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Water Scarcity

The Food Factor

With ever more water needed to raise crops to feed the burgeoning global population, efforts to produce more food with less water are critical to averting a crisis.

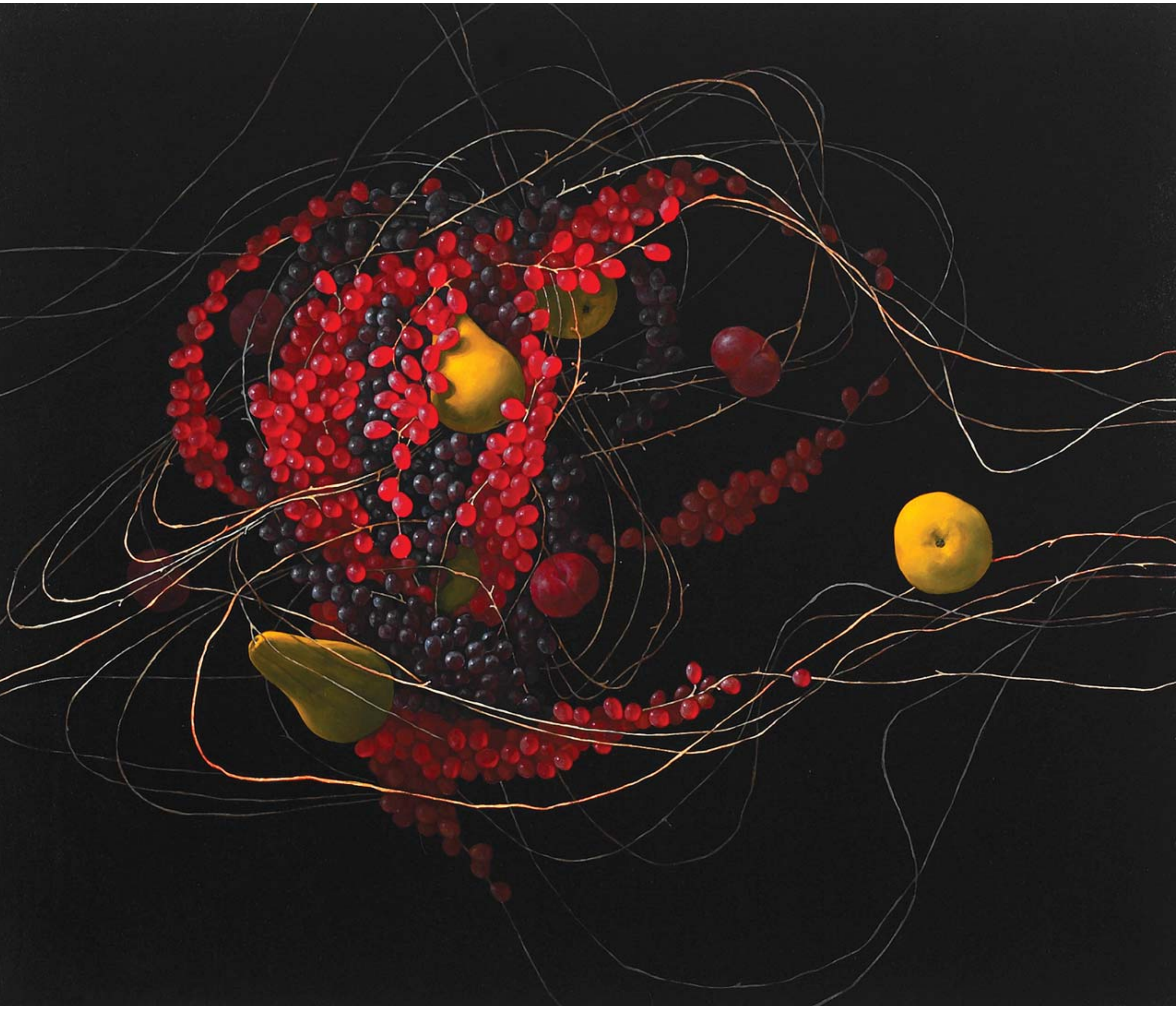
With so much talk about a global water crisis, about water scarcity, and about increasing competition and conflicts over water, it would be easy to get the impression that Earth is running dry. You could be forgiven for wondering whether, in the not-too-distant future, there will be sufficient water to produce enough to eat and drink.

But the truth is that the world is far from running out of water. There is land and human resources and water enough to grow food and provide drinking water for everyone. That doesn't mean, however, that the global water crisis is imaginary. Around the world there are already severe water problems.

