is a potential and often increasingly serious problem. In mountainous countries, such as Indonesia, Nepal, and Peru, sloping land can quickly lose its topsoil to water erosion.

In the early 1990s, some 250 scientists from 21 ecological regions concluded that 2 billion hectares of land, including cropland, rangeland, and woodland, had been degraded to some degree. This is roughly three times the 700 million hectares planted to grain worldwide. The overwhelming share of this land—84 percent—suffered from the erosion of soil, either by wind or by water.[9]

Scores of countries, mostly developing ones, are suffering a decline in inherent land productivity because of erosion. This does not necessarily mean that the harvest is declining, because in many situations advances in technology are more than offsetting the gradual loss of topsoil. But the cultivation of land that is losing its topsoil eventually becomes uneconomic, regardless of the level of technology.

As soil erodes, the land initially suffers from declining productivity, and eventually it may be abandoned. A dozen or so U.S. studies analyzing the effect of soil erosion on corn and wheat yields found that the loss of an inch of topsoil typically lowered yields by 6 percent. If the erosion continues indefinitely, it will eventually reduce the productivity of the land to the point where it can no longer be economically farmed. When the cost of producing food exceeds its value, the land is abandoned. For farmers, the cost of this ecological deficit is abandonment of their farms. For society, it represents a loss of natural capital that cannot be replaced in any meaningful time frame.[10]

Ohio State University agronomist Rattan Lal estimates that soil erosion has reduced Africa's grain harvest by 8 million tons, or roughly 8 percent. He projects this loss will double to 16 million tons by 2020 if soil erosion is not reduced. So Africa is projected to lose, in effect, the capacity to feed 80 million people at African levels of consumption during a period when its population is projected to increase by 288 million.[11]

Given the fastest population growth of any continent and some of the world's worst soil erosion, it comes as no surprise that grain production per person in Africa has been declining for the last few decades. While grain output per person in Europe, where population has stabilized and soil erosion is minimal by comparison, has nearly doubled over the last 40 years, in Africa it has fallen by nearly one fifth. (See Figure 1–2.) Of even more concern, there are no shifts in national population and agricultural policies currently in prospect in Africa to

reverse this deteriorating food situation.[12]

U.S. farmers have also suffered from land mismanagement. Despite their experience with the Dust Bowl in the 1930s, a new generation of farmers was again overplowing in the 1970s in response to record high world grain prices. As a result, soil erosion increased sharply. By the early 1980s, the United States was losing over 3 billion tons of topsoil a year, an amount equal to the topsoil on 1.2 million hectares (3 million acres). This would produce 7 million tons of grain, enough, at average world consumption levels, to supply 21 million people.[13]

The erosion in the 1980s, mostly from water, was concentrated in the midwestern Corn Belt, whereas the earlier erosion of the Dust Bowl in the 1930s, mostly from wind, was concentrated in the Great Plains. In 1985, the Congress, with strong support from environmental groups, created the U.S. Conservation Reserve Program

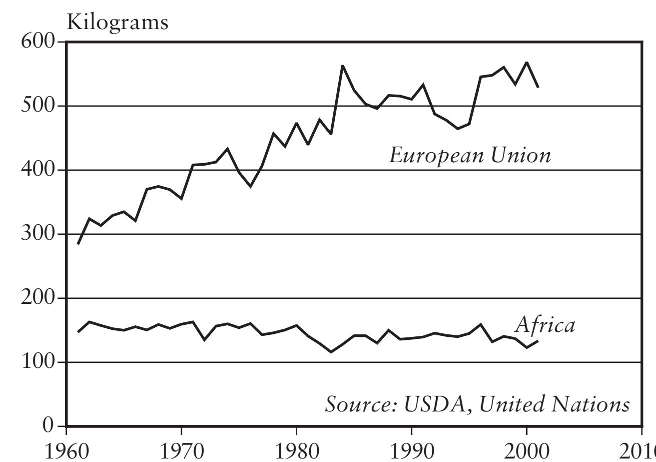

Figure 1–2. *Grain Production Per Person in Africa and the European Union, 1961–2001*

(CRP), which paid farmers to plant highly erodible cropland with grass or trees under 10-year contracts (most of which have been renewed). Within a few years, the CRP had removed some 14 million hectares (35 million acres) of cropland, nearly one tenth of the U.S. cropland total, from production. Of this land, roughly half should never have been plowed in the first place because it was so erodible. The other half could be brought back into production, if needed, with the proper soil management techniques. (Interestingly, the one tenth of cropland being converted to grass or trees is roughly the same as the share of China's cropland that is slated for conversion to trees during this decade.)[14]

