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Water News: Bad, Good and Virtual

Rational thinking about water may be key to ensuring a clean, plentiful supply

Vaclav Smil

Water quality and its impact on human health have been perennial concerns. People have also always worried about the adequacy of water resources on the local or small-regional level. But the closing decades of the 20th century brought attention to more acute and more widespread water shortages. Long-term forecasters began to envision per-capita water supply falling close to the minimum existential level or even slipping below it in dozens of countries, and in entire regions (the Middle East, large parts of Africa), in just a single generation. And the first years of a new millennium have brought even more troubling predictions of swiftly retreating mountain glaciers, melting ice shields and severe droughts in many regions.

Perhaps most worrisome are certain extreme events that might result from global climate change. Although the odds of such calamities may be small (and difficult to estimate), the consequences would be extraordinarily destabilizing. A key case in this category is the possibility that the rise in sea level is larger than anticipated.

The latest report from the Intergovernmental Panel on Climate Change, citing the uncertainties in understanding some key drivers of sea-level rise, refused to spell out either the best value or an upper bound of that change

(its midrange projection is 20 to 43 centimeters by 2100). But James Hansen, a climatologist at NASA's Goddard Institute for Space Studies, believes that these numbers may be too low. He suggests that "scientific reticence" prevents many experts from admitting that they think a much faster rise is very likely.

Such catastrophic predictions have been thoroughly covered by the media, but the real news about water is more complex, more interesting and largely untold. What's more, not all of it is necessarily bad.

Will Wetter Be Better?

Given the complexities of the Earth's biosphere, it is inevitable that some unfolding water trends will have both negative and positive consequences. Although it is hard to imagine positive effects of an unusually rapid sea-level rise, the most notable long-term change affecting the global water cycle—its intensification (acceleration)—will undoubtedly bring both benefits and problems. The intensification of the water cycle itself is one of the few entirely indisputable consequences of global warming: As the bottom layer of the atmosphere warms, it will enhance both evaporation (from oceans, freshwater surfaces and soils) and evapotranspiration (from vegetated areas), although higher photosynthetic water-use efficiency with higher CO₂ levels will make the second effect smaller than it would otherwise be. Warmer air will also have greater moisture-holding capacity (specific humidity), resulting in increased precipitation.

Because the expected rainfall increase is between 1 and 3 percent per degree Celsius, this effect should be evident even with the relatively small average global temperature rise (about 0.7 degree) that took place during the

20th century. And indeed it has been: The globally averaged annual precipitation over the continents increased by 9 millimeters during the past century (compared with the global mean of about 950 millimeters per year for nonglaciated land). There have been some interesting regional studies of this trend. One of them, based on oxygen isotope records from tree rings, showed that the 20th century was the wettest one of the past millennium in the high mountains of northern Pakistan because of much higher snowfalls in the Karakorum.

Higher precipitation should, of course, lead to increased river flows, and this trend has been confirmed by a number of regional studies, particularly in high latitudes. Given the recent concerns about CO₂ emissions causing the acidification of seawater (the pH of which has dropped 0.1 unit since the onset of industrialization), it is important to note that North America's largest river has become an increasing exporter of alkalinity—in part because of higher flow due to increased rainfall in the river's basin.

The increase in precipitation will very probably continue during this century: Modeling points to an overall 6 percent increase in the global mean by the year 2100. Naturally, other variables will change as well: average frequency, intensity, duration and number of precipitation events. What will not change is what always has been a hallmark of global water cycle—a highly uneven spatial distribution of additional rainfall. Unfortunately, some already-arid and semi-arid subtropical regions will receive less rain, and some already-wet regions will get more. Areas of increased rainfall will be predominantly in higher latitudes, in the equatorial zone and over large parts of Asia.

*Vaclav Smil is a Distinguished Professor at the University of Manitoba. His interdisciplinary research deals with interactions of energy, environment, food, economy, population and technical advances. He is the author of 25 books on these topics, the latest ones (both in 2008) being *Energy in Nature and Society* and *Global Catastrophes and Trends: The Next 50 Years*. Address: N306 Duff Roblin Building, University of Manitoba, Winnipeg, MB, Canada R3T 2N2. Internet: vsmil@cc.umanitoba.ca*