The problem is the quantity of water required for food production. People will need more and more water for more and more agriculture. Yet the way people use water in agriculture is the most significant contributor to ecosystem degradation and to water scarcity. Added together, these problems amount to an emergency requiring immediate attention from government institutions that make policy, from water managers, from agricultural producers—and from the rest of us, because we are all consumers of food and water.

The crisis is even more complex than it first appears to be because many policies that on the surface appear to have nothing to do with water and food make a bigger difference to water resources and food production than even agricultural and water management practices. But people who make these decisions often do not consider water to be part of them. Water professionals need to communicate these concerns better, and policymakers need to be more water-aware.

In early 2007, the Comprehensive Assessment of Water Management in Agriculture, which explored ways to cope with this crisis, was released. The assessment gathered research and opinions from more than 700 researchers and practitioners from around the world. They addressed these questions: How can water be developed and managed in agriculture to help end poverty and hunger, promote environmentally sustainable practices, and find a balance between food and environmental security? The Comprehensive Assessment provides a picture of how people used water for agriculture in the past, the water challenges that people are facing today, and policy-relevant recommendations charting the way forward. Food and environmental communities joined efforts to produce the assessment, which was jointly sponsored by the United Nations Food and Agricultural Organization, the Convention on Biological Diver-



Mia Brownell, *Still Life with Pear, Plum and Grape VII,* Oil on canvas, 30 x 36 inches, 2005.

Mia Brownell

Mia Brownell, an associate professor of art at Southern Connecticut State University, New Haven, introduces a new relevancy to the age-old genre of the still life. With a fluid old-masters' touch and jewel-like color, she depicts clusters of fruit such as grapes, plums, and pears twining in the coiling structures of DNA, amino acids, and protein chains. Today, the structures of life stand increasingly revealed and exposed to scientific experiment, and food sources are increasingly modified through the crossing of disparate genetic materials. In her recent paintings Mia Brownell subtly suggests that there is really nothing "still" about life.

Brownell's exhibition, *Proteomics*, will be on display at the National Academy of Sciences from October 10 to December 20, 2007 (www7.nationalacademies.org/arts/Mia_Brownell_Paintings.html).

sity, the Consultative Group on Agricultural Research, and the Ramsar Convention on Wetlands. (A summary of the assessment is available at http://www.iwmi.cgiar.org/Assessment/index.htm and the book at www.earthscan.co.uk.)

Crisis, what crisis?

If there's plenty of water for drinking and growing food, then what's the crisis all about? Many in the developed world are complacent about the supply of water and food. Global food production has outpaced population growth during the past 30 years. The world's farmers produce enough for everyone, and food is cheap. Water resources development, which has played a critical role in fueling agricultural growth, can be seen as one of humankind's great achievements. Why isn't the type of water resource development that served us well in the past sustainable?

For one thing, agriculture must feed another 2 to 3 billion people in the next 50 years, putting additional pressure on water resources. More than 70% of the world's 850 million undernourished people live in rural areas, and most depend directly or indirectly on water for their livelihoods. Yet for millions of rural people, accessing enough food, enough water, or both is a daily struggle. Rain may be plentiful for some farmers, but in many places it falls when it is not needed and vanishes during drought. The Indian rural development worker Kalpanatai Salunkhe put it succinctly: "Water is the divide between poverty and prosperity."

In addition, policies seemingly unrelated to water drive increased water use. For example, using biofuels may be a way to reduce greenhouse gases, but growing the crops to produce them demands additional water. Increased reliance on biofuels could create scarcity by pushing up agricultural water use. In India, increased biofuel production to meet 10% of its transportation fuel demand by 2030 will require an estimated 22 cubic kilometers more irrigation water, about 5% of what is currently used in Indian food production, pushing the country further into water scarcity. India can ill afford these additional water resources.

Trade has the potential to markedly reduce water use. Yet trade policies rarely if ever take water into account. As a first step, trade officials could consider the water implications of trade. Subsidies and economic incentives lead to better soil and water management. Countries set subsidy policies as an economic incentive. If farmers have access to cheaper fertilizer or water, or the prospect of higher prices for their crops, they will invest in better practices. But agricultural subsidies consider a country's political interests (such as rural employment) rather than water. Subsidies in countries such as the United States allow cheaper food to be exported and drive down the prices of commodities such as corn and wheat. Farmers in Africa and poor countries elsewhere then have trouble competing with these artificially low prices. Local, national, and international policymakers should carefully consider the water implications of their actions along with local politics.

How much water do we eat?

The water-food-environment dilemma starts with everybody because everybody eats. The water people need for drinking is essential, but it is only about 0.01% of the water people require to produce their food.