Other countries that are also pulling back include Algeria, which is fighting a losing battle to protect its grainland as the desert moves northward. As a result, it has decided to convert the southernmost 20 percent of its grainland to permanent crops, either orchards or vineyards, as it tries to maintain agriculture and halt the advance of the desert. Whether or not this will succeed remains to be seen.[15]

There are few opportunities to expand production to new cropland to offset these losses. As the world demand for food has tripled over the last half-century, it has forced agriculture into areas that should not be plowed. Perhaps the most dramatic example of this is Kazakhstan. This former Soviet republic was the site of the vast Virgin Lands project during the 1950s, an initiative its supporters promised would expand grain production sufficiently to make the Soviet Union an agricultural superpower. Within a matter of years, the expanding area of grassland plowed and planted to wheat in Kazakhstan surpassed the wheat-growing area of Canada and Australia combined. It was a massive effort, but one that was destined to fail. From roughly 1960 to 1980, Kazakh

farmers cultivated some 26 million hectares of grain. But by 1980 wind erosion was reducing yields to where farmers were abandoning their land because it was no longer economic to farm. By 2000, the area in grain had fallen to less than 13 million hectares. Within two decades, Kazakhstan had abandoned half of its grainland, an area equal to Canada's wheatland. Wheat yields on the remaining land average scarcely 1 ton per hectare, only a fraction of the 7 tons per hectare of France, Western Europe's largest wheat producer.[16]

Despite the history of overplowing experience in key countries, there are still a few high-risk expansion efforts under way. One consists of replacing tropical rainforests in Indonesia and Malaysia with palm oil plantations. Although this is producing cheap palm oil, it is devastating the biological diversity of the region, and without any assurance that these exposed tropical soils will sustain cultivation over the long term.[17]

A far more ambitious effort is under way in Brazil as farmers plow the cerrado—a vast, semiarid savannah that is to the south and west of the Amazon basin. This land has helped Brazil become the world's second-ranking soybean producer, after the United States. The excitement within Brazil at this region's potential is remarkably similar to that displayed by the Soviets during the Virgin Lands Project in Kazakhstan some 45 years ago. Only time will tell whether the newly plowed cerrado will sustain cultivation over the long term.[18]

The Fast-Growing Water Deficit

While the soil deficit is growing slowly, the water deficit is growing rapidly. The world water deficit—historically recent, largely invisible, and growing fast—may be the most underestimated resource issue facing the world today. Because it typically takes the form of aquifer overpumping, the resulting fall in water tables is not visible. Unlike shrinking forests or invading sand dunes, falling water tables cannot be readily photographed. They are often discovered only when wells go dry.

In round numbers, 70 percent of all the water pumped from underground or diverted from rivers worldwide is used for irrigation, 20 percent is used by industry, and 10 percent goes to residences. But the demand for water in industry and for residential purposes is growing even faster than population, putting a squeeze on the amount available for agriculture.[19]

In some 18 countries, population growth has reduced the fresh water supply per person to less than 1,000 cubic meters per year, the minimal amount needed to satisfy basic needs for drinking, hygiene, and food production. By 2050, U.N. population projections show that 39 countries, with 1.7 billion people, will be experiencing such water deprivation.[20]

For most ecological deficits, we do not have a global estimate of their size. But for water we do. In her book *Pillar of Sand*, Sandra Postel, using data for India, China, the United States, North Africa, and Saudi Arabia, estimated the annual water deficit in terms of aquifer overpumping at over 160 billion tons per year. Using the rule of thumb of 1,000 tons of water to produce 1 ton of grain, this would be enough to produce 160 million tons of grain. With current world grain consumption of 300 kilograms per person, this would feed 533 million people. Stated otherwise, 533 million of us, out of the world population of 6.1 billion, are being fed with grain that is produced with the unsustainable use of water.[21]

The world water deficit is concentrated in China, the Indian subcontinent, the Middle East, North Africa, and North America. This problem is historically recent, a product of the tripling of world water usage since 1950 and the spreading use of powerful diesel and electrically driven pumps. When the pumping of water from wells depended on human or animal power, the amount pumped was limited, but now with powerful mechanically driven pumps, aquifers can be depleted in a matter of years.[22]

In a world where the demand for water continues its steady growth while the sustainable yield of aquifers is essentially fixed, the deficits grow larger year by year. The longer that governments delay in addressing this issue, the larger the annual deficit becomes, the faster water tables fall, and the more difficult it is to deal with. Scores of countries are now experiencing water deficits—from smaller ones like Iran or Yemen to the world's most populous country, China. (See Table 1–4.)[23]

