I

The Challenges

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Population Pressure: Land and Water

The French use a riddle to teach schoolchildren the nature of exponential growth. A lily pond, so the riddle goes, contains a single leaf. Each day the number of leaves doubles—two leaves the second day, four the third, eight the fourth, and so on. "If the pond is full on the thirtieth day, at what point is it half full?" Answer: "On the twenty-ninth day."[1]

Trends in world cropland area and irrigation water supplies suggest that we are living in the thirty-first day. After expanding modestly from 1950 to 1981, world grain area stopped growing and the area declined somewhat as land losses from erosion and conversion to nonfarm uses offset new land brought under the plow. On close to one third of the world's cropland, topsoil is eroding faster than new soil is being formed by geological processes, slowly reducing the land's inherent productivity.[2]

The world's irrigated area tripled from 1950 to 2000 but has expanded little since then. It could soon begin to decline—as it is already doing in some countries—as aquifers are depleted by overpumping and as the mountain glaciers that sustain so many of the world's rivers and irrigation systems melt and disappear.

Many irrigation systems, whether dependent on underground water or on river water, are at risk.[3]

We cannot escape the water intensity of food production. Worldwide, we drink on average close to 4 liters of water per day, either directly or in coffee, juice, soda, wine, and other beverages. But it takes 2,000 liters of water to produce the food we consume each day—500 times as much as we drink. In effect, we "eat" 2,000 liters of water each day.[4]

Soil erosion initially reduces the inherent productivity of the land and then, after a point, leads to cropland abandonment. Both effects of erosion are undermining world food security. A combination of population growth and soil erosion has caused a number of countries that were once self-sufficient in grain to become heavily dependent on imports.

With water tables now falling in almost every country that irrigates with underground water, many of these countries are facing hunger-inducing losses of irrigation water as aquifers are depleted and wells go dry. Overpumping—the pumping of aquifers that exceeds the natural recharge—presents a classic case of ecological overshoot and collapse. It is a way of satisfying current food needs that virtually guarantees a future drop in food production when aquifers are depleted. In effect, we have created a "food bubble economy." Both soil erosion and aquifer depletion reflect an emphasis on current consumption at the expense of the next generation.[5]

Civilization's Foundation Eroding

The thin layer of topsoil that covers the planet's land surface is the foundation of civilization. This soil, typically 6 inches or so deep, was formed over long stretches of geological time as new soil formation exceeded the natural rate of erosion. But sometime within the last century, as human and livestock populations expanded, soil erosion began to exceed new soil formation over large areas.

This is not new. In 1938, Walter Lowdermilk, a senior official in the Soil Conservation Service of the U.S. Department of Agriculture (USDA), traveled abroad to look at lands that had been cultivated for thousands of years, seeking to learn how these older civilizations had coped with soil erosion. He found that some had managed their land well, maintaining its fertility

over long stretches of history, and were thriving. Others had failed to do so and left only remnants of their illustrious pasts.[6]

In a section of his report entitled "The Hundred Dead Cities," he described a site in northern Syria, near Aleppo, where ancient buildings were still standing in stark isolated relief, but they were on bare rock. During the seventh century, the thriving region had been invaded, initially by a Persian army and later by nomads out of the Arabian Desert. In the process, soil and water conservation practices used for centuries were abandoned. Lowdermilk noted, "Here erosion had done its worst....if the soils had remained, even though the cities were destroyed and the populations dispersed, the area might be re-peopled again and the cities rebuilt, but now that the soils are gone, all is gone."[7]

Now fast-forward to a trip in 2002 by a U.N. team to assess the food situation in Lesotho, a small country of 2 million people embedded within South Africa. Their finding was straightforward: "Agriculture in Lesotho faces a catastrophic future; crop production is declining and could cease altogether over large tracts of the country if steps are not taken to reverse soil erosion, degradation, and the decline in soil fertility." Michael Grunwald reported in the *Washington Post* that nearly half of the children under five in Lesotho are stunted physically. "Many," he wrote, "are too weak to walk to school."[8]

The U.N. team report was on the mark. During the last 10 years, Lesotho's grain harvest dropped by 40 percent as its soil fertility fell. Its collapsing agriculture leaves Lesotho heavily dependent on food supplied by the U.N. World Food Programme (WFP), its lifeline for survival.[9]

In the western hemisphere, Haiti, one of the early failing states, was largely self-sufficient in grain 40 years ago. Since then it has lost nearly all its forests and much of its topsoil, forcing it to import over half of its grain. Like Lesotho, Haiti is also dependent on a WFP lifeline.[10]

A similar situation exists in Mongolia, where over the last 20 years three fourths of the wheatland has been abandoned and wheat yields have fallen by one fourth, shrinking the harvest by four fifths. Mongolia—a country almost three times the size of France with a population of 2.6 million—is now forced to import nearly 70 percent of its wheat.[11]

Whether the land is in Lesotho, Mongolia, Haiti, or any of

the many other countries losing their soil, the health of the people living on it cannot be separated from the health of the land itself. A large share of the world's 1 billion hungry people live on soils worn thin by erosion.[12]

You do not need to visit soil-devastated countries to see the evidence of severe erosion. Dust storms originating in the new dust bowls are now faithfully recorded in satellite images. On January 9, 2005, the National Aeronautics and Space Administration released images of a vast dust storm moving westward out of central Africa. This huge cloud of tan-colored dust stretched over 5,300 kilometers (some 3,300 miles), enough to cover the United States from coast to coast.[13]

