



# Water Utilization: An Analytical White Paper

## Executive Summary

- The intervention of humans does not really cause problems with the “use” of water, but rather with the movement of water from one place to another, and with the rate at which that water moves. The solutions to each of these issues are likely to be quite different.
- Transpiration is the movement of water through a plant, to carry nutrients and generate cooling, and accounts for about 10% of all evaporation. Water movement away from a field surface can be via leaching, evaporation, or transpiration: in many situations these are combined, and called evapotranspiration.
- It has been calculated that, on average, the 48 continental states receive enough precipitation in one year to cover the land to a depth of ~30 inches (USGS, 2009). Suggesting there is no real shortage of water falling in the US but, in reality, shows how averages can be misleading.
- From 1950 to 1980, there was increasing water utilization and a growing concern that, with population and economic growth, there would be a large increase in the volume required. However, due to water awareness, economic factors, and newer technologies being applied, water volume utilization has been about flat since around 1980, despite population and economic growth.
- Irrigation water utilization volume was ~40% of the total and included water that is applied for pre-irrigation, frost protection, application of chemicals, weed control, field preparation, crop cooling, harvesting, dust suppression, leaching salts from the root zone, and water lost in conveyance. Irrigation of golf courses, parks, nurseries, turf farms, cemeteries, and other self-supplied landscape-watering uses also are included.
- The trend for less water application per acre supports the fact that there have been considerable improvements in water use efficiency across most crop sectors: mostly due to changes in irrigation practice and systems.
- More timely information and availability of current data is important. At present, the data being used is possibly no longer relevant, or is not a clear current picture.
- Corn is a relatively small user in terms of irrigation. Across the US, the acres of corn irrigated represent 21% of the total irrigated area. However, the volume of water utilized in corn irrigation represents only 7% of all irrigation water.



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For NCGA by Dr. J. McLaren, StrathKirn Inc.

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## 1. Defining the Basic Issue and the Global Water Situation

Trends in water utilization are showing that continuous improvement is now underway in many countries, yet numerous challenges remain in the realm of water. For example, some of the top issues include: population pressures, infrastructure needs, food production and agricultural changes, energy generation, an ever-changing climate, and environmental concerns. While these issues are important, and deserve attention, there is a larger underlying problem related to water in that the fundamental water situation is not well-defined, the data is non-uniform, the definitions are varied (and often technically inaccurate), and water is often a political hammer which leads to emotional statements and actions. And, as illogical as it sounds, all of this on a planet where water covers ~70% of the surface.

In order to develop solutions to a problem it is first important to properly define the situation in realistic terms, and to identify the top priority issues for resolution. Humans talk a lot about “water use” but what does that really mean? Are we removing water from the planet? Are we changing it into something else? Or, are we just moving it around from place-to-place? According to Connor *et al* (2009), common definitions around water include:

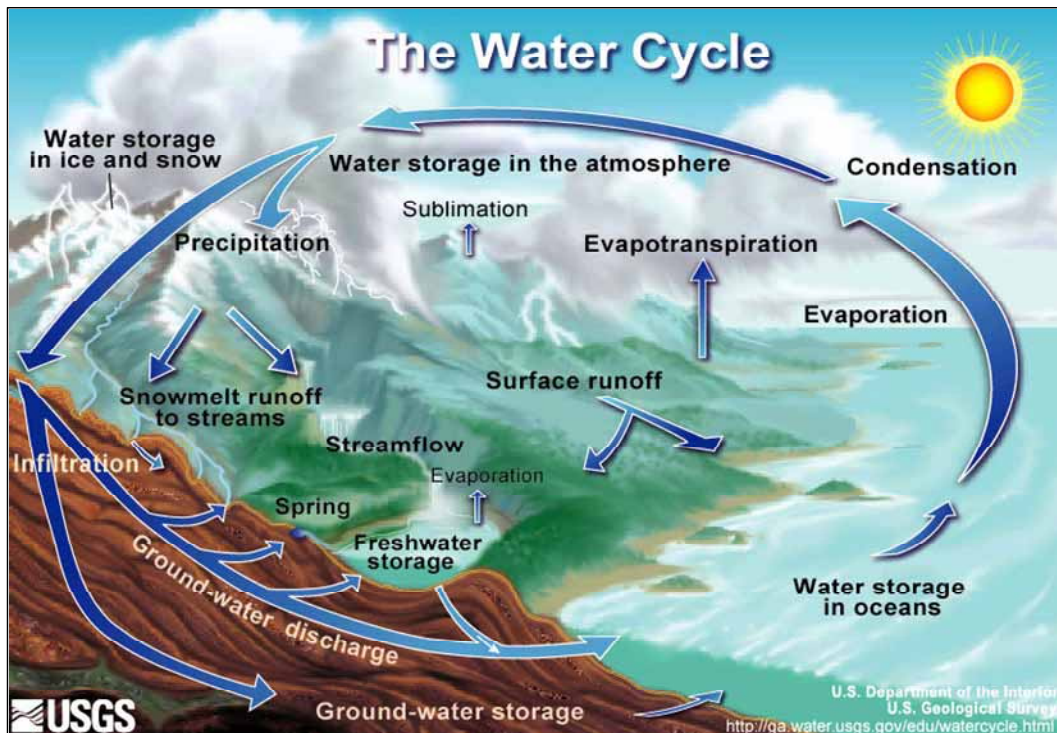
- **Water use** refers to water that is being put to beneficial use by humans. Detailed water accounting, however, requires more precise definition.
- **Water withdrawal** is the gross amount of water extracted from any source in the natural environment for human purposes. Differentiating withdrawals by type of source is useful to understand the pressure put on different parts of the system.
- **Water demand** is the volume of water needed for a given activity. If supply is unconstrained, water demand is equal to water withdrawal.
- **Water consumption** or consumptive use refers to that part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment.

While these definitions are a good start and help set a common baseline, in most situations “water use” or “water consumption” is not the technical equivalent of water being chemically, or reactively,

removed from the environment, and this aspect is not defined. For example, in industrial processes water may be utilized in a chemical reaction to make a particular product (e.g. hydration of a polymer for plastic film) or, alternatively, in some situations it may be utilized for cooling and then be re-cycled. In one situation water is used (not easily recoverable) and in the other case water is utilized by moving it from one place in the environment to another place in the environment. In agriculture, water may be “used” in photosynthesis, where H<sub>2</sub>O is physically split into hydrogen and oxygen and the hydrogen is incorporated into fixed carbon-based materials for food and energy. Or, for most crop situations, water is moved in a natural process called evapotranspiration, where water moves from the soil to the air via the plant tissues resulting in a cooling effect. In case of photosynthesis, water is “used” and is permanently removed from the total water pool, while in the case of evapotranspiration water is moved from one place to another in the environment.

Therefore, the intervention of humans does not really cause problems with the “use” of water, but rather with the movement of water from one place to another, and with the rate at which that water moves. The solutions to each of these issues are likely to be quite different.

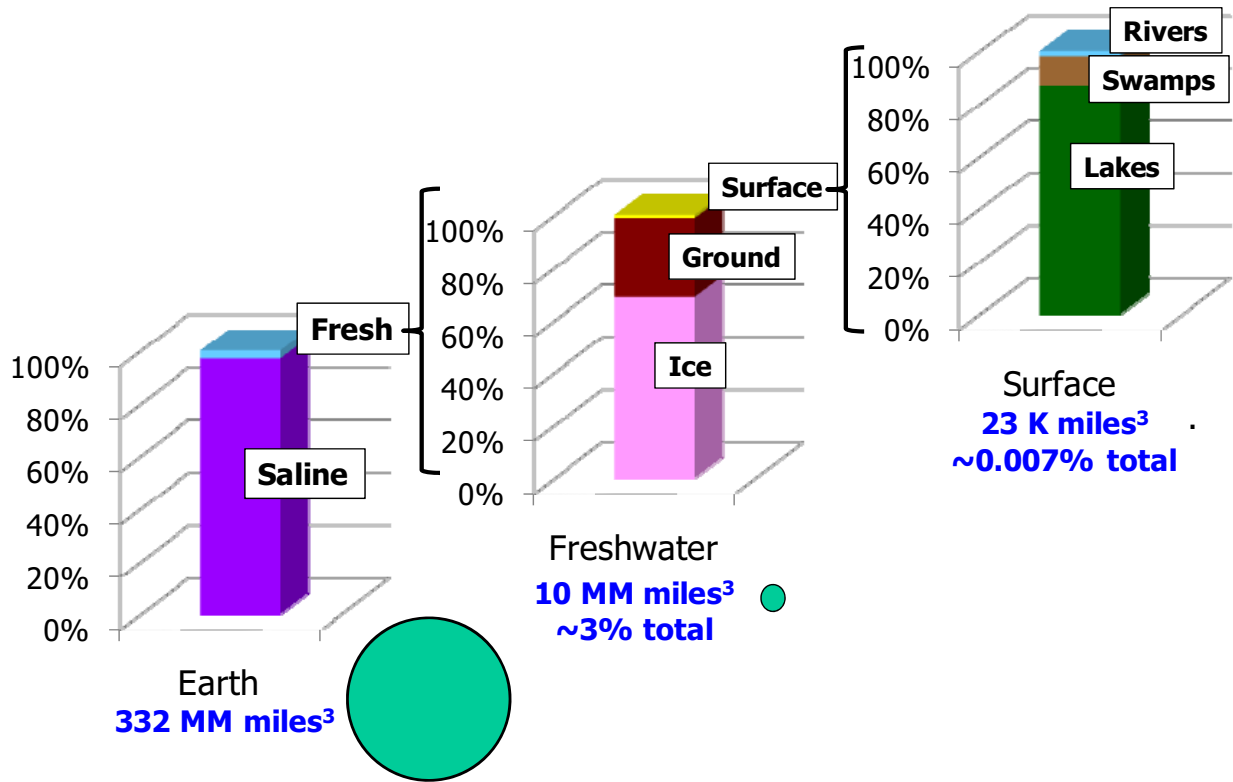
In nature, water can be found as a solid (ice), liquid, or gas, and is continually moving among the types and from one place to another. This process is called the hydrologic or water cycle:



Water evaporates from the ocean and, as it reaches cooler altitudes, the vapor condenses to form clouds. Clouds may move around but within a few days the water returns to the surface as precipitation. Much of the precipitation returns the water directly to the ocean, but about 25% falls over land. From the ground, water may evaporate again, or penetrate the surface and be a) taken up by plants and move back into the atmosphere by transpiration, b) enter into the river/lake system to be evaporated or