Why does food production need so much water? It is largely because of the physiologic process of plant transpiration. Huge amounts of water are evaporated constantly from pores on the surface of a plant's leaves. This evaporation is part of the process of photosynthesis, in which a plant manufactures its own energy from sunlight. Evaporation also helps cool the plant and carries nutrients to all its parts. In addition to transpiration, some liquid water is turned to vapor through evaporation from wet soils or leaves.

Crop yield is roughly proportional to transpiration; more yield requires more transpiration. It takes between 500 and 4,000 liters of evapotranspiration (ET, the combined process of evaporation and transpiration) to produce just one kilogram of grain. When that grain is fed to animals, producing a kilogram of meat takes much more water—between 5,000 and 15,000 liters. Thus, vegetarian diets require less water (2,000 liters of ET daily) than do high-calorie diets that include grain-fed meat (5,000 liters of ET daily.)

The bottom line is that although people individually need just 2 to 5 liters of drinking water and 20 to 400 liters of water for household use every day, in reality they use far more: between 2,000 and 5,000 liters of water per person per day, depending largely on how productive their agriculture is and what kind of food they eat. An estimated 7,100 cubic kilometers of water are vaporized to produce food for today's 6.6 billion people. On average, each of us requires about 1,000 cubic meters of water each year for food, or about 3 cubic meters (3 tons, or 3,000 liters!) of water per day. For country-level food security, about 2,800 to 3,000 calories must reach the market in order for each of us to consume about 2,000 calories. Thus, about one liter of water is required per calorie of food supply.

Water for crops comes either directly from rain or indirectly from irrigation. Growing food with rainwater has much different water and land-use implications than does intensive irrigation. Meat produced on rangeland uses much less water than industrial meat production in feed-based systems. In addition, although both grazing and industrial livestock systems need water, the soil moisture in grazing land cannot be piped into a city and therefore does not reduce the domestic water supply, although it does reduce the amount of water available to the natural ecosystem that is being grazed.

The importance of meat to water consumption and livelihoods is quite different in developed and developing countries. Animal products are extremely important in the nutrition of families who otherwise consume little protein. They are also precious to African herders and farmers who use livestock for transport, for plowing, for living food storage, and often for a walking bank account as well. In the developed world, by contrast, most livestock production is for meat and comes from industrial feed-based processes.

Reaching the limits

Every year, the rain falling on Earth's surface amounts to about 110,000 cubic kilometers. About 40,000 cubic kilometers contributes to rivers and groundwater. The remainder evaporates directly from soil. People withdraw 3,700 cubic kilometers from rivers and aquifers for cities, industries, and agriculture. Agricultural irrigation takes most of that: 2,600 cubic kilometers or 70% of total withdrawals. Agriculture also consumes 7,100 cubic kilometers per year through ET, about 80% of which comes directly from rain and 20% from irrigation. Rainfall supplies plenty of water for food production. But often it fails to rain in the right place or at the right time.

Limits have already been reached or breached in several river basins. These basins are "closed" because people have used all the water, leaving just an inadequate trickle for the ecosystem. The list of closed basins includes important breadbaskets around the Colorado River in the United States, the Indus River in southern Asia, the Yellow River in China, the Jordan River in the Middle East, and the Murray Darling River in Australia.

Many agricultural and city users prefer groundwater, the underground water in aquifers and streams beneath Earth's surface that supplies springs and wells. The present boom in groundwater use for irrigation that began in the 1970s is occurring because this water is easy to tap with cheap pumps and the supply is reliable. But for millions of people, the groundwater boom has turned to bust as groundwater levels plummet, often at rates of 1 to 2 meters per year. Groundwater is declining in key agricultural areas in Mexico, the North China plains, the Ogallala aquifer in the U.S. high plains, and in northwest India.

Patterns of water use are also changing in response to changes in the amount of grazing land and the productivity of fisheries. Further expansion of grazing is unlikely to be available to support expanded meat and milk production, so more livestock will have to come from industrial feed-based systems. That will require more water, especially for feed production. Ocean and freshwater fisheries have in many cases surpassed their limits, yet consumption of fish and fish products is booming. So in the future, more fish products will come from aquaculture, which requires yet more fresh water.

Water scarcity resulting from physical, economic, or institutional constraints is already a problem for one-third of the world's population. About 1.2 billion people live in areas plagued by physical water scarcity, meaning they lack enough water to satisfy demand, including enough water to sustain ecosystems. These are Earth's deserts and other arid regions. Physical water scarcity also occurs in areas with plenty of water, but where supply is strained by the overdevelopment of hydraulic infrastructure. Another 500 million people live where the limit to water resources is fast approaching. All of these people are beginning to experience the symptoms of physical water scarcity: severe environmental degradation, pollution, declining groundwater supplies, and water allocations in which some groups win at the expense of others.