Andrew Goudie, professor of geography at Oxford University, reports that the number of Saharan dust storms—once rare—has increased 10-fold during the last half-century. Among the African countries most affected by soil loss from wind erosion are Niger, Chad, Mauritania, northern Nigeria, and Burkina Faso. In Mauritania, in Africa's far west, the number of dust storms jumped from 2 a year in the early 1960s to 80 a year recently.[14]

The Bodélé Depression in Chad is the source of an estimated 1.3 billion tons of wind-borne soil a year, up 10-fold since measurements began in 1947. The nearly 3 billion tons of fine soil particles that leave Africa each year in dust storms are slowly draining the continent of its fertility and biological productivity. In addition, dust storms leaving Africa travel westward across the Atlantic, depositing so much dust in the Caribbean that they cloud the water and damage coral reefs.[15]

People in China are all too familiar with dust storms that originate in the country's northwest and western Mongolia, but the rest of the world typically learns about this fast-growing ecological catastrophe when the massive soil-laden storms leave the region. On April 18, 2001, the western United States—from the Arizona border north to Canada—was blanketed with dust. It came from a huge dust storm that originated in northwestern China and Mongolia on April 5. Measuring 1,200 miles across when it left China, the storm carried millions of tons of topsoil, a resource that will take nature centuries to replace.[16]

Almost exactly one year later, on April 12, 2002, South Korea was engulfed by a huge dust storm from China that left people

in Seoul literally gasping for breath. Schools were closed, airline flights were cancelled, and clinics were overrun with patients having difficulty breathing. Retail sales fell. Koreans have come to dread the arrival of what they now call "the fifth season," the dust storms of late winter and early spring.[17]

These two dust storms, among the 10 or so major dust storms that now occur each year in China, offer visual evidence of the ecological catastrophe unfolding in northern and western China. Overgrazing is the principal culprit.[18]

A U.S. Embassy report entitled "Desert Mergers and Acquisitions" describes satellite images showing two deserts in north-central China expanding and merging to form a single, larger desert overlapping Inner Mongolia (Nei Monggol) and Gansu Provinces. To the west in Xinjiang Province, two even larger deserts—the Taklimakan and Kumtag—are also heading for a merger. Highways running through the shrinking region between them are regularly inundated by sand dunes.[19]

Water erosion also takes a toll on soils. This can be seen in the silting of reservoirs and in satellite photographs of muddy, silt-laden rivers flowing into the sea. Pakistan's two large reservoirs, Mangla and Tarbela, which store Indus River water for the country's vast irrigation network, are losing roughly 1 percent of their storage capacity each year as they fill with silt from deforested watersheds.[20]

Ethiopia, a mountainous country with highly erodible soils, is losing close to 2 billion tons of topsoil a year, washed away by rain. This is one reason Ethiopia always seems to be on the verge of famine, never able to accumulate enough grain reserves to provide a meaningful measure of food security.[21]

Soil erosion from the deterioration of grasslands is widespread. The world's steadily growing herds of cattle and flocks of sheep and goats forage on the two fifths of the earth's land surface that is too dry, too steeply sloping, or not fertile enough to sustain crop production. This area supports most of the world's 3.3 billion cattle, sheep, and goats, all ruminants with complex digestive systems that enable them to digest roughage, converting it into beef, mutton, and milk.[22]

An estimated 200 million people make their living as pastoralists, tending cattle, sheep, and goats. Since most land is held in common in pastoral societies, overgrazing is difficult to

control. As a result, half of the world's grasslands are degraded. The problem is highly visible throughout Africa, the Middle East, Central Asia, and northwest China, where the growth in livestock numbers tracks that in human numbers. In 1950, Africa was home to 227 million people and 273 million livestock. By 2007, there were 965 million people and 824 million livestock. With livestock demands now often exceeding grassland carrying capacity by half or more, grassland is turning into desert.[23]

Nigeria, Africa's most populous country, is losing 351,000 hectares (867,000 acres) of rangeland and cropland to desertification each year. While Nigeria's human population was growing from 37 million in 1950 to 148 million in 2007, a fourfold expansion, its livestock population grew from roughly 6 million to 102 million, a 17-fold jump. With the forage needs of Nigeria's 16 million cattle and 86 million sheep and goats exceeding the sustainable yield of grasslands, the northern part of the country is slowly turning to desert. If Nigeria continues toward its projected 289 million people by 2050, the deterioration will only accelerate.[24]

Iran, with 73 million people, illustrates the pressures facing the Middle East. With 8 million cattle and 79 million sheep and goats—the source of wool for its fabled rug-making industry—Iran's rangelands are deteriorating from overstocking. In the southeastern province of Sistan-Balochistan, sand storms have buried 124 villages, forcing their abandonment. Drifting sands have covered grazing areas—starving livestock and depriving villagers of their livelihood.[25]

Neighboring Afghanistan is faced with a similar situation. The Registan Desert is migrating westward, encroaching on agricultural areas. A U.N. Environment Programme (UNEP) team reports that "up to 100 villages have been submerged by windblown dust and sand." In the country's northwest, sand dunes are moving onto agricultural land in the upper reaches of the Amu Darya basin, their path cleared by the loss of stabilizing vegetation from firewood gathering and overgrazing. The UNEP team observed sand dunes 15 meters high blocking roads, forcing residents to establish new routes.[26]

