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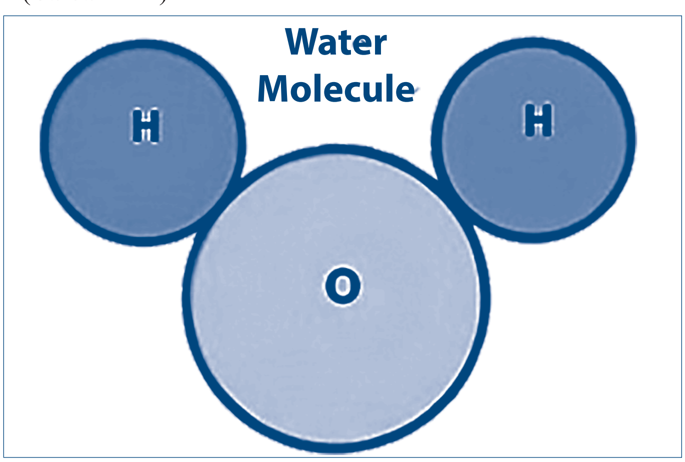
DYING OF THIRST: POPULATION GROWTH, CLIMATE CHANGE AGGRAVATE WATER SHORTAGES

An NPG Forum Paper
by Leon Kolankiewicz

Water – Much More Than Just the "Universal Solvent"

Chemists refer to water – H_20 or H-O-H – as the "universal solvent," because it is capable of dissolving a wide range of different substances. In fact, more substances or chemical compounds can dissolve in water than in any other liquid.

Water's unique chemical composition and physical properties are what make it such an excellent solvent. Each water molecule possesses a "polar" configuration of one oxygen and two hydrogen atoms – one side (hydrogen) has a positive electrical charge while the other side (oxygen) has a negative charge. This permits the water molecule to become "attracted" to many other different types of molecules. Water can be so strongly attracted to a compound like salt (sodium chloride or NaCl), that it can override the attractive forces that bind together the sodium and chloride ions in a salt molecule and thus dissolve it (USGS 2015).



The magic molecule

But to biologists and ecologists, water is more – much, much more – than the universal solvent. It is the stuff of life. Water is both integral and indispensable to all life on Earth (and perhaps the universe): human and non-human, plant and animal, vertebrate and invertebrate, microscopic and macroscopic, prokaryotic and eukaryotic, multi-cellular and unicellular, terrestrial and aquatic alike. Water occurs both inside and outside of the cellular membranes and biochemical walls that demarcate the boundary between biotic (living) and abiotic (non-living) matter. Up to 90 percent or more of the weight of healthy, living plant and animal tissue is water. The human body overall consists of more than 60 percent water, while our blood is 92 percent water and our brain and muscles are 75 percent water. Even bones are about 22 percent water (WIP 2015).

To focus for a moment on a single organ – the kidney – it and water's properties as a solvent partner to keep us humans and all other vertebrates alive and healthy. Kidneys filter out substances that enter our bodies with the foods and drinks we ingest. The kidneys then have to expel these substances from our bodies after they accumulate them. Hence the role of water: as such an effective solvent, water flushing through the kidneys dissolves these substances and helps our bodies eliminate them.

Both economies and ecosystems wither without water. Where water in the liquid state is not present or plentiful, as in Antarctica or the world's driest deserts, life itself is also not present or plentiful. Water is an especially important feature in most of America's national wildlife refuges, for example. Many species of wildlife that abound there occur *only* because water and the wetland habitats that derive from water are present.

Drowning in Water and Dying of Thirst at the Same Time

Fortunately for *Homo sapiens* and all other organisms, the Earth is blessed with an unfathomably enormous volume of water: 332,500,000 cubic miles (mi^3) to be exact (USGS 2014a). That's equal to 250 million cubic yards for each of the 7.3 billion inhabitants of the planet, or about 70,000 Olympic-sized swimming pools. This volume of water has remained essentially unchanged for billions of years, even as it circulates and recirculates over and over again through the timeless loop known as the hydrologic cycle. All that fluctuates over vast reaches of geologic time are the relative proportions of water that are liquid and saline (in the oceans), liquid and fresh (surface water in rivers and lakes, and groundwater beneath continents and islands), fresh and frozen (in Antarctica, Greenland, and the world's glaciers), frozen and saline (sea ice in the Arctic Ocean, Bering Sea, and others), and gaseous (as water vapor) in the atmosphere.

Indeed, there is so much water that famed oceanographer and documentary filmmaker Jacques Cousteau used to call Earth the "Ocean Planet." The sea covers 71 percent of the Earth's surface. With such a staggering abundance of this primordial liquid, it seems paradoxical that humanity could ever run short of "the wet stuff." Yet both acute and chronic water shortages are ever more pronounced – and destined to become even more

Nesting pair of trumpeter swans (*Cygnus buccinator*) in marsh habitat at Agassiz National Wildlife Refuge in Minnesota. Waterfowl such as swans, geese, ducks and wading birds such as herons and egrets exhibit what ecologists call "obligate dependence" on water and wetland habitats.

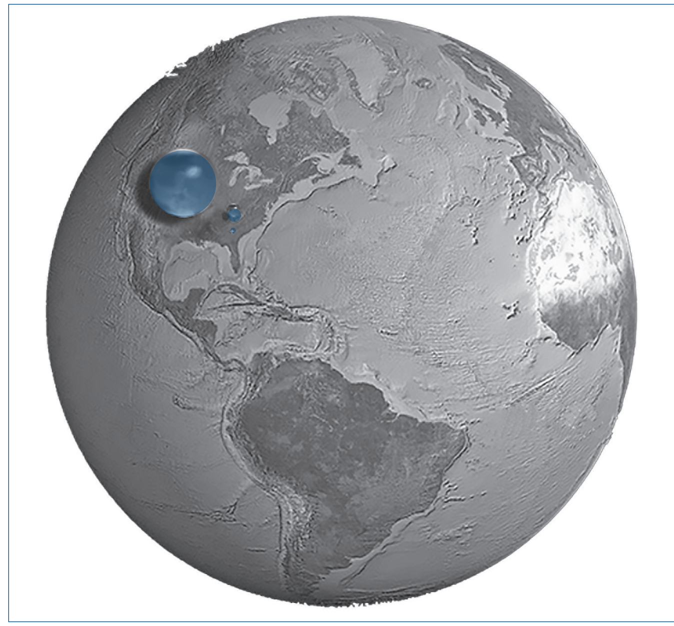
severe as this century progresses. Water is not unlimited. There simply isn't enough to meet the demands, whims, and needs of 7.3 billion thirsty human beings making ever greater claims on this limited liquid.

Part of this seeming paradox – vast abundance versus scarcity – is resolved by looking at the image of the globe with the smallish bubbles of water suspended above it. To begin with, only three percent of the Earth's water is fresh, while 97 percent is saline, that is, in the oceans. While saltwater can be converted to potable freshwater, or desalinated, through reverse osmosis and other desalinization technologies, these are costly economically, energetically, and environmentally, and thus, barring a technical breakthrough, are unlikely to be practicable or sustainable on a large scale or over the long term.