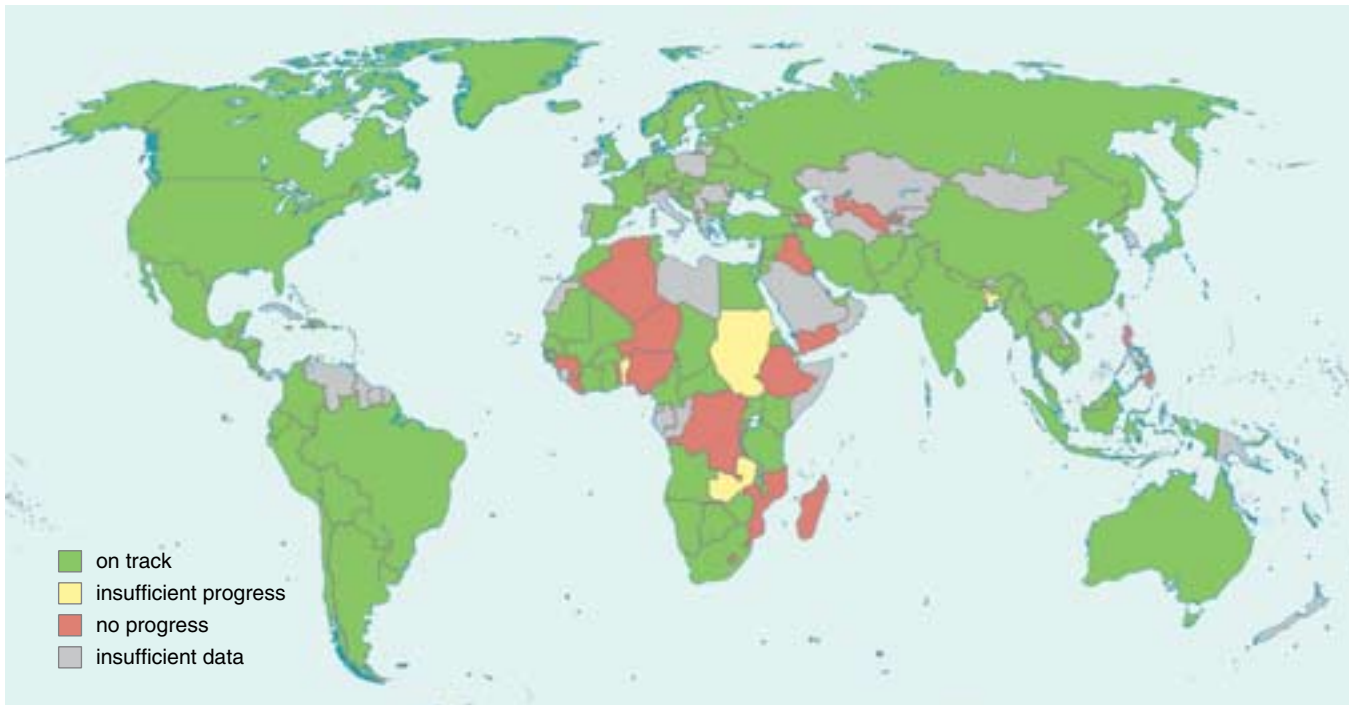


Figure 2. In 2000, as a part of its millennium development goals, The United Nations Educational, Scientific and Cultural Organization (UNESCO) set as Target 10 the reduction by half by 2015 of the proportion of people worldwide without safe drinking water. Shown here is the progress toward those goals as of 2004. Global climate change may make attainment of this target easier or more difficult, depending on how climate in particular regions is affected—predictions that are largely beyond the capabilities of current global climate models.

Redistribution and Reclamation

Is there any unequivocally good water news? Yes, but you must look for it because it has not been making many (and in some cases any) headlines. For example, the marshes of southern Iraq, which used to cover some 20,000 square kilometers, were devastated by Saddam Hussein, who ordered them drained to weaken the resistance of their residents, a remarkable group of the marsh Arabs. By 2003 the marsh shrank by more than 90 percent to less than 2,000 square kilometers, but since the United States invaded Iraq these wetlands have seen a steady and substantial recovery.

A similar trend has been even more impressive in the case of the north-

Figure 1. Quality drinking water of sufficient quantity rivals the availability of food as a global concern—but the two concerns cannot really be unbound; indeed, one can even be thought of as a proxy for the other. The concept of *virtual water* is an attempt to recognize this intimate relation and to quantify what the acquisition of one human necessity means to the prevalence of the other. The author hopes that this more rational approach to utilizing these resources will lead to their more equitable distribution—particularly as the planet faces disruptions brought on by global climate change. Shown here, villagers in Kotri, 160 kilometers from Karachi, Pakistan, search for water after their wells dried up.

ern part of the Aral Sea. Soviet-era mismanagement of water in the Amu Darya and Syr Darya rivers appeared to sentence the Aral Sea to inevitable disappearance, and the southern part of the sea is still shrinking. But after the doubling of the Syr Darya's flow and the building of a 13-kilometer dike, the smaller northern part has seen an unexpectedly rapid recovery and could cover two-thirds of its pre-desiccation extent in a matter of years.

Another hopeful sign is the steady progress in desalination technology, which offers an increasingly realistic prospect of an economic supply of freshwater for drinking and for household use. Reverse osmosis (RO) is the process of choice, and its minimum theoretical electricity needs are about 0.86 kilowatt-hour per cubic meter. Reverse-osmosis plants of the 1990s needed 5 to 7 kilowatt-hours per cubic meter. But in 2005 the world's largest such installation, in Ashkelon on Israel's Mediterranean coast, began to operate at 3.85 kilowatt hours per cubic meter. And in December 2005, the Affordable Desalination Coalition in San Leandro, California, broke the 2-kilowatt-hour barrier in its demonstration plant. Members of this coalition expect that with new low-energy membranes the number will approach

1.5 kilowatt-hours. For comparison, the electricity required to process *freshwater* by California's State Water Project averages about 2.5 kilowatt-hours per cubic meter, and the Colorado River Aqueduct Project needs about 1.6 kilowatt-hours.

This development suggests that in suitable coastal locations a combination of efficient RO plants and wind turbines will create a very appealing source of freshwater for urban needs. On a windy day a single large (3-megawatt) wind turbine could generate enough electricity to desalinate (at 2 kilowatt-hours per cubic meter) as much as 20,000 cubic meters of water, enough to cover domestic needs of nearly 40,000 Americans.

