

THE RENEWABLE DEAL, ASPECT TWO

PLANK FOUR: INCREASE FRESH WATER SUPPLIES

(Revised 11 Feb 09)

Summary and Overview

There are two ways of reducing the worldwide spread of “water stress” due to the sustainable supply of fresh water falling short of agricultural, domestic, and industrial use needs:

- You can increase the capture of precipitation into underground aquifers and perennial surface stream flows through land use management practices. Best Available Management Practices for increasing precipitation capture efficiency are described in Section One of Plank Four.
- You can increase the efficiency with which waters diverted from surface streams or underground aquifers are used. According to the United Nations, currently 70 percent of all fresh water diverted on Earth for human use is consumed by agriculture, 20 percent by industrial uses, and 10 percent by domestic (“culinary”) uses. Section Two of Plank Four describes water efficiency Best Available Technology and Best Available Management Practices in these three sectors in this order: Part One: agricultural water use efficiency; Part Two: industrial water use efficiency; Part Three: culinary water use efficiency.

The Worldwide Crisis in Availability of Fresh Water

According to the National Aeronautics and Space Administration’s Goddard Center, 326 quintillion gallons of water is cycling in the Earth’s surface and atmosphere. Of this, 97 percent is salty.

Each year one hundred and ten thousand cubic kilometers of water falls as precipitation onto the earth’s land surface, on average. Fifty-six percent of this total precipitation flows through the landscape, and 36 percent of total precipitation on land ends up in the oceans. 38.8 percent of total precipitation on land is called “blue water:” this portion falling on or flowing through rivers, lakes, wetlands and groundwater is in theory available for withdrawal before it reaches the ocean or evaporates. 61.1 percent of the total precipitation on land is called “green water” because it is absorbed by soil and plants and then released back into the air through evaporation or evapotranspiration. Of the 56 percent of total precipitation that flows through the landscape, 5.1 percent is consumed by crops or livestock and represents use as “natural farm irrigation.” Of the “blue water,” 1.4 percent is diverted for farm irrigation, 0.1 percent is used by cities and industries (municipal and industrial use), and 1.3 percent evaporates from open water. Thus, only 1.5 percent of “blue water” and 5.1 percent of “green water,” or 6.7 percent of annual precipitation on the land surface of Earth, is used by people. This volume of natural precipitation would easily fulfill the water requirements of everyone on the planet if the water arrived when and where people needed it for use. It does not.

Scientists have arrived at the standard of 1,000 cubic meters per year as the minimum water each person requires for drinking, hygiene, and growing food.

According to Zurich-based Sustainable Asset Management, use of fresh water by human activities has doubled since World War II to 4,000 cubic kilometers a year as of 2008, and fresh water use is projected by the firm to increase 25 percent from 2008 to 2030. Peter Rogers, Gordon McKay Professor of Environmental Engineering and professor of city and regional planning at Harvard University, working with the Global Water Partnership, estimated that worldwide water requirements would rise from 3.350 cubic kilometers in 2000 to 4,900 km³ if income and prices remained as they were in 1998. Demand would grow almost threefold to 9,250 km³ if the incomes of the poorest nations climbed to levels equivalent to middle-income countries and governments pursued no special policies to restrict water use. Rogers' projections agree fairly well with forecasts made by the International Water Management Institute in its 2007 study *Water for Food, Water for Life*.

In 1997, the UN Commission on Sustainable Development estimated that one-third of the world's population then suffered "water stress," and that the figure would rise to two-thirds of the world population by 2025. Recent United Nations reports project as much as three quarters of the world population could face scarcity of freshwater by 2050. London-based International Alert has identified 46 countries with a total population of 2.7 billion people where water shortages and disputes create a "high risk of violent conflict" by 2025. Lester Brown points out that "Many of the countries high on the list of failing states are those where populations are outrunning their water supplies, among them Sudan, Iraq, Somalia, Chad, Afghanistan, Pakistan, and Yemen."

Water scarcity is becoming more common because of a collision of four factors: (1) the world's population is rising; (2) many people enjoy rising incomes and thus increase demand for water, largely in the form of water embedded in foods which increases as one adds more meat to the diet; (3) global climate change is exacerbating aridity and reducing freshwater supply in many regions; (4) many water sources are threatened by faulty waste disposal, releases of industrial pollutants, fertilizer runoff, and influx of saltwater into aquifers near the seacoast as groundwater is depleted from them.

As of 2007 1.1 billion people worldwide lack clean water, 2.6 billion people go without sanitation, and 1.8 million children die every year because of lack of clean drinking water or disease due to lack of sanitation, or both. The minimum budget of fresh water per day per person is 20 to 50 liters (5-13 gallons). In a report issued in November, 2006, the United Nations declared water "a global crisis," announcing that 55 member nations are failing to meet their water-related Millennium Development Goal target, agreed upon in 2000, of halving the proportion of people without clean water and sanitation by 2015. Studies have shown that providing clean water and sanitation produces tremendous benefits in terms of lowering health costs, increasing productivity, and increasing lifespan among adults of working age, thus amortizing the investment in their education. But, as Harvard's Rogers says, "The problem is [water] yields social benefits, so no one individual can afford to do it."

The burgeoning middle class in Southeast Asia, India, and China is causing an increase in per capita fresh water use as flush toilets and switch from vegetable-based to meat-heavy diets occurs. The industries which are creating the wealth in these developing nations also consume water. In the late 1990s, public spending on water and sanitation was 2 percent of GDP in most countries. By 2007, it is less than 1 percent as countries devote more resources to education, roads, and other priorities. Foreign aid for water development has stagnated at \$15 billion a year, with the World Bank calling for twice that amount.

Damage to women: A 2004 study by Consumers International found that poor rural women in developing nations spend eight hours a day collecting and carrying more than 40 pounds of water - a load that can damage spines and cause other health problems. Manual flush latrines or caring for a person with AIDS can quadruple the amount of water a woman has to carry daily. This has financial implications: in India, women spend 150 million workdays each year fetching water. If this time was spent in paid labor, it would add \$227 million to women's income nationally. The study also found that 10 percent of girls do not attend school when they're menstruating and many drop out altogether once they hit puberty because of lack of sanitation at school.

Fresh Water Crisis Exacerbation by Global Warming

Richard Seager of Columbia University's Lamont Doherty Earth Observatory's global-climate change-induced precipitation modeling predicts that more rain and snow will fall in those regions closer to the poles. Many subtropical regions closer to the equator will dry out. More of annual precipitation will fall during sporadic, intense storms and less from smaller, more frequent storms. Climate models are better at predicting temperature than precipitation. However, the higher average temperatures from global warming produce predictable results on fresh water supplies. Overall snowmelt runoff decreases and snow melt comes earlier, leaving no perennial water from high-elevation snowmelt in rivers in summer. Irrigation water demand increases because plants need to transpire more water to stay cool enough for their enzymes to function. More surface water in reservoirs is lost to evaporation.