China faces similarly difficult challenges. After the economic reforms in 1978 that shifted the responsibility for farming from

large state-organized production teams to farm families, China's cattle, sheep, and goat populations spiraled upward. While the United States, a country with comparable grazing capacity, has 97 million cattle, China has a slightly smaller herd of 82 million. But while the United States has only 9 million sheep and goats, China has 284 million. Concentrated in China's western and northern provinces, sheep and goats are destroying the land's protective vegetation. The wind then does the rest, removing the soil and converting productive rangeland into desert.[27]

China's desertification may be the worst in the world. Wang Tao, one of the world's leading desert scholars, reports that from 1950 to 1975 an average of 600 square miles turned to desert each year. By century's end, nearly 1,400 square miles (3,600 square kilometers) were going to desert annually.[28]

China is now at war. It is not invading armies that are claiming its territory, but expanding deserts. Old deserts are advancing and new ones are forming like guerrilla forces striking unexpectedly, forcing Beijing to fight on several fronts. Wang Tao reports that over the last half-century, some 24,000 villages in northern and western China have been entirely or partly abandoned as a result of being overrun by drifting sand.[29]

Soil erosion often results from the demand-driven expansion of cultivation onto marginal land. Over the last century or so there were massive cropland expansions in two countries—the United States and the Soviet Union—and both ended in disaster.[30]

During the late nineteenth century, millions of Americans pushed westward, homesteading on the Great Plains, plowing vast areas of grassland to produce wheat. Much of this land—highly erodible when plowed—should have remained in grass. This overexpansion culminated in the 1930s Dust Bowl, a traumatic period chronicled in John Steinbeck's novel *The Grapes of Wrath*. In a crash program to save its soils, the United States returned large areas of eroded cropland to grass, adopted strip-cropping, and planted thousands of miles of tree shelterbelts.[31]

The second major expansion came in the Soviet Union beginning in the mid-1950s. In an all-out effort to expand grain production, the Soviets plowed an area of grassland larger than the wheat area of Australia and Canada combined. The result, as Soviet agronomists had predicted, was an ecological disaster—another Dust Bowl. Kazakhstan, where the plowing was

concentrated, has abandoned 40 percent of its grainland since 1980. On the remaining cultivated land, the wheat yield per acre is one sixth of that in France, Western Europe's leading wheat producer.[32]

A third massive cropland expansion is now taking place in the Brazilian Amazon Basin and in the *cerrado*, a savannah-like region bordering the basin on its south side. Land in the *cerrado*, like that in the U.S. and Soviet expansion, is vulnerable to soil erosion. This cropland expansion is pushing cattle ranchers into the Amazon forests, where ecologists are convinced that continuing to clear the area of trees will end in disaster. Reporter Geoffrey Lean, summarizing the findings of a 2007 Brazilian scientific symposium in London's *Independent*, notes that the alternative to a rainforest in the Amazon would be "dry savannah at best, desert at worst."[33]

Water Tables Falling

Nowhere are falling water tables and the shrinkage of irrigated agriculture more dramatic than in Saudi Arabia, a country as water-poor as it is oil-rich. After the Arab oil export embargo in the 1970s, the Saudis realized they were vulnerable to a counter embargo on grain. To become self-sufficient in wheat, they developed a heavily subsidized irrigated agriculture based largely on pumping water from a deep fossil aquifer.[34]

After being self-sufficient in wheat for over 20 years, in early 2008 the Saudis announced that, with their aquifer largely depleted, they would reduce their wheat planting by one eighth each year until 2016, when production will end. By then Saudi Arabia will be importing roughly 15 million tons of wheat, rice, corn, and barley for its population of 30 million. It is the first country to publicly project how aquifer depletion will shrink its grain harvest.[35]

The Saudis are not alone. Scores of countries are overpumping aquifers as they struggle to satisfy their growing water needs. Most aquifers are replenishable but some are not. For example, when aquifers in India and the shallow aquifer under the North China Plain are depleted, the maximum rate of pumping will be automatically reduced to the rate of recharge.

But for fossil aquifers, like the Saudi aquifer, the vast Ogallala aquifer under the U.S. Great Plains, or the deep aquifer

under the North China Plain, depletion brings pumping to an end. Farmers who lose their irrigation water have the option of returning to lower-yield dryland farming if rainfall permits. But in more arid regions, such as in the southwestern United States and parts of the Middle East, the loss of irrigation water means the end of agriculture.[36]

In Yemen, a nation of 23 million people neighboring Saudi Arabia, the water table is falling by roughly 6 feet a year as water use outstrips aquifer recharge. With one of the world's fastest-growing populations and with water tables falling everywhere, Yemen is quickly becoming a hydrological basket case. Grain production has fallen by half over the last 35 years. By 2015, irrigated fields will be a rarity and the country will be importing virtually all of its grain. Living on borrowed water and borrowed time, Yemen ranks high on the list of failing states.[37]

Falling water tables are already adversely affecting harvests in some larger countries, including China, which rivals the United States as the world's largest grain producer. A groundwater survey released in Beijing in August 2001 revealed that the water table under the North China Plain, an area that produces over half of the country's wheat and a third of its corn, was falling fast. Overpumping has largely depleted the shallow aquifer, forcing well drillers to turn to the region's deep aquifer, which is not replenishable.[38]

The survey reported that under Hebei Province in the heart of the North China Plain, the average level of the deep aquifer was dropping nearly 3 meters (10 feet) per year. Around some cities in the province, it was falling twice as fast. He Qingcheng, head of the groundwater monitoring team, notes that as the deep aquifer is depleted, the region is losing its last water reserve—its only safety cushion.[39]