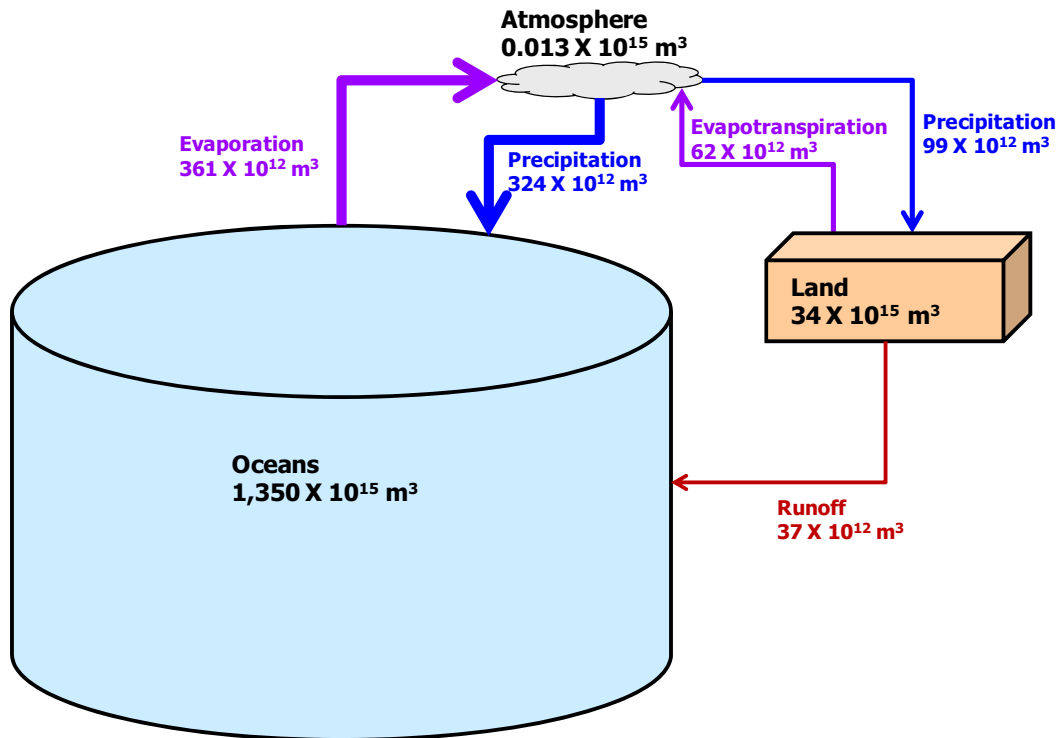
carried back to the ocean, or c) be stored for many years in underground aquifers. In general, there is continuous movement of water, but the actual rates of movement and residence time in various locations depend on several factors, including anthropogenic intervention. For example, the average residence time in the atmosphere is 7-9 days while underground aquifer residence time can be over 100,000 years.

The size of the various location reservoirs is also important, and meaningful relative to the flux (out and in) rates, and how these are impacted by human actions. Current estimates (Gleick, 1996) put the world's total water volume at ~332.5 million cubic miles, with ~97% being salt water. Of the ~3% total freshwater, about two-thirds is held in ice and glaciers, and ~30% is in the ground. Rivers, lakes and other fresh-water surface volumes are only ~23,000 cubic miles (0.007% total), yet humans tend to focus on this small amount of water rather than on the massive volumes in other locations. These relative volumes are depicted in the following diagram:



In the above diagram, the circles provide a visual representation of the large size differences in various locations, and the number provides an estimate of the total volumes in cubic miles.

In addition to the large differences in location pool sizes, it is important to understand the flow rates between the various locations. The following diagram provides a global estimate (WW2010, 2009) of the main flow rates between major water locations, and demonstrates the balance achieved in the hydrologic cycle:



On a global scale the location sizes remain constant, with the evaporation being balanced by the total return volumes via precipitation and runoff. Note that water does not disappear: i.e. it is not “used” but rather moves from location to location. The energy required to drive the movement around the hydrologic cycle is obtain from the sun.

Transpiration is the movement of water through a plant, to carry nutrients and generate cooling, and accounts for about 10% of all evaporation. Water movement away from a field surface can be via leaching, evaporation, or transpiration: in many situations these are combined, and called evapotranspiration. The process of photosynthesis does “use” a small amount of water but this is not measurable on the global scale.

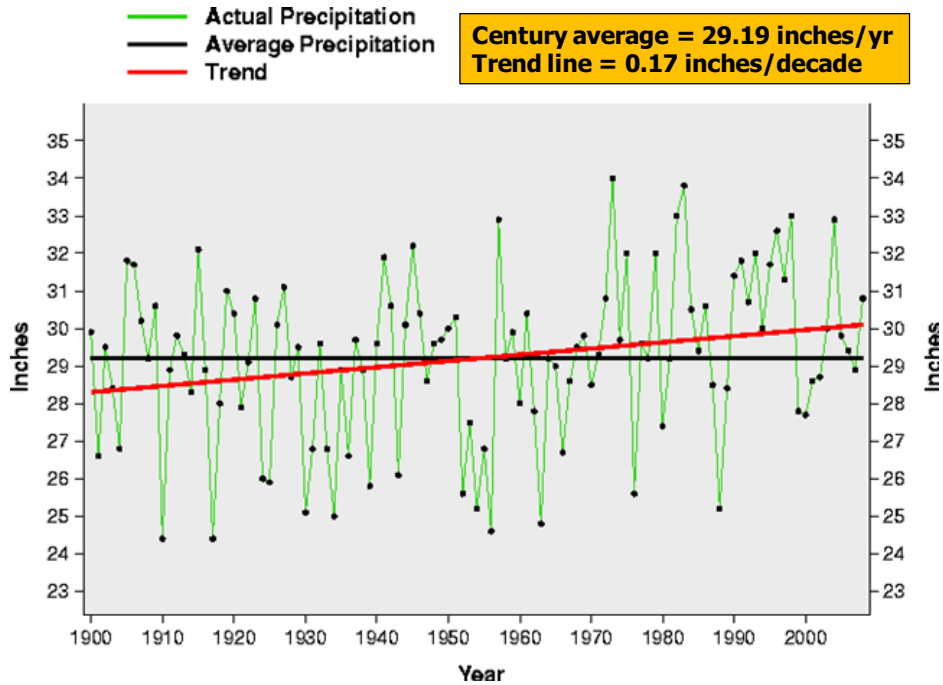
## 2. Overall US Water Situation

### Supply & Reserves

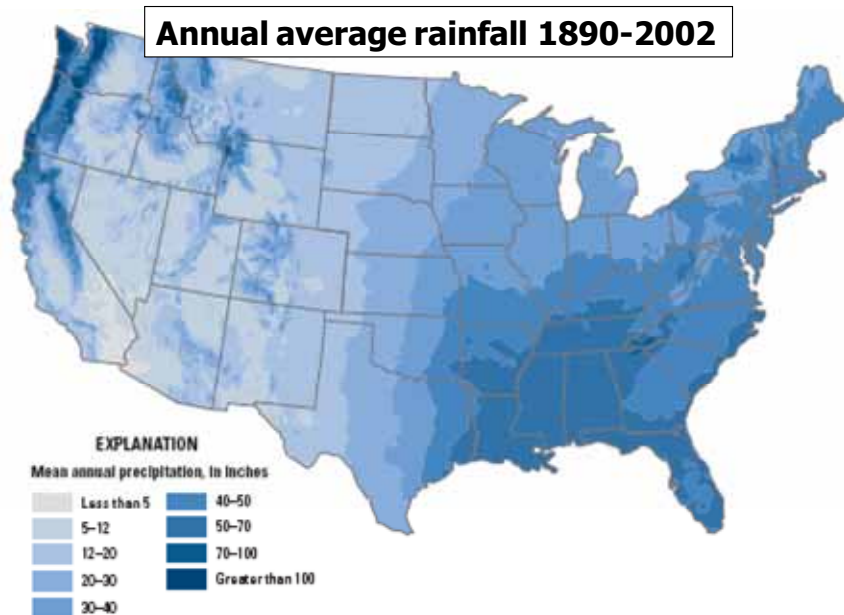
It has been calculated that, on average, the 48 continental states receive enough precipitation in one year to cover the land to a depth of ~30 inches (USGS, 2009). This example suggests that there is no real shortage of water falling in the US but, in reality, shows how averages can be misleading.

Clearly, the overall US precipitation is considerable but does not occur in a uniform distribution, and evaporation is not uniform, leading to some wet areas contrasted with dry areas across the country (see charts below). However, this example does highlight the point that water issues typically arise due to location rather than total volume. The additional dimension to be considered is time, since precipitation and flow rates between locations may vary over time.