Capacities of reverse-osmosis plants are also getting much bigger, making them significant additions to a nation's or a city's overall supply. The Ashkelon plant, rated at 275,000 cubic meters per day, provides about 13 percent of Israel's domestic consumer demand; China's largest RO plant near Tianjin will have a capacity of 150,000 cubic meters per day; and in 2007, Thames Water received approval for a 140,000 cubic-meter-per-day plant in East London that will provide water during dry spells. (Given the city's size, in per capita terms it normally

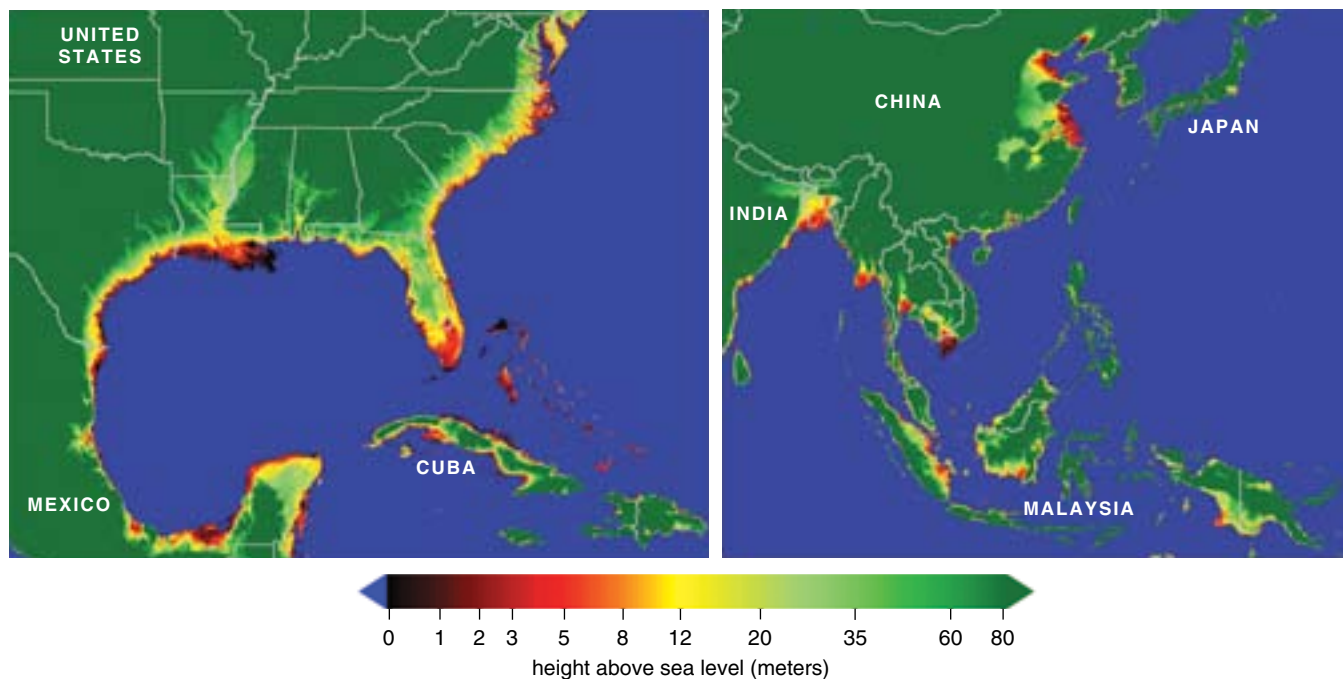


Figure 3. One of the few effects of global climate change that has little potential for benefit is sea-level rise. Although the actual predicted rise is not well constrained, owing to uncertainties in both the climatic response to accumulating greenhouse gases and the behavior of land-based ice masses, the effects of given sea levels are quite predictable. Show here are areas of inundation predicted for a range of sea-level increases, as mapped by Sea Level Rise Explorer at the Global Warming Art Site (www.globalwarmingart.com).

has less water at its disposal than does semi-arid Madrid).

Other recent, widely scattered, good water news includes the absence of any upward trend in the frequency of extreme floods in densely populated central Europe. This concern was raised by catastrophic flooding on the Elbe and Oder rivers in 2002 and by repeated forecasts of an increased probability of extreme events induced by global warming.

Another piece of excellent news arrived in 2007, when North America's first full-scale commercial water-treatment facility capable of removing phosphorus began operating in Edmonton, the capital of Alberta: After the increasingly common removal of nitrogen, the removal of phosphorus is an important step to minimize the eutrophication of streams, lakes and coastal waters. (It is taken out as struvite, ammonium magnesium phosphate, an excellent phosphorous fertilizer) But perhaps the most interesting water news of this decade has been the rising interest in virtual water, a new way of looking at using and trading this unique resource.

Virtual Water and Rational Behavior

The concept of virtual water was introduced by John Anthony Allan of the

School of Oriental and African Studies of the University of London during the 1990s as a part of his studies of water and food in the Middle East and North Africa. In 1998 Allan noted that the United States and European Union "export to the region as much water as flows down the Nile into Egypt for agriculture each year. The volume is more than 40 billion tonnes ... embedded in 40 million tonnes of grain."

The notion of virtual water has since become widely accepted, and many publications and meetings have explored the idea in great quantitative detail on scales ranging from national to global. Readers familiar with energy analysis will readily recognize that this concept, although relatively new to water studies, is nothing but the water equivalent of energy intensity (energy cost, embodied energy) whose many rates, expressed in joules or in oil equivalents per unit mass of a product, have been available since the early 1970s.