Then, of the three percent of the water on Earth that is fresh, nearly 70 percent is frozen as ice in Antarctica, Greenland and thousands of glaciers. The above-right graphic illustrates the surprising lack of water on our planet. If you were to drill a hole through the Earth from pole to pole, the diameter would be approximately 7,900 miles. The image of the globe without seas – our planet's mass of solid land – simply dwarfs the three distinct "bubbles" representing our world's various water resources. The largest fluid sphere, 860 miles in diameter, includes all of the water on Earth: the oceans, ice caps, lakes, rivers, aquifers (groundwater), atmospheric water, and even every living organism. The smaller sphere hovering above Kentucky represents the world's entire volume of freshwater, and it has a diameter of just 170 miles.

The tiny, barely-visible dot poised just above Atlanta, Georgia stands for all of the world's freshwater located in lakes and rivers. (Most of the water people and other living things use on a daily basis comes from these surface water sources.) The volume of this sphere is about 22,339 mi3 – just 35 miles in diameter (USGS 2014a).

Thirty percent of the Earth's freshwater is groundwater, while only 0.3 percent – a mere one-third of one percent, is surface water in rivers and streams, swamps, and lakes. Nearly 90 percent of the world's surface fresh water is in lakes, while only two percent is in rivers at any given time.



Planetary perspective – maybe not so superabundant after all? All of Earth's water combined and freshwater alone shown as a big sphere and a smaller sphere, respectively, and compared with the sphere of the Earth
Image: Jack Cook, Woods Hole Oceanographic Institution

The table shows how all water on Earth is distributed among the various stocks or sources.

Water source	Water volume in cubic miles	Percent of fresh water	Percent of total water
Oceans, seas, and bays	321,000,000	--	96.54
Ice caps, glaciers, and permanent snow	5,773,000	68.7	1.74
Groundwater	5,614,000	--	1.69
Fresh	2,526,000	30.1	0.76
Saline	3,088,000	--	0.93
Soil moisture	3,959	0.05	0.001
Ground ice and permafrost	71,970	0.86	0.022
Lakes	42,320	--	0.013
Fresh	21,830	0.26	0.007
Saline	20,490	--	0.006
Atmosphere	3,095	0.04	0.001
Swamp water	2,752	0.03	0.0008
Rivers	509	0.006	0.0002
Biological water (within organisms)	269	0.003	0.0001

Source: Shiklomanov (1993)

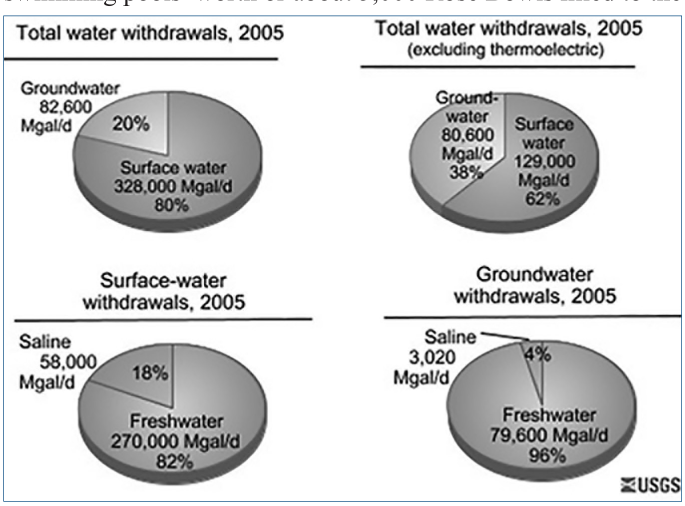
About 3,100 cubic miles of water, mostly in the form of water vapor, is dispersed in the atmosphere at any one time. If it all fell at once as rain, the Earth would be covered with only about one inch of water. The 48 contiguous United States receive a total volume of about four cubic miles of precipitation each day. Each day, globally, 280 cubic miles of water evaporate or transpire into the atmosphere (USGS 2014a).

The worldwide distribution of water resources is extremely uneven. While the global hydrologic cycle provides enough freshwater in aggregate to meet minimum human requirements, the great bulk of this total water in circulation is concentrated in particular regions, leaving other regions with water shortages or deficits (Pimentel et al. 2010) . By 1993, water demands already exceeded supply in nearly 80 nations worldwide (Gleick 1993)

A U.S. Water Primer

Except for the American Southwest, the United States is comparatively well endowed with water resources and uses prodigious quantities of both surface water (withdrawn from man-built reservoirs, natural lakes and rivers) and groundwater (pumped from subterranean aquifers) to supply agriculture, industry, and municipalities.

In 2005, about 410,000 million gallons of water every day (see figure) – more than a thousand gallons per person – was withdrawn for use in the United States – over four million swimming pools' worth or about 5,000 Rose Bowls filled to the



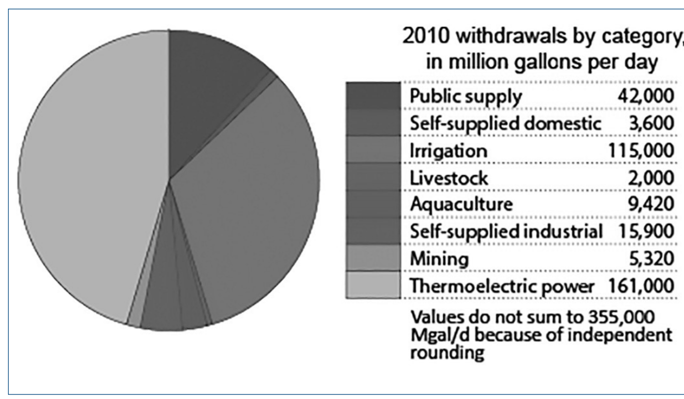
rim. About 80 percent of our water supply is from surface water and the remaining 20 percent from groundwater (Barber 2009; USGS 2014a).

We use water to irrigate our crops, manufacture all manner of products ranging from steel to silicon chips to soft drinks, to water our lawns, fill our cooking pots, wash away our wastes, and even to cool our thermal (nuclear and coal) power plants. About 80 percent of water used in the U.S. is for agriculture (Pimentel et al. 2004), which is very water-intensive because crops (like all healthy plants) need it for photosynthesis and transpiration. All plants demand huge amounts of water during the growing season; much of this water is transpired, that is, evaporated back to the atmosphere through pores in leaves called stomata.

Since 1950, the U.S. Geological Survey (USGS) has estimated water use in the United States in total and state-by-state every five years. Estimates are provided both for groundwater and surface-water sources, for fresh and saline water quality, as well as by sector or category of use (USGS 2014b).