British journalist Fred Pearce wrote *When the Rivers Run Dry*. Paleontologist Tim Flannery wrote *The Weather Makers: The History and Future Impact of Climate Change*. In an interview Flannery said, "We're just getting much less usable water than we did a decade or two or three decades ago. It's a sort of thing again that the climate models are predicting. In terms of the floods, again we see the same thing. You know, a warmer atmosphere is just a more energetic atmosphere." The world media tends to report one flood, heat wave, drought, or wildfire at a time, and report regional events only except for spectacular international disasters like the huge number of heat deaths during the European heat wave (with no accompanying information about crop losses in Europe). Nobody in the mainstream media has been connecting these events into a bigger picture that shows clearly what is happening to the global climate and fresh water supply. Blogs <RealClimate.org> and <ClimateProgress.org> keep up with drought news, and the National Oceanic and Atmospheric Administration has set up a new website to encourage drought coverage <www.drought.noaa.gov> and also presents its collection of paleo-drought

data at <www.ncdc.noaa.gov/paleo/drought/drght_home.html>. A new organization of journalists, “Circle of Blue,” plan to concentrate on world water issues.

Pat Mulroy, head of the Southern Nevada Water Authority, observes: “We have an exploding human population, and we have a shrinking clean-water supply. Those are on colliding paths.”

Aurora, Colorado water manager Peter Binney observes that our desert civilization model cannot last under these circumstances. “We’ve decoupled land use from water use. Water is the limiting resource in the West. I think we need to match them back together again.” Binney thinks we may have already exceeded the water “carrying capacity” of the Western United States. He predicts we will soon be talking about our “water footprint” as we now talk about our carbon footprint.

The World Is Drying Up: Vignettes Across the Globe:

Africa: Some call the violence in Darfur, sparked in part by drought-induced stress and famine, the first climate-change war.

Australia: Australia’s breadbasket, the Murray-Darling river basin, which has provided 40 percent of Australia’s agricultural production, is in the grip of a six-year drought. In 2007, all irrigation of farms in the basin was suspended. The drought is attributed to the change in the El Niño-La Niña current cycle in the south Pacific ocean due to global warming, which has increased air temperatures over Australia so that water in the atmosphere is unable to condense as often into rain.

“Over the last decade, 15-20% decreases in precipitation have been recorded. These water losses have been accompanied by record temperatures and increasing wildfires in areas where populations have been growing rapidly. A fierce drought has settled in - of the hundred-year variety. Lawns can be watered but just for a few hours a day (and only by bucket); four-minute showers are the max allowed. Car washes are gone, though you can clean absolutely essential car windows and mirrors by hand.” -Australian news item on the “Big Dry”

China: Adventure capitalist Jim Rogers was asked, “What’s the biggest domestic risk to China’s expansion?” His answer: “It’s their water problem. In all of northern China, there are shortages of water developing.” Industrialization in China is projected to cause a fivefold increase in water use by 2030.

Europe: Much of southern Europe suffered record temperatures, exceptionally low precipitation approaching or exceeding 50 percent of normal, failing farm crops, and spreading wildfires. After its 100-year record heat wave, Greece lost 10 percent of its forests to wildfire. Moldova, Albania, Croatia, Bulgaria and Macedonia are all suffering in this drought.

India: As oceans store more heat, the temperature difference between water and land dissipates, sapping power from rainmaking monsoons. Melting of glaciers in the Himalayan

highlands are projected to render the Ganges and Indus Rivers go dry except from runoff during the monsoon rainy season by 2100.

Mexico: In the Tehuacán Valley where corn was first domesticated, there has not been a good rain since 2003 and subsistence farming is now not possible. Mike Davis wrote: “Abandoned ranchitos and near-ghost towns throughout Coahuila, Chihuahua and Sonora testify to the relentless succession of dry years - beginning in the 1980s but assuming truly catastrophic intensity in the late 1990s - that has pushed hundreds of thousands of poor rural people toward the sweatshops of Ciudad Juárez and the barrios of Los Angeles.”

Turkey: “Water rationing has hit the capital. Car washing and lawn watering are prohibited within city limits. Harvests in the region have dropped by 15-30%. By the end of summer, local reservoirs and dams were holding 5% of their capacity.” -Ankara, Turkey newspaper

United States: U.S. citizens lead the world in consuming 400-600 liters per day, or as much as 158 gallons per capita.

Steven Chu, Nobel laureate, director of the Lawrence Berkeley National Laboratory, and now Secretary of the Department of Energy under the Obama administration, says that diminished supplies of fresh water might prove a far more serious problem to human civilization than rising seas due to global warming. Chu notes that the most optimistic models for the second half of this century suggest that 30 to 70 percent of the snowpack on the Sierra Nevada range which supplies irrigation water to California agriculture will disappear. “There’s a two-thirds chance there will be a disaster,” Chu says, “and that’s in the best scenario.”

In June, 2007, Bradley Udall, director of the Western Water Assessment Bureau in the National Oceanographic and Atmospheric Administration, appeared before a Senate subcommittee assessing the nation’s fresh water problems in an era of global warming. (Udall’s great-great-grandfather, John D. Lee, founded Lee’s Ferry on the Colorado River.) Pointing to increasing demands, warmer temperatures, the prospect of recurrent droughts, and diminishing snowpack, and the fact that the driest states in the United States have become some of our fastest-growing, Udall said, “As we move forward, all water-management actions based on ‘normal’ as defined in the 20th century will increasingly turn out to be bad bets.”

According to the National Climate Data Center, 43 percent of the contiguous U.S. was in “moderate to extreme drought” as of 2007. Twenty-six percent of the Southeast is rated as being in “exceptional drought” by the U.S. Weather Service, and 78 percent is “drought-affected.” 2006-2007 was the driest year on record for North Carolina and Tennessee, and Georgia’s drought broke every historical record for soil moisture, river flow, or inches of rain. Although the water wars in the Southeastern U.S. between Atlanta, Georgia, and Florida and Alabama over diminishing river flows and empty reservoirs has been prominent in the news, in fact it is Los Angeles, San Diego, Oxnard, and Riverside California that top the national drought ratings in 2007; in 2007 Pasadena had its driest year since records have been kept. The Southwest is

considered to be in the grip of a “mega-drought” which the United States Geologic Service paleo-precipitation research shows to be the worst in at least 1,400 years. The upper Midwest is short of rain, with water levels in the Great Lakes dropping to new lows.

The Colorado River Basin Compact v. Reality

In 2007 the seven western states agreed to a modification of the Colorado River Compact that divides the river basin’s flow up among the states. The agreement swapped the historic use-it-or-lose-it system for a more flexible, market-style approach. It lets downriver (“lower basin”) states create liquid bank accounts, allowing them to save up surplus water in wetter years in reservoirs, and then use these reserves in dry years. The agreement permits lower basin states to pay for other states to conserve water in order to bolster the supply available to the state. This agreement is an improvement over the preceding status quo, but it fails to address two major problems with the Colorado River Compact: it is based on a basin flow that was extraordinarily above average under historic climate and precipitation regimes, and this basin flow is dropping due to precipitation and evapotranspiration changes due to global climate change.