The energy cost of commonly used products (expressed in kilograms of oil per kilogram) ranges from low rates of 0.1–0.2 for bricks and cement to medium values of 0.5–1 for glass and high-quality steel to 2.5 for cars, 5 for aluminum and more than 400 for microchips. Similarly, water intensity

(virtual water) ranges from just 6 liters per kilogram for steel to 16,000 liters per kilogram for microchips. But virtual water for industry is a decidedly minor concern when compared with aggregate needs in agriculture. The reason is that photosynthesis involves an inherently, and extremely, lopsided trade-off between CO_2 and H_2O . The difference between the concentration of water vapor inside the leaves and in the ambient air is two orders of magnitude higher than the difference between external and internal CO_2 levels. So as the stomata of leaves open to take in the requisite CO_2 , water vapor streams out.

As a result, most cultivated plants (those following the C_3 metabolic pathway, including wheat, rice, tubers and vegetables) need 900–1,200 moles, and some up to 4,000 moles, of H_2O to fix 1 mole of CO_2 . The more-efficient C_4 plants (including corn and sugar cane) can manage with 400–500 moles of water to fix 1 mole of CO_2 . In practice this means that evapotranspiration of wheat plants requires about 1,300 liters of water to produce one kilogram of grain. For rice the rate is about 2,300 liters per kilogram. The extremes for common foodstuffs range from 100–200 liters per kilogram for many vegetables (cabbages, eggplants, onions)

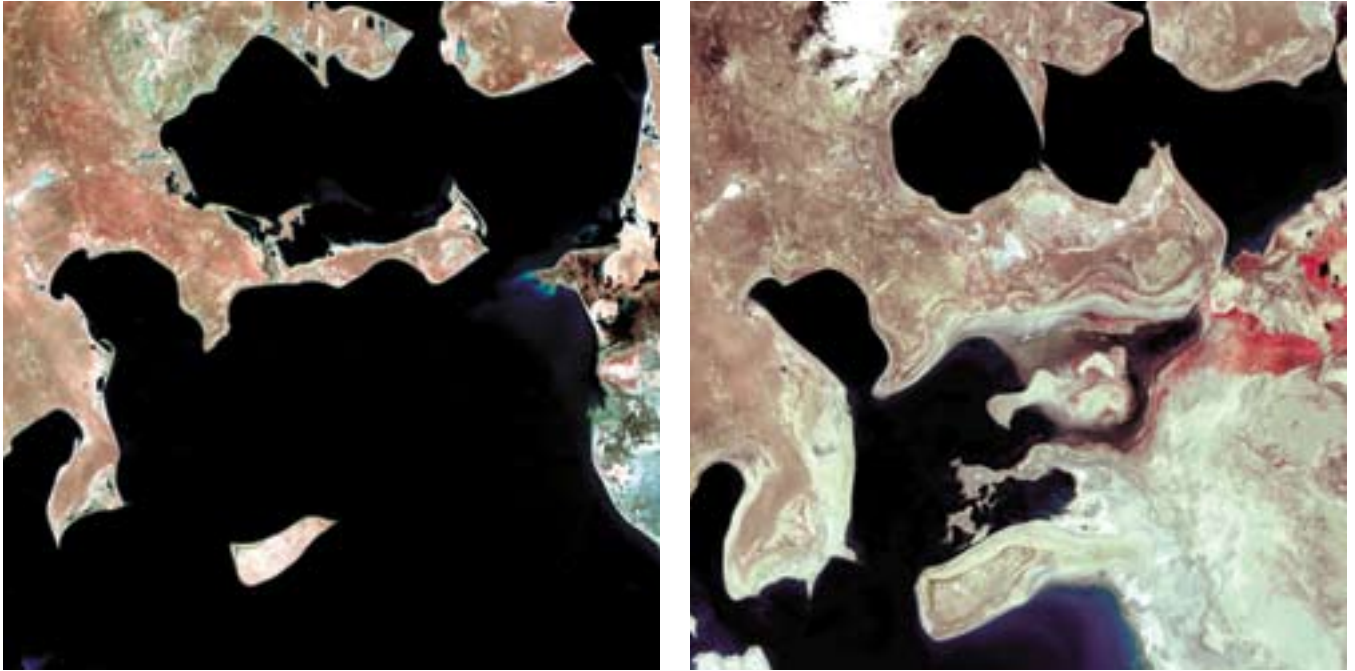


Figure 4. Not all water news is bad. Soviet-era mismanagement of water in the Amu Darya and Syr Darya rivers during the 1970s and '80s appeared to sentence the Aral Sea to inevitable disappearance. Satellite imagery from NASA shows the northern part of the Aral Sea in 1973 (*left*) and 2000 (*right*). But after the Syr Darya's flow was doubled and a 13-kilometer dike was built, the northern part of the sea began to recover. In a matter of years it may cover two-thirds of its original area. Unfortunately, the southern portion of the Aral continues to shrink.

to 2,000–4,000 liters per kilogram for various legumes (beans and peas).

Given the relative inefficiency of animal feeding, the virtual water requirements of dairy foods and meat are considerably higher than those of cereal and leguminous grains. In 2005 (the last year for which the U.S. Department of Agriculture rates are available), even the most efficient of all mass-meat-producing systems in North America—raising broilers fed an optimal diet in a controlled climate—averaged about 2.2 units of feed (expressed in corn-equivalent units) per unit of live weight. About 55 percent of a broiler's mass is edible, hence about 4 kilograms of feed were needed to produce a kilogram of meat. The feed is typically a combination of corn (for carbohydrate) and soybeans (for protein), plants whose production in the Corn Belt requires, respectively, about 500 and 1,900 liters of water per kilogram of harvested grain. Feed used to produce a kilogram of chicken meat thus requires at least 4,000 liters of evapotranspired water, and the rates are substantially higher for boneless pork (about 10 kilograms of feed per kilogram of boneless meat, amounting to at least 10,000 liters of water) and at least 15,000 liters (and as much as 30,000 liters) per kilogram of boneless

beef. (All of these figures also include feed needed for the growth and reproduction of sire and dam animals as well as direct water needs for drinking and sanitation.)