The annual average precipitation trend, over the past century in the US, shows a very slight increase in rainfall (approx 0.17 inch/decade increase): as show in the following chart with data from NCDC (2009):

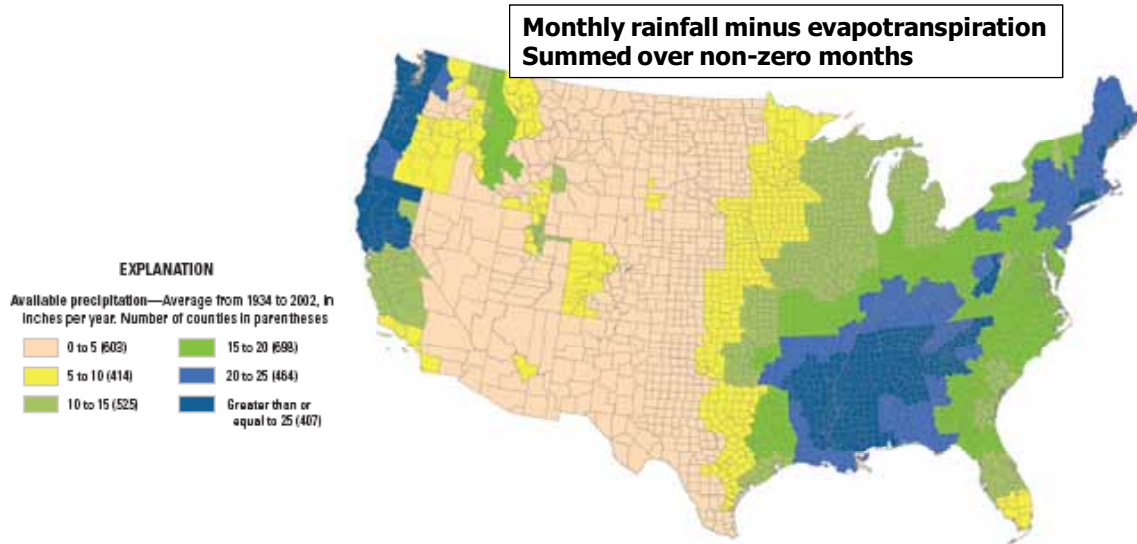


The distribution of precipitation is demonstrated by mapping the annual average rainfall over 1890-2002 (Reilly *et al*, 2008):

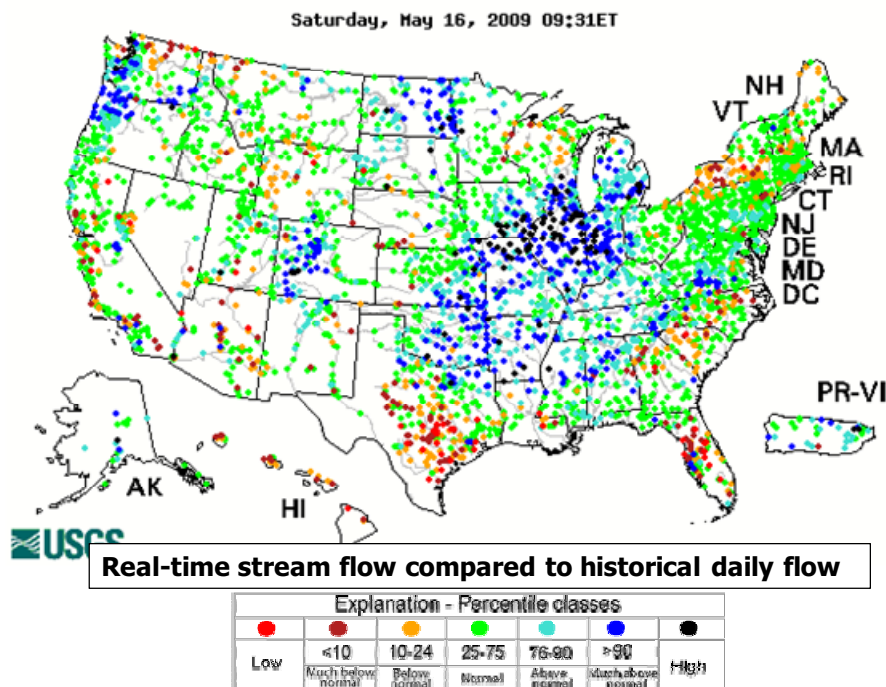


This precipitation is the resource that currently accounts for evapotranspiration, run-off via streams, and re-charge of lakes and ground-water aquifers. Thus, it is not all available for interception by humans. The following chart shows an estimate of the precipitation available for run-off and re-charge, over 1943-

2002: calculated as the difference between monthly precipitation and monthly potential evapotranspiration, then summing the non-zero months (Reilly *et al*, 2008):



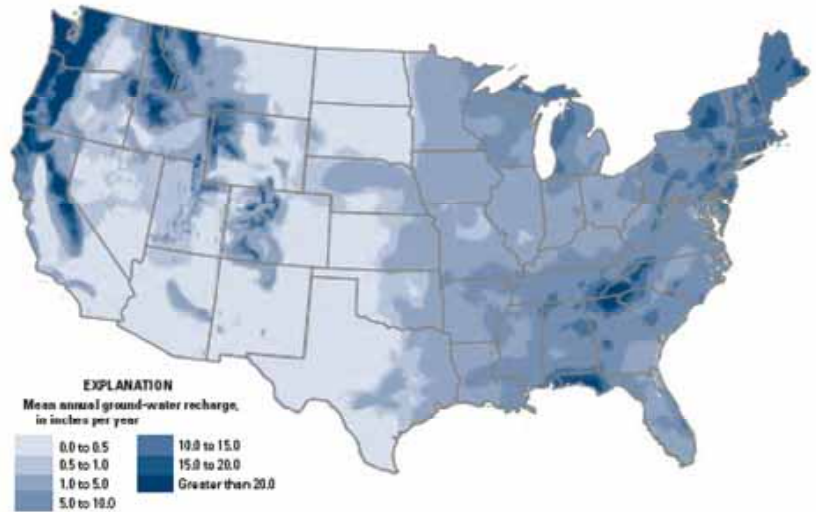
Run-off impacts stream flow which is highly variable for any particular location over time. Real-time data is now available to track such changes (USGS, 2009), for example:



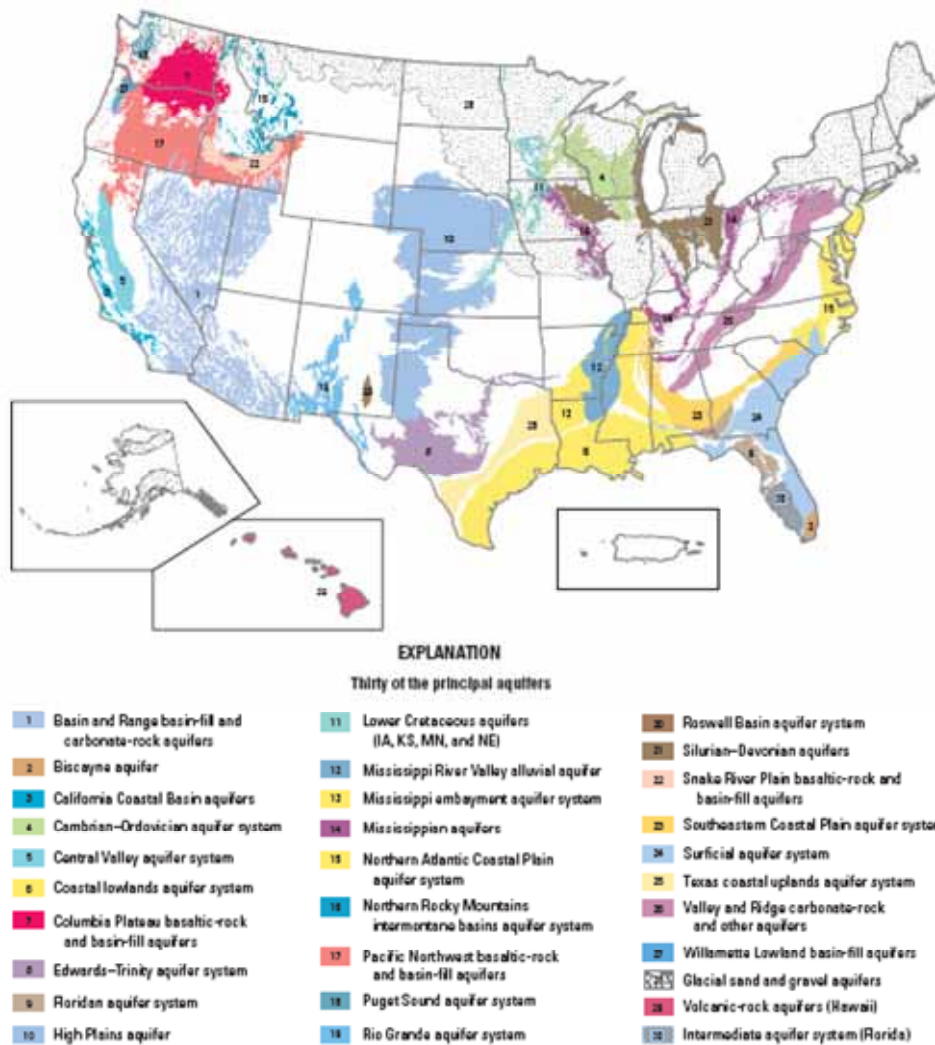
The estimated average water available for re-charge (Reilly *et al*, 2008) has been estimated (not necessarily accurate for all conditions today, but gives an approximation of the distribution). This potential re-charge capability can be compared to the locations of the ground-water aquifers, as shown in the next two charts:

Distribution of the average available water for re-charge.

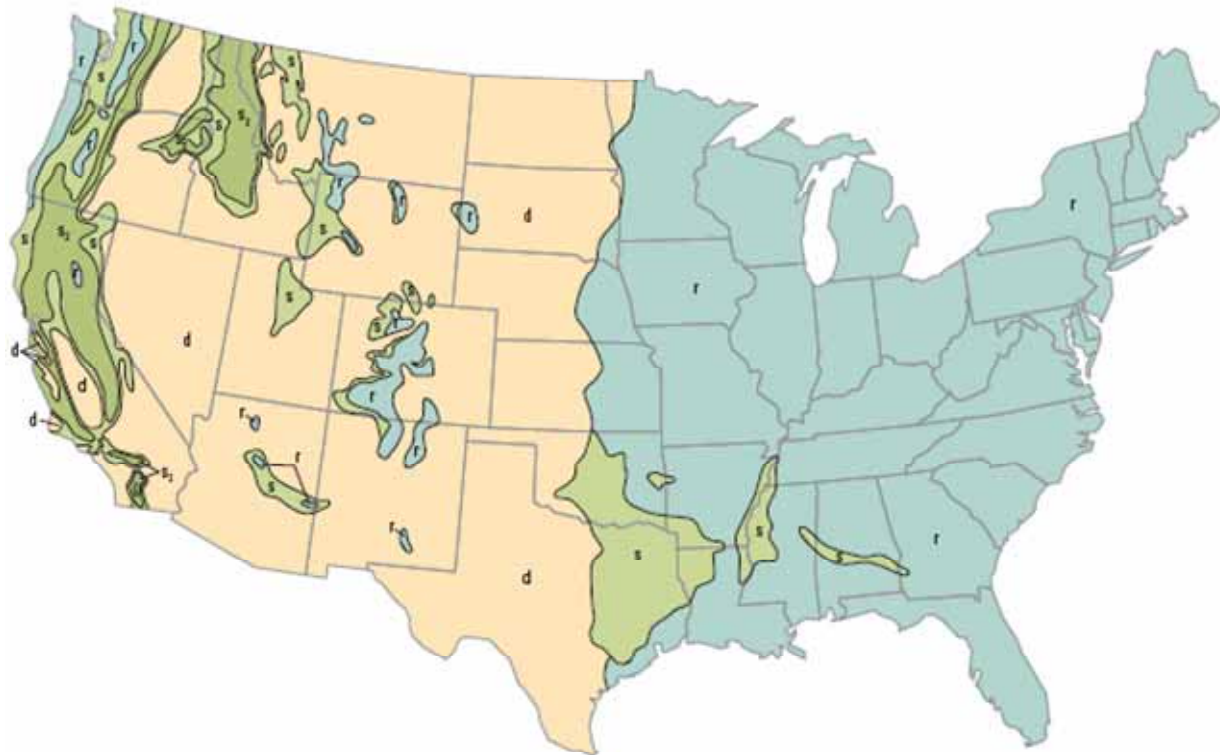
[At 1-km resolution and for the period 1951-1980].