The USGS estimated total freshwater and saline-water withdrawals for 2010 at 355,000 million gallons per day (Mgal/d), or 397,000 thousand acre-feet per year (acre-ft/yr). This was 13 percent *less* than in 2005. Freshwater withdrawals comprised 86 percent of the total, while saline-water withdrawals made up the remaining 14 percent. Most saline-water withdrawals were of seawater and brackish coastal water for use in thermoelectric (coal and nuclear) power plants (Maupin et al. 2014; USGS 2014b).

Withdrawals for thermoelectric power and irrigation remained the two largest uses of water in 2010, and totals for both were less than in 2005: 20 percent less for thermoelectric power and nine percent less for irrigation. Similarly, other uses showed reductions compared to 2005, specifically public supply (–5%),



self-supplied domestic (–3%), self-supplied industrial (–12%), and livestock (–7%). Only mining (39%) and aquaculture (7%) reported larger withdrawals in 2010 compared to 2005 (Maupin et al. 2014).

Aggregate water use (withdrawals) in the U.S. actually decreased 13 percent from 2005 to 2010. During this same period, the U.S. population also increased by about 10 million inhabitants or three percent. This demonstrates that the relationship between population size and aggregate water consumption is not a simple one. Every added increment of population does not necessarily guarantee an added increment of water consumption:

1 additional unit of population ≠
1 additional unit of water use

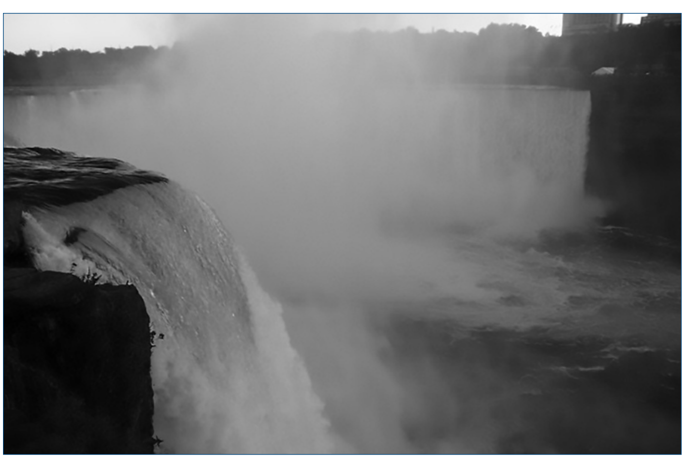
In all likelihood, the decrease in aggregate water withdrawals between 2005 and 2010 was due mostly to the economic slowdown associated with the Great Recession of 2008.

In addition to population size, economic structure and level of activity, water conservation, reuse and efficiency measures all have a bearing in determining total water consumption. To a point, for a period of time, under special conditions, and with strong public commitment and political support, total water use can be reduced – or at least held constant – even with a growing U.S. population, as it has been in recent years. However, the crux of the matter is that under these special circumstances, if the U.S. population were smaller (and non-growing, therefore sustainable), aggregate water use could be cut even more. We must simply commit to both population reduction and water conservation, reuse, and efficiency, allowing still more water to remain where nature intended it – in streams, rivers, and lakes.

In-Stream Water Flows Provide Crucial Benefits to Ecosystems and Society

In these natural settings, water performs valuable ecosystem services and functions. These functions not only include supporting aquatic biota (vertebrates and invertebrates, plants and animals), fisheries and wildlife (such as waterfowl and other water-dependent animals), but also commercial navigation, hydroelectric generation, recreation (e.g., boating, fishing, swimming), and even sight-seeing and tourism.

A prominent example of the latter is Niagara Falls. The Niagara River drains all of the Great Lakes (Superior, Michigan, Huron, and Erie), except for Lake Ontario, into which it flows. The water that courses down the Niagara River and over its mighty waterfall is part of the huge St. Lawrence River Basin or watershed, one of the largest in North America. Since 1961, up to 375,000 gallons of water every second have been diverted from the Niagara River upstream of the falls into gigantic conduits or penstocks (NYPA no date). The water flows downward by gravity and spins turbines and generators that convert its mechanical energy into clean, low-cost, renewable electric energy (hydroelectric power).

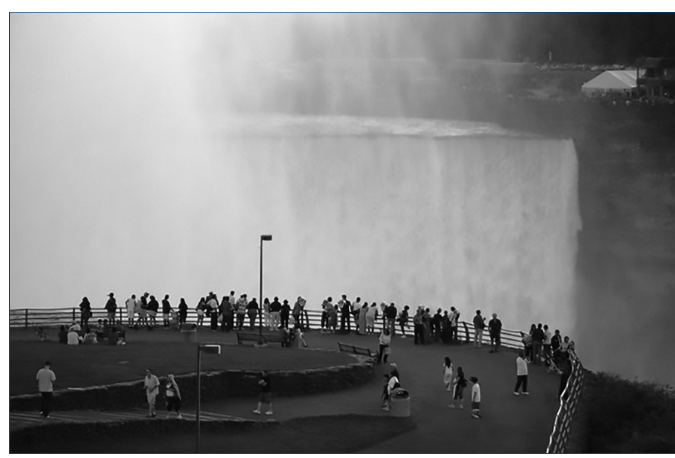


Niagara Falls from the New York side

Hydroelectric plant on the Niagara River

The Niagara generating station is the largest electricity producer in the entire State of New York, with a capacity of 2,400 megawatts – enough power to light 24 million 100-watt incandescent light bulbs simultaneously – or 96 million 25-watt compact fluorescent light bulbs. If hydro developers had received permission to divert the entire Niagara River into the hydroelectric plant, there would be none left to flow over the escarpment that constitutes Niagara Falls, and a spectacular wonder of nature and crucial tourism resource would be wiped out. What would be visible instead is a dry cliff or escarpment 167 feet high, surely not nearly as impressive as one of the world's great waterfalls, pouring and pounding thunderously as it has for thousands of years.

Fortunately, Americans and Canadians were wiser than this (the U.S.-Canadian border cuts Niagara Falls roughly in half). To balance the potential for power generation with the imperative of preserving the beauty of Niagara Falls, the U.S. and Canadian governments signed a treaty in 1950 that limits the amount of water that can be diverted for hydroelectricity production. On average, more than 200,000 cubic feet per second (cfs), or 1.5 million gallons of water a second, pours from Lake Erie into the Niagara River. The 1950 treaty requires that at least half that amount of water – 100,000 cfs – spill over the Falls during the daylight hours in the tourist season, April through October. This flow may be cut in half (to 50,000 cfs) at night during the April-October tourism period and during the rest of the year with low tourist visitation (NYPA no date).