Drinking from the Virtual Pail

The concept of virtual water is thus straightforward, subsuming all freshwater required for a crop or an animal foodstuff in the place of its origin.



AP Photo/Ghassan al-Yassiri

Figure 5. Saddam Hussein drained the marshes of southern Iraq, near the confluence of the Euphrates and Tigris Rivers, in an attempt to subjugate the Arabs who live there. By 2003, the marshes were more than 90 percent drained, shrinking their area to less than 2,000 square kilometers. With Hussein's ouster, however, the marshes have seen a steady and substantial recovery. These fishermen were photographed in a marsh near Karbala in summer 2007.



Eitan Simanor / Alamy

Figure 6. Technology also offers a bright spot in the water picture. The efficiency of reverse osmosis, the process of choice for desalination, has improved considerably in recent years. Plants built in the 1990s required 5 to 7 kilowatt-hours to process a cubic meter of water. Shown here, Israel's Ashkelon installation (the world's largest) came on line in 2005 processing Mediterranean water for only 3.85 kilowatt-hours per cubic meter. Later that year, a demonstration plant in San Leandro, California, broke the 2 kilowatt-hour barrier, and efficiencies are expected to approach 1.5 kilowatt-hours per cubic meter in the near future. By comparison, California's State Water Project averages about 2.5 kilowatt-hours per cubic meter to deliver freshwater.

But calculations are always only approximations of the real process, and, unfortunately, the use of terms such as "embedded water," "embodied water," "virtual water exports" and "virtual water trade" evoke, erroneously, images of the actual presence of water in produced and traded commodities and create an impression that could be entirely or partly misleading. An uninitiated reader taking the adjective "embedded" at its face value would be grotesquely misinformed. Only a very small part of virtual water actually gets incorporated into plants: Grains, by far the most important plant foods, are harvested when their moisture content drops below 20 to 25 percent and, to prevent excessive spoilages, are marketed at between 10.5 and 14.5 percent moisture. A metric ton of traded wheat that needed 1,300 tonnes (cubic meters) of water to produce contains only about 110 kilograms of water, an order-of-magnitude difference.

Someone new to the concept must also take care to note that it differs in a fundamental way from embedded energy, which is essentially no longer available for use once it is invested in making a product. In contrast, evapotranspired water reenters

the atmosphere, and its subsequent fate can range from rapid condensation on nearby plants or soil surfaces to extended transport of hundreds or thousands of kilometers downwind before being precipitated on the same continent or overseas. Consequently, the same water molecules that helped to produce Nebraska corn may help to produce, just a few hours later, an alfalfa crop in a nearby field, Indiana soybeans two days later and then an excellent harvest of winter wheat in East Anglia a week afterwards.

These realities must be kept in mind when appraising calculations of overall virtual water content of traded commodities and finding out which nations are major exporters of virtual water and which ones are its major recipients. Such quantifications of virtually traded water can offer a particularly useful tool for possible worldwide optimization of crop cultivation, but they require careful interpretation. If corn can be grown in the U.S. Corn Belt with just 500 liters of water per kilogram of grain, and its cultivation in Egypt needs twice as much water, the Egyptian purchases of American corn will save some of Egypt's always limited irrigation water, which could then be

reallocated to higher-value vegetable, fruit or flower crops. Calculations have shown that in the absence of global cereal trade, more than 100 cubic kilometers of irrigation water would be needed in the importing countries to produce those grains. (For comparison, that is about as much water as is actually withdrawn annually for all uses in Germany, France and Italy.)

And yet agricultural trade is not consciously guided by even rough estimates of the volumes of virtual water involved in the transactions: Demand, price and land availability are the main overt considerations. Moreover, most of the trade in agricultural commodities does not result in any virtual water gains. When Japan replaces some of its rice by imports from California there will be no overall water savings, and when it imports rice from Thailand there will be a net virtual water loss. And modeling studies show that Japan, the world's largest importer of grains, buys (largely U.S., Australian and Brazilian) crops grown overwhelmingly with rainwater rather than with water taken from rivers, reservoirs or aquifers—and most of that water would be evapotranspired anyway by natural vegetation had it not been used for agriculture.

That does not mean that we should not use water as efficiently as possible, because every unused drop will perform essential biospheric services by replenishing soil moisture, recharging aquifers, enhancing wetlands or increasing natural stream flow. Much like in the case of energy use, higher efficiency of existing water uses has been promoted as the principal approach toward securing more dependable water futures. But, as with energy, conservation in itself may not be enough and, in fact, can lead to using more water more efficiently. That is why we should be ready to examine some unorthodox approaches that could yield very large water savings even as they bring other environmental and social benefits. There are two kindred courses of action that would not only result in substantially reduced agricultural water demand in all affluent countries but that would also bring non-trivial reductions in their energy use and greenhouse gas emissions even as it would improve health and increase longevity of their populations. My preferred names for these are *rational food production* and *sensible carnivory*.