The US has over 60 large aquifers, with the main 30 aquifers accounting for ~94 percent of the total ground-water withdrawals for public supply, irrigation, and self-supplied industrial uses combined:



Other water reserves include the Great Lakes (shared with Canada), with a total volume of ~2,900 mile<sup>3</sup> which is 21% of the total surface fresh water on the planet. All the other US lakes, rivers, and reservoirs are estimated at 2,540 mile<sup>3</sup>. However, from the previous distribution charts it is clear that most of the lake resources are not in areas where water deficits are common. Much of the western United States, except for some coastal areas, has far less water available for ground-water recharge and use than the rest of the country. The following chart has been compiled from various data (see Reilly et al, 2008) and shows areas of little or no water deficiency, areas of seasonal moisture variation (summer deficiency and winter surplus), and areas with little or no water surplus:



**EXPLANATION**

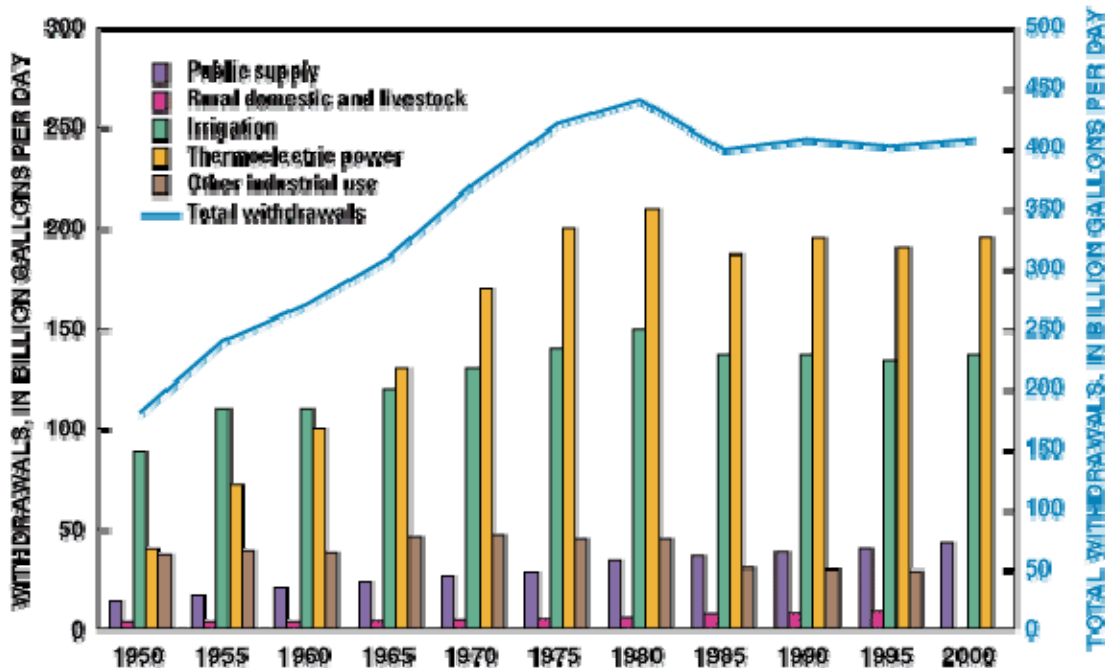
- r **Little or no water deficiency in any season—Occurs only in moist climates**
- s **Moderate seasonal moisture variation with summer the driest season—**  
Summer water deficiency in moist climates; winter water surplus in dry climates
- s<sub>2</sub> **Large seasonal moisture variation with summer the driest season—**  
Summer water deficiency in moist climates; winter water surplus in dry climates
- d **Little or no water surplus in any season—Occurs only in dry climates**

Finally, there is a large water resource in the US coastline, although this tends to be ignored due to the saline nature of the water. In the future, this resource will become a key source from which to move water to irrigate, propagate, utilize, and even re-charge the aquifers.

## Utilization

The USGS has compiled data on water withdrawals by state, source of water, and category of use, at 5-year intervals since 1950 (USGS, 2009B). The most recent report released is "Estimated use of water in the United States in 2000", and marks 50 years of water-use data. (note that 2005 data is still under analysis and is projected for release around mid-2009). While USGS refers to water use, it should be kept in-mind that this water is not "used" but rather "utilized" for various purposes by moving it from one location to another, or by moving from a location for a period of time. There are multiple dimensions to water utilization: e.g. geographical factors, saline/freshwater, type of utilization, source of withdrawal, return to re-charge rates, quality changes, and temporal patterns. Dealing with each dimension and the interactions between the factors results in hundreds of views. For this report, we include the higher level views for each type of utilization plus some additional detail for specific selected situations and geographies.

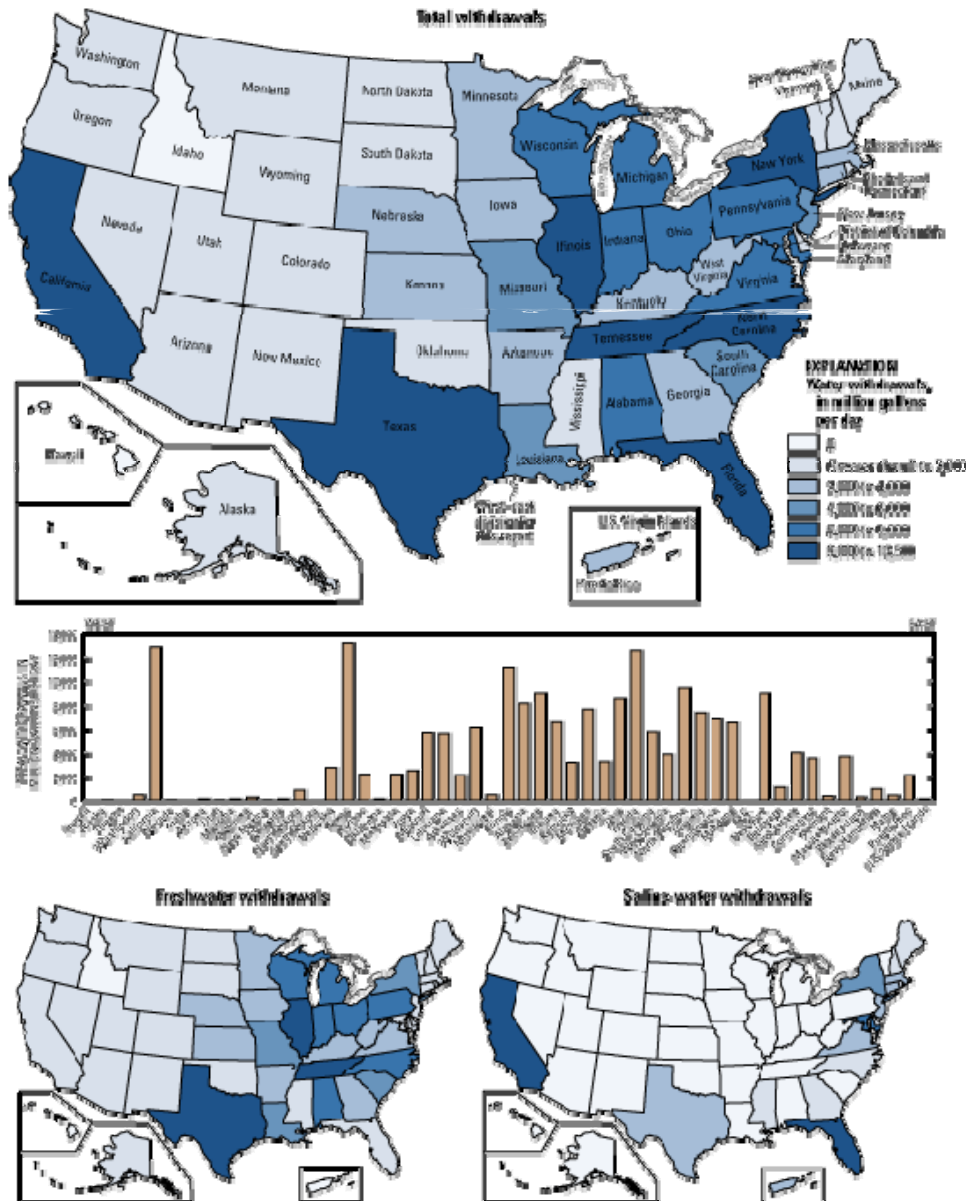
From 1950 to 1980, there was increasing water utilization and a growing concern that, with population and economic growth, there would be a large increase in the volume required. However, due to water awareness, economic factors, and newer technologies being applied, water volume utilization has been about flat since around 1980, despite population and economic growth. These trends are shown in the following chart with data from USGS (2009B), with details shown in the appendix:



At the last official estimate, in 2000, some 408 B gal/day were withdrawn for all uses during the year, and that was less than in 1980: water is now being utilized more efficiently. Decreases in total volume occurred in thermoelectric, irrigation, other industrial (e.g. mining/manufacturing) applications, which more than off-set increases in public supply, rural domestic supply, livestock and aquaculture. [It will be interesting to see if the trends continued through 2005, when the most recent data are released.]