Tourists on the New York side of Niagara Falls

U.S. Water Withdrawals by Sector

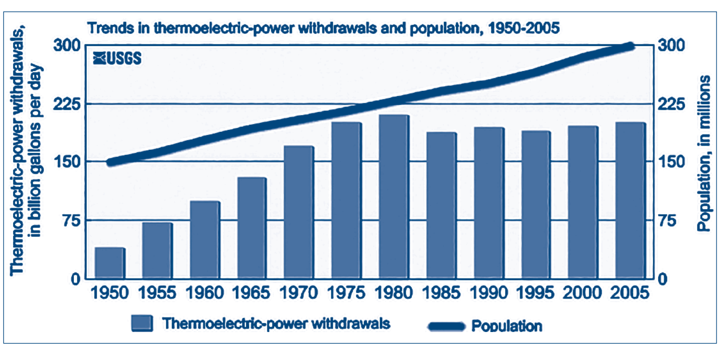
The three largest sectors of water withdrawal and use in the United States are thermoelectric, irrigation, and municipal supply.

Thermoelectric Power

Generation of electricity is one of the largest uses of water in the United States and worldwide (USGS 2014c). Water for thermoelectric power is used to generate electricity with steam-driven turbine generators. In 2010, about 161,000 Mgal/d were used nationwide to produce electricity (excluding hydroelectric power). Surface water was the source of more than 99 percent of total thermoelectric-power withdrawals. In coastal areas, the use of saline water instead of freshwater expands the overall available water supply. Thermoelectric-power use accounted for almost half of total water withdrawals in the U.S., 41 percent of total freshwater withdrawals for all categories, and 53 percent of fresh surface-water withdrawals (USGS 2014c).

One of the main uses of water in the power industry is to cool the power-producing equipment. Water used for this purpose does cool the equipment, but at the same time, as dictated by the laws of thermodynamics, the hot equipment transfers heat to the cooling water. Excessively hot water cannot be released back immediately into the aquatic environment, because of the harm it would cause, so the water itself must first be cooled. The most common way of doing this is to build and operate very large cooling towers and to spray the water inside the towers. Evaporation then occurs and in the process, water left behind in a liquid state is itself cooled. The essential need for water is why large generating stations are often located near rivers, lakes, and the ocean (USGS 2014c).

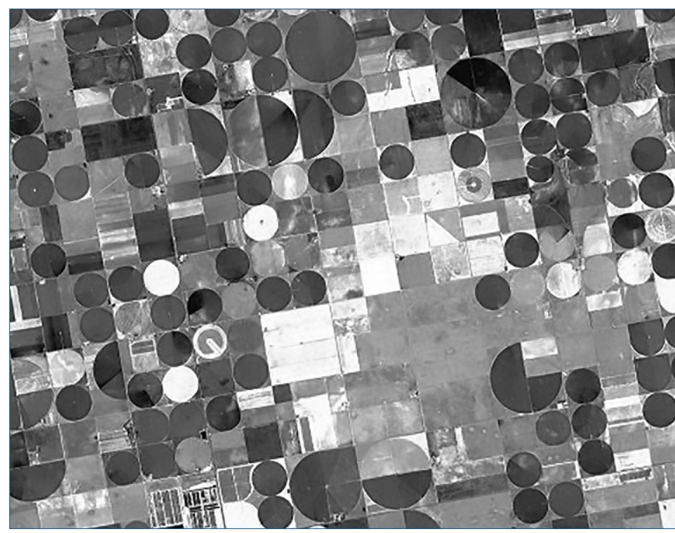
Withdrawals by thermoelectric-power plants increased from 40,000 Mgal/d during 1950 to 210,000 Mgal/d during 1980 (see graph). Withdrawals for thermoelectric power decreased and then have stabilized since 1980, despite the fact that total U.S. population has continued to increase; the total withdrawal of 201,000 Mgal/d for 2005 is slightly above that of 2000. In 2010, however, as noted above, thermoelectric-power withdrawals fell again, by 20 percent, to 161,000 Mgal/d.



What accounts for thermoelectric-power withdrawals having become "decoupled" from U.S. population growth in the last three decades? It is not that thermoelectric power production hasn't increased, for it has. Rather, technological and cultural innovation has occurred. Since the 1970s, an increasing number of generating stations were built with or converted to recirculating cooling systems or dry cooling systems, which use less cooling water than power plants with once-through cooling systems. Also, withdrawals at power plants have decreased in some states because of the implementation of new rules designed to minimize adverse effects to aquatic life at power plant intakes. A decline in the use of coal and a corresponding increase in use of natural gas (as a result of a sharp drop in natural gas prices from new supplies made available by hydro-fracking of shale gas), as well as new power plants coming online that use more water-efficient cooling technology also have helped to lessen withdrawals for thermoelectric power (Maupin et al. 2014).

Irrigation

Irrigation water is essential for growing fruits, vegetables, and grains to feed the world's population. This has been true for thousands of years. The USGS estimates that almost 60 percent of all the world's freshwater withdrawals go towards irrigation uses. Irrigation represents an even larger share – 70 percent – of the world's "consumptive water use," that is, those uses that withdraw water from reservoirs, lakes, rivers or aquifers but do not return it in some fashion to these water bodies. That is because the water is incorporated into the crops themselves or is transpired back to the atmosphere as the crops photosynthesize and grow. Large-scale farming could not provide food for the world's large and growing population without the irrigation of crop fields by water taken from rivers, lakes, reservoirs, and wells. Without irrigation on a vast scale, high-value crops could never be grown in the deserts of California or Arizona or even the Western plains (USGS 2014d).

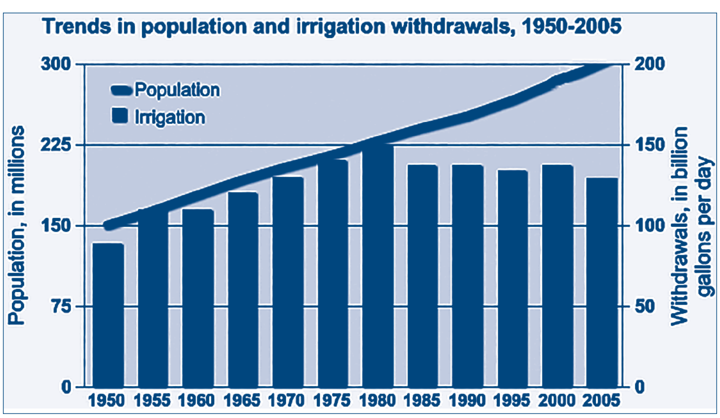


Irrigated crop circles in Finney County, Kansas
Sources: NASA, USGS
Note: Many passengers in cross-country flights may have noticed circles like these plastered across the landscape far below. They are center-pivot irrigation crop circles. In center-pivot irrigation systems, water is pumped from a well in the center of the circle from an underground aquifer and distributed through a giant, long sprinkler that pivots around a central point. In the past, large spray guns were used to spray water through the air onto the crops, but now more efficient low-pressure sprinklers hang from the pipes to aim water closer to the ground, a much more efficient method that saves water. This NASA satellite photo shows large crop circles that are between 0.5 mile and one mile in diameter. This particular area utilizes irrigation water from the Ogallala aquifer, which underlies an area stretching from Wyoming in the north to Texas in the south (USGS 2014d). The Ogallala is a "fossil" aquifer, one which contains ancient water that is not being recharged; thus it is being "mined" and it is a non-renewable resource. In general, when people use water at home, or when an industry uses water, about 90 percent of it used is eventually returned to the environment ("return flows") where it replenishes water sources. That is, water returns to a stream or lake, or it infiltrates down into the ground and returns to groundwater, and it can be used for other purposes, although it often requires treatment or cleaning first at a water or wastewater treatment plant. However, of the water used

for irrigation, only about one-half is reusable. The rest is lost by evaporation into the air, evapotranspiration from plants, or is lost in transit, through a leaky pipe, for example (USGS 2014d).