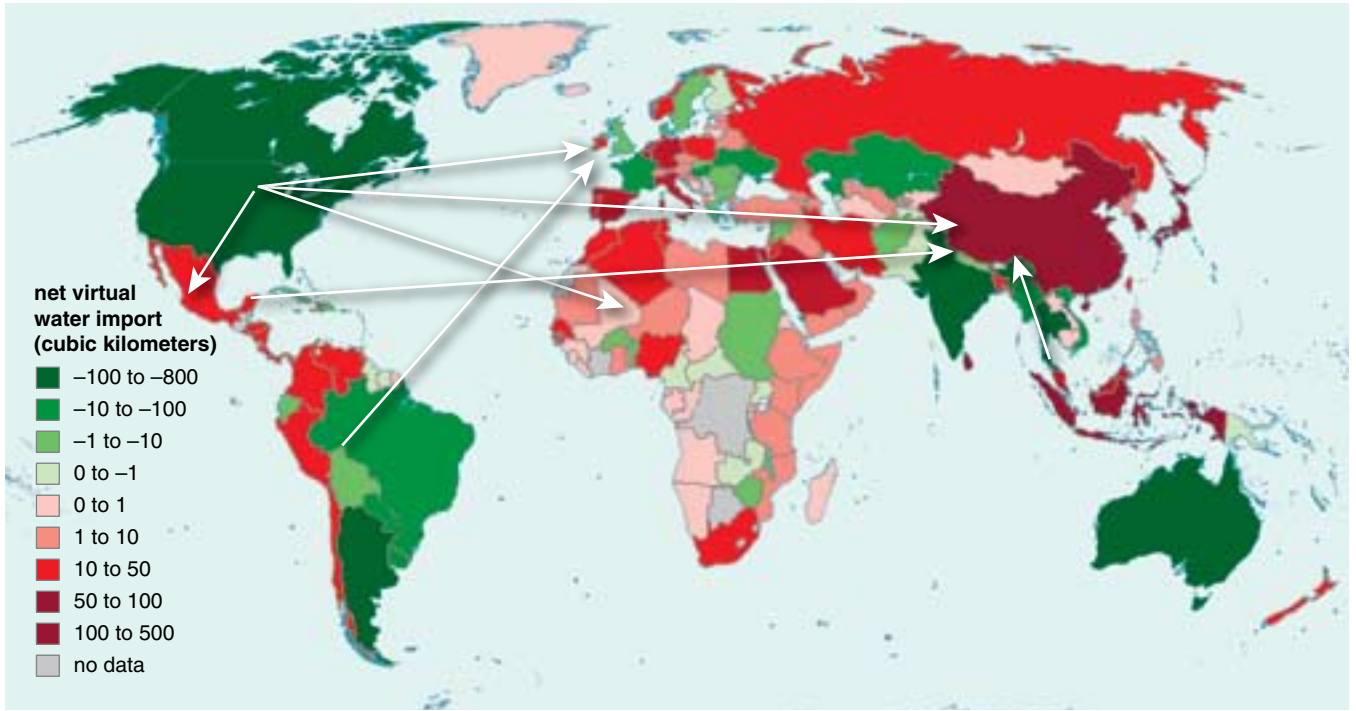


Figure 7. Virtual water, a concept introduced by John Anthony Allan of the School of Oriental and African Studies of the University of London, is analogous to energy intensity—the amount of energy (or water) required to make (or to grow) a finished product. Because the process of photosynthesis requires so much water to be transpired in order for CO₂ to be taken in, agriculture accounts for much more virtual water than do industrial processes. Thus, when wheat, for example, is exported from a grain-producing country such as Canada, a large amount of virtual water is, in effect, exported with that wheat. Shown here are virtual water importing and exporting countries. White arrows indicate regional transfers. (Adapted from Hoekstra and Hung 2003.)

Waste Not...

According to the USDA, average national per-capita food supply now amounts to about 3,900 kilocalories per day. This is a truly obscene total when you consider that both infants and housebound grannies need less than 1,500 kilocalories per day—and that even young active males can do with 2,900 kilocalories per day. The latest (2003–2004) USDA food-consumption surveys indicate that the average population intake (for all people two years and older) is about 2,200 kilocalories per day. Thus about 45 percent of the American food supply (which amounts to 80 percent of average daily food supply in Bangladesh) is wasted. Perhaps the actual waste is somewhat lower (say, 35 percent instead of 45 percent), because most of the people participating in dietary surveys may underreport their overeating, a plausible explanation given the prevalence of overweight (one-third) and obese (one-third) adult Americans.

Using a detailed breakdown of consumed foodstuffs, average feed-to-meat conversion rates in U.S. animal husbandry and the best available virtual water rates needed to grow food and feed crops, I calculated the mean

virtual water content of the country's food supply to be at least 5,000 liters per day. If the average per-capita food availability were to decrease to "just" 3,000 kilocalories per day (still leaving a generous 35-percent safety mar-

gin above the mean necessary intake) virtual water needs would decline by about 25 percent: For the population of 300 million people that would amount to an impressive aggregate of 140 cubic kilometers of water a year.