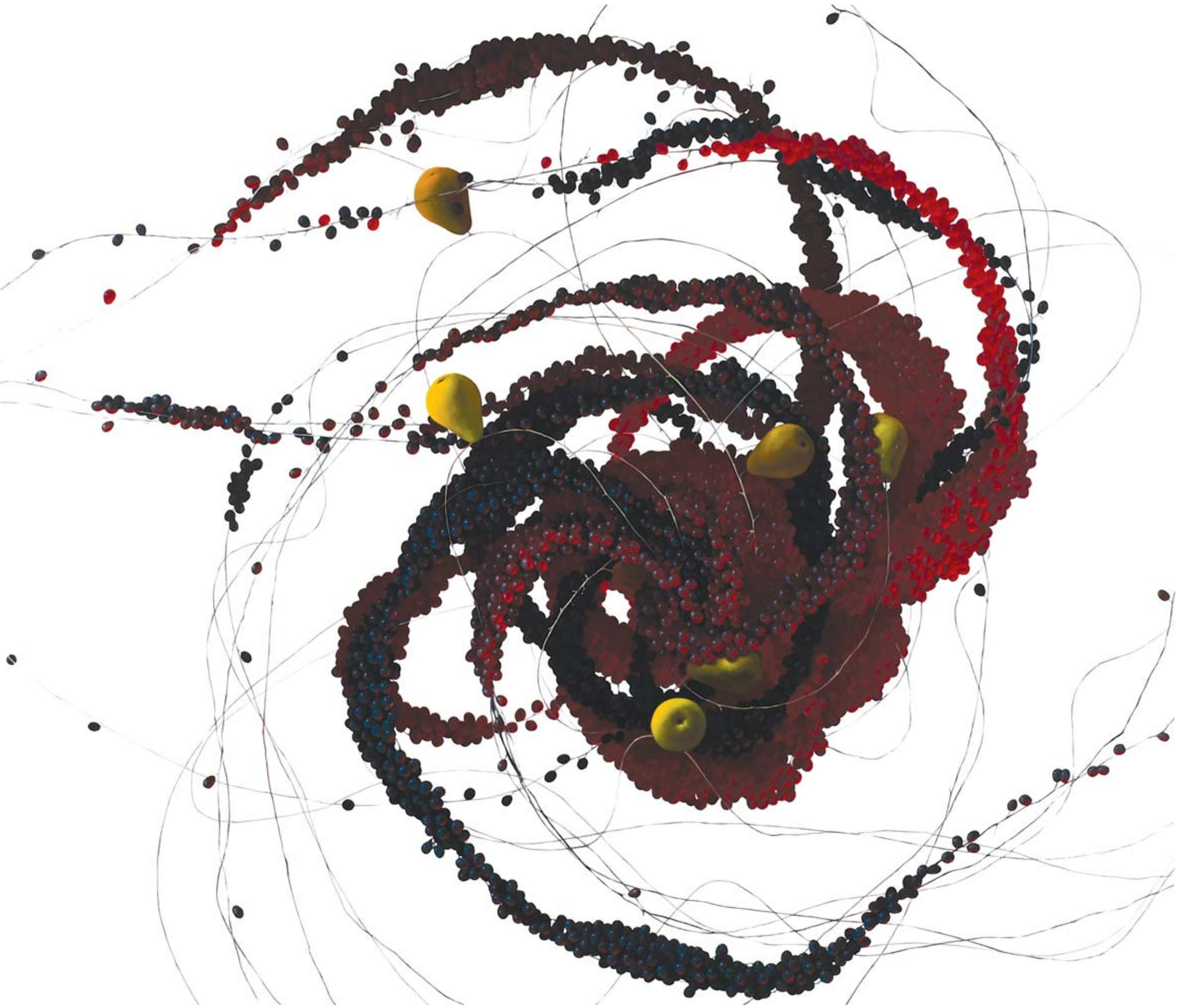
Economically water-scarce basins are home to more than 1.5 billion people. In these places, human capacity or financial resources are likely to be insufficient to develop local water, even though the supply might be adequate if it could be exploited. Much of this scarcity is due to the way in which institutions function, favoring one group while not hearing the voices of others, especially women. Symptoms of economic water scarcity include scant infrastructure development, meaning that there are few pipes or canals to get water to the people. Even where infrastructure exists, the distribution of water may be inequitable. Sub-Saharan Africa is characterized by economic water scarcity. Water development could do much to reduce poverty there.