In the U.S., irrigation withdrawals constitute about 37 percent of total freshwater withdrawals and 62 percent of total freshwater withdrawals for all categories, if thermoelectric power withdrawals are excluded. Surface water accounted for 58 percent of the total irrigation withdrawals. Sixty-seven percent of all groundwater withdrawals went to irrigation. About 61.1 million acres were irrigated in the U.S. in 2005. About 26.6 million acres were irrigated with surface (flood) systems, 4.05 million acres with microirrigation systems, and 30.5 million acres with sprinkler systems. The national annual average application rate was 2.35 acre-feet per acre (USGS 2014d).

The majority of irrigation withdrawals (85 percent) and irrigated acreage (74 percent) were in the 17 conterminous Western states. These are situated in areas west of the 100th Meridian, where average precipitation is typically less than 20 inches annually and is inadequate to sustain cultivated crops without supplemental water. Surface water was the primary source of irrigation water in the arid West and Rocky Mountain States. California, Idaho, Colorado, and Montana combined accounted for 49 percent of the total irrigation withdrawals and 64 percent of surface-water irrigation withdrawals. Nearly 90 percent of the groundwater used for irrigation was withdrawn in 13 states, and each of these states withdrew more than 1,000 Mgal/d (1,120 thousand acre-feet per year) of groundwater for irrigation in 2005. Among these 13 states, groundwater was the primary source for irrigation in Nebraska, Arkansas, Texas, Kansas, Mississippi, and Missouri (USGS 2014d).



From 1950 to 1980, irrigation withdrawals increased by more than 68 percent (from 89,000 to 150,000 Mgal/d). Withdrawals have decreased since 1980 and have stabilized at between 134,000 and 137,000 Mgal/d between 1985 and 2000 (see bar chart). They were 128,000 in 2005 and 115,000 in 2010. Depending on the geographic area of the United States, this overall decrease, in spite of an increasing U.S. population, can be attributed to climate, crop type, improvements in irrigation efficiency, and higher energy costs (USGS 2014d).

Public Supply (Municipal)

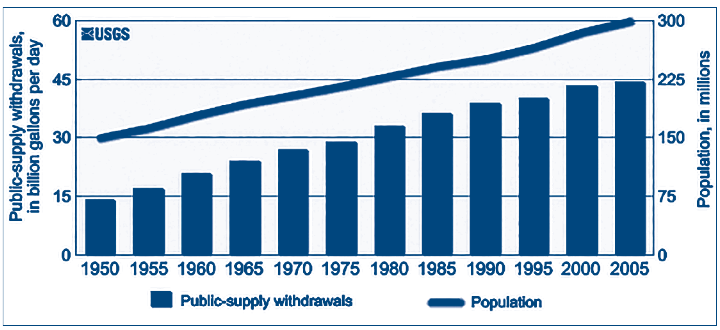
Public water-supply systems, also called county and city water departments, or municipal water districts, are vitally important to all urban, suburban and small town residents. These are government, quasi-government, or privately-run agencies with facilities that withdraw water from rivers, lakes, reservoirs, and wells and then treat and deliver it to America's homes, businesses, schools, and governments. At present, the lion's share of the U.S. population (about 86 percent) of the United States obtains its water from public-supply systems (USGS 2014e). In the past, when the American population was largely rural, most families used to have to dig their own wells and create storage tanks for their private, domestic water supply; water quality from those wells was not generally monitored or even known, and was sometimes substandard. Now the public water supply systems have taken over this role.

Lake Lanier, north of Atlanta, Georgia
Note: Lake Lanier was created by the impoundment of water behind Buford Dam on the Chattahoochee River in 1956; it is also supplied by the waters of the Chestatee River. It is the main water supply for millions of people downstream.

Portion of a municipal water treatment plant in Texas

An estimated 258 million people rely on public water supplies for their household use. States with the largest populations (California, Texas, New York, and Florida) withdraw the largest amounts of water for public supply. Two-thirds of water withdrawn for public supply in 2010 was from surface sources, such as lakes and streams; the other third was from groundwater. A total of 38 states rely on surface water for more than half their public supplies. Only 15 states obtain more than half their public water supplies from groundwater. California, Texas, New York, Illinois, and Pennsylvania each withdrew more than 1,000 Mgal/d of surface water for public supply in 2005, and 45 percent of the total surface-water withdrawals for public supply occurred in these five populous states. Three states – Florida, California, and Texas – each withdrew more than 1,000 Mgal/d of groundwater for public supply in 2005 and together accounted for 32 percent of total groundwater withdrawals for this sector (USGS 2014e).

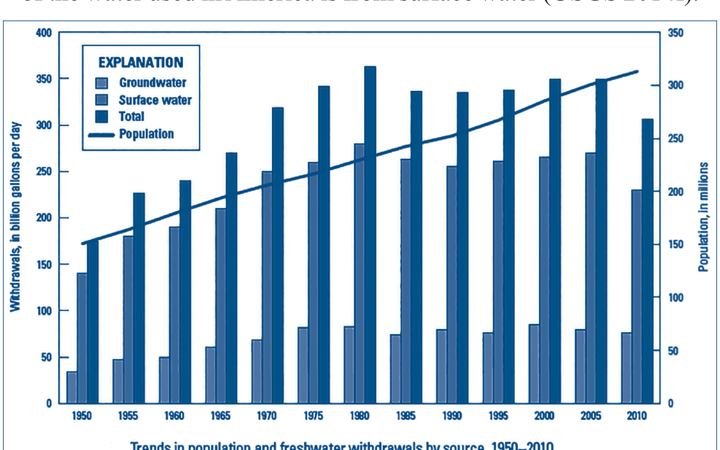
Estimated water withdrawals for public supply have increased continually since 1950 along with the population served by public suppliers of water (see bar chart). Public-supply withdrawals more than tripled during this half-century period; they also increased by about two percent from 2000 to 2005. The percentage of the U.S. population served by public water suppliers increased from 62 percent for 1950 to 86 percent for 2005. Public-supply withdrawals represented about eight percent of total withdrawals for 1950 and about 11 percent for 2005. The percentage of groundwater use for public supply increased from 26 percent for 1950 to 40 percent for 1985 and was about 33 percent in 2005 (USGS 2014e).