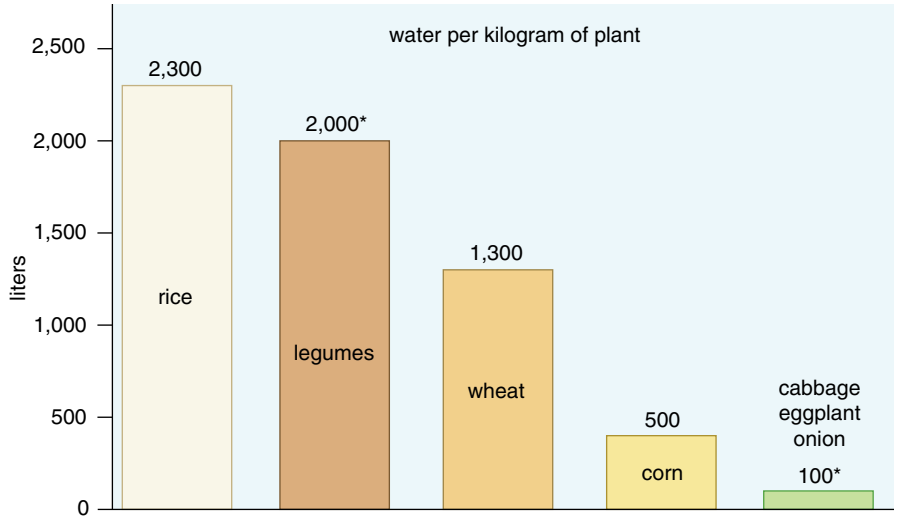


Figure 8. Plants transpire large amounts of water during growth. Rice tops the list at 2,300 liters per kilogram, whereas the most important plants in international trade (corn and wheat) range from about 500 to about 1,300 liters per kilogram. It is important to understand that this water is transpired by, not bound up in, the plant and may, in fact, be used again later downwind. Asterisks indicate large ranges based on the particular species. When making decisions about global trade in grains, virtual water is seldom, if ever, considered. Yet, its implementation could lead to better use of available resources by exporters and importers alike.

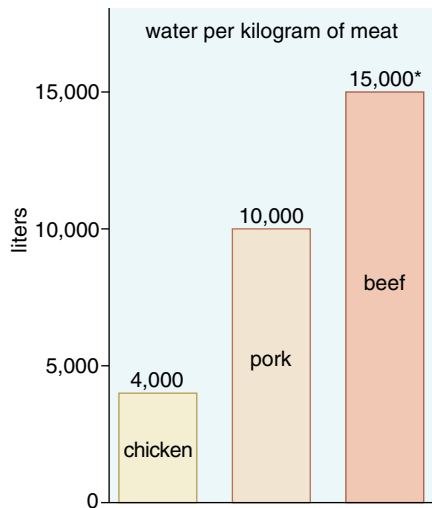


Figure 9. Boneless meat products are particularly water intensive, as the animals are typically fed a combination of harvested corn and soybeans. In western countries, for example, about 60 percent of all agricultural crops are used to feed animals for slaughter. Chickens are most efficient but still require the use of 4,000 liters of water per kilogram of meat produced. Beef takes a minimum of 15,000 liters per kilogram and may entail the use of as much as 30,000 liters per kilogram. Because western diets rely so heavily on meat—the typical U.S. diet includes about 85 kilograms per year—the virtual water content of the produced food is extraordinarily high.

Alternatively, Americans could moderate their consumption of meat. The currently very high per-capita intakes of meat (about 85 kilograms per year in terms of boneless trimmed cuts, nearly 125 kilograms in terms of carcass weight) confer no health or longevity advantages in comparison with diets that are only moderately rich in animal foods. Indeed, just the opposite is true as modern high-meat diets in conjunction with decreased physical activity are associated with an unprecedented prevalence of obesity and its associated ailments.

In Western countries more than 60 percent of all crops (by harvested mass) are grown for animal feeding, hence 60 to 70 percent of all virtual water used in this agriculture goes into meat, egg and dairy production: My calculations show that in the United States in 2005 two-thirds of all virtual water used in growing food for domestic consumption was used in meat production. Consequently, if Americans were to reduce their consumption of beef, pork and poultry by a third they would still eat nearly 60 kilograms of meat a year per capita, but such a dietary modification would save annually 120 to 140

cubic kilometers of virtual water. I hasten to add that even after this reduction the average daily protein intake would remain close to 100 grams per capita (far above the need) and that the overall food energy availability would hardly change (meat supplies about 40 percent of all dietary protein but less than 15 percent of the country's food energy). Neither the overall reduction of food supply nor lowered meat intakes would thus call for any sacrifices, just for curbing exorbitant waste or excessive carnivory.

The United States is far from alone in perpetuating unconscionable food overproduction and waste. Comparisons of annual per-capita intakes of major foodstuffs in the United States and the European Union show that the only large difference is in the sweeteners category, a result of America's high reliance on corn derivatives. The European Union's per-capita food energy and meat supply (in excess of 3,500 kilocalories per day and 110 kilograms per year) are within 10 percent of the U.S. rates. Consequently, the European Union, with its nearly 500 million people, could easily reduce its food supply by 15 percent without any ad-