Iran, a country of 70 million people, is facing an acute shortage of water. Under the agriculturally rich Chenaran Plain in northeastern Iran, the water table was recently falling by 2.8 meters a year. But the cumulative effect of a three-year drought and the new wells being drilled to supply the nearby city of Mashad, one of Iran's largest, dropped the aquifer by an extraordinary 8 meters in 2001. Villages in eastern Iran are being abandoned as aquifers are depleted and wells go dry, generating a flow of water refugees.[24]

In Yemen, which has a population of 17 million, World Bank data indicate that the water table under most of the country is falling by roughly 2 meters a year as water use far exceeds the sustainable yield of aquifers. World Bank official Christopher Ward observes that "groundwater is being mined at such a rate that parts of the rural economy could disappear within a generation." In the basin where the capital, Sana'a, is located, the water table is reportedly falling at 6 meters (nearly 20 feet) per year. The Bank estimates that the aquifer will be

Table 1–4. *Selected Examples of Aquifer Depletion*

Country	Region	Description of Depletion
China	North China Plain	Water table falling by 2–3 meters per year under much of the Plain. As pumping costs rise, farmers are abandoning irrigation.
United States	Southern Great Plains	Irrigation is heavily dependent on water from Ogallala aquifer, largely a fossil aquifer. Irrigated area in Texas, Oklahoma, and Kansas is shrinking as aquifer is depleted.
Pakistan	Punjab	Water table is falling under the Punjab and in the provinces of Baluchistan and North West Frontier.
India	Punjab, Haryana, Rajasthan, Andhra Pradesh, Maharashtra, Tamil Nadu, and other states	Water tables falling by 1–3 meters per year in some parts. In some states extraction is double the recharge. In the Punjab, India's breadbasket, water table falling by nearly 1 meter per year.

depleted by the end of this decade. In the search for water, the Yemeni government has drilled test wells in the basin that are 2 kilometers (1.3 miles) deep—depths previously associated only with the oil industry. But they have failed to find water. Those living in Yemen's capital may soon be forced to relocate within the country or to migrate abroad, adding to the swelling flow of water refugees.[25]

Table 1–4 *continued*

Iran	Chenaran Plain, northeastern Iran	Water table was falling by 2.8 meters per year but in 2001 drought and drilling of new wells to supply nearby city of Mashad dropped it by 8 meters.
Yemen	Entire country	Water table falling by 2 meters per year throughout country and 6 meters a year in Sana'a basin. Nation's capital, Sana'a, could run out of water by end of this decade.
Mexico	State of Guanajuato	In this agricultural state, the water table is falling by 1.8–3.3 meters per year.

Source: See endnote 23.

In China, water tables are falling virtually everywhere that the land is flat. Under the North China Plain, which produces at least one fourth of the country's grain, the fall in the underground water table of 1.5 meters (5 feet) per year of the early 1990s has recently increased to 2–3 meters per year in some areas. In many parts of China, well drilling, either the deepening of wells or the drilling of new ones, has become a leading industry.[26]

The big three grain producers—China, the United States, and India, which together account for nearly half of world output—depend on irrigation in varying degrees. In China, 70 percent of the grain produced comes from irrigated land. In India, the figure is 50 percent, and in the United States, 15 percent. In each country, water tables are falling in key agricultural areas. When farmers lose their irrigation water, whether from aquifer depletion or diversion to cities, and return to rainfed farming, they typically experience a drop in yields of one half or so.[27]

Historically, water shortages were local, but in an increasingly integrated world economy, these shortages can cross national boundaries via the international grain trade. Water-scarce countries often satisfy the growing needs of cities and industry by diverting water from irrigation and importing grain to offset the resulting loss of production. Since 1 ton of grain equals 1,000 tons of water, importing grain is the most efficient way to import water.[28]

Although it is often said that future wars in the Middle East are more likely to be fought over water than oil, the competition for water in the region seems more likely to take place in world grain markets. This can be seen in Iran and Egypt, both of which now import more wheat than Japan, traditionally the world's leading importer. Imports now supply 40 percent of the total consumption of grain—wheat, rice, and feedgrains—in both countries. Numerous other water-short countries in the Middle East also import much of their grain. Morocco imports half of its grain. For Algeria and Saudi Arabia, the figure is over 70 percent. Yemen imports nearly 80 percent of its grain, and Israel, more than 90 percent.[29]