**Thermoelectric Power (50% of 2000 total)**

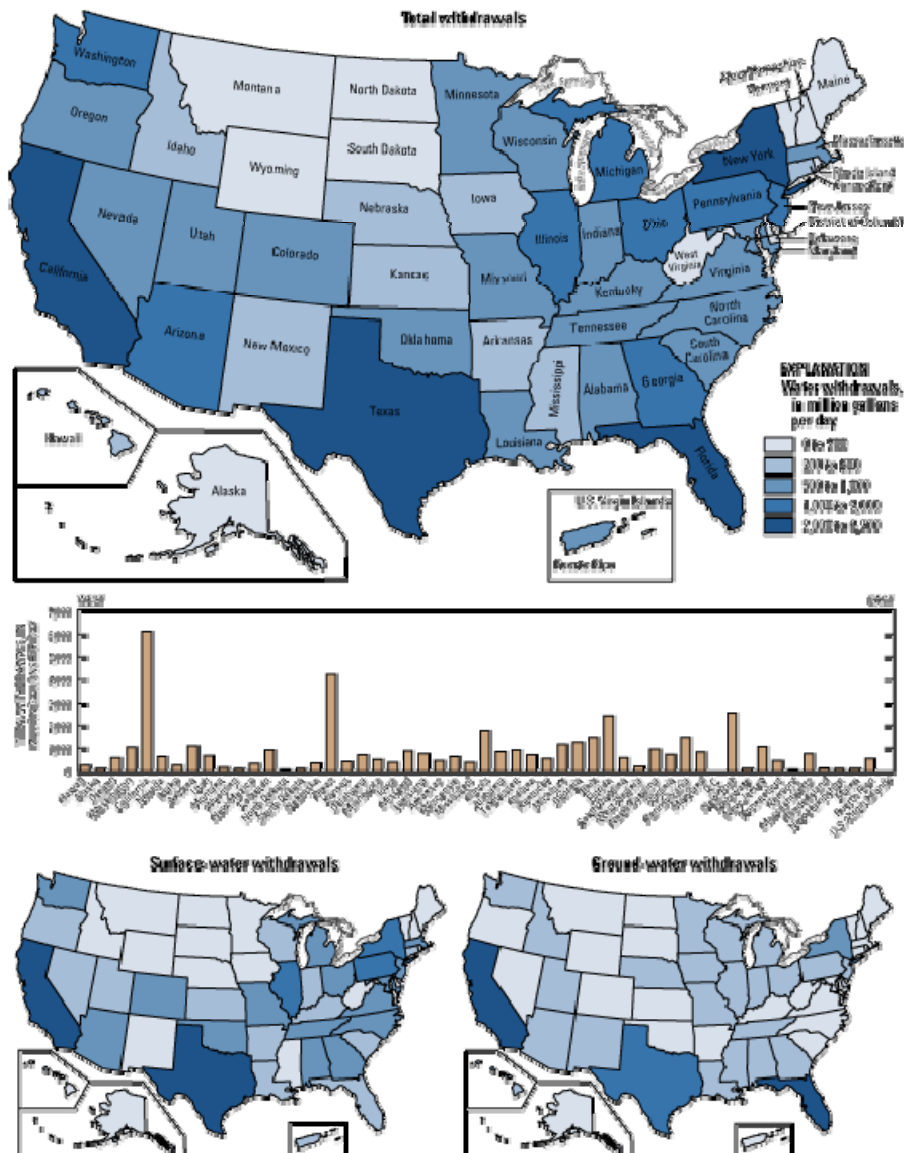
Note that hydroelectric power is considered an in-stream use and is not included in the USGS use report. Water withdrawal for cooling at thermoelectric generation facilities accounts for ~50% of the total water utilized in the US (~3% increase from 1995 to 2000). Surface water was the source for >99% of these withdrawals, and ~30% was surface saline water. The following chart shows the distribution (USGS, 2009B):



Fresh and saline water withdrawals in the eastern states were 83 percent of the total. Texas is the single largest state for this type of utilization. The states around the Great Lakes withdraw a high volume for cooling – the electricity generation facilities were often designed to have access to this water resource.

## Public Water Supply (13% of 2000 total)

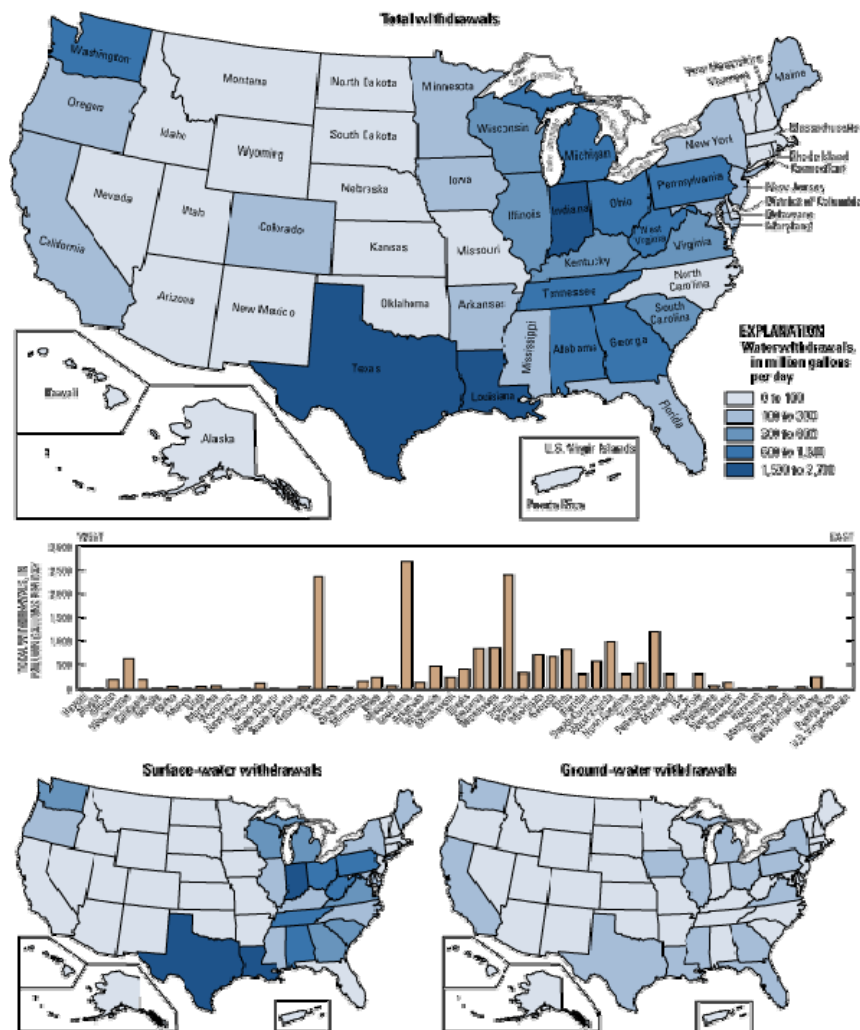
Public supply is defined as water withdrawn by public and private water suppliers that furnish water to at least 25 people or have a minimum of 15 connections, and may be delivered to users for domestic, commercial, industrial, or thermoelectric-power purposes. The public-supply withdrawals are mostly all fresh-water. Public-supply withdrawals were ~13% of total withdrawals and ~63% is withdrawn from surface sources. States with the largest populations withdrew the largest quantities of water: California, Texas, New York, Florida, and Illinois accounted for 40 percent of total public-supply withdrawals. The geographic distribution of public supply withdrawals is as follows (USGS, 2009B):



In 1950, only ~62% of the US population received water from public supply while by 2000 that had risen to ~85%. The trend to more public supply water is expected to continue.

## Industrial Water (5% of 2000 total)

Note that the data for this section refers to “self-supply” industrial, while in reality additional industrial water may be supplied via the public supply. Industrial water utilization was ~5% of the total. Utilization and use purposes include fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product; or for sanitation needs within the manufacturing facility. Examples of industries with large water utilization include: food, paper, chemicals, refined petroleum, and primary metals. In 2000, surface water was the source for 82 percent of total industrial withdrawals. Nearly all (92 percent) of the surface-water withdrawals and nearly all (99 percent) of the ground-water withdrawals for industrial use were freshwater. For 2000, total industrial withdrawals were 11 percent less than during 1995. As shown in the following chart (USGS , 2009B), Louisiana, Indiana, and Texas accounted for almost 38 percent of total industrial withdrawals. The largest fresh surface-water withdrawals were in Louisiana and Indiana, which together accounted for 32 percent of the total fresh surface-water withdrawals. The largest fresh ground-water withdrawals were in Georgia, Louisiana, and Texas, which together accounted for 23 percent of the total fresh ground-water withdrawals. Texas accounted for 71 percent of the saline surface-water withdrawals for industry.



## **Other** (4-5% of 2000 total)

**Mining** water use is water for the extraction of minerals, coal, iron, sand, and gravel; liquids such as crude petroleum; and natural gas. The category includes quarrying, milling (crushing, screening, washing, and flotation of mined materials), re-injecting extracted water for secondary oil recovery, and other operations associated with mining activities. All mining withdrawals were ~1% of the 2000 total.

**Domestic** water use is water utilized for a range of purposes including, drinking, preparing food, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens. Water for domestic use may be delivered from a public supplier (reported under public supply) or be self-supplied – typically, from a well. For self-supplied domestic water, the withdrawals were ~1% of the 2000 total.

**Livestock** water use is water associated with livestock watering, feedlots, dairy operations, and other on-farm needs. All livestock water withdrawals were less than 1% of the 2000 total.