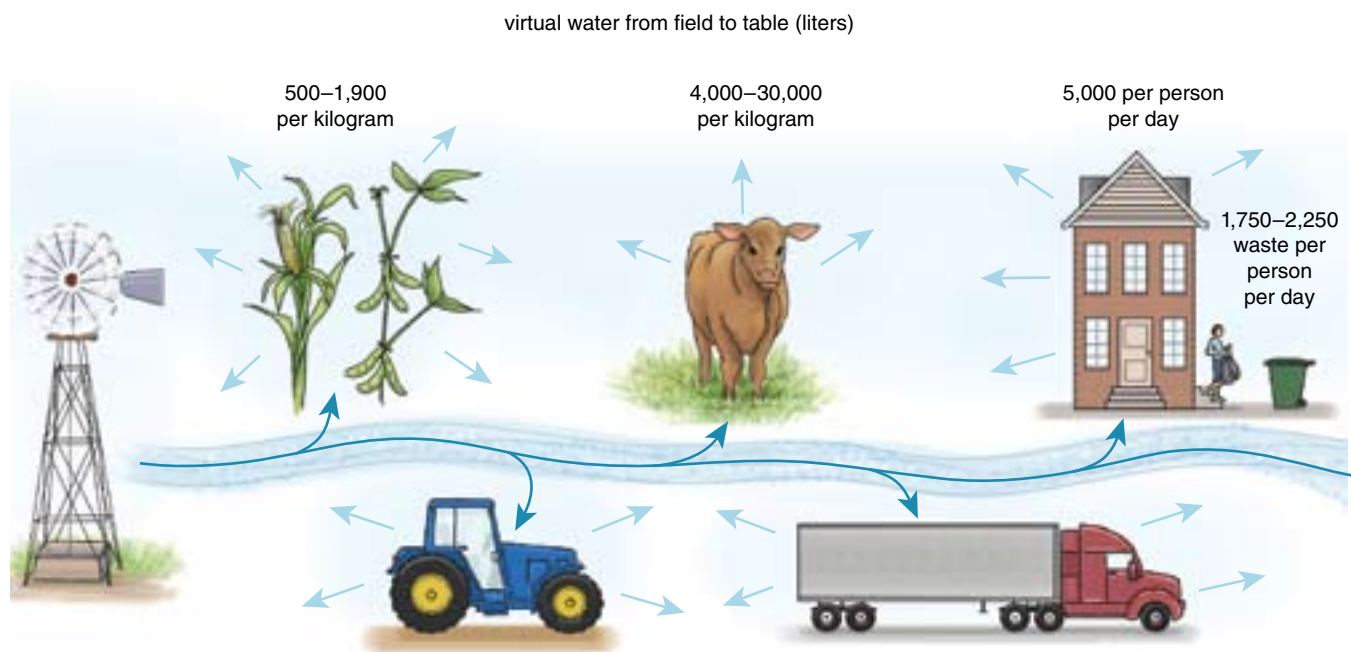


Figure 10. A rational approach to food takes into consideration the water used from planting to production to harvest to animal husbandry to distribution to the table and to the garbage. In western countries, this process is remarkably inefficient for a variety of reasons. First, and perhaps foremost, the average U.S. citizen "consumes" 3,900 kilocalories per day, far more than the 1,500 to 2,900 kilocalories per day needed for good health. Of this, some 35 to 45 percent goes to waste—enough to supply 80 percent of the typical Bangladeshi's diet. Altogether, this amounts to about 5,000 liters of virtual water per day per person, distributed between water to grow plants that are in turn fed to animals, which are then fed to human beings, who deposit at least a third in the garbage. The author argues that by simply practicing *sensible carnivory* (reducing meat eating by 30 percent), U.S. and European Union residents could eliminate the need for about 250 cubic kilometers of virtual water each year.

verse effects on health while saving annually at least 120 cubic kilometers of virtual water.

Rational food production and healthier eating in America and Europe could thus eliminate the need for at least 250 cubic kilometers of virtual water every year. This would be more than twice as much as is saved annually by the international trade in food and feed, and it would suffice to produce 200 to 250 million tonnes of cereals that could be exported to water-deficient nations, nearly doubling the mass of grain that is now traded annually worldwide. Or, as already noted, people could lower their overall appropriation of water, leaving this volume alone to perform its natural functions.

For All the Right Reasons

These dietary adjustments would result in other, non-water benefits, too. There would be a significant lowering of synthetic fertilizer inputs, particularly of highly energy-intensive nitrogen produced by Haber-Bosch synthesis of ammonia. (The U.S. and E.U. use about 25 percent of the world's fertilizer nitrogen.) The ensuing reduction of nitrate leaching would improve some of the most heavily contaminated groundwater and ease the coastal eutrophication in European waters and in the Gulf of Mexico with its dead zone along Louisiana and Texas shores. Reduced crop cultivation would lower energy consumption and hence the emissions of CO₂—directly because of fewer field

operations and indirectly because of savings in the synthesis of agrochemicals and production of feed. Reducing nitrogen applications to crops would also lower emissions of N₂O, a potent greenhouse gas. And, a long-term benefit with major financial implications would be healthier populations.

There is no rational excuse for deliberately overproducing food while stressing some key biospheric services. Low-income developing countries need higher crop outputs and higher food intakes, but for affluent nations the best way ahead is not to produce more food more efficiently but to live within rational confines. Such wealthy nations should apply this strategy to all other resource demands as well, rather than pursuing costly, complicated, energy-intensive, arcane and environmentally questionable "solutions" aimed at keeping or expanding high rates of output. Current infatuations of this irrational kind range from carbon sequestration (burn more fossil fuel and hide the carbon underground) to grain-derived ethanol (produce more automotive fuel by intensifying soil erosion, and increasing nutrient and water use in order to feed a fleet of grossly inefficient vehicles).

As long as we remain unwilling to put absolute limits on the anthropogenic flows of materials and energy through the biosphere, all the talk about sustainable development will remain risible, and all international environmental agreements will bring only temporary slowdowns of a down-

ward spiral. Appropriating ever larger shares of the biospheric goods and services with a steadily, even impressively, rising efficiency is a strategy that cannot be pursued indefinitely. The notion of virtual water provides some useful quantitative insights into one category of these unsustainable appropriations and makes it easier to think about living within rational limits.

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