A World Bank study indicates that China is mining underground water in three adjacent river basins in the north—those of the Hai, which flows through Beijing and Tianjin; the Yellow; and the Huai, the southern most of the three. Since it takes 1,000 tons of water to produce 1 ton of grain, the shortfall in the Hai basin of nearly 40 billion tons of water per year (1 ton equals 1 cubic meter) means that when the aquifer is depleted, the grain harvest will drop by 40 million tons and China will lose the food supply for 130 million of its people.[40]

As serious as water shortages are in China, they are even more serious in India, where the margin between food consumption and survival is so precarious. To date, India's 100 million farmers have drilled more than 21 million wells, investing some $12 billion in wells and pumps. In August 2004 Fred Pearce reported in *New Scientist* that "half of India's traditional hand-dug wells and millions of shallower tube wells have already dried up, bringing a spate of suicides among those who rely on them. Electricity blackouts are reaching epidemic proportions in states where half of the electricity is used to pump water from depths of up to a kilometer."[41]

As water tables fall, well drillers are using modified oil-drilling technology to reach water, going down a half mile or more in some locations. In communities where underground water sources have dried up entirely, all agriculture is now rain-fed and drinking water must be trucked in. Tushaar Shah, who heads the International Water Management Institute's groundwater station in Gujarat, says of India's water situation, "When the balloon bursts, untold anarchy will be the lot of rural India."[42]

Growth in India's grain harvest, squeezed both by water scarcity and the loss of cropland to non-farm uses, has slowed since 2000. A 2005 World Bank study reports that 15 percent of India's food supply is produced by mining groundwater. Stated otherwise, 175 million Indians are fed with grain produced by water mining.[43]

In the United States, the USDA reports that in parts of Texas, Oklahoma, and Kansas—three leading grain-producing states—the underground water table has dropped by more than 30 meters (100 feet). As a result, wells have gone dry on thousands of farms in the southern Great Plains, forcing farmers to return to lower-yielding dryland farming. Although the depletion of underground water is taking a toll on U.S. grain production, irrigated land accounts for only one fifth of the U.S. grain harvest, compared with close to three fifths of the harvest in India and four fifths in China.[44]

Pakistan, a country with 177 million people that is growing by 4 million per year, is also mining its underground water. In the Pakistani part of the fertile Punjab plain, the drop in water tables appears to be similar to that in India. Observation wells near the twin cities of Islamabad and Rawalpindi show a fall in the water table between 1982 and 2000 that ranges from 1 to nearly 2 meters a year.[45]

In the province of Balochistan, which borders Afghanistan, water tables around the capital, Quetta, are falling by 3.5 meters per year—pointing to the day when the city will run out of water. Sardar Riaz A. Khan, former director of Pakistan's Arid Zone Research Institute in Quetta, reports that six of Balochistan's basins have exhausted their groundwater supplies, leaving their irrigated lands barren.[46]

Iran is overpumping its aquifers by an average of 5 billion tons of water per year, the water equivalent of one fourth of its annual grain harvest. It too faces a day of reckoning.[47]

Israel, even though it is a pioneer in raising irrigation water productivity, is depleting both of its principal aquifers—the coastal aquifer and the mountain aquifer that it shares with Palestinians. In response, Israel has banned the irrigation of wheat, its staple food, and is now importing nearly all the wheat it consumes. Conflicts between Israelis and Palestinians over the allocation of water are ongoing.[48]

In Mexico—home to a population of 109 million that is projected to reach 129 million by 2050—the demand for water is outstripping supply. Mexico City's water problems are well known. Rural areas are also suffering. In the agricultural state of Guanajuato, the water table is falling by 2 meters or more a year. In the northwestern state of Sonora, farmers once pumped water from the Hermosillo aquifer at a depth of 10 meters (35 feet). Today they pump from more than 120 meters. At the national level, 51 percent of all water extraction is from aquifers that are being overpumped.[49]

Since the overpumping of aquifers is occurring in many countries more or less simultaneously, the depletion of aquifers and the resulting harvest cutbacks could come at roughly the same time. And the accelerating depletion of aquifers means this day may come soon, creating potentially unmanageable food scarcity.

Farmers Losing Water to Cities

The world's freshwater supplies are shrinking, and the world's farmers are getting a shrinking share of this shrinking supply. While water tensions among countries are more likely to make

news headlines, it is the jousting for water between cities and farms within countries that preoccupies local political leaders. The economics of water use do not favor farmers in this competition, simply because it takes so much water to produce food. For example, while it takes only 14 tons of water to make a ton of steel, it takes 1,000 tons of water to grow a ton of wheat. In countries preoccupied with expanding the economy and creating jobs, agriculture becomes the residual claimant.[50]

Many of the world's largest cities, such as Los Angeles, Cairo, and New Delhi, can increase their water consumption only by taking it from agriculture. This rural-urban competition for underground water resources is intensifying throughout India. Nowhere is this more evident than in Chennai (formerly Madras), a city of 7 million in southern India. As a result of the city government's inability to supply water for some of the city's residents, a thriving tank-truck industry has emerged that buys water from farmers and hauls it to the city's thirsty residents.[51]

For farmers surrounding the city, the price of water far exceeds the value of the crops they can produce with it. Unfortunately, the 13,000 tankers hauling the water to Chennai are mining the region's underground water resources. Water tables are falling and shallow wells have gone dry. Eventually even the deeper wells will go dry, depriving these communities of both their food supply and their livelihood.[52]

Chinese farmers along the Juma River downstream from Beijing discovered in 2004 that the river had suddenly stopped flowing. A diversion dam had been built near the capital to take river water for Yanshan Petrochemical, a state-owned industry. Although the farmers protested bitterly, it was a losing battle. For the 120,000 villagers downstream from the diversion dam, the loss of water could cripple their ability to make a living from farming.[53]