China regained grain self-sufficiency during the late 1990s in part by overpumping its aquifers, running up a huge water deficit. India is also essentially self-sufficient in grain, but it has achieved this by overpumping. Neighboring Pakistan, a country of 154 million people, is overpumping its aquifers for the same reason. Overpumping is by definition a short-term phenomenon. At some point, as aquifers are depleted, it will end.[30]

Farmers who are overpumping underground water for irrigation are facing a double squeeze. Like the rest of the economy, they face cutbacks from aquifer depletion. But

in addition, they face cutbacks as irrigation water is diverted to higher value uses in industry, where the value of output per ton of water used can be easily 50 times that in agriculture. Countries seeking to create jobs and raise living standards cannot afford to use scarce water for irrigation if it deprives industry of needed water.[31]

Water deficits are already spurring heavy grain imports in numerous smaller countries, but it is unclear when they will do so in larger countries, such as India or China. Two things are obvious: the water deficits are growing larger in literally scores of countries, and they are doing so more or less simultaneously. National water shortages are not isolated events.

If countries like India, Pakistan, and China are already experiencing water deficits, what happens if their populations continue to grow as projected, demanding ever more water at a time when sharp cutbacks from aquifer depletion are imminent?

The risk is that growing water deficits in populous countries could push grain import needs above supplies in the handful of countries that export grain, triggering a rise in grain prices. It is one thing for small countries to turn to the world for much of their grain supply, but when a country like China, which consumes 390 million tons of grain per year, or India, which consumes 180 million tons, does so, it has the potential to overwhelm world grain markets, as noted earlier. If world grain prices were to double, as they did between 1972 and 1974, the ranks of those who are hungry and malnourished—estimated at 815 million—could expand dramatically as the urban poor are squeezed between low incomes and rising food prices.[32]

Humanity is moving into uncharted territory in the water economy. With the demand for food climbing, and with the overpumping of aquifers now common in industrial and developing countries alike, the world is facing a convergence of aquifer depletions in scores of countries within the next several years. As this occurs, pumping will necessarily be reduced to the rate of recharge. Unfortunately, the world has no experience in responding to water deficits on the scale now unfolding.

World agriculture, already burdened with soil and water deficits, is facing a projected addition of 3 billion people and billions of low-income people who want to move up the food chain, consuming more livestock products. These soaring demands on an agricultural system that is already ecologically stressed are leading to some basic structural changes in the world food economy.[33]

The Changing Food Economy

The biggest prospective structural changes are in the animal protein sector. During the second half of the last century, a time when population was more than doubling and incomes were nearly tripling, the world demand for animal protein was climbing. For much of this period, growth in animal protein was satisfied by turning to rangelands and oceanic fisheries. Between 1950 and 1990, beef and mutton production more than doubled and the oceanic fish catch expanded fivefold. Since then, growth in the output of these two natural systems has slowed or leveled off as demands have pressed against their sustainable-yield limits. Indeed, in many cases demand has far exceeded sustainable yields, leading to the desertification of rangelands and collapsing fisheries. Today overgrazing and overfishing are the rule, not the exception.[34]

Even as these natural systems were approaching their limits, the demand for animal protein was growing at a record rate. As it did so, the world turned to grain-fed beef, pork, poultry, eggs, milk, and farmed fish. Population growth and the strong desire to move up the food chain has driven the demand for meat steadily higher.

Indeed, except for the recession year of 1960, the world demand for meat has climbed to a new high every year since 1950. (See Figure 1–3.) Meat consumption per person more than doubled, climbing from 17 kilograms in 1950 to 39 kilograms in 2001.[35]

Wherever incomes rise, people try to diversify their diets, reducing their overwhelming dependence on a starchy food staple, such as rice, and augmenting it with meat, eggs, and milk products. This desire to move up the food chain as incomes rise appears to be innate, perhaps a genetic legacy of 4 million years as hunter-gatherers.

Given the rising demand for animal protein in diets, now principally in developing countries, the question is how to satisfy that demand most efficiently. At the first level, the advantage goes to ruminants that can convert roughage into edible forms of animal protein. The roughage may come from rangelands or from crop residues. Once the use of roughage is fully exploited,