Over the past centuries there are clumps of a few years in which rainfall is extraordinarily heavy. These are called “**pluvials.**” The largest pluvial since 1000 AD occurred in 1911-1917. The Colorado River Compact flow allocation was based on this pluvial, during which the average precipitation in the Colorado River watershed was 12.22 inches per annum above average.

The Bureau of Reclamation bases their dam spillway maximum flow-handling capacity on the largest flood in historic times, which occurred at 125,000 cubic feet a second (cfs) on July 4, 1884. Studies done since found evidence of two floods of 371,000 cfs within the past 2100 years. The 500-year flood on the Colorado during the last 2000 years is 300,000 cfs.

The National Atmospheric and Oceanographic Administration’s report to Congress says that 75 percent of all climate modeling agrees that Colorado River basin runoff will decline between 10 to 30 percent through 2060, largely due to less annual precipitation falling as snow, with snowpack diminishing in extent and melting earlier. Overall annual precipitation is not predicted to change to a large degree in these models. If runoff in the Colorado is 10 percent below normal through 2060, then Powell Reservoir ends up 150 feet below full and stays there through 2025. During the ongoing drought, the flow of the Colorado at Lee’s Ferry were the lowest since measurement began 85 years ago. The latest research into long-term patterns of precipitation in the Colorado River basin identified the existence of an epochal Southwestern megadrought [May 2007 *Geophysical Research Letters*]. Drought cycles of over 60 years of below-average precipitation have recurred, and a couple of these were apparently responsible for driving the Anasazi Indians out of the Four Corners region.

The report states that limited Colorado River water supplies, increasing demands, warmer temperatures and the prospect of recurrent droughts “point to a future in which the potential for conflict” among those who use the river will be ever-present. The driest Western states are among the fastest-growing in the U.S. California’s Department of Finance predicted that there

will be 60 million Californians by midcentury, up from 36 million in 2007. Colorado projects a population of 8 million by mid-century, up from 5 million in 2007. A study by Martin Hoerling and Jon Eischeid found that the western region is already past “peak water,” meaning that the Colorado River’s supply will now trend downward for the predictable future.

According to Peter Binney, water manager for Aurora, Colorado, cities in the Denver area which use only groundwater will exhaust their aquifers by 2050. Aurora is looking at recycling its treated wastewater as culinary supplies “to extinction” by pulling water from the South Platte, returning effluent to the Platte, and then extracting the same water again. Referring to Richard Seager’s research at the Lamont Doherty Earth Observatory at Columbia University on future precipitation trends in response to global warming, Binney remarked that the future predicted by Seager has already set in. “You can’t call it drought anymore, because it’s going over to a drier climate. No one says the Sahara is in drought.” Las Vegas is examining a scheme through which Nevada would pay for building a nuclear desalinization plant in California to supply potable water to California and Mexico in return for being able to use Colorado River water from Lake Mead.

Roger Pulwarty, a climatologist with the National Oceanographic Atmospheric Administration, observes that “You don’t need to know all the numbers of the future exactly. You just need to know that we’re drying. It’s irrelevant. Because in the long run, that decrease, accumulated over time, is going to dry out the system.” Pulwarty stated that 20 years of average flow on the Colorado River would be required to refill Lake Powell, and “Even in normal conditions we don’t get 20 years of average flow.”

In *Nation*, Mike Davis ponders whether the prolonged drought in the southwest U.S. will turn out to be “on the scale of the medieval catastrophes that contributed to the notorious collapse of the complex Anasazi societies at Chaco Canyon and Mesa Verde during the twelfth century?”

Colorado River Open Source Simulator (CROSS): Living Rivers developed this simulation tool using the same techniques as the Bureau of Reclamation’s forecasters. It allows members of the public to explore a more complete range of scenarios for what nature may have in store for Colorado River water users. CROSS reportedly validates well against Reclamation’s far more sophisticated and expensive model.

Niklas Christensen developed CROSS; previously he did a study funded by the Department of Energy which predicted 10 percent reduction in Colorado River flows by the end of the century. Martin Hoerling from the National Oceanic and Atmospheric Administration predicts the change will be quicker and larger, resulting in 40 percent reduction in Colorado flows by mid-21st-century. CROSS runs show that a reduction of precipitation capture in the basin of 20 percent by 2100 - the middle between Christensen and Hoerling’s models - leave Lake Mead never filling to full again and possibly being empty for good by 2050. If flows continue at the rate seen so far this century, CROSS shows Lake Powell and Lake Mead becoming operationally empty within the next five years. CROSS requires the use of Microsoft Excel installed on a Windows operating system. <www.onthecolorado.org/cross.cfm>.

The Bureau of Reclamation's forecasting is based on a Colorado River flow of 15.0 million acre feet per year, the recorded average streamflow from 1900-2005. These streamflows are recognized to be the wettest in 1,200 years. Current estimates of Colorado annual flow in the future run from 13.0 to 14.7 million acre feet per annum. Using 15.0 maf, Reclamation's shortage assumptions and planning have Lake Mead holding steady throughout 2008-2060. CROSS illustrates how at 14.0 maf, Reclamation's new shortage allocation policy will be taxed, requiring consultation with the Secretary of Interior to determine who gets what water and when. At 13.0 maf, the new system collapses altogether; Lake Mead becomes operationally empty by 2020, and rises for only brief periods through the rest of the century.

The trade in "virtual water"

The water used to grow food is embedded in the food. For example, each kilogram of grain represents one ton of water. If that food is shipped for consumption in an arid area, it relieves demand for irrigation water to grow the same food in the receiving area. Thus, trade in food is trade in "virtual water." The magnitude of annual global trade as of 2008 in virtual water exceeds 800 billion m³ of water a year. Truly free farm trade by eliminating tariff and other restrictions could increase that trade delivery of virtual water to 1.7 trillion m³, according to Peter Rogers.

Privatizing Fresh Water: The "New Petroleum"

The worldwide rush by investors to privatize fresh water source, storage and distribution into a profitable commodity is described in many articles under the rubric that "water is the new oil" - see 30 May 08 *Christian Science Monitor*. According to the 2007 *Global Investment Report*, the global water market was \$500 billion and growing fast; the global water market assessment included drinking water systems, agricultural irrigation water systems, and contaminated water recovery for re-use systems such as wastewater treatment plants. According to the National Association of Water Companies, 16 percent of U.S. water systems are currently privately owned by for-profit entities.

June 26 Bloomberg News (Saijel Kishan and Madelene Pearson): Jean-Marie Messier lost billions of euros turning the world's biggest water company into entertainment conglomerate Vivendi Universal SA. He should have stuck with water. The lack of usable water worldwide has made it more valuable than oil. The Bloomberg World Water Index of 11 utilities returned 35 percent annually since 2003, compared with 29 percent for oil and gas stocks and 10 percent for the S&P 500 index. From hedge fund manager Boone Pickens to buyout specialist Guy Hands, the world's biggest investors are choosing water as the commodity that may appreciate the most in the next several decades."