In the U.S. southern Great Plains and the Southwest, where there is little unclaimed water, the growing water needs of cities and thousands of small towns can be satisfied only by taking water from agriculture. A monthly publication from California, *The Water Strategist*, devotes several pages each issue to a listing of water sales that took place in the western United States during the preceding month. Scarcely a working day goes by without another sale.[54]

Colorado has one of the world's most active water markets. Fast-growing cities and towns in a state with high immigration are buying irrigation water rights from farmers and ranchers. In the upper Arkansas River basin, which occupies the southeastern quarter of the state, Colorado Springs and Aurora (a suburb of Denver) have already bought water rights to one third of the basin's farmland.[55]

Far larger purchases are being made by cities in California. In 2003, San Diego bought annual rights to 247 million tons (200,000 acre-feet) of water from farmers in the nearby Imperial Valley—the largest farm-to-city water transfer in U.S. history. This agreement covers the next 75 years. And in 2004, the Metropolitan Water District, which supplies water to 18 million southern Californians in several cities, negotiated the purchase of 137 million tons of water per year from farmers for the next 35 years. Without irrigation water, and with sparse rainfall, the highly productive land owned by these farmers is wasteland. The farmers who are selling their water rights would like to continue farming, but city officials are offering far more for the water than the farmers could possibly earn by irrigating crops. Irrigated area in California shrank 10 percent between 1997 and 2007 as farmers sold their irrigation water to cities.[56]

Whether it is outright government expropriation, farmers being outbid by cities, or cities simply drilling deeper wells than farmers can afford, tillers of the land are losing the water war.

Historically, water scarcity was a local issue. It was up to national governments to balance water supply and demand. Now this is changing as scarcity crosses national boundaries via the international grain trade. Since it takes so much water to produce grain, importing grain is the most efficient way to import water. Countries are, in effect, using grain to balance their water books. Similarly, trading in grain futures is in a sense trading in water futures. To the extent there is a world water market, it is embodied in the grain market.[57]

The Middle East and North Africa—from Morocco in the west through Iran in the east—has become the world's fastest-growing grain import market. With virtually every country in the region pressing against its water limits, the growing urban demand for water can be satisfied only by taking irrigation water from agriculture. Egypt has become the leading importer

of wheat in recent years. It now imports close to 40 percent of its total grain supply, a dependence that reflects a population that is outgrowing the grain harvest that can be produced with the Nile's water. Algeria, with 34 million people, imports more than 70 percent of its grain.[58]

Overall, the water required to produce the grain and other farm products imported into the Middle East and North Africa last year exceeded the annual flow of the Nile River at Aswan. In effect, the region's water deficit can be thought of as another Nile flowing into the region in the form of imported food.[59]

It is often said that future wars in the Middle East will more likely be fought over water than oil, but in reality the competition for water is taking place in world grain markets. Beyond this, several countries in the region are now attempting to acquire land in other countries and, what is more important, the water that comes with it.

Knowing where water deficits are developing today tells us where grain deficits will be concentrated tomorrow. Thus far, the countries importing much of their grain have been smaller ones. Now we are looking at the growing water deficits in both China and India, each with more than a billion people. At what point does water scarcity translate into food scarcity?[60]

Land and Water Conflicts

As land and water become scarce, competition for these vital resources intensifies within societies, particularly between the wealthy and those who are poor and dispossessed. The shrinkage of life-supporting resources per person that comes with population growth is threatening to drop the living standards of millions of people below the survival level, leading to potentially unmanageable social tensions.

Access to land is a prime source of social tension. Expanding world population has cut the grainland per person in half since 1950 to a mere quarter-acre, equal to half of a building lot in a U.S. suburb. The shrinkage in cropland per person not only threatens livelihoods; in largely subsistence societies, it threatens survival itself. Tensions within communities begin to build as landholdings shrink below that needed for survival.[61]

The Sahelian zone of Africa, with its fast-growing populations, is an area of spreading conflict. In troubled Sudan, 2 million people have died and over 4 million have been displaced in the long-standing conflict between the Muslim north and the Christian south. The more recent conflict in the Darfur region in western Sudan that began in 2003 illustrates the mounting tensions between two Muslim groups—camel herders and subsistence farmers. Government troops are backing the Arab herder militias, who are engaging in the wholesale slaughter of black Sudanese farmers in an effort to drive them off their land, sending them into refugee camps in neighboring Chad. An estimated 300,000 people have been killed in the conflict or died of hunger and disease in the refugee camps.[62]

Overgrazing and declining rainfall are combining to destroy the grasslands in this region. But well before the rainfall decline, the seeds of the conflict were being sown as Sudan's population climbed from 9 million in 1950 to 40 million in 2007, a fourfold rise. Meanwhile, the cattle population increased from 7 million to 41 million, an increase of nearly sixfold. The number of sheep and goats increased from 14 million to 94 million, a near sevenfold increase. No grassland can survive such rapid continuous growth in livestock populations.[63]

In Nigeria, where 151 million people are crammed into an area not much larger than Texas, overgrazing and overplowing are converting grassland and cropland into desert, putting farmers and herders in a war for survival. As Somini Sengupta reported in the *New York Times* in June 2004, "in recent years, as the desert has spread, trees have been felled and the populations of both herders and farmers have soared, the competition for land has only intensified."[64]