Both economic and physical water scarcity pose special problems that can be particularly difficult to deal with. But, as we have said, water problems also occur in areas with adequate water. Institutions—laws, rules, and a supportive organizational framework—are key to mitigating water problems. Where there is inequitable water distribution or ecosystem degradation, water problems can be traced back to ill-adapted or poorly functioning institutions. Rarely is there an overriding technological constraint.

As economies develop and people's incomes rise, their diets tend to change. In developed areas, more grain is grown for feeding animals than for feeding people. The reverse is true in sub-Saharan Africa, where grains are a major part of the human diet. With economic development, the trend is toward much more meat in the diet, as in East Asia. There, average annual meat consumption is expected to double, from 40 to 80 kg per person, by 2050.

With growing incomes and changes in diet worldwide, food and feed demand could double by the year 2050. If there is no increase in water productivity—the amount of water it takes to produce a unit of food—water consumed by agri-

MIA BROWNELL, *Still Life with Double Double,* Oil on canvas, 72 x 54 inches, 2006.



MIA BROWNELL, *Still Life with Pear and Grape VII,* Oil on canvas, 54 x 64 inches, 2005.

culture must double as well. The environmental impact of that massive human demand for water would be stunning. Therefore, the amount of food per unit of water, which has tended to grow in the past, needs to grow much faster.

Water for more food

There are five main options for getting water for more food:

- Expand irrigated areas by diverting more from rivers, lakes, and aquifers
- Expand rain-fed areas by turning more natural area into arable land
- Get "more crop per drop" through increases in water productivity
- Trade food from areas of high to low water productivity
- Look beyond water and crops by managing demand through dietary changes or reduced food wasting

Irrigation has been the key water resources development strategy in Asia and the Western industrialized countries: Build dams, divert water to irrigate crops, and intensify production. Irrigation has succeeded in combating famine and poverty and has helped stimulate economic growth in early stages of development; for example, in India and China. Particularly in Asia, this achievement is often referred to as the Green Revolution, which combined improved crop varieties with increased chemical fertilizer use and irrigation. In Asia there were few other options, because the population density in many countries precluded converting land to agriculture.

In Africa, on the other hand, the key strategy has been the opposite: to expand the area under cultivation with very little irrigation or agricultural intensification. Latin America has adopted a mixed strategy.

A downside of irrigation expansion is its several effects on aquatic ecosystems. Dams fragment rivers. Increased ET causes river flows to diminish and groundwater levels to drop. Intensive irrigation has led to closed basins where all water is allocated to specific uses, including water for the environment. In fact, irrigation has been the single most important reason for closing river basins and creating physical water scarcity.

Nevertheless, the continued expansion of irrigated land remains an important strategy. Storing water behind dams or in groundwater is arguably an important way of coping with climate change because it helps reduce uncertainties of supply. Scenario analysis shows that irrigation could contribute 55% of the total value of food supply by 2050, up from 45% today. But that expansion would require 40% more water to be withdrawn for agriculture, surely a threat to many aquatic ecosystems and fisheries. Fisheries would compete with irrigated crops for water. Highly nutritious fish products, important for some of the poorest of the poor, are threatened when water is diverted to crops.

Sub-Saharan Africa is a special case because there is now so little irrigation there. Irrigation expansion seems warranted. Doubling the irrigated land in sub-Saharan Africa would increase irrigation's contribution to the food supply from only 5% today to, optimistically, 11% by 2050.

Typical water productivity figures for the staple cereal crops rice and wheat are 0.5 kilogram per cubic meter in low-performing irrigation systems, 0.2 kilogram per cubic meter in rain-fed sub-Saharan Africa, and up to 2 kilogram per cubic meter in both Asian state-of-the-art irrigation systems and rain-fed systems in Europe and North America. Today, 55% of the gross value of our food is produced by rainfall on nearly 72% of the world's cropland.

Rain-fed agriculture could be upgraded to meet food and livelihood needs through better management, not just of water but also of soil and land. These tactics can increase water productivity, adding a component of irrigation water through smaller-scale interventions such as rainwater harvesting: capturing rain before it gets to rivers by building small earthen dams across streams or diverting water from roads or rooftops into storage.