Many public water systems around the world have been turned over to private water companies on the theory that private operators could marshal the capital needed to replace aging infrastructure and that private enterprise is always, as a matter of free-marketeer ideology, more efficient at managing anything than government, and so should lower overhead costs and thus

water use rates to customers. For the most part, these privatization experiments have been a dismal failure. There have been riots abroad and political turmoil in the U.S. when water rates went up radically without corresponding service or investment improvements under private operators. Many privatized public drinking water systems have been returned to government ownership and operation.

Religious and secular ethical systems generally view access to adequate food and fresh water as basic human rights. Certainly, there can be no enjoyment of human rights or the dignity of the human person in the absence of adequate food and water to sustain life, health, and sufficient vigor so that the person can “pursue happiness.” In *Blue Covenant*, Manda Barlow documents the fledgling worldwide “water justice” movement that asserts this ethical position.

The investment needed in the world water infrastructure

Booz Allen Hamilton has estimated that to provide water needed for all users through 2030, the world will need to invest as much as \$1 trillion a year on applying existing technologies for conserving water, maintaining and replacing infrastructure, and constructing sanitation systems. This sum is about 1.5 percent of world gross national product, or about \$120 per capita.

Water investment needs 2005-2030 by area of the world are:

9.0 trillion	Asia/Oceania
5.0 trillion	South/Latin America
4.5 trillion	Europe
3.6 trillion	U.S./Canada
0.2 trillion	Africa
0.2 trillion	Middle East

“Maintenance of the water infrastructure is crucial to prevent deterioration, leaks and outright breaches. At the same time, growing populations and those becoming more affluent need new, efficient water-delivery systems. To help conserve freshwater supplies, developed nations and some less developed ones will have to spend trillions of dollar on maintaining and creating efficient infrastructures during the next quarter of a century.”

Exploiting Advanced Desalination Technology

During reverse osmosis, salty water flows into the first of two chambers that are separated by a semipermeable membrane through which water molecules can pass but larger molecules cannot pass. The second chamber contains freshwater. When a substantial amount of pressure is applied to the salt water side, water molecules are forced through the membrane to the freshwater side. Although considerable energy is required to produce the pressure on the salt water side, membrane reverse-osmosis is the most energy-efficient desalination technology yet developed.

Engineers have already achieved cost savings by implementing a variety of upgrades to

membrane reverse-osmosis technology, such as better membranes that require less pressure to operate, and system modularization which makes construction easier and cheaper.

Scientists are now working on reverse-osmosis filters composed of carbon nanotubes that offer better separation efficiencies and the potential of lowering desalination costs by an addition 30 percent. This technology has been demonstrated in prototypes and is being engineered for commercial use.

SECTION ONE

Increasing the Efficiency of Precipitation Capture in Watersheds

SECTION TWO

Part 1: Increase Agricultural Water Use Efficiency

The International Water Management Institute's 2007 *Water for Food, Water for Life* report estimates that meeting world food requirements by 2050 without any technological improvements to irrigated agriculture methods will require an increase in irrigation water use from the current 2,700 km³ to 4,000 km³. A ten percent increase in irrigation efficiency could be achieved worldwide by stopping up leaks in the irrigation-water-delivery infrastructure and by implementing low-mass storage of irrigation water to limit evaporation losses. Additional increases in irrigation efficiency can be achieved by using more efficient ways of delivering irrigation water to the crop.

The most efficient way to use water in agriculture is to not irrigate in the first place. Dryland farming is the technique which has been utilized in areas where annual precipitation is 20 inches or less. In California, early Spanish and Italian pioneers brought dryland farming techniques with them to grow wine grapes. Successful dryland farming involves cultivating the soil to maximize its retention of water from natural rainfall - the organic agricultural techniques described below accomplish this most effectively. In California, overall yields in wine grapes and vegetables with dry farming are slightly less than with irrigation, but dry-farmed produce has noticeably richer tastes and better quality.

Irrigation techniques, in order of increased efficiency, are flood irrigation, sprinkler irrigation, surface drip irrigation systems, and buried drip irrigation systems. Putting compost or mulch on the surface has been shown to increase irrigation efficiency by between 25 percent and 40 percent in avocado orchards by reducing evaporation and creating a moisture layer in the vadose zone. On average, the highest-efficiency drip irrigation system will produce the same crop yield with 40 percent of the water applied through a flood irrigation system. Surface application of compost both feeds the crop with slow-release nutrients and increases irrigation efficiency, but there is insufficient data on the additional efficiency gained by combining compost mulching with high-efficiency drip irrigation to support a summary statement.

Surface water projects consist of dams that deliver water to farmers through a network of canals. Irrigation efficiency of surface water projects is limited because some of the diverted surface water evaporates before it reaches the crop, some percolates into the ground - particularly from unlined canals, and some irrigation water applied to the crop field runs off. Water policy analysts Sandra Postel and Amy Vickers of the Earth Policy Institute found that “surface water irrigation efficiency ranges between 25 and 40 percent in India, Mexico, Pakistan, the Phillipines, and Thailand; between 40 and 45 percent in Malaysia and Morocco; and between 50 and 60 percent in Israel, Japan, and Taiwan.” The latter three countries make extensive use of high-efficiency mini-sprinkler and drip irrigation technology. In 2004, China’s Minister of Water Resources Wang Shucheng outlined plans to raise China’s overall irrigation efficiency from 43 percent in 2000 to 55 percent in 2030.

Switching from a flood or furrow irrigation system to a low-pressure sprinkler irrigation system reduces irrigation water use by about 30 percent. A surface drip irrigation system without mulch uses about 50 percent of the irrigation water that a flood or furrow system does to achieve the same crop yield.

Drip irrigation systems are labor intensive and water efficient, so they are particularly well suited to countries with plentiful labor and a shortage of irrigation water. Cyprus, Israel and Jordan rely heavily on drip irrigation. Drip irrigation is used on about 3 percent of irrigated land in India and China and roughly 4 percent in the United States. For smallholders with family labor, small-scale drip-irrigation systems have been developed that dramatically raise yields and profitability, paying for themselves in one year. The simplest system is in essence a bucket that feeds flexible plastic tubing by gravity, irrigating roughly 100 plants in 25 square meters. Larger drum-fed systems irrigate 125 square meters. New drip systems have been developed for large-scale applications using plastic lines that are easily moved.

Institutional shifts in irrigation management: Experience in several nations demonstrates that shifting responsibility for managing irrigation systems from distant government agencies to local water users associations results in more efficient use of irrigation water. The farmers in the local water user associations have an economic stake in good water management as well as immediate apprehension of local conditions.