Unfortunately, the division between herders and farmers is also often the division between Muslims and Christians. The competition for land, amplified by religious differences and combined with a large number of frustrated young men with guns, has created what the *New York Times* described as a "combustible mix" that has "fueled a recent orgy of violence across this fertile central Nigerian state [Plateau]. Churches and mosques were razed. Neighbor turned against neighbor. Reprisal attacks spread until finally…the government imposed emergency rule."[65]

Similar divisions exist between herders and farmers in northern Mali, the *New York Times* noted, where "swords and sticks

have been chucked for Kalashnikovs, as desertification and population growth have stiffened the competition between the largely black African farmers and the ethnic Tuareg and Fulani herders. Tempers are raw on both sides. The dispute, after all, is over livelihood and even more, about a way of life."[66]

Rwanda is a classic case study in how mounting population pressure can translate into political tension, conflict, and social tragedy. James Gasana, who was Rwanda's Minister of Agriculture and Environment in 1990–92, offers some insights. As the chair of a national agricultural commission in 1990, he had warned that without "profound transformations in its agriculture, [Rwanda] will not be capable of feeding adequately its population under the present growth rate." Although the country's demographers projected major future gains in population, Gasana said in 1990 that he did not see how Rwanda would reach 10 million inhabitants without social disorder "unless important progress in agriculture, as well as other sectors of the economy, were achieved."[67]

Gasana's warning of possible social disorder was prophetic. He further described how siblings inherited land from their parents and how, with an average of seven children per family, plots that were already small were fragmented further. Many farmers tried to find new land, moving onto steeply sloping mountains. By 1989, almost half of Rwanda's cultivated land was on slopes of 10 to 35 degrees, land that is universally considered uncultivable.[68]

In 1950, Rwanda's population was 2.4 million. By 1993, it had tripled to 7.5 million, making it the most densely populated country in Africa. As population grew, so did the demand for firewood. By 1991, the demand was more than double the sustainable yield of local forests. As trees disappeared, straw and other crop residues were used for cooking fuel. With less organic matter in the soil, land fertility declined.[69]

As the health of the land deteriorated, so did that of the people dependent on it. Eventually there was simply not enough food to go around. A quiet desperation developed. Like a drought-afflicted countryside, it could be ignited with a single match. That ignition came with the crash of a plane on April 6, 1994, shot down as it approached the capital Kigali, killing President Juvenal Habyarimana, a Hutu. The crash unleashed an

organized attack by Hutus, leading to an estimated 800,000 deaths of Tutsis and moderate Hutus in 100 days. In some villages, whole families were slaughtered lest there be survivors to claim the family plot of land.[70]

Africa is not alone. In India, tension between Hindus and Muslims is never far below the surface. As each successive generation further subdivides already small plots, pressure on the land is intense. The pressure on water resources is even greater.

With India's population projected to grow from 1.2 billion in 2008 to 1.6 billion in 2050, a collision between rising human numbers and shrinking water supplies seems inevitable. The risk is that India could face social conflicts that would dwarf those in Rwanda. As James Gasana notes, the relationship between population and natural systems is a national security issue, one that can spawn conflicts along geographic, tribal, ethnic, or religious lines.[71]

Disagreements over the allocation of water among countries that share river systems is a common source of international political conflict, especially where populations are outgrowing the flow of the river. Nowhere is this potential conflict more stark than among Egypt, Sudan, and Ethiopia in the Nile River valley. Agriculture in Egypt, where it rarely rains, is wholly dependent on water from the Nile. Egypt now gets the lion's share of the Nile's water, but its current population of 82 million is projected to reach 130 million by 2050, thus greatly expanding the demand for grain and water. Sudan, whose 41 million people also depend heavily on food produced with Nile water, is expected to have 76 million by 2050. And the number of people in Ethiopia, the country that controls 85 percent of the river's headwaters, is projected to expand from 81 million to 174 million. Beyond this, recent acquisitions of vast tracts of land in Sudan by other countries for farming will further boost demands on the Nile.[72]

Since there is little water left in the Nile when it reaches the Mediterranean, if either Sudan or Ethiopia takes more water, Egypt will get less, making it increasingly difficult to feed an additional 48 million people. Although there is an existing water rights agreement among the three countries, Ethiopia receives only a minuscule share of water. Given its aspirations for a better life, and with the headwaters of the Nile being one

of its few natural resources, Ethiopia will undoubtedly be taking more.[73]

To the north, Turkey, Syria, and Iraq share the waters of the Tigris and Euphrates river system. Turkey, controlling the headwaters, is developing a massive project on the Tigris to increase the water used for irrigation and power. Both Syria, which is expected to grow from 21 million people to 37 million by mid-century, and Iraq, which is projected to more than double its population of 30 million, are worried because they too will need more water.[74]

In the Aral Sea basin in Central Asia, there is an uneasy arrangement among five countries to share two rivers, the Amu Darya and the Syr Darya, that drain into the sea. The demand for water in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan already exceeds the flow of the two rivers by 25 percent. Turkmenistan, which is upstream on the Amu Darya, is planning to develop still further its irrigated area. Racked by insurgencies, the region lacks the cooperation needed to manage its scarce water resources. On top of this, Afghanistan, which controls the headwaters of the Amu Darya, plans to use some of the water for its development. Geographer Sarah O'Hara of the University of Nottingham, who studies the region's water problems, says, "We talk about the developing world and the developed world, but this is the deteriorating world."[75]