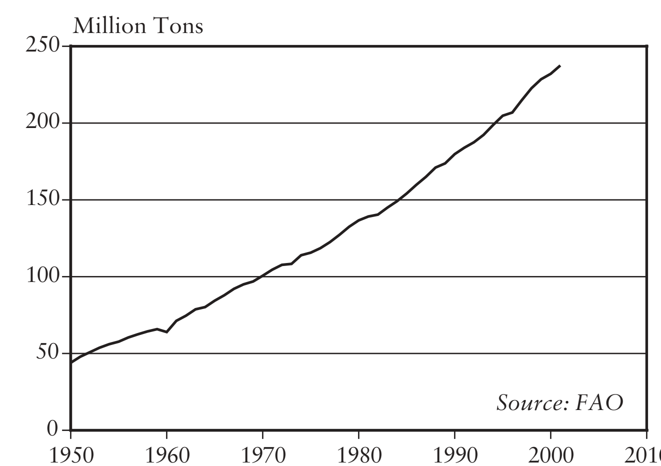

Figure 1–3. *World Meat Production, 1950–2001*

then the advantage goes to those grain-dependent forms of animal protein that are most efficient. This shift to more grain-efficient, lower-cost, animal protein sources is already under way.

There are some encouraging success stories in efficiently satisfying the hunger for animal protein. In India, for example, milk production has soared over the last few decades, spurred by local dairy cooperatives that provide a marketing link between villagers, who typically have only two to three cows, and consumers in other villages and nearby cities. Milk production in India, which has overtaken that of the United States, the longstanding leader, is based almost entirely on the use of local forage and crop residues. Little grain is fed to cattle in India.[36]

China is using a similar approach to expand beef production. In areas that produce grain, particularly those that double-crop grains, such as winter wheat and corn in east-central China, there are large amounts of crop residues—either straw from wheat or rice or the stalks from corn—that can be fed to cattle. Cattle, being ruminants, can easily convert crop residues into protein, leaving the manure to fertilize fields. The amount of beef now produced in this manner in the east-central provinces greatly exceeds that being produced on rangelands in the overgrazed northwest.[37]

The pattern of animal protein production worldwide has shifted substantially over the last decade. The growth in beef and mutton production, most of which comes from rangelands, was less than 1 percent a year from 1990 to 2001. Pork grew by nearly 3 percent, poultry production by over 4 percent. But the most rapid growth of all was in aquaculture, which expanded by 10 percent a year. (See Table 1–5.)

The variation in growth rates is explained largely by the efficiency with which various animals convert grain

into protein. With cattle in feedlots, it takes roughly 7 kilograms of grain to produce a 1-kilogram gain in live weight. Growth in the number of feedlots is now minimal. For pork, the figure is close to 4 kilograms per kilogram of weight gain, for poultry it is just over 2, and for herbivorous species of farmed fish, such as carp, tilapia, and catfish, it is less than 2. The market is shifting production to the animals that convert grain most efficiently, thus lightening the pressure on soil and water resources. Health concerns are also helping to shift consumption from beef and pork to poultry and fish.[38]

Egg production is growing fast, again because laying hens can convert grain into protein rather efficiently.

Table 1–5. *Annual Growth in World Animal Protein Production, by Source, 1990–2001*

Source	1990	2001	Annual Growth
	(million tons)		(percent)
Beef	53	57	1
Pork	70	92	3
Mutton	10	11	1
Poultry	41	69	4
Eggs	38	56	4
Oceanic Fish Catch[1]	86	95	1
Aquacultural Output[1]	13	36	10

[1]Latest figures available for oceanic fish catch and aquacultural production are for 2000.

Source: Based on FAO, *1948–1985 World Crop and Livestock Statistics* (Rome: 1987); FAO, *FAOSTATS Statistics Database*, updated 28 May 2002; FAO, *Yearbook of Fishery Statistics: Capture Production* and *Aquaculture Production* (various years).

In addition, eggs are a popular source of animal protein in developing-country villages where there is no refrigeration.

Once the potential for relying on ruminants to convert roughage into food products that are edible by humans is fully exploited, then the question is how to satisfy the additional need for high-quality protein. One way of doing this is to convert grain into animal protein at varying degrees of efficiency. Another way is to supplement grain with various beans, peas, and other leguminous crops that contain high-quality protein. This can be seen, for example, in the corn-and-beans diet of Mexico or the wheat-and-lentils combination of northern India. The basic choice is whether to use the land to produce leguminous crops for direct consumption or to produce grain and convert it into animal protein.