As of 2002, farmers associations managed more than 80 percent of Mexico’s publically irrigated land. The cost of maintaining the irrigation system has been assumed locally by the farmers associations, reducing the drain on the federal treasury. The production gains from local management of irrigation water supplies has exceeded the additional costs the associations have to charge for irrigation water to cover system maintenance costs.

In Tunisia, water users associations manage both irrigation and residential water systems. The number of associations has increased from 340 in 1987 to 2,575 in 1999. The associations not only manage publically developed irrigation systems, but also monitor groundwater use in order to stabilize water tables and thus avoid the disruption resulting from aquifer depletion.

The effects of organic agricultural techniques on water quality and efficiency:

Farmers who rely on chemical fertilizers often apply the nitrogen for the crop weeks or months before the crop actually needs it. The capacity of the soil to absorb and retain nitrogen which is delivered in one large dose is limited. Since nitrogen is water soluble, as moisture passes through the root (vadose) zone into groundwater free nitrogen which has not been bound by soil micro-organisms or absorbed by plants is carried with it. This is the source of fugitive nitrogen which then turns up as nitrates in groundwater and in surface waters where it promotes algal blooms that deplete oxygen, resulting in giant anerobic “dead zones” in lakes and the oceans at river deltas.

Organic farming techniques build quality soils, mainly by increasing organic matter which in turn feeds a bloom of useful soil biota. Organic matter is the chief measure of soil quality, or “tilth.” It is also the measure of soil carbon. As organic material/soil carbon levels increase in the soil, the soil’s moisture holding capacity increases. As water is held in the capillaries of organic soil by bacteria and in the “sponge” of organic material, more of the water applied to the soil by rainfall or irrigation remains in the vadose zone available to plants instead of percolating through the vadose zone into ground water.

Increasing soil organic matter also increases the moisture infiltration rate. Water applied to the surface of the soil by precipitation or irrigation penetrates the surface faster, so less of the applied water runs off. The more water than is absorbed, the less run-off to cause erosion and a loss of top soil, lowering the amount of silt and sediment in rivers and streams.

Thus, organic farming techniques which build soil organic matter result in far more efficient capture and use of both water and soil nutrients by crops. Organic matter and the soil biota it feeds hold water and nutrients efficiently in the root zone for plants to use. USDA research and numerous university studies have shown “compost amended soil” retains moisture better and reduces irrigation demands.

Sustainable rainwater harvesting systems:

<www.indiatogether.org/agriculture/articles/rjndrght.htm> describes a system in India in which rainwater harvesting has created an oasis with year-around water for culinary and agricultural use.

Farm land management approaches such as creating levies, berms, swales and ditches all effectively capture rainwater for local recharge of the soil water column.

High-efficiency agricultural irrigation systems:

Sprinkler systems are x times more efficient in water delivery to crop per acre than flood irrigation systems are. Drip irrigation systems, invented by an Israeli engineer in the 1950's, are x times more efficient than flood or furrow irrigation.

Adranga Ranch, California: This organically-certified walnut orchard placed soil moisture monitors at 18, 36 and 60 inch depths, resulting in a large reduction in total irrigation water use through the hard line underground pipe delivery system in the orchard. The monitors enable the operator to maintain ideal soil moisture levels. The lack of excess water prevents leaching of nutrients from the soil. The monitors also allow the operator to detect pipe leaks. The hard line underground pipe system replaced an above-ground, gated pipe flood irrigation system. The underground pipe system feeds 615 sprinklers which can water the 24 acres of walnut trees in one day. A dwarf grass cover crop underneath the walnut trees retains moisture in the soil, as well as providing a cushion when nuts are harvested.

Negev Desert, Israel: A 150-acre tomato and pepper-growing farm in the Negev Desert of Israel grows plants in greenhouses with elaborate trellises. Treated sewage water is pumped through drip irrigation lines covered tightly with black plastic to prevent evaporation. A pumping station outside each greenhouse is equipped with a computer that tracks how much water and fertilizer is used. These computers are monitored on a laptop computer in the farm manager's office.

The Israeli government strictly regulates how much water farmers can use and requires many of them to irrigate with treated sewage effluent, which is pumped to farms from the treatment plants in purple pipes. The Israeli government is building a desalinization plant to provide additional irrigation water. Shalom Simhon, Israel's agriculture minister, says "In the future, another 200 million cubic meters of marginal water are to be recycled, in addition to promoting the establishment of desalinization plants." Four years of drought 2004-2008 have created what Mr. Simhon calls a "deep water crisis," forcing the country to cut farmer's quotas of irrigation water.

Part Two: Increase Industrial Water Use Efficiency

Part Three: Increase Culinary Water Use Efficiency

Principle One: Use treated, high-quality culinary water indoors, not outdoors.

Principle Two: Stop using treated, high-quality culinary water to move wastes.

Principle Three: Use "gray water" and collected rainwater for outside irrigation.

Principle Four: Reclaim and recycle residential and industrial "black water" for re-use.

Principle Five: Improve maintenance of and thus lower losses from water delivery systems.

All five of these principles are served by appropriate water pricing. Peter Rogers writes:

"In the past the cost of freshwater in the U.S. and other economic powers has been too low to encourage users to save water: as often happens when people exploit a natural resource, few worry about waste if a commodity is so cheap that it seems almost free.

...Higher water prices can...spur the adoption of measures such as the systematic reuse of used water (so-called gray water) for nonpotable applications. It can also encourage water agencies to build recycling and reclamation systems.

Raising prices can in addition convince municipalities and others to reduce water losses by improving maintenance of water-delivery systems. One of the major consequences of pricing water too low is that insufficient funds are generated for future development and preventive upkeep. In 2002 the U.S. Government Accountability Office reported that many domestic water utilities defer infrastructure maintenance so that they can remain within their limited operating budgets....The cost of repairing and modernizing the water infrastructure of the U.S. and Canada to reduce losses and ensure continued operation will be high, however. The consulting firm Booz Allen Hamilton has projected that the two countries will need to spend \$3.6 trillion combined on their water systems over the next 25 years.”

Principle One: Use treated, high-quality culinary water indoors, not outdoors

Principle One, Part One: Utilities use untreated “secondary water” systems to supply water for outdoor irrigation use:

In a secondary water system, a water utility places untreated water of less than 2,000 microSiemens per centimeter conductance in a storage and distribution system which supplies customers with water for outside use. The water is sometimes diverted from surface flows and stored in an irrigation reservoir, then gravity-fed to the customers. Some systems use open ditches for part or all of the landscape watering distribution system, others use pressurized pipes. Some systems pump irrigation wells to supply the secondary system water, with or without a storage reservoir or tank being involved in the system. Some systems meter the secondary water, but most have not in the past due to the meters then available clogging on particles and debris in untreated water coming from a storage reservoir filled by surface water diversion. Recently, new water meters that measure venturi waveforms induced by water flowing through an open measurement gap in the meter body have been developed which are accurate to 1/100th a gallon and do not clog or require any maintenance.