Growth of U.S. population and public-supply water withdrawals, 1950-2005

Water Use Trends in the United States, 1950-2010

The bar chart below shows the amount of water used for various categories of water use in the U.S. for the 60-year period from 1950 to 2010. This chart shows the trends in surface water, groundwater, and total-water withdrawals for the United States during this period. Against a background of steady growth during the first half of the period and relative stability in the second half, the relative amounts of surface- and groundwater withdrawals (in percentages) have remained fairly constant. About three-quarters of the water used in America is from surface water (USGS 2014f).



Long-term population and freshwater withdrawal trends by source

What is extraordinary about this graph is that it reveals that America's water use peaked 35 years ago in 1980 and has been relatively constant since then. Many of the pressures forcing greater water use have only increased since 1980, such as population (which grew by more than 80 million from 1980 to 2010), the need to grow more food (irrigation), more industry, more power plants, and so forth, yet in spite of these total water use has not risen. What this shows clearly is that water conservation and reuse efforts and greater efficiency in using water have made a big difference in the last 35 years (USGS 2014f). However, as mentioned previously, to see a greater drop in overall water use, we must also reduce U.S. population in conjunction with these conservation efforts.

Water and Ecosystem Services

Most of this paper has focused on water supplies withdrawn from nature and put to some beneficial use by human beings. However, freshwater of course also plays an integral role in aquatic ecosystems: watercourses (streams and rivers), waterbodies (ponds and lakes), wetlands (marshes, swamps, bogs, etc.), springs, and estuaries (semi-enclosed brackish water bodies that are transition zones between land and sea, where fresh and saltwater mix). Aquatic ecosystems perform many important ecological functions and services. They recycle nutrients, purify water, attenuate floods, recharge groundwater and provide habitats for wildlife (Loeb and Spacie 1994).

Indeed, these ecosystems and the thousands of plant and animal species that live within them and depend upon them – what ecologists call "communities" – would not exist at all were it not for the availability of water. When water is appropriated or taken from these ecosystems for use by human beings, there may be less or no water left behind to perform critical ecosystem services and functions. The integrity of these aquatic ecosystems is often adversely affected or even fundamentally altered.

Example of a small estuary. The nation's two largest estuaries are Chesapeake Bay on the East (Atlantic) Coast and Puget Sound on the West (Pacific) Coast.

Aquatic ecosystems may also be modified and often damaged by human activity other than direct removal of water. This can occur from:

- flood control facilities (e.g., levees, channelization, dams)
- an increase in the amount of developed areas and impervious surfaces within a watershed, which increases the volume and rate of runoff and discharge during storm events
- land use practices within a watershed (e.g., crop cultivation, grazing, logging, deforestation) that cause

erosion and lead to sedimentation within waterbodies
- non-point sources of pollution within a watershed, such as discarded engine oil, fertilizers and nutrients like phosphorus and nitrogen, and even pet feces
- construction within floodplains that impedes the flow of water
- navigation facilities within rivers, such as locks and dams on the Mississippi and Ohio rivers and many others
- dredging of rivers and bays to maintain navigation channels
- ports constructed and maintained in rivers, lakes, and bays
- construction of dams/reservoirs for hydroelectricity, recreation, flood control, water supply, and irrigation.

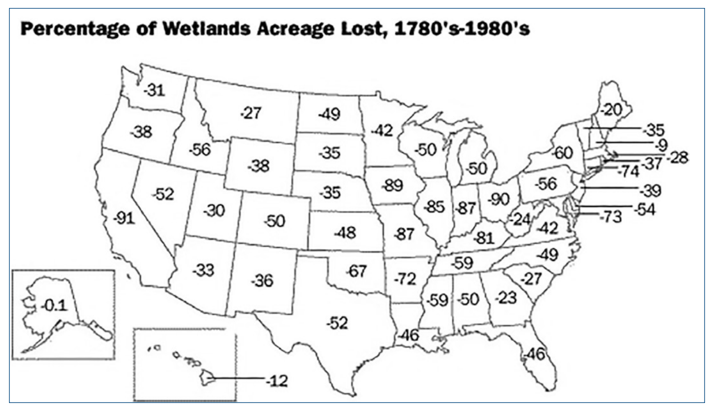
As a result of the above activities, plus water pollution and water withdrawals, more than 123 species of freshwater fauna have been driven extinct in North America since the year 1900. Hundreds of additional species of fishes, mollusks, crayfishes, and amphibians are considered imperiled today. Of North American freshwater species, nearly half of all mussel species, 23 percent of gastropods, 33 percent of crayfishes, 26 percent of amphibians, and 21 percent of fishes are listed as either endangered or threatened because of anthropogenic (manmade) influences.

The pink mucket pearlymussel (*Lampsilis orbiculata*) in the Midwest and East is endangered because dams and reservoirs have flooded most of its riverine habitat (mud and sand and in shallow riffles and shoals). Erosion caused by strip mining, logging and farming adds silt to many rivers, which can clog the mussel's feeding siphons and even bury it completely (USFWS 20).

Recent extinction trends are due largely to extensive habitat deterioration from sedimentation and loading with organic compounds and nutrients, toxic contaminants, stream fragmentation and flow regulation by dams, channelization and dredging projects, and increasing numbers of invasive (introduced, non-native) species. Of 3.2 million miles of stream habitat in the U.S., less than two percent (< 62,000 miles) is of sufficiently pristine quality to be federally protected and only 40 rivers are still free-flowing after more than a century of intensive growth and development (Ricciardi and Rasmussen 1999).

In the 1600s, over 220 million acres of wetlands are believed to have existed in the contiguous (Lower 48) states (Dahl 1990). Since that time, extensive, widespread losses have occurred, and more than half of the original wetland acreage has been drained, dredged, or filled and converted to other uses. Some 22 states have lost more than 50 percent of their original wetlands, and seven states – California, Iowa, Indiana, Illinois, Kentucky, Missouri, and Ohio – have lost more than 80 percent. Both Ohio and California have lost 90 percent or more. The years from the mid-1950s to the mid-1970s saw massive wetland destruction, but since then the rate of loss has diminished substantially (EPA 2013).

Since the 1970s, the largest losses of wetlands have been in Louisiana, Mississippi, Arkansas, Florida, South Carolina, and North Carolina (Mitsch and Gosselink 1993). For the last couple of decades, national policy has been that there should be "no net loss" of wetlands, which has slowed but not stopped wetlands loss. The net wetland loss nationwide was estimated to be 62,300 acres between 2004 and 2009 (DOI 2011).



Total cumulative wetland losses by state, 1780s to 1980s
Sources: EPA (2013), Mitsch and Gosselink (1993)

The health of an aquatic ecosystem can be degraded when the ecosystem's ability to tolerate, absorb, or assimilate a stress has been exceeded. A stress on an aquatic ecosystem results from physical, chemical or biological modifications of the environment. Physical modifications include changes in water temperature, water flow patterns, bank and substrate structure, and light availability. Chemical modifications include changes in the loading rates of nutrients such as nitrogen and phosphorus, oxygen-consuming materials (measured by Biochemical Oxygen Demand or BOD), and toxic substances. Biological modifications include overharvesting of commercial species and the introduction of invasive, exotic species. Human populations can readily impose excessive stresses on aquatic ecosystems (Loeb and Spacie 1994).