Contrary to popular opinion, the latter may sometimes represent a more efficient use of land simply because the yield per hectare of soybeans, lentils, chickpeas, and other leguminous crops is so low compared with grain. In the United States, for example, which produces roughly 40 percent of the world corn and soybean harvests, the ratio of corn yields, at 8.7 tons per hectare, to soybean yields, at 2.7 tons per hectare, is 3.2 to 1. (The United States offers an ideal comparison between corn and soybean yields because they are grown on the same land, often in a two-year rotation.)[39]

If land is used to produce corn that is fed to a herbivorous species of fish, such as carp in China or catfish in the United States, which convert 1.5–2 kilograms of grain into 1 kilogram of live weight, or if it is fed to chickens, which use about 2 kilograms of grain to produce a kilogram of live weight, it may yield more high-quality protein than land planted to soybeans for direct consumption, for example, as tofu. In summary, the more grain-efficient forms of animal protein may not require any more land or water resources per unit of protein than legumes. At this point, whether someone consumes tofu, lentils, carp, catfish, or chicken may be less a question of the efficiency of land and water-resource use and more a question of taste.[40]

If the alternative is producing beef in feedlots, then the 7-to-1 conversion of grain to live weight of cattle is much less efficient than using land to produce beans for direct consumption. If the option is pork production and the pork is produced with table waste, as it often is in villages in China, the advantage goes to pork. But if pork is produced with grain, as is the case elsewhere and, increasingly, in China, then consuming beans directly would be more efficient.[41]

Perhaps the most impressive growth of any animal protein-producing enterprise has been fish farming in China, where a carp-polyculture has been highly successful. Over the last two decades China's aquacultural output, consisting largely of carp, has expanded from 3 million tons per year to 25 million tons. Indeed, fish-farm output in China is now double the U.S. beef output of 12 million tons.[42]

As the growth in animal protein production has shifted over the last decade or so from largely oceanic fisheries and rangelands to primarily pork, poultry, and fish farming, the pressure on croplands has intensified. Expanding protein production by feeding animals, whether fish, poultry, or pigs, means expanding grain use. At the same time, land is required by these enterprises themselves. For example, in China 5 million hectares are now devoted to fish ponds, an area equal to 6 percent of China's harvested grainland. In the United States, catfish ponds, the dominant source of U.S. farmed fish, occupy nearly 50,000 hectares (190 square miles) of land, most of it concentrated in Mississippi.[43]

As animal protein production shifts to more grain-efficient sources, it is automatically shifting to the more water-efficient sources, helping to lower the water deficit. This interaction between the expanding demand for animal protein and the need for greater efficiency in the use of grain and water is reshaping the food economy.

The Soybean Factor

Closely related to these structural changes in the world food economy is the expanding role of the soybean, perhaps the best single indicator of the world growth in animal protein consumption over the past half-century. One of the keys to the efficient conversion of grain into animal protein is the incorporation of small amounts of high-quality protein, such as that found in soybeans, into the feed ration. A modest amount of protein supplementation can boost sharply the efficiency with which grain is converted into animal protein, sometimes nearly doubling it.

Protein supplements typically come from oilseed meals, the product of crushing soybeans, cottonseed, peanuts, or sunflower seeds to extract oil. Over the last 50 years, the soybean has emerged as the world's dominant source of protein for supplementing livestock, poultry, and fish rations, exceeding all other high-protein meals combined. Between 1950 and 2001, the world soybean harvest expanded from 17 million tons to 184 million tons, a spectacular gain of nearly 11-fold. (See Figure 1–4.)[44]

The soybean, domesticated by farmers in central China some 5,000 years ago, was introduced into the United States in 1804 when Thomas Jefferson was President. After languishing as a novelty crop for a century and a half, its production began expanding rapidly following World War II, climbing from less than 6 million tons in 1950 to 79 million tons in 2001, or 43 percent of the world harvest. Brazil, now in second place, produces 24 percent of the harvest, and Argentina 16 percent. China, which once dominated the world harvest, now accounts for only 8 percent.[45]

In the United States, the harvested area of soybeans first overtook that of wheat in 1973 and that of corn in 1999. Most U.S. soybeans are produced in the Corn Belt, often in an alternate-year rotation with corn, which has a ravenous appetite for nitrogen. Since the soybean fixes nitrogen, its yields are not very responsive to the application of fertilizer. As a result, farmers get more soybeans largely by planting more land in soybeans.[46]

China, whose soybean meal use is doubling every five years as meat and egg consumption climbs, and whose direct consumption of soybeans for food is also climbing, is now the world's dominant soybean importer. Its principal supplier is the United States. The soybean connec-