The Spanish Valley secondary water system being installed by the Grand Water and Sewer Service Agency (GW&SSA) in Grand County, Utah, in 2008, puts water under gravity pressure through a closed pipeline system fed by Ken’s Lake irrigation reservoir, into which some Mill Creek and Pack Creek surface flows are diverted. For developments with a culinary and secondary water system installed, the GW&SSA provides water through two separate water pipelines into two separate meter pits. The culinary and secondary water meters are read separately and a lower rate per thousand gallons of irrigation water is charged than for culinary.

Principle Two: Stop using treated, high-quality culinary water to move wastes

The use of water through flush toilets to move human waste takes nutrients originating in the soil

and typically ends up dumping them either into a body of water, or if treated in a modern wastewater treatment facility, into a landfill in the form of the solids extracted from the wastewater. This outdated “flush and forget” system is outdated, expensive, disrupts the nutrient cycle, and can be a major source of disease.

The Centre for Science and the Environment in India calculates that an Indian family of five, producing 250 liters of excrement a year and using a flush toilet, contaminates 150,000 liters of water with its wastes. As currently designed, India’s sewer system is actually a pathogen-dispersal system. In the United States, our sewer systems are turning out to be drug residue dispersal systems.

The low cost alternative is the composting toilet. This is a simple, waterless toilet linked to a composting chamber. Dry composting turns human fecal material into a humus scarcely 10 percent of the original volume. Table waste can be incorporated into the compost chamber. The composting chamber needs to be emptied every year or so, depending on size, design, and number of people using it. In nations using large numbers of these composting toilets, vendors typically collect the humus and market it as a soil supplement, insuring the organic nutrients in the waste return to the soil nutrient cycle as the natural fertilizer they are.

In *Plan B 3.0*, Lester Brown writes:

The U.S. Environmental Protection Agency now lists several brands of dry compost toilets as approved for use. Pioneered in Sweden, these toilets work well under the widely varying conditions in which they are now used, including Swedish apartment buildings, U.S. private residences, and Chinese villages.

Interest in ecological sanitation, or ecosan, as it is commonly referred to, is spiraling upwards as water shortages intensify. Since 2005, international ecosan conferences have been held in several countries, including India, South Africa, Syria, Mexico, and China. The movement, led by the Swedish International Development Agency, can now point to projects in at least a dozen countries. Although ecosan is not yet mainstream, it is fast becoming so.

The first large community to be built with dry compost toilets in every residence is on the outskirts of Dongsheng in Nei Monggol (Inner Mongolia). Designed to house 7,000 people, the town is scheduled for completion by the end of 2007. In this system, urine, which contains 80 percent of the nutrients leaving the human body, is diverted into designated container. It is then collected and recycled directly onto the land as a fertilizer supplement. Both human solid waste and kitchen waste are composted into a rich humus, sanitized, and used as an organic fertilizer. For many of the 2.6 billion people who lack sanitation facilities, composting toilets may be the answer.

China has emerged as the world leader in this field, with some 100,000 urine-diverting, dry compost toilets now in use. Among the other countries with these toilets in the demonstration stage or beyond are India, Uganda, South Africa, Mexico, Bolivia, and

seven countries in West Africa. Once a toilet is separated from the water use system, recycling household water becomes a much simpler process.

Principle Three: Use “gray water” and collected rainwater for outside irrigation

Principle Three, Part One: Gray water collection and use systems:

Principle Three, Part Two: Rain water collection and use systems: Rain water collection and storage systems have been in use for centuries throughout the world. In these, water that falls on hardened surfaces such as the roofs of houses is collected in gutters or channels at lower drainage edge of these surfaces. The captured precipitation water is usually directed to storage containers such as barrels or cisterns, from which it is taken as needed for use. Uses of stored rainwater include watering house and garden plants, and use as washwater for laundry or other cleaning tasks.

In the desert southwest, the ancestral pueblo Indians, the Anasazi, built low retaining dam structures across low-pitch areas with soil to capture precipitation runoff in shallow pools. This captures runoff into the soil water column where food crops can be planted, as well as preventing erosion of desert soils. Two thousand years later, *Organic Gardening* magazine runs articles advising homeowners how to build swales and channels in one’s yard to capture precipitation runoff into the soil water column, direct runoff into densely landscaped areas, and prevent water standing where it can cause inconvenience or drown the roots of particular landscaping plants.

The problem of U.S. western water laws: Water laws in some western states interfere with installation of rainwater collection and use systems by individual homeowners in the state. For example, in the Colorado State constitution, all water arriving in the state is allocated to “senior water right holders” to diversion of surface waters in each state watershed. Thus, a homeowner who captures runoff from snowmelt or rainfall from the roofs of his buildings or other property surfaces is illegally diverting surface water that already belongs to a senior water rights holder downstream in the watershed. Since 2007, some western state legislatures have considered legislation to amend their laws to allow private citizens to legally capture and use precipitation which falls on their residential improvements located on residentially-zoned parcels of record. In practice, since no permit is required to install a precipitation capture system on the buildings on one’s residential property, citizens install such systems in ignorance or contempt of the state’s water law, and the state remains blissfully unaware of these installations.

Examples of household rain water collection and use systems:

Tesuque, NM, system designed by a Santa Fe firm, Design With Nature, Donna Bone, landscape architect. Fourteen inches per year average precipitation falling on the house is funneled through canales into pipes that take the runoff water into a 35,000-gallon concrete cistern. From the cistern, rainwater is pumped directly to the root zones of the landscaping plants via a drip irrigation system.

Principle Four: Reclaim and recycle residential and industrial “black water” for re-use

Wastewater treatment: Best Available Technology: Louis Moureas invented the septic tank in 1860, but it was not named until 1895. The septic tank is equivalent to a clarifier tank unit in a 1950's sewage treatment plant. Bacterial action in the low-oxygen environment of the tank causes solids to settle to the bottom. Dissolved nutrients flow into the leach field where a biofilm grows around the soil particles outside the discharge holes, digesting most of the dissolved nutrients from the septic tank effluent discharge. In 1868 the trickling filter for wastewater treatment was developed by Edward Frankland. The trickling filter sprinkles water over a complex surface medium like rocks on which the fixed biofilm which consumes dissolved wastes from the wastewater grow. Because of contact with air, the water flow has a high oxygen content so the digesting bacteria are largely aerobic. The first trickling filter wastewater treatment unit was installed in the U.S. in 1901. The standard clarifier-and-trickling-filter type wastewater treatment plant which was the U.S. standard in the 1950s doesn't de-nitrify well, produces a “30/30” effluent (Biological Oxygen Demand or BOD = 30 and Total Suspended Solids or TSS = 30) discharge, and develops anoxic pockets of bacteria that produce ammonia and other odor compounds.