At the global level, the potential for rain-fed agriculture is large enough to meet present and future food demand through increased productivity alone. An optimistic scenario, in which farmers reach 80% of the maximum practically obtainable yield, assumes significant progress in upgrading rain-fed systems while relying on minimal increases in irrigation. This leads to annual growth of 1%, increasing an average rain-fed yield of 2.7 metric tons per hectare in 2000 to 4.5 tons in 2050. From 1961 to 2000, the clearing of land expanded the cropped area by 24%, at the expense of terrestrial ecosystems. But with productivity gains, expansion can be limited to 7% from now until 2050, in spite of the rising demand for agricultural commodities. The Millennium Ecosystem Assessment identified agricultural land expansion as the most important driver of ecosystem change, so limiting this expansion would have important ecological payoffs.

But it has been extremely difficult to improve yields from rainfall alone. If adoption rates of improved technologies are low and yield improvements do not materialize, the rain-fed cropped area required to meet rising food demand by 2050 would need to expand by 53% instead of 7%. Globally, the land for this is available. But additional natural ecosystems would have to be converted to agriculture, which would encroach on marginally suitable lands and add to environmental degradation.

There are reasons to be optimistic about water productivity gains. There is still ample scope for higher physical water productivity in low-yielding rain-fed areas and in poorly performing irrigation systems, where poverty and food insecurity prevail. Good agricultural practices—managing soil fertility and reducing land degradation—are important for increasing crop per drop. The Comprehensive Assessment reveals scope for improvements in livestock and fisheries as well, which is important because of the growing demand for meat and fish. Farmers and water managers can do these things with the right incentives.

But caution and care must be mixed with this optimism. There are misperceptions about the scope for increasing physical water productivity. Much of the potential gain in physical water productivity has already been met in high-productivity regions. There is less water wasted in irrigation than commonly thought. Irrigation water is often reused locally or downstream; farmers thirsty for water do not carelessly let it flow down the drain. A water productivity gain by one user may be a loss to another. Upstream gain may be offset by a loss in fisheries, or the gain may put more agrochemicals into the environment.

But increases in yield almost always require that more water be transformed to water vapor through ET. Most gains in water productivity can be made by increasing yields in areas of the world where yield is extremely low, roughly 1 to 2 tons per hectare. Doubling crop yield by improved soil and water management can actually triple water productivity in these areas, because plants stressed by thirst perform so poorly and because there is excess evaporation from soils.

Today's low-yielding areas can generate the biggest increases in water productivity. These are the rain-fed areas of sub-Saharan African and South Asia, where improved soil fertility combined with better water management can make big differences. Adding supplemental irrigation will be a key. A second payoff is that these are areas with a lot of rural poverty and few jobs outside agriculture. Increases in agricultural productivity can boost incomes and economic growth.

Where yields are already fairly high, say 6 tons per hectare, increasing yield by one-third typically takes about one-third more water. Still, even at these higher yields water productivity can be bettered, although improvements are more difficult to obtain.

Major gains and breakthroughs, such as those in the past from breeding and biotechnology programs, are much less likely to take place in the future. In fact, the Comprehensive Assessment concluded that although breeding had played the most significant role in water productivity gains in the past, today it is improved management that is most likely to generate more increases. Drought- and disease-resistant varieties are crucial for reducing the risks of farming, but higher yields from these crops tend to consume more water. Perhaps a breakthrough will come by breeding traits of water-efficient crops (such as maize and sugarcane) and low-transpiration crops (such as cactus and pineapple) into the more common but thirstier crops (such as wheat and barley).

Many view water pricing as the way to improve water productivity by reducing water waste in irrigation. But this has proven extremely difficult to implement because of political realities and lack of water rights. Gains are also hard to realize because of the complex web of hydrological flows. But well-crafted incentives that align society's interest in using water better with farmers' interest in profitable crops still hold promise. One such incentive: Urban users could compensate farmers for moving water originally intended for irrigation (and stored behind dams) from agriculture to cities facing rising demand.

There is more reason to be optimistic about increasing economic water productivity. Switching to crops with higher value or reducing crop production costs both lead to higher economic water productivity. Integrated approaches—agriculture/aquaculture systems, better integrating livestock into irrigated and rain-fed systems, using irrigation water for households and small industries—all are important for increasing value and jobs per drop.