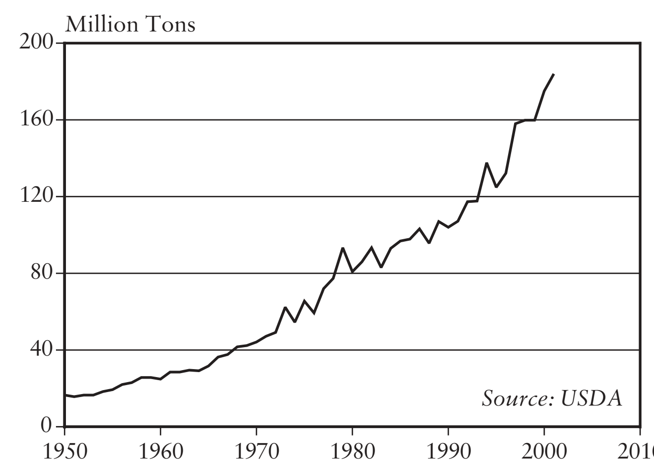

Figure 1–4. *World Soybean Production, 1950–2001*

tion between the country that gave the world the soybean and the one that made it into a world-class crop is likely to grow even stronger in the years ahead as China's appetite for animal protein continues to climb. At issue is whether soybean production can continue to expand, supporting the growth in demand for animal protein without clearing additional areas of the Brazilian cerrado, where the expansion is concentrated.[47]

Future Food Security

Future food security depends on expanding many ongoing activities such as agricultural research, agricultural extension, farm credit (especially microcredit programs designed for small farmers in developing countries), and the support prices that stabilize prices and encourage farmers to invest in land improvement. The keys to future food security now are to eliminate the soil deficit and the water deficit and to stabilize population and climate.

Reducing soil losses below the rate of new soil formation is possible, but it will take an enormous worldwide effort. Based on the experience of key food-producing countries such as China, the United States, and numerous smaller countries, easily 5 percent of the world's cropland is highly erodible and should be converted back to grass or trees before it becomes wasteland. The first step is to pull back from the fast-deteriorating margin.[48]

Wind erosion is concentrated in arid and semiarid regions, while water erosion is concentrated on sloping lands in regions with higher rainfall. Wind erosion, common on cropland and rangelands, is the source of dust and sand storms. Water erosion is the source of the silt that raises riverbeds, fills irrigation and hydroelectric reservoirs, clogs harbors, and suffocates marine ecosystems.

The key to controlling wind erosion is to keep the land covered with vegetation as much as possible and to slow wind speeds at ground level. Ground-level wind speeds can be slowed with shrubs, trees, and crop residues left on the surface of the soil. For areas that are particularly rich in wind and in need of electricity, such as northwestern China, wind turbines can simultaneously slow wind speed and provide cheap electricity. This approach converts a liability—strong winds—into an asset.

One of the time-tested methods of dealing with water erosion is terracing, as is so common with rice paddies in the mountainous regions of Asia. On land that is less steeply sloping, contour farming as in the midwestern United States has worked well.

Another tool, a relatively new one, in the soil conservation toolkit is conservation tillage, which includes both no tillage and minimum tillage. After being taught that seedbeds required plowing and careful preparation prior to planting, farmers are now learning that less tillage may be better. Instead of plowing land, then discing or harrowing it to prepare the seedbed, then planting with a seeder and cultivating row crops with a cultivator two or three times to control weeds, farmers simply drill seeds directly into the land without any preparation at all. Weeds are controlled with herbicides. This means the only tillage is often a one-time disturbance in a narrow band of soil where the seeds are inserted, leaving the remainder of the soil undisturbed.[49]

This practice, now widely used in the production of corn and soybeans in the United States, has spread rapidly in the western hemisphere over the last few decades. (See Table 1–6.) Data for crop year 1998/99 show the United States with 19.3 million hectares of land under no-till. Brazil had 11.2 million hectares, and Argentina 7.3 million hectares. Canada, at 4 million hectares, rounds out the "big four."

In the United States, the combination of retiring the highly erodible land under the CRP and shifting part of the remaining land in row crops to conservation tillage has sharply reduced soil erosion. By 2000, U.S. farmers were no-tilling 21 million hectares (51 million acres) of crops. An additional 23 million hectares were minimum-tilled, for a total of 44 million hectares of conservation tillage. This was used on 12 million hectares (30 million acres) of corn—or 37 percent of the crop. For soybeans, it was 17 million hectares—57 percent of the crop. For wheat and other small grain crops, the conservation tillage area totaled 11 million hectares (30 percent of the planted area).[50]

Once farmers begin to practice no-till, its use can

Table 1–6. *Cropland Area Under No-Till in Key Countries, 1998/99*

Country	Area
	(million hectares)
United States	19.3
Brazil	11.2
Argentina	7.3
Canada	4.1
Australia	1.0
Paraguay	0.8
Mexico	0.5
Bolivia	0.2
Others	1.1
Total	45.5