After fixed film trickling filters, two other types of film-based treatment technologies were developed. Integrated Fixed Film Activated Sludge units have a media for the biofilm to grow on which can be floating, hanging, or supported in the wastewater tank. Such units have to have a screen to keep the media in the sludge basin. Introduced air from coarse bubble diffusers in the bottom plus the complex-surface media doubles the treatment capacity of the sludge chamber over a fixed film unit. A typical unit shown had sponge balls filling half the sludge chamber; the balls bounced around in the air stream, producing a constant movement of the wastewater over the biofilm on the media in an aerobic environment.

The other type of film-based treatment technology uses fixed media mounted in frames - membranes or ropes. These frames are suspended in the sludge tank, and are aerated with fine bubble diffusers in the bottom. The frames can be removed to clean or repair the media. Fixed media treatment units can be colonized by redworms; you lower the oxygen to get rid of them.

New technologies of wastewater treatment have been developed in response to four wastewater treatment criteria: (1) lower BOD and TSS in effluent being required by changing regulations and the increasing fresh water shortage motivating re-use of wastewater treatment plant effluent directly into secondary water systems and the like. (2) ease of operation, thus lowering labor costs. (3) operational cost reduction per 1,000 gallons treated. (4) wastewater treatment facilities having limited areas for treatment plant footprints, and sited in inhabited areas with neighbors sensitive to odors. On 26 Feb 08 engineer Brad Rasmussen discussed four emerging technologies in wastewater treatment at the Utah Rural Water Conference.

1. **STM Aerotors:** is a type of fixed film activated sludge treatment which has a small footprint and a lower power requirement than the integrated fixed film and fixed media types of

fixed film treatment units. Invented by a fish farmer in 1964, the first wastewater treatment plant application was in 1973 and there are now over 1,000 installed worldwide. Rasmussen showed examples of units installed to increase the capacity of existing 1950s clarifier-and-trickling-filter wastewater treatment plants without expanding their footprints.

The Aerotor is a huge wheel mounted on a shaft with a cog wheel on one end over which a chain from an electric motor turns the wheel. The wheel is 80 percent submerged in a clarifier or sludge tank. Between its stainless steel cage sides, the wheel has two ranks of cylinders with a slot in them, which is the opening to a spiral interior in each disk of which the cylinders are composed. As the motor turns the wheel, the cylinders that rise from the tank full of “mixed liquor” wastewater from the tank pour out their contents in exchange for air, which is then carried under the surface as they sink. During the turn under the surface, the air bubbles out, aerating the tank, and is replaced by more mixed liquor. The bacterial biofilms are on the surfaces of the interior of the disks in the cylinders. This produces much faster sludge settling than is achieved with an oxidation ditch, and lowers the load on a following clarifier unit. The rotation motor uses much less power than the compressors that provide coarse or fine bubble diffusion in the other fixed film activated sludge treatment techniques, but produces equivalent aeration of the mixed liquor in the sludge tank. An installed Aerotor in a Price trickling filter plant built in 1954 takes wastewater with 200 milligrams/liter of both BOD and TSS coming in, and discharges 15 BOD/10 TSS mg/l effluent. The 4 million gallon per day unit achieves this with two 80x20x15 foot Aerotor tanks. The facility has four 60 horsepower centrifugal blowers for aeration other than the Aerotor. A trickling filter plant in Payson was converted, replacing the trickling filters with 8 STM Aerotor wheels in a basin. This did as well in lowering BOD, TSS, and nitrates as a covered/heated trickling filter control. The control used 47 horsepower in the summer and 94 per million gallons treated in the winter versus 39 horsepower year-around by the 8 Aerotors.

Spanish Fork has a 4 MGD STM Aerotor assembly, using them as roughing filters on the front end of the treatment train. The rule of thumb is that the largest feasible STM Aerotor tank will process 2 MGD. For larger capacities, do tank increments of 2 MGD in parallel. The smallest feasible STM Aerotor is 10,000 gpd. They are cost-effective over 15,000 gpd plant capacity. The only weak link (pun intended) is the chain drive. The chains last at most 18 months before having to be replaced. Otherwise they are maintenance-free and work indefinitely as long as you keep the biofilms wet by running them.

2. **Membrane BioReactors:** work with a wastewater train starting with a 3 mm screen followed by reactor basins, the last of which has membranes in it which separate water from wastes. The facility we toured in Payson had a screen followed by a de-gritting low-speed centrifuge, then an anoxic tank for de-nitrification, followed by a mixed liquor tank into which air was bubbled by diffusers in the bottom to aerate the bacteria in it, followed by a tank full of membranes mounted on cassettes. Membrane BioReactors can operate with high mixed liquor concentrations: 8,000 to 18,000 mg/l of BOD and TSS versus 2-4,000 in a trickling filter plant. Membrane BioReactor plants are very compact. A one million gallon per day plant fits into a 70 x 100 foot closed building. The facility in Payson we visited was disguised as a horse barn and

there was no odor whatsoever inside or out. Membrane BioReactors achieve below 8 log removal of bacteria, 3 log removal of viruses, lower nitrogen (nitrates) below 3 mg/l, and ammonia below 0.1 mg/l.

Door-Oliver invented Membrane BioReactor treatment in 1969. In the 1980's the Japanese developed immersed membrane wastewater treatment systems. Kubota developed a flat plate system which is the one most widely installed with over 2,000 treatment plants in the U.S. and Japan. Its current membrane technology has been installed since 1989 and is very durable. Kubota membrane plants range from 2 to 20 MGD in size. 2 MGD can be treated in a 1 MGD plant footprint by double-stacking the cassettes (the EW400 model). Discharge from Kubota plants meets California Title 22 standards for re-use. The Payson Kubota membrane plant we visited was discharging both BOD and TSS values too low to measure with wastewater treatment plant equipment, exceeding drinking water standards by five times.

Zenon, Mitsubishi, Koch/Puron, and Siemens use a hollow fiber membrane system. Some 1,500 Mitsubishi units are installed; they are described as suitable for wastewater treatment applications of less than 50,000 gallons flow a day. Some 400 Zenon units are installed worldwide, 400 in the U.S. Zenon uses a ultra-filtration, reinforced, hollow fiber design. The latest edition of the Zenon technology is one fifth the cost, handles 10 times the flow, and uses one fifth as much scour air to stay clean. A 250,000 gpd Zenon facility in Oakley is inside a closed 70x80 foot building. Koch fibers are not fixed at their top. Air is pumped into each bundle of fibers at their bottom in the Puron system. There are 13 Siemens MemJets installed in the U.S.: they feature uniform distribution of flow and solids by pumping mixed liquor mixed with air into the fiber bundles, with the clean leachate going out through the fiber into the tank.

All Membrane BioReactor plants are resistant to shock loading, and handle low flows well, making them particularly good for applications where there are wide variations in wastewater flow in the collection system. They are relatively expensive, but becoming cheaper compared to alternatives. They use a lot of energy for the compressors which provide the scour air in the mixed liquor and membrane tanks. Good front-end screening is critical in MBR plants to protect the membranes from abrasive suspended solids.