There are many examples of excessive stresses with adverse impacts or negative consequences. The Great Lakes of North America have been subject to multiple stresses, such as water pollution, overharvesting and invasive species (Vallentyne 1974). Puget Sound, Chesapeake Bay, and North Carolina's Pamlico Sound are all estuaries under pressure from multiple human stressors, including chemical pollution, eutrophication from excessive nutrients, and overharvest of fish and shellfish. Lakes Pontchartrain and Maurepas next to New Orleans along the Lower Mississippi and Gulf of Mexico illustrate the negative effects of different stresses including levee construction, logging of swamps, invasive species and salt water intrusion (Keddy et al. 2007).

The mighty Mississippi River, including all of the major tributaries in its huge basin, such as the Missouri, Platte, Ohio, Illinois, Allegheny, Monongahela, Tennessee, and Cumberland rivers, have all suffered from some combination of serious water quality degradation, excessive water withdrawals, alteration of flow regimes to provide for navigation, and exotic species invasions. These have sharply compromised the integrity of aquatic biota in and along these rivers.

California's San Joaquin and Sacramento rivers are overdrafted and overtaxed. The Columbia River system in the Pacific Northwest has been overregulated by 60 dams, devastating its once famous salmon runs, especially those of the king or Chinook salmon. Flows in the Colorado River and Rio Grande in the Southwest have been highly altered and ecosystems in and alongside these rivers have been changed and impaired permanently. The integrity of the famous "river of grass" at the southern tip of Florida, the Everglades, has been badly compromised by invasive species but especially by diversions of water to support agriculture and population growth in Miami, Fort Lauderdale, and the rest of the Southern Florida megalopolis.

Every summer, a massive, hypoxic (low dissolved oxygen [DO], less than 2 parts per million of DO) or anoxic (no DO) "dead zone" develops at the mouth of the Mississippi River in the Gulf of Mexico as a result of all the nutrients carried downstream by the river due to fertilizer runoff from the tens of thousands of farms in the Mississippi drainage basin. The dead zone can expand to 7,000 square miles in area. The zone occurs between the inner and mid-continental shelf in the northern Gulf of Mexico, beginning at the Mississippi River delta and extending westward to the upper Texas coast.

The dead zone is caused by nutrient enrichment or eutrophication from the Mississippi basin, particularly by nitrogen and phosphorous fertilizers. Watersheds within the Mississippi River Basin drain much of the central U.S., from Montana in the west to Pennsylvania in the east and extending southward along the Mississippi River itself. Most of the nitrogen loading originates in major farming states in the Mississippi River Valley.

Dissolved nitrogen and phosphorous flow into the river through upstream runoff of fertilizers, soil erosion, animal wastes, and sewage. In a natural, pristine system, these nutrients are not significant factors in algae growth because they are not found in artificially high concentrations and they are largely used in the soil by upland plants. However, with anthropogenically increased nitrogen and phosphorus input from fertilization to boost crop yields, aquatic algae growth is no longer constrained. Thus, algal blooms appear, the food pyramid is altered, and DO in the area is depleted. The size of the dead zone at the mouth of the Mississippi River fluctuates seasonally and it is exacerbated by modern farming practices. It is also affected by weather events such as Mississippi River floods and Gulf of Mexico hurricanes (Bruckner 2012).

The Outlook for Water under a Changed Climate Regime: Not a Pretty Picture

The U.S. National Climate Assessment of the U.S. Global Change Research Program was initiated at the request of the U.S. government and released to the public in 2014 (Melillo et al. 2014). It was prepared by a team of more than 300 experts guided by a 60-member National Climate Assessment and Development Advisory Committee – the largest and most diverse group ever assembled to produce a U.S. climate assessment. The 2014 Assessment draws on a large body of peer-reviewed scientific publications, technical reports, and other publicly available sources.

With regard to water resources, the 2014 National Climate Assessment found that: "Water quality and water supply reliability are jeopardized by climate change in a variety of ways that affect ecosystems and livelihoods." Climate change is predicted to have the following effects on the water cycle:

- Increases in annual precipitation and river-flow in the Midwest and the Northeast regions.
- Increases in very heavy precipitation events (damaging downpours) and flooding in all regions of the country.
- Increases in the length of dry spells in most areas, especially the southern and northwestern portions of the contiguous U.S.
- Intensified short-term (seasonal or shorter) droughts in most U.S. regions.
- Intensified longer-term droughts in large areas of the Southwest, southern Great Plains, and Southeast.
- Intensified flooding in many U.S. regions, even in areas where total precipitation is projected to decline.
- Changes in water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.
- Compromised sustainability of coastal freshwater aquifers and wetlands due to sea level rise, storms and storm surges, and changes in surface and groundwater use patterns.
- Decreased river and lake water quality, including increases in sediment, nitrogen, and other pollutant loads from increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts (Melillo et al. 2014).

The 2014 Climate Assessment predicted that climate change will have large impacts on water use and management. It will affect water demand and the ways water is utilized within and across regions and economic sectors. The Southwest, Southeast, and Great Plains are especially liable to changes in water supply and demand. Changes in precipitation and runoff, combined with changes in water consumption and withdrawal, have already reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses. At the same time, an increasing risk of flooding will threaten human safety and health, property, infrastructure, economies, and ecology in many water basins across the United States (Melillo et al. 2014).

As the century progresses, ***all of these ill effects will be greatly exacerbated by the much larger future U.S. population projected by demographers as a result of continuing mass immigration into the United States.***

The two fastest-growing regions in the country – the Southwest and the Southeast – are expected to be hit, in effect, with a double whammy: many more people exerting greater demands on a constrained, diminished water resource.

The 2014 Climate Assessment states this about the Southwest:

> *The Southwest is the hottest and driest region in the U.S., where the availability of water has defined its landscapes, history of human settlement, and modern economy. Climate changes pose challenges for an already parched region that is expected to get hotter and, in its southern half, significantly drier.*
>
> *Increased heat and changes to rain and snowpack will send ripple effects throughout the region, affecting 56 million people – a population expected to increase to 94 million by 2050 – and its critical agriculture sector. Severe and sustained drought will stress water sources, already over-utilized in many areas, forcing increasing competition among farmers, energy producers, urban dwellers, and ecosystems for the region's most precious resource (Melillo et al. 2014).*

"Heat, drought, and competition for water supplies will increase in the Southwest with continued climate change." – 2014 U.S. National Climate Assessment

The Southeast is also anticipated to run into severe problems for similar reasons. The Climate Assessment notes: "Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water and affect the region's economy and unique ecosystems." Furthermore, the natural and built environments and the economy of the Southeast will be threatened by sea level rise, which is already causing problems in places like the Tidewater region of Virginia (Norfolk, Virginia Beach, etc.) and South Florida (Miami, Miami Beach, Fort Lauderdale, West Palm Beach, etc.).