Source: Rolf Derpsch, "Frontiers in Conservation Tillage and Advances in Conservation Practice," in D. E. Stott, R. H. Mohtar, and G. C. Steinhardt (eds.), *Sustaining the Global Farm* (2001), pp. 248–54.

spread rapidly. In the United States, the no-till area went from 7 million hectares in 1990 to nearly 21 million hectares in 2000, tripling within a decade.[51]

Recent U.N. Food and Agriculture Organization reports describe the growth in no-till farming over the last few years in Europe, Africa, and Asia. In addition to reducing both wind and water erosion, and particularly the latter, this practice also helps retain water and reduces the energy needed for crop cultivation.[52]

While the soil deficit has been building over the last few centuries, the water deficit is much more recent, a product of the half-century or so since diesel and electrically powered pumps have become widely available for irrigation. And, as noted earlier, it is growing fast.

The potential disruption of world grain markets by water shortages calls for a global effort to raise water productivity, an effort similar to that launched 50 years ago regarding land. When it was realized after World War II that there was not much new land to bring under the plow, a worldwide effort was undertaken to raise land productivity. It included heavy investment in agricultural research to raise crop yields, the development of agricultural extension services to disseminate the research results to farmers, and the adoption of support prices to stabilize prices of farm commodities. This effort was highly successful, boosting world land productivity from 1.1 tons of grain per hectare worldwide in 1950 to 2.7 tons per hectare in 2001.[53]

Future food security now depends on raising water productivity not only in agriculture but in all sectors of the economy—ranging from more water-efficient household appliances to more water-efficient irrigation systems. Of all the policy steps to raise water efficiency, by far the most important is establishing a price for water that will reflect its value to society. Because water policies evolved in an earlier age, when water was relatively abundant, the world today is sadly lacking in policies that reflect reality. Raising the price of water to reflect its value would affect decisions involving its use at all levels and in all sectors. To be successful, the price should go up in concert with what some countries describe as "lifeline rates," where individual residences get the amount of water needed to satisfy basic needs at an easily affordable price. But once water consumption exceeds this minimum needs level, then the cost would escalate, thus encouraging investment in water efficiency.

The underpricing of water permeates water systems throughout the world. Some governments, such as India, heavily subsidize the use of irrigation water by providing electricity for pumping water to farmers at a nominal cost.[54]

Since 70 percent of all water that is diverted from rivers or pumped from underground is used for irrigation, investment in more water-efficient irrigation practices and technologies is central to any effective strategy to raise water productivity. In simplest terms, this means shifting from less water-efficient flood or furrow irrigation to more-efficient sprinkler and drip irrigation. Drip irrigation—now used on some 2.4 million hectares of cropland worldwide—can easily reduce irrigation water use by half while boosting yields. Its drawback is that it is much more labor-intensive. But in countries with widespread unemployment, switching to drip irrigation for many crops would simultaneously raise water productivity and employment. Although drip irrigation is not economic in all situations, there are many where it is economic but not yet used.[55]

There is also the possibility of adopting irrigation practices that use water more efficiently. In some situations, for example, rice need not be permanently flooded

throughout the growing season but can be flooded periodically without any loss in yield.[56]

Cropping patterns are also being altered to favor more water-efficient crops. Both Egypt and China restrict the production of rice because of its high water requirements, favoring wheat instead. Anything that raises the efficiency of grain conversion into animal protein also raises water efficiency.

For those who are living high on the food chain—that is, who are consuming excessive amounts of fat-rich livestock products—moving "down" the food chain will both improve personal health and lower grain use and, therefore, water use. Consuming less fat also reduces obesity and the associated costs of treating obesity-related illnesses.

A third step to enhance future food security is to stabilize world population growth sooner rather than later. Current U.N. projections for 2050 range from a low projection of 7.9 billion to the high of 10.9 billion. The prospects of everyone having enough food will be greatly enhanced if the world can reach only the lower number. Even with existing populations, many developing countries do not have enough water to meet basic needs. What happens if their populations double again, as some are projected to do in the next few decades? The key now is to invest in the education of young females throughout the developing world and to improve the status of women by giving them the same ownership, inheritance, and voting rights as men. This, combined with filling the family planning gap, so that couples everywhere have access to family planning services, is the key to future food security and to making sure that people everywhere will have enough food to develop their full physical and mental potential.[57]

The other key to future food security is climate stabilization. World agriculture as it exists today evolved over 11,000 years during a period when climate was remarkably stable. If temperature and rainfall levels and patterns begin to change, agriculture as it currently exists will be out of sync with the ecosystem, forcing the need for constant adjustment as the climate system itself changes. Climate change is now the wild card in the food security deck of cards.