3. **Textile Filters** are for smaller plant and individual home applications as a replacement for septic tank treatment. In Utah, the largest flow for which a septic tank is allowed is 15,000 gallons per day of wastewater. Textile filters are a late arrival to the packed bed filter method of wastewater treatment; earlier versions use sand, foam, and peat as the filtering medium. Textile filters follow a septic tank, taking the place of the leach field; in textile filters, the biofilm forms on the textile fibers. It is a fixed film, not submerged (saturated) treatment technology. A zoogel film of aerobic microbes absorbs nutrients from waste as it flows by. The trick is to control the flow rate so the bacteria eat each other as well as the waste nutrients, which lowers the amount of sludge which settles out. On the textile filters, the upper areas are aerobic while the lower areas are anoxic and de-nitrify the nitrogenous wastes. Textile filter installations can lower BOD and TSS to 5 mg/l, and nitrates to 20 mg/l. The engineers showed actual figures on an installation: 248.4 BOD mg/l in, 10.5 mg/l out.

AdvanTex makes filter modules, but they are concerned with lowering BOD and TSS, not nitrates, and their effluent does not meet mechanical treatment standards for N in effluent although they do lower N by about 60 percent. AdvanTex installations size tanks to accommodate 3-5 days HRT. Their filters like uniform flow, and it is critical to get the grease out of the wastewater - it will ruin the fiber filters. One installation in Weber County serves 30 cabins with a flow of 12,000 gpd, using recirculating filters.

4. **Multi-Stage Activated Biological Process (MSABP)** uses multiple biological selectors in series. The tanks in series have different submerged media, in which different organisms comprising a food chain grow. The result is that no sludge comes out the end of the tank series. The system was developed in Russia and first installed in 1997. Pictures of an installation showed a series of 12 “selectors” or closed tanks, each with different designs of submerged media (made from polyamide and polypropylene mounted on stainless steel support frames) in it which encourage different organisms to colonize appropriate to consume from the wastes that reach the tank from the prior one. Each trophic level in a tank converts more organic mass from the wastewater stream into metabolic energy, which is why no organic wastes remain in the effluent or settle out as sludge.

1 millimeter screens are needed to remove inerts and grit from entering the tank train. Nothing but organics in the wastewater can break down in the system. The train adapts to varying loads and de-nitrifies very well. Hydraulic retention time is 16-24 hours. Aeration blowers are needed, as is monitoring of oxygen in the tank train. The oxygen level in each tank is supposed to be higher than the last. TSS is below 10 mg/l at discharge with no clarifier in the system. Municipal wastewater treatment plant installations produce BOD and TSS below 10 mg/l, < 1mg/l of ammonia and <10 mg/l total N. One study found input NH₃ at 28.3, output from Stage 12 = 0.021 mg/l, with total N going from 51.2 at input to 9.3 at output. Most wastewater treatment installations of MSABP are in Israel and Spain. The plants offer compact footprints, simple operation, no MSS control or monitoring needed, and they are load and shock insensitive. In situations where sludge handling is difficult and expensive, the MSABP plant will be cheaper to operate overall than its alternatives.

5. **Molecular Separation Technology** was developed in 1977 by Dr. Suominen in Finland. Its first application was to culinary water purification systems on a Finnish farm in 1990, then to treating industrial wastes at industrial facilities in Holland in 1997. The first installation for detoxifying landfill waste leachate was in 2005. The system has also been installed to treat black water on cruise ships, producing water that exceeds drinking water standards for re-use.

The system works by passing a direct current through a vertical cylinder containing the contaminated water to be cleaned. In the bottom is a sacrificial iron cathode. As the current flows, the cathode releases ferric ions, hydroxide ions, and hydrogen gas. The ferric ions group themselves into an ultrafiltration molecular mesh or net which is pushed upwards through the liquid by the hydrogen gas bubbles. As the ferric ion net rises, almost everything except water molecules cannot pass through it and are lifted to the top of the cylinder where they are extracted

into a second, longer cylinder next door called the “flocculate separator.” The flocculates containing the contaminants rise to the top of this cylinder and go into a waste collection tank, while the clean water goes out of the bottom into a buffer tank. Water from the buffer tank still contains a substantial number of ferric ions and has a “rusty” color, so it goes through an iron oxidizer and remover before discharge.

Studies from industrial applications: (1) 2005 industrial potato waste stream cleaning: 30,000 mg/l solids going in, 512 mg/l solids going out; 635 N going in, 15.6 going out. 324 phosphorous going in, 0 going out. (2) Landfill leachate: molecular separator removed 3.5% salt, heavy metals, over 90% of all contaminants in leachate. (3) Salty whey from cheesemaking: removed salt, BOD 63,560 going in and 61.7 going out; other contaminants similarly lowered. (4) Slaughterhouse wastewater: fecal coliform going in >1,000, going out <1. (5) Mine effluent with heavy metal contamination; heavy metals recovered in flocculant; Total Dissolved Solids 2000 going in, <100 going out, a 95% reduction on TDS and 99% reduction on all other measured contaminants.

Molecular separation technology is very robust for cleaning culinary water or salt water compared to reverse osmosis using membranes. Treating one million gallons per day of contaminated culinary water would cost \$123 for electricity a day. The technology offers low cost, no consumables used except for iron cathode replacement, no use of reaction chemicals; it is fully automated, extremely reliable, and produces water that meets drinking water standards from high BOD waste streams while also lowering salt, heavy metals, and most pathogens. A 10 MGD wastewater treatment plant using this technology could be fitted into a 1,000 square foot footprint, using a large number of these separators running in parallel. Each has a very small footprint since it consists of vertical cylinders which can be packed next to each other.

Examples of wastewater reclamation to drinking water installations:

1. Orange County, California has built a \$490 million wastewater reclamation plant that uses pressurized micro-filters, hydrogen peroxide and ultraviolet light to remove bacteria, viruses, carcinogens, hormones, chemicals, heavy metals, fertilizers, pesticides, and dissolved pharmaceuticals from wastewater. The result is so close to distilled water that lime has to be added to the effluent to keep it from corroding water lines. The cost of producing the better-than-drinking-water effluent is \$550 per acre foot.

Techniques for Removing Specific Hydrocarbon Pollutants

Beer Bran, or, why drinking beer is good for the planet: Researchers at Kobe Pharmaceutical University found beer bran, a barley brewing by-product, to be 76.2 percent efficient at absorbing benzene and 92.5 percent efficient at absorbing trichloroethylene from water. The effect occurred over a wide range of pH levels. The researchers speculate the beer bran absorbs organic pollutants from water through the action of spherosomes, intracellular particles widely found in plants.

Activated carbon is now used to filter out organic pollutants such as benzene. It is made by heating coal to 900° Centigrade. It is therefore expensive and energy-consuming to produce. Beer bran is 100 times cheaper and works about as well.

Principle Five: Improve maintenance of and thus lower losses from water delivery systems

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