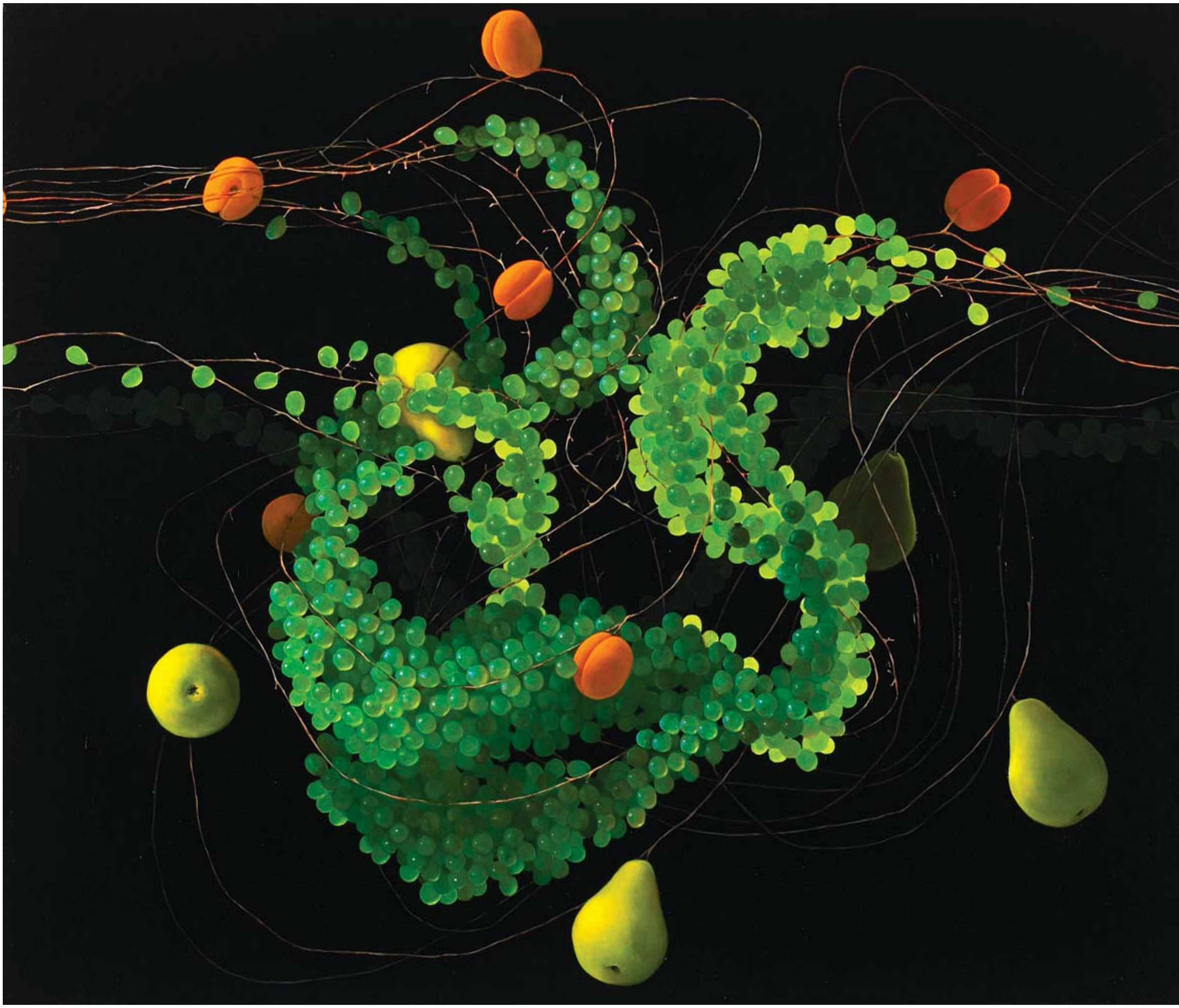
Increases in physical and economic water productivity reduce poverty in two ways. First, targeted interventions enable poor people or marginal producers to gain access to water or to use it more productively for nutrition and income generation. Second, the multiplier effects on food security, employment, and income can benefit the poor. But programs must ensure that the gains reach the poor, especially poor rural women, and are not captured by wealthier or more powerful users. Inclusive negotiations increase the chance that all voices will be heard.

Can trade avert water stress?

By importing agricultural commodities, a country "saves" the amount of water it would have required to produce those commodities domestically. Many contend that this trade in virtual water—the equivalent water it takes to grow food—could solve problems of water scarcity. Egypt, a highly water-stressed country, imported 8 million metric tons of grain from the United States in 2000. To produce this amount of grain Egypt would have needed about 8.5 cubic kilometers of irrigation water, a substantial proportion of Egypt's annual supply from Lake Nasser of 55.6 cubic kilometers.

The cereal trade has a moderating impact on the demand for irrigation water because the major grain exporters—the United States, Canada, France, Australia, and Argentina—produce grain with highly productive rainfall. A contrasting example is found in Japan, a land-scarce country and the world's biggest grain importer. Japan would require an additional 30 billion cubic meters of crop water to grow the food it imports. A strategic increase in international food trade, and thus trade in virtual water, could mitigate water scarcity and reduce environmental degradation. Instead of striving for food self-sufficiency, water-short countries would import food from water-abundant countries. But there are forces working against this trade.