The Great Plains, while not projected to undergo massive, destabilizing population growth like the Southwest and the Southeast, is nonetheless projected to see increasing water scarcity as a result of higher temperatures. In parts of the region, there will be increasing competition for water among municipalities, farmers, energy producers, and in-flow requirements (ecological needs for surface flows in watercourses).

The trend toward drier days and higher temperatures across the Southern Plains will increase evaporation and evapotranspiration, decrease water supplies, and increase air conditioning demands, placing a greater load on electrical generation, transmission, and distribution systems. These changes will in turn intensify stresses on limited water resources and impinge on political and managerial decisions related to irrigation, municipal use, and energy generation. Increased drought frequency and intensity can transform marginal lands into deserts (Melillo et al. 2014).

There may well be less water available for irrigated agriculture even as there are more people dependent on the crops that irrigation produces.

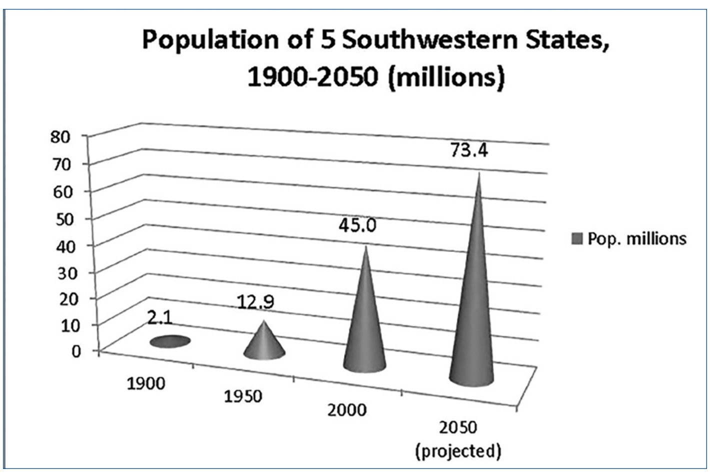
In sum, as the century progresses, there will be increasing water shortages in several key regions of the country considerably exacerbated by: 1) global warming and, 2) immigration-driven population growth. The first factor is virtually a *fait accompli*, given the climate change locked into place by inertia in the climate system and greenhouse gas emissions that have already occurred. The second factor is not at all a given, unless Americans meekly acquiesce to the high, unsustainable immigration rates pushed relentlessly by vested interests and feckless politicians.

A Texas Parks and Wildlife ranger walks across a dry and cracked lakebed during the drought of 2011. This lake once covered more than 5,400 acres (8.5 square miles).

Conclusion: Population Growth and Climate Change Will Intensify Water Scarcity

Readers may be familiar with the IPAT equation, first introduced in a 1971 paper in the journal *Science* by biologist Paul Ehrlich and physicist John Holdren (Erhlich and Holdren 1971). IPAT is shorthand for Impact (I) = Population (P) x Affluence (A) x Technology (T). The case of water resources in the United States since the 1980s is an excellent illustration of IPAT, in particular, the potential of the Affluence and Technology factors to decrease per capita water consumption, in many instances achieving a reduction in overall, aggregate water consumption (I or Impact), even as the U.S. population continued to increase quite rapidly (graph).

Just what are these Affluence and Technology factors with respect to water resources? Affluence in this case refers to cultural/social/economic choices that either reduce water consumption or reallocate water to make it go further. In the arid Southwest, substituting expansive, inappropriate green lawns with xeriscaping – landscaping with drought-tolerant, preferably native plants – can sharply reduce residential and institutional water consumption. Taking shorter showers helps too. Similarly, replacing or retiring agricultural crops requiring large amounts of irrigation water, such as many fruits and nuts and water-intensive grains like rice can save huge amounts of water. Growing one head of broccoli takes 5.4 gallons of water, one walnut 4.9 gallons, one head of lettuce 3.5 gallons, one tomato 3.3 gallons, one almond 1.1 gallons, and so forth. The water that is saved by fallowing or not growing these crops can then be redirected toward urban areas and municipal uses. In theory, the food could be grown somewhere else with more abundant water.



Population growth in five Southwestern states (California, Nevada, Utah, Arizona, and New Mexico) from 1900 with projections to 2050

Water-saving technologies and water conservation, efficiency, and reuse offer tremendous scope for reducing water consumption both in agriculture and in municipal and residential uses. A few examples of water-saving technologies and systems available even now for crop irrigation include the following:

- Pressurized water application methods (drip or micro-irrigation)
- Drought-tolerant crops and seeds
- System modernization
- Water saving rice irrigation
- Controlled drainage
- Use of lower quality waters (water reuse and recycling)
- GPS-based technology
- Reducing wastage along the food chain

These are some of the technologies and innovations that are being invented and implemented at scale to reduce the aggregate amount of water needed to irrigate and grow crops as a result of increasing perceptions of scarcity. Similarly, a number of advances have been made in recent years that increase water efficiency and conservation in residential, commercial, and institutional settings.

Water efficiency, conservation, recycling, and reuse at home, in municipalities, and in irrigated agriculture can save large amounts of water and stretch existing developed supplies much further, but they cannot work miracles or accommodate infinite or rapid, sustained population growth. This is illustrated by the case of one of the largest water utilities in the rapidly growing state of Texas, the North Texas Municipal Water District (USACE 2015). Chapter 1 of the 2015 draft environmental impact statement (DEIS) on the Section 404 permit application to the U.S. Army Corps of Engineers for the proposed Lower Bois d'Arc Creek Reservoir identified the purpose and need for this water supply reservoir on a tributary of the Red River in northeast Texas: "State population projections show the… service area population increasing from 1.6 million to 3.3 million by 2060." Chapter 1 of the DEIS specifies that although advanced water conservation, efficiency, reuse, and recycling measures are able to offset a large share of the increase in municipal and residential water demand associated with a doubling of the service area population, they are unable to negate it entirely.

What is true for Texas is true for the USA as a whole: sustained population growth will inevitably, sooner or later, wipe out conservation and efficiency gains, triggering water shortages and/or a need for new environmentally damaging water projects. As noted earlier in this paper, water saved from conservation and efficiency should be returned to or left in aquatic ecosystems, not piped to a new housing subdivision or a new power plant necessitated by the nation's addiction to population growth. Water savings from efficiency and conservation should not be squandered to accommodate still more population growth.

Climate change and global warming will severely aggravate water scarcity in much of the United States, especially the booming Southwest and Southeast. Projected changes in precipitation patterns and reduced water availability will severely impact both ecosystems and economies in these regions. An intelligent response to this dilemma would begin by recognizing that unnecessarily adding tens of millions of additional residents to these beleaguered regions from mass immigration will only worsen the situation and occasion even harsher hardship, scarcity, and impacts.

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