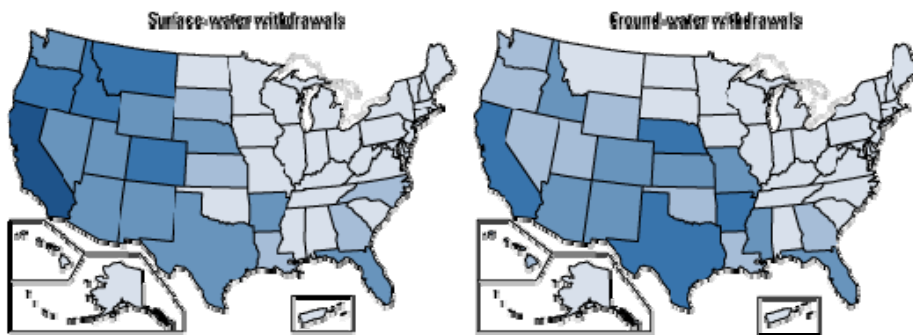
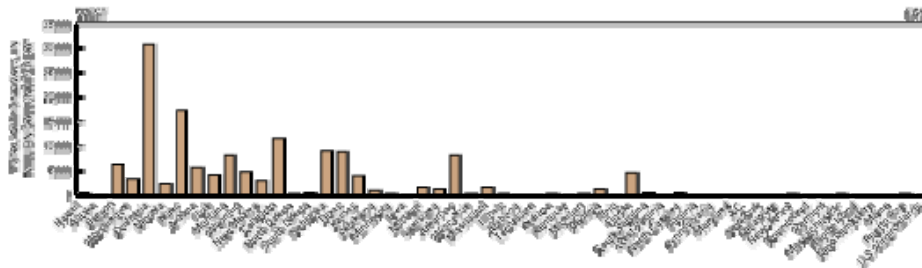
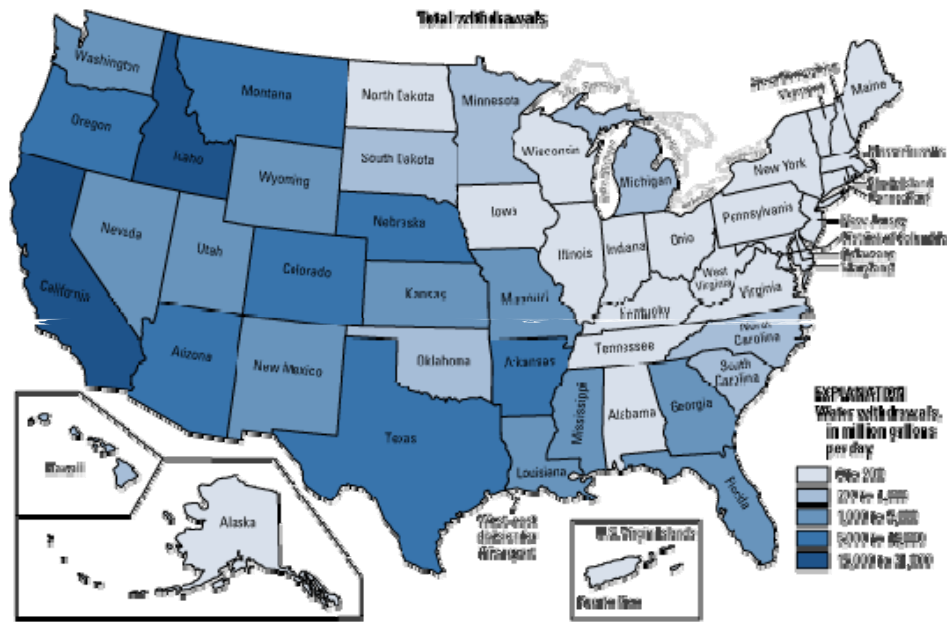
**Aquaculture** water use is water associated with raising organisms that live in water for food, restoration, conservation, or sport. Aquaculture production occurs under controlled feeding, sanitation, and harvesting procedures primarily in ponds, flow-through raceways, and, to a lesser extent, cages, net pens, and closed-recirculation tanks. All aquaculture water withdrawals were almost 1% of the 2000 total.

## **Irrigation** (40% of 2000 total)

Irrigation water utilization volume was ~40% of the total and included water that is applied for pre-irrigation, frost protection, application of chemicals, weed control, field preparation, crop cooling, harvesting, dust suppression, leaching salts from the root zone, and water lost in conveyance. Irrigation of golf courses, parks, nurseries, turf farms, cemeteries, and other self-supplied landscape-watering uses also are included. All irrigation withdrawals were considered freshwater and 58% was taken from surface-water sources, but the central states had the majority taken from ground-water sources. The average application rate was 2.48 acre-feet per acre, across the 61,900 irrigated acres reported in 2000.

The following chart (USGS, 2009B) shows that the majority of irrigation withdrawals (86 percent) and irrigated acres (75 percent) were in the 17 conterminous western states, especially where average precipitation was less than 20 inches. The top 5 states for irrigation volume, in the 2000 survey, were California, Idaho, Colorado, Nebraska, and Texas and accounted for over 50% of the total irrigation water withdrawals. California and Idaho accounted for 40 percent of surface-water withdrawals. California and Nebraska accounted for one-third of ground-water withdrawals.

Estimates of total irrigation withdrawals for 2000 were about 2 percent more than during 1995. Surface-water withdrawals were about 5 percent less for 2000 compared to 1995, but ground-water withdrawals were 16 percent more. The estimated number of irrigated acres was about 7 percent more, which resulted in a slightly lower average application rate for 2000.



About 61.9 million acres were irrigated in 2000. Application rates were greatest in the arid West and the Mountain states where surface water was available and surface (flood) application was the predominant method of irrigation (29 MM acres). In Arizona, Montana, and Idaho, application rates exceeded 5 acre-feet per acre. states that utilized the High Plains aquifer (Nebraska, Texas, Kansas, and Oklahoma) or the Mississippi River alluvium (Arkansas, Missouri, Mississippi, and Louisiana) for irrigation relied mostly on ground water and had application rates ranging between 1 and 2 acre-feet per acre. Sprinkler irrigation (28 MM acres) was the predominant application method in the Central Plains states of Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas. California alone accounted for 72 percent of the irrigated acreage by micro-irrigation systems (4 MM acres). Surface irrigation was the predominant application method in Arkansas, Louisiana, Mississippi, and Missouri.

## Other irrigation information

The USDA carried out a specific survey on irrigation as a supplement to the 2007 Agricultural Census. The results will be available November 30, 2009.

### Current USDA Information for all crops

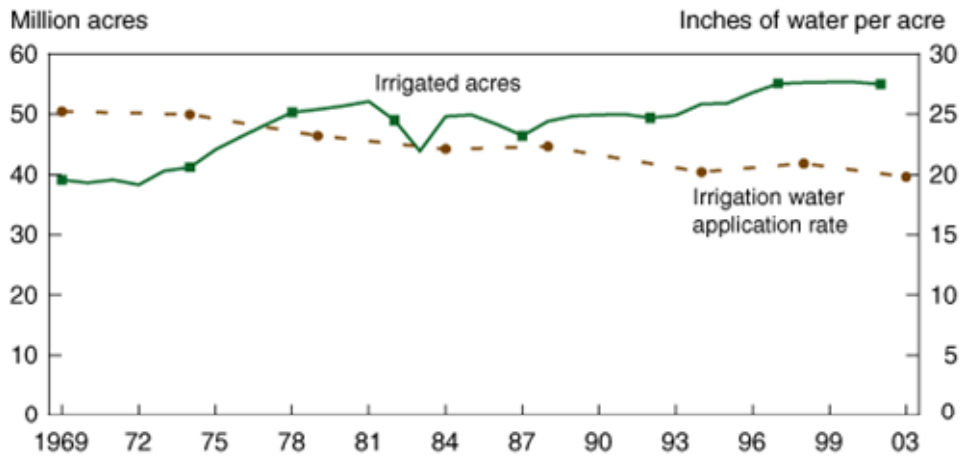
While the USGS has irrigation volume at 61.9 MM acres, the USDA irrigation acres in the range of 50-55 MM acres: we believe the difference here is that USGS includes golf courses and other landscape areas, while the USDA area is based on actual crops. The USDA reports the following regional irrigation areas:

Region or crop	1969 <sup>1</sup>		1997 <sup>2</sup>		2002 <sup>2</sup>	
	1,000 acres	Percent	1,000 acres	Percent	1,000 acres	Percent
United States <sup>3</sup>	39,100	100	56,289	100	55,311	100
<b>Region</b>						
Eastern regions <sup>4</sup>	4,200	11	12,308	22	13,288	24
Northern Plains	4,600	12	10,312	18	10,907	20
Southern Plains	7,400	19	6,273	11	5,592	10
Mountain	12,800	33	13,603	24	13,011	24
Pacific Coast	10,000	26	13,713	24	12,440	22
<b>Crop</b>						
Corn for grain	3,200	8	10,816	19	9,710	18
Other grains	9,200	24	9,245	16	7,703	14
Soybeans	700	2	4,238	8	5,460	10
Cotton	3,100	8	5,152	9	4,802	9
Alfalfa hay	5,000	13	6,087	11	6,809	12
Vegetables and orchards	3,900	10	6,722	12	6,734	12
Other lands in farms <sup>5</sup>	14,000	36	14,030	25	14,093	25
<sup>1</sup> Census of Agriculture.						
<sup>2</sup> Census of Agriculture, adjusted for non-response.						
<sup>3</sup> Includes Alaska and Hawaii.						
<sup>4</sup> Northeast, Appalachian, Southeast, Lake States, and Corn Belt.						
<sup>5</sup> Other uses with more than 500,000 irrigated acres include corn silage, other hay, dry beans, potatoes, sugar beets, nursery crops, cropland pasture, and other pasture.						
Source: USDA, Census of Agriculture, selected years.						

The data support the observation that irrigation in most regions is flat to down in terms of acres, except in the Eastern region where irrigated acres have increased slightly in recent years. *These trends were up until 2002 and the 2007 data are not yet released but we know for example that 2007 corn irrigated acres were reported at 13.2 MM acres – a considerable increase over 2002.*

While acres may have increased, the volume of water utilized for irrigation has declined (or been flat) since 1980. The application rate per acre has declined, as shown in the following chart:

### Trends in acres irrigated and water application rate from 1969 to 2003



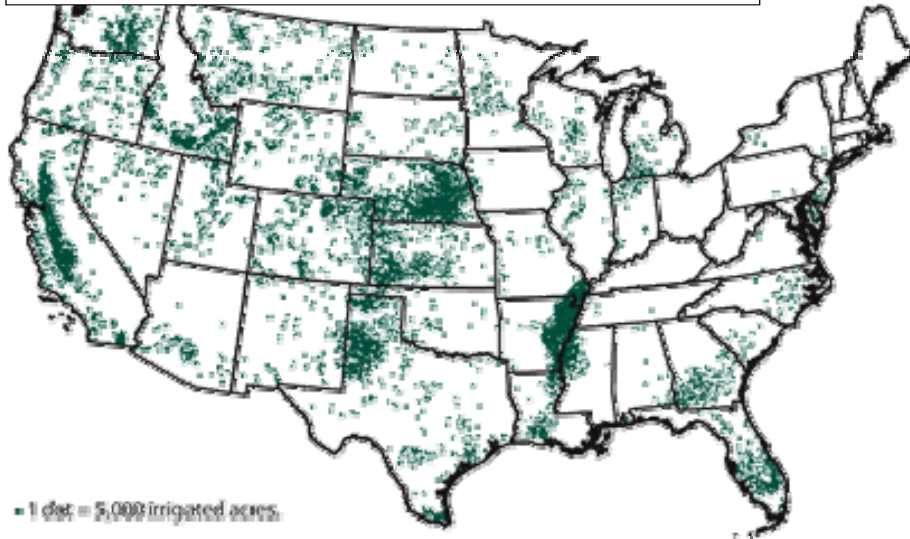
Source: USDA, Census of Agriculture and Farm and Ranch Irrigation Surveys, various years. Variation between Census of Agriculture years based on ERS estimates.