Cars and People Compete for Grain

At a time when excessive pressures on the earth's land and water resources are of growing concern, there is a massive new demand emerging for cropland to produce fuel for cars—one that threatens world food security. Although this situation had been developing for a few decades, it was not until Hurricane Katrina in 2005, when oil prices jumped above $60 a barrel and U.S. gasoline prices climbed to $3 a gallon, that the situation came into focus. Suddenly investments in U.S. corn-based ethanol distilleries became hugely profitable, unleashing an investment frenzy that will convert one fourth of the 2009 U.S. grain harvest into fuel for cars.[76]

The United States quickly came to dominate the crop-based production of fuel for cars. In 2005, it eclipsed Brazil, formerly

the world's leading ethanol producer. In Europe, where the emphasis is on producing biodiesel, mostly from rapeseed, some 2.1 billion gallons were set to be produced in 2009. To meet its biodiesel goal, the European Union, under cropland constraints, is increasingly turning to palm oil imported from Indonesia and Malaysia, a trend that depends on clearing rainforests for oil palm plantations.[77]

The price of grain is now tied to the price of oil. Historically the food and energy economies were separate, but now with the massive U.S. capacity to convert grain into ethanol, that is changing. In this new situation, when the price of oil climbs, the world price of grain moves up toward its oil-equivalent value. If the fuel value of grain exceeds its food value, the market will simply move the commodity into the energy economy. If the price of oil jumps to $100 a barrel, the price of grain will follow it upward. If oil goes to $200, grain will follow.

From 1990 to 2005, world grain consumption, driven largely by population growth and rising consumption of grain-based animal products, climbed by an average of 21 million tons per year. Then came the explosion in grain used in U.S. ethanol distilleries, which jumped from 54 million tons in 2006 to 95 million tons in 2008. This 41-million-ton jump doubled the annual growth in world demand for grain almost overnight, helping to triple world prices for wheat, rice, corn, and soybeans from mid-2006 to mid-2008. A World Bank analyst attributes 70 percent of the food price rise to this diversion of food to produce fuel for cars. Since then prices have subsided somewhat as a result of the global economic downturn, but as of mid-2009 they are still well above historical levels.[78]

From an agricultural vantage point, the world's appetite for crop-based fuels is insatiable. The grain required to fill an SUV's 25-gallon tank with ethanol just once will feed one person for a whole year. If the entire U.S. grain harvest were to be converted to ethanol, it would satisfy at most 18 percent of U.S. automotive fuel needs.[79]

Projections by Professors C. Ford Runge and Benjamin Senauer of the University of Minnesota in 2003 showed the number of hungry and malnourished people decreasing steadily to 2025. But their early 2007 update of these projections, which took into account the biofuel effect on world food prices,

showed the number climbing rapidly in the years ahead. Millions of people living on the lower rungs of the global economic ladder, who are barely hanging on, are losing their grip and beginning to fall off.[80]

Since the budgets of international food aid agencies are set well in advance, a rise in food prices shrinks food assistance. The WFP, which is now supplying emergency food aid to more than 30 countries, cut shipments as prices soared. Hunger is on the rise, with 18,000 children dying each day from hunger and related illnesses.[81]

The emerging competition between the owners of the world's 910 million automobiles and the 2 billion poorest people is taking the world into uncharted territory. Suddenly the world is facing an epic moral and political issue: Should grain be used to fuel cars or feed people? The average income of the world's automobile owners is roughly $30,000 a year; the 2 billion poorest people earn on average less than $3,000 a year. The market says, let's fuel the cars.[82]

For every additional acre planted to corn to produce fuel, an acre of land must be cleared for cropping elsewhere. But there is little new land to be brought under the plow unless it comes from clearing tropical rainforests in the Amazon and Congo basins and in Indonesia or from clearing land in the Brazilian *cerrado*. Unfortunately, this has heavy environmental costs: a massive release of sequestered carbon, the loss of plant and animal species, and increased rainfall runoff and soil erosion.

While it makes little sense to use food crops to fuel cars if it drives up food prices, there is the option of producing automotive fuel from fast-growing trees, switchgrass, prairie grass mixtures, or other cellulosic materials, which can be grown on wasteland. The technologies to convert these cellulosic materials into ethanol exist, but the cost of producing cellulosic ethanol is close to double that of grain-based ethanol. Whether it will ever be cost-competitive with ethanol from grain is unclear.[83]

There are alternatives to this grim scenario. The decision in May 2009 to raise U.S. auto fuel efficiency standards 40 percent by 2016 will reduce U.S. dependence on oil far more than converting the country's entire grain harvest into ethanol could. The next step is a comprehensive shift to gas-electric plug-in hybrid cars that can be recharged at night, allowing most short-distance driving—daily commuting and grocery shopping, for example—to be done with electricity.[84]

As the leading grain exporter and ethanol producer, the United States is in the driver's seat. It needs to make sure that efforts to reduce its heavy dependence on imported oil do not create a far more serious problem: chaos in the world food economy. The choice is between a future of rising world food prices, spreading hunger, and growing political instability and one of more stable food prices, sharply reduced dependence on oil, and much lower carbon emissions.[85]

The Rising Tide of Environmental Refugees

Our early twenty-first century civilization is being squeezed between advancing deserts and rising seas. Measured by the biologically productive land area that can support human habitation, the earth is shrinking. Mounting population densities, once generated solely by population growth, are now also fueled by the relentless advance of deserts and may soon be affected by the projected rise in sea level. As overpumping depletes aquifers, millions more are forced to relocate in search of water.