Poor countries depend, to a large extent, on their national agriculture sector, and they often lack funds to buy food from the world market. At present, for example, Uganda and Ethiopia simply cannot afford to buy their food from other



MIA BROWNELL, *Still Life with Pear, Apricot and Grape III*, Oil on canvas, 30 x 36 inches, 2005.

countries, and even if they could, getting it to people through the local marketing system would be a daunting task. Struggling with food security, these countries remain wary of depending on imports to satisfy basic needs. Even countries such as India and China that could afford to import more food instead of expanding irrigation may instead embrace a politically appealing degree of national food self-sufficiency. Australia, on the other hand, is a major exporter of food and virtual water in spite of scarce water and the environmental problems arising from it.

At present, countries trade for economic or political reasons, not for water. So it is unlikely that food trade will solve water scarcity problems in the near term. But water, food, and their environmental implications should enter more firmly into discussions of trade.

Looking for more water

Where else can water gains be found? Water resources rarely enter the discussions of livestock scientists and managers, and if they do, the talk usually concerns livestock drinking water. But water needed to generate food for livestock far surpasses what animals need for drinking. Yet these are areas where significant increases could be found. Colleagues at the International Livestock Research Institute have shown that the water productivity of livestock could easily be doubled or tripled by, for example, changing the type of food fed to animals or enhancing the production of milk, meat, and eggs. Better grazing practices could help reduce the environmental impact. There are large gains to be had in aquaculture systems too, but these are rarely quantified.

In addition, policies that focus on diets could have a profound impact on water resource use. Although for many people undernourishment is a key concern and better diets an issue, the opposite is also true. Households in the developed world waste as much as 20% to 30% of their food, and therefore the water it took to produce it. In developing countries much food is wasted too, particularly in moving it from farm to market. And although overeating may not waste food, it still wastes water.

The ultimate cause of our water problems is inadequate institutions. Behind water scarcity, unequal distribution of benefits from water development, and failure to take advantage of known technologies lie policies, laws, and organizations that influence how water is managed. With rapidly growing cities, expanding agriculture, and changing societal demands, the water situation is changing rapidly in most places in the world. Yet institutions rarely adapt rapidly enough to keep pace. Reform is needed.

A prime example is the slow adoption of productivity-enhancing measures. Technologies that boost water productivity are known or could be readily developed, but the institutional environment does not support it. Risk-averse farmers are unlikely to invest in water technologies or improved management practices if there might be a dry spell that will ruin crops. In much of sub-Saharan Africa, crops could be grown, but there is no market or else no roads to take the goods to market. Farmers are asked to employ water-saving technologies that benefit cities, but rarely are there sufficient incentives and compensation for farmers to do so.

Compounding this are the hydrologic complexities brought about by the increasingly intertwined nature of water users. The development of upstream water for crops may take water away from downstream fisheries, but there is no mechanism to bring both types of agricultural producers to the table to discuss the issue. Institutions need to become much better at integrating policies across sectors and at using science to see opportunities and pitfalls when making changes.

Donor agencies and international institutions have advocated a host of panaceas—water pricing, water markets, farmer management of irrigation systems, drip irrigation—using blueprint solutions, donor funds, and leverage to hasten reforms. It is frustrating when these ideas are ignored. A major reason is that reforms are simply not right for local conditions. For example, new river basin organizations may be promoted, but they ignore or replace informal arrangements that already exist.

What is needed is a reform of this reform process, one in which solutions can be better crafted to meet local needs in the specific political and institutional context. This will require building coalitions among the partners. Civil society and the private sector are key actors. Government institutions are key, too, but often the slowest to take up reform.

Actions are required now. Here are some possibilities:

- All of us should think about the water implications of the food we eat—and waste.
- Consumers and the private sector should be prepared to pay the environmental costs of food production.
- Politicians and trade negotiators should consider the water implications of trade and energy use and pay the water costs.
- Governments should fund the development of water for food.
- City dwellers should compensate farming communities for water that is taken away from them.
- Governments should set up mechanisms for negotiating water disputes.
- Governments, civil society, and the private sector should spend time and money to empower poorer water users to compete equally with wealthier ones.

We tend to defer these choices to the next generation, which will feel the consequences of scarcer groundwater or ecosystem degradation. But we can learn from the mistakes of the past. We can provide incentives to produce more food with less water. All of us and our governments should recognize that there are limits to water, and that more and more water is not always a solution.

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