This trend for less water application per acre supports the fact that there have been considerable improvements in water use efficiency across most crop sectors: mostly due to changes in irrigation practice and systems. The USDA data from special Farm and Ranch Irrigation Surveys associated with each agricultural census (USDA, 2004) also supports this trend as follows:

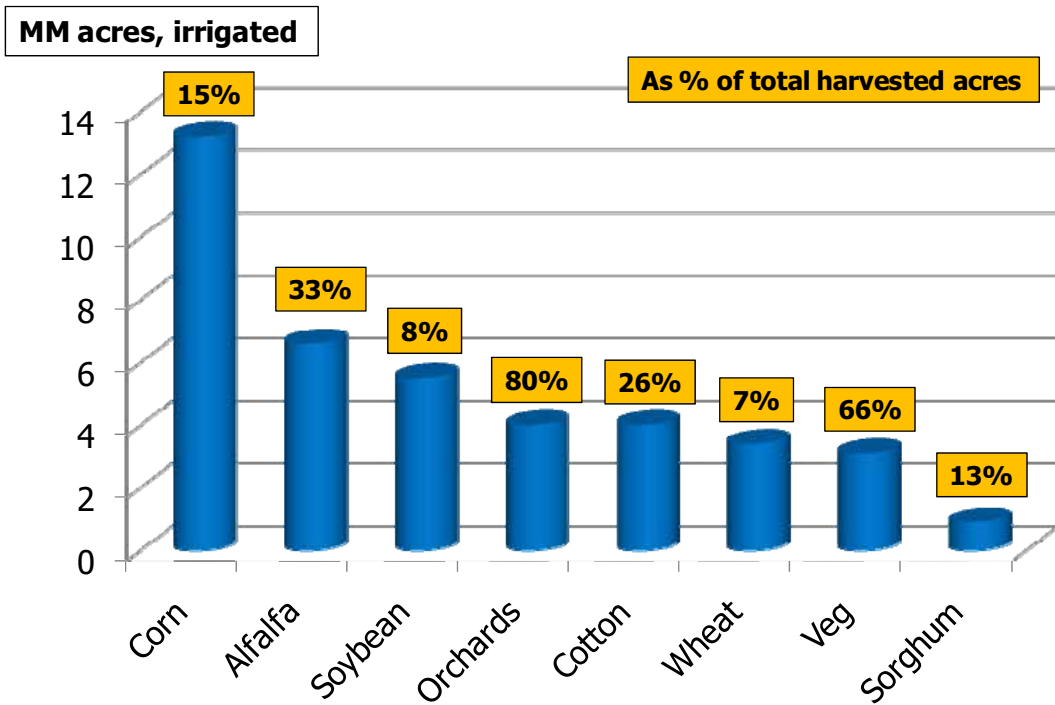
System	1979	1998	2003	Change 1979-98	Change 1998-2003
	<b>Million acres</b>			<b>Percent<sup>a</sup></b>	
All systems	50.2	54.2 <sup>b</sup>	52.6	8	-3
Gravity-flow systems	31.2	26.8	23.1	-14	-14
Sprinkler systems	18.4	24.6	26.9	34	9
Center pivot	8.6	18.5	21.3	115	15
Mechanical move	5.1	3	2.7	-41	-10
Hand move	3.7	1.9	1.7	-49	-11
Solid/permanent set	1	1.2	1.2	20	0
Low-flow irrigation (drip/trickle and micro-sp)	0.3	2.2	3	633	36
Subirrigation	0.2	0.6	0.3	200	-50
<sup>a</sup> Numbers in ( ) indicate a decrease.					
Based on USDA NASS 2001 revised estimate for 1998 due to re-weighting for undercoverage. (The sum of subcategories will differ slightly from aggregates because of rounding error.)					
Source: USDA-ERS, based on Farm and Ranch Irrigation Surveys					

The main trends in the data indicate that gravity-flow systems have been declining, low-flow type systems have been increasing, and sub-irrigation has been highly variable (low base acres). The total acres reported as irrigated in this data is less than the USDA reported in the census data, and we are uncertain where the differential arises. Therefore, we use the commonly quoted 55 MM acres for crop irrigation across the US. The distribution of all agricultural irrigation is:

**Distribution of irrigated land in farms, 2002.  
Total area is estimated at ~55 MM acres**



The distribution of irrigation by crop in terms of acres and in relation to the % of total harvested acres is as follows:



Corn has the highest number of acres irrigated but it is a relatively low percent of the total corn acres harvested.

## Other notes on overall irrigation of crops

The USDA often quotes irrigation as being “80 % of consumptive water use” which is a misleading number based on the definition – which excludes water utilization in thermoelectric situations. As we saw from the USGS water volume data (previous charts), thermoelectric is actually the largest volume of water withdrawals and, when that is included then irrigation accounts for ~40% of the water volume utilized across the country (yr 2000 numbers).

**NOTE:** the total withdrawals of water for irrigation can be calculated as:

$$61,900,000 \text{ acres} \times 2.48 \text{ acre feet} = 153,512,000 \text{ acre-ft/year}$$

The USDA estimates that, as a whole, the US has abundant freshwater supplies. Annual renewable supplies in surface streams and aquifers total roughly 1,500 million acre-feet per year (maf/yr).

On aggregate the refresh volume (stream run-off plus aquifer re-charge) is 10X higher than the water withdrawal volume. Where does that water go? Either re-charge or run-off excess to the sea.

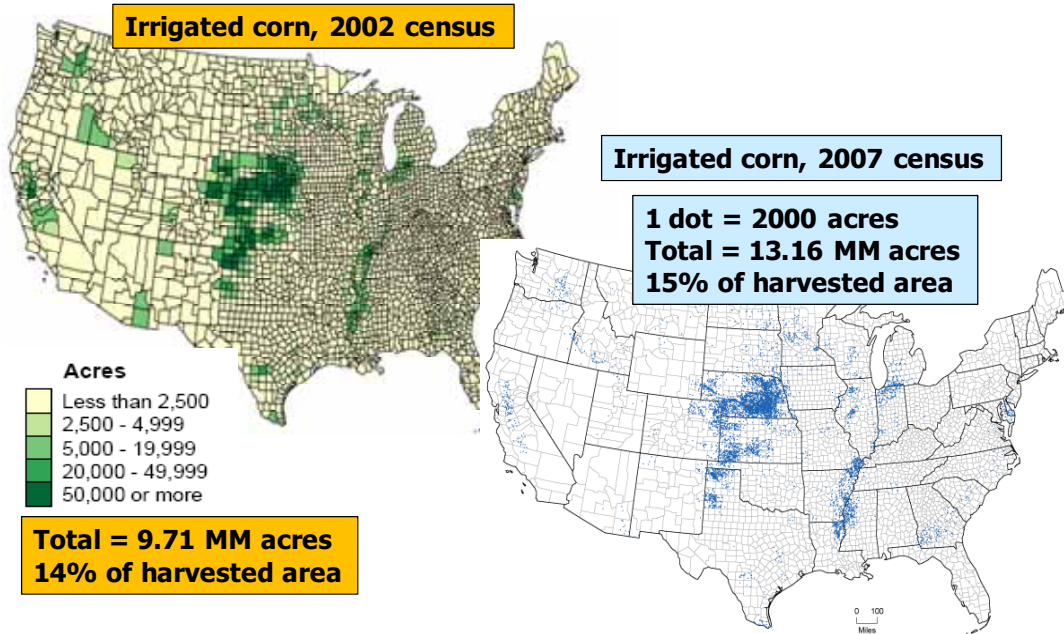
Of course, as pointed out by the USDA, an abundance of water in the aggregate belies increasingly limited water supplies in many areas, reflecting the uneven distribution of the Nation's water resources. In the arid West, more than half of the renewable water supplies are consumed under normal precipitation conditions. In drought years, water use often exceeds renewable flow through the increased use of water stored in aquifers and reservoirs. While droughts exacerbate supply scarcity, water demands continue to expand with resulting reallocations among uses (e.g. urban growth).

In other words, water supply may be an issue but this only arises in particular areas for particular crops with particular types of irrigation and is not a universal national problem.

### 3. Corn Water Utilization

#### Irrigated corn area

The estimated number of acres for irrigated corn varies between reports: USDA data based on the Census of Agriculture estimates that ~15% of corn acres receive irrigation, and various USGS data indicate that irrigated corn is ~15% of total. The distribution of acres is as follows:



The majority of irrigated acres are in Nebraska, Kansas, and N Texas, roughly following the position of the High Plains aquifer, and the Platte River in Nebraska. Smaller areas of intense irrigation also occur in California, Michigan, and along the Mississippi river system.

#### Normal needs of corn (focus on Nebraska since it has largest irrigation area)

Corn requires water for germination, photosynthesis, cell turgor, and transpiration (water movement to the atmosphere via movement through the growing plant). Of these processes, only photosynthesis actually “uses” water (to generate oxygen and hydrogen). Transpiration involves the largest volume utilization of water, cooling the plant as it moves through and back to the atmosphere. Some evaporation of water occurs at the soil surface, especially prior to canopy closure: this is typically included in the total water return to the atmosphere and is called evapotranspiration (ET).