Desert expansion in sub-Saharan Africa, principally in the Sahelian countries, is displacing millions of people—forcing them to either move southward or migrate to North Africa. A 2006 U.N. conference on desertification in Tunisia projected that by 2020 up to 60 million people could migrate from sub-Saharan Africa to North Africa and Europe. This flow of migrants has been under way for many years.[86]

In mid-October 2003, Italian authorities discovered a boat bound for Italy carrying refugees from Africa. After being adrift for more than two weeks and having run out of fuel, food, and water, many of the passengers had died. At first the dead were tossed overboard. But after a point, the remaining survivors lacked the strength to hoist the bodies over the side. The dead and the living shared the boat, resembling what a rescuer described as "a scene from Dante's *Inferno*."[87]

The refugees were believed to be Somalis who had embarked from Libya, but the survivors would not reveal their country of origin, lest they be sent home. We do not know whether they

were political, economic, or environmental refugees. Failed states like Somalia produce all three. We do know that Somalia is an ecological disaster, with overpopulation, overgrazing, and the resulting desertification destroying its pastoral economy.[88]

Perhaps the largest flow of Somali migrants is into Yemen, another failing state. In 2008 an estimated 50,000 migrants and asylum seekers reached Yemen, 70 percent more than in 2007. And during the first three months of 2009 the migrant flow was up 30 percent over the same period in 2008. These numbers simply add to the already unsustainable pressures on Yemen's land and water resources, hastening its decline.[89]

On April 30, 2006, a man fishing off the coast of Barbados discovered a 20-foot boat adrift with the bodies of 11 young men on board, bodies that were "virtually mummified" by the sun and salty ocean spray. As the end drew near, one passenger left a note tucked between two bodies: "I would like to send my family in Basada [Senegal] a sum of money. Please excuse me and goodbye." The author of the note was apparently one of a group of 52 who had left Senegal on Christmas Eve aboard a boat destined for the Canary Islands, a jumping off point for Europe. They must have drifted for some 2,000 miles, ending their trip in the Caribbean. This boat was not unique. During the first weekend of September 2006, police intercepted boats from Mauritania with a record total of nearly 1,200 people on board.[90]

For those living in Central American countries, including Honduras, Guatemala, Nicaragua, and El Salvador, Mexico is often the gateway to the United States. In 2008, Mexican immigration authorities reported some 39,000 detentions and 89,000 deportations.[91]

In the city of Tapachula on the Guatemala-Mexico border, young men in search of jobs wait along the tracks for a slow-moving freight train passing through the city en route to the north. Some make it onto the train. Others do not. The Jesús el Buen Pastor refuge is home to 25 amputees who lost their grip and fell under a train while trying to board. For these young men, says Olga Sánchez Martínez, the director of the refuge, this is the "end of their American dream." A local priest, Flor María Rigoni, calls the migrants attempting to board the trains "the kamikazes of poverty."[92]

Today, bodies washing ashore in Italy, Spain, and Turkey are a daily occurrence, the result of desperate acts by desperate people. And each day Mexicans risk their lives in the Arizona desert trying to reach jobs in the United States. On average, some 100,000 or more Mexicans leave rural areas every year, abandoning plots of land too small or too eroded to make a living. They either head for Mexican cities or try to cross illegally into the United States. Many of those who try to cross the Arizona desert perish in its punishing heat. Since 2001, some 200 bodies have been found along the Arizona border each year.[93]

With the vast majority of the 2.4 billion people to be added to the world by 2050 coming in countries where water tables are already falling, water refugees are likely to become commonplace. They will be most common in arid and semiarid regions where populations are outgrowing the water supply and sinking into hydrological poverty. Villages in northwestern India are being abandoned as aquifers are depleted and people can no longer find water. Millions of villagers in northern and western China and in parts of Mexico may have to move because of a lack of water.[94]

Advancing deserts are squeezing expanding populations into an ever smaller geographic area. Whereas the U.S. Dust Bowl displaced 3 million people, the advancing desert in China's Dust Bowl provinces could displace tens of millions.[95]

Africa, too, is facing this problem. The Sahara Desert is pushing the populations of Morocco, Tunisia, and Algeria northward toward the Mediterranean. In a desperate effort to deal with drought and desertification, Morocco is geographically restructuring its agriculture, replacing grain with less thirsty orchards and vineyards.[96]

In Iran, villages abandoned because of spreading deserts or a lack of water already number in the thousands. In the vicinity of Damavand, a small town within an hour's drive of Tehran, 88 villages have been abandoned. And as the desert takes over in Nigeria, farmers and herders are forced to move, squeezed into a shrinking area of productive land. Desertification refugees typically end up in cities, many in squatter settlements. Others migrate abroad.[97]

In Latin America, deserts are expanding and forcing people to move in both Brazil and Mexico. In Brazil, some 66 million

hectares of land are affected, much of it concentrated in the country's northeast. In Mexico, with a much larger share of arid and semiarid land, the degradation of cropland now extends over 59 million hectares.[98]

While desert expansion and water shortages are now displacing millions of people, rising seas promise to displace far greater numbers in the future, given the concentration of the world's population in low-lying coastal cities and rice-growing river deltas. The numbers could eventually reach the hundreds of millions, offering yet another powerful reason for stabilizing both climate and population.[99]

In the end, the issue with rising seas is whether governments are strong enough to withstand the political and economic stress of relocating large numbers of people while suffering heavy coastal losses of housing and industrial facilities.

During this century we must deal with the effects of trends—rapid population growth, advancing deserts, and rising seas—that we set in motion during the last century. Our choice is a simple one: reverse these trends or risk being overwhelmed by them.