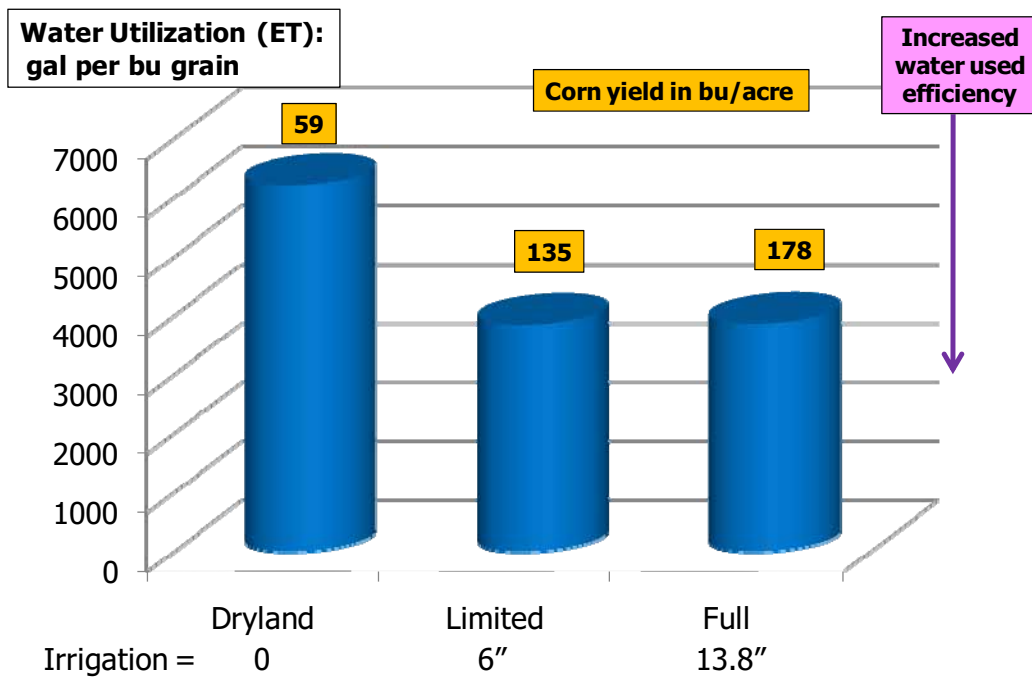
While Nebraska has a large area of irrigated corn, this does not mean that all those acres must receive 100% of the required water from irrigation. There is an optimum volume of water required and this is calculated based on ET need, rainfall, and soil holding capacity (Nebguide, 1996). Too much irrigation has a cost penalty and can move nutrients out of the root zone, too little irrigation results in a high yield

penalty. The yield impact of reaching an optimum ET is shown in the following chart of corn yield, irrigation and ET, in Nebraska:

	Dryland	Limited Irrigation	Full Irrigation
Irrigation (in)	0	6	13.8
ET (in)	13.5	19.1	25.3
Grain Yield (bu/ac)	59	135	178
Grain/ET (bu/ac-in)	4.3	7.1	7.1

The optimum ET for corn in Nebraska ranges from 23" (West) to 28" (East). Specific ET values are published for specific locations. (See Nebguide, 1996)

In terms of production, this translates to 4.3 bu/in for dryland and 7.1 bu/in for irrigation up to the maximum required ET amount. The interesting outcome of this data is that under dryland conditions the corn plant is stressed to the point of becoming inefficient in production. The addition of even some irrigation water actually increases the efficiency of water utilization (less water per unit of grain produced), as shown in the following chart:



In this case, irrigating to full ET requirement provided the highest grain yield and required the lowest amount of water per unit grain produced. Irrigation actually improved the utilization of water under conditions where ET was not met from soil water alone.

The corn that is irrigated, across the US, on average receives ~10 acre-inches of irrigation water (~750 gal/acre/day, if corn grew every day of the year.) If that same water were applied to all corn acres it would represent 1.5 ac-in additional water: put in context this is only about 3% of the average rainfall on each acre of corn grown.

All water required to optimize ET need returns to the atmosphere where, within 1-9 days, it returns again as precipitation. Thus, the issue of not that growing corn “uses” water, it only borrows the water for a short time. The only issue that might become important is that some irrigation water is moved from the underground aquifer to the atmosphere at a faster rate than would otherwise occur. Then the rate of re-charge of the aquifer from precipitation and run-off also becomes important (see section on High Plains Aquifer).

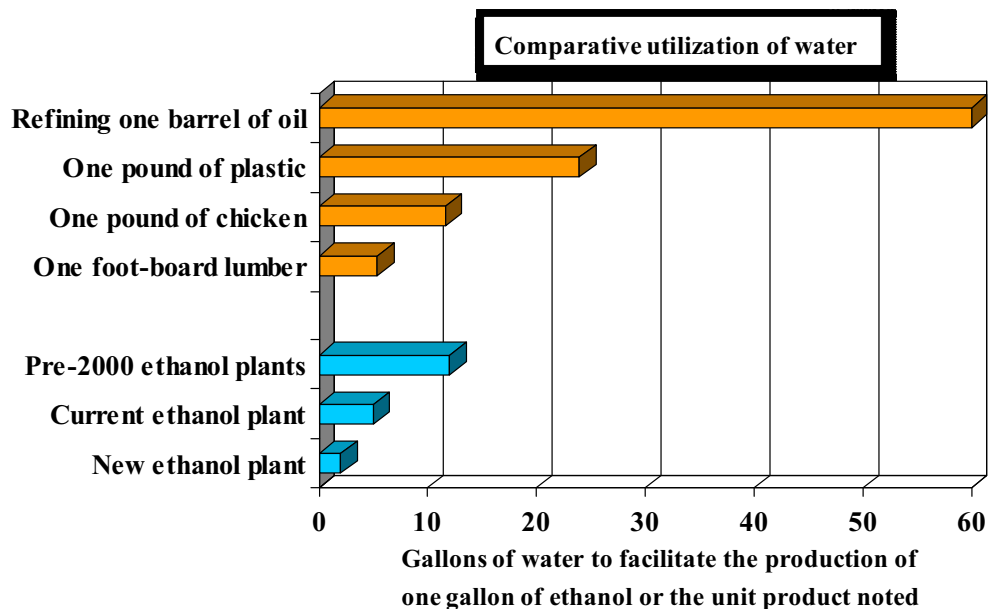
For comparison: over the course of a growing season, each corn plant will move about 14 gallons of water through itself and back into the atmosphere. A typical person in America will drink more than that amount every month.

**Off-take**

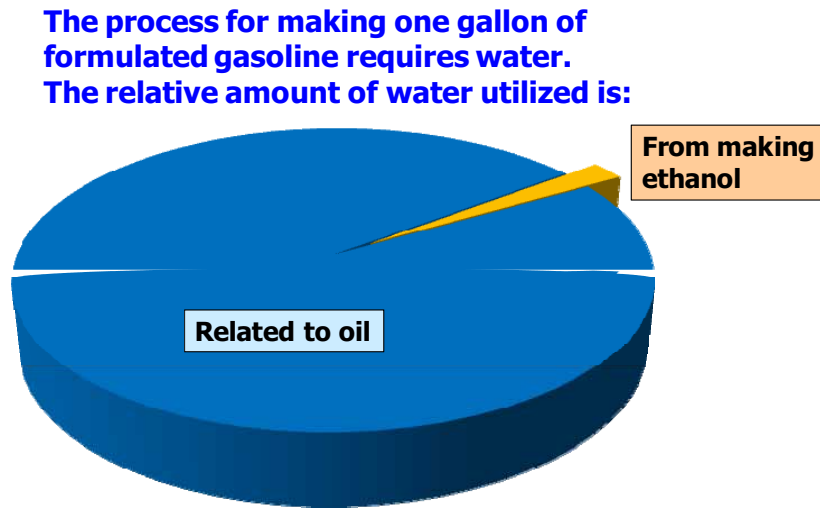
While ET moves water to the atmosphere, a small amount of water is taken with the harvested crop. Typically, 14-20% of the grain weight is moisture content. This amount is equal to ~150 gal H<sub>2</sub>O/acre corn grown, which is A) a small amount, B) available for utilization in the process where corn is used (livestock feed or fuel/industrial processing). Some 2B gal water is exported in the corn grain and this relatively small amount could be considered to be “used” since it is removed from the national water budget (but still remains in the global water pool).

**Processing**

Much has been made of the water “use” during the commercial process of generating ethanol from corn grain. Again, the vast majority of this water is not “used” but is utilized to facilitate the fermentation process. Water treatment and an ever growing volume of recycled water at ethanol facilities, minimizes the volume that utilized. The following chart shows the comparative utilization in processing:



Another perspective on this is that most ethanol is used as the required oxygenate for octane value and cleaning burning gasoline, which means that over 95% ethanol is used in E10 blends. One gallon of formulated gasoline requires ~27.5 gal water to produce. The relative proportions of that process water are as follows:



While making ethanol from corn requires water, the comparative amount utilized is relatively small and the amount that is “used” is negligible.

### High Plains Aquifer

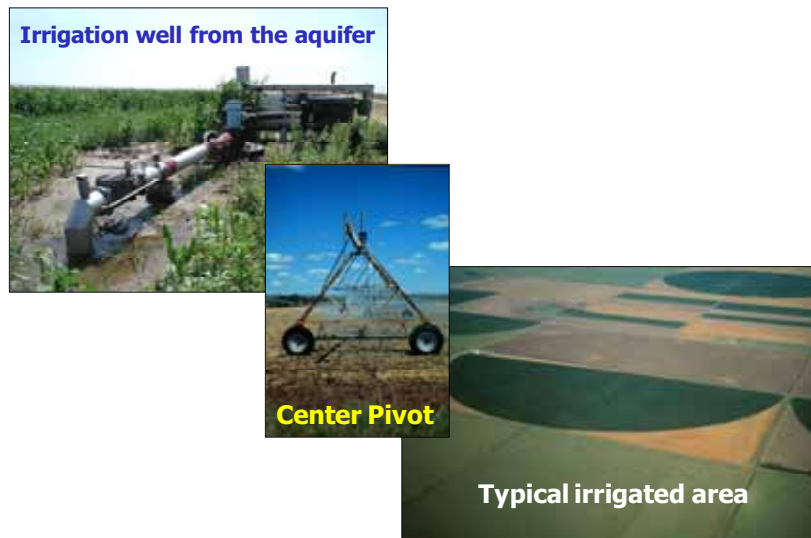
The majority of irrigated corn lies over the High Plains aquifer and the removal of water without any recharge could be a long-term issue – for future irrigation of corn itself and for other removal needs. Understanding the situation and dynamics of the High Plains aquifer is important for future actions.

The High Plains aquifer lays under 8 states and has an estimated area of 174,000 mile<sup>2</sup>. The irrigated land over this aquifer represents ~27% of the total US irrigated area, and the aquifer supplies ~30% of the total irrigation water utilized. The aquifer also provides drinking water to over 80% of the people living above the aquifer boundary (~2.5 MM people).

The High Plains aquifer was created primarily by a geological unit called the Ogallala Formation (Nebraska Sand Hills and alluvial deposits), which underlies ~80% of the High Plains. Saturated thickness of the High Plains aquifer ranges from 0 to more than 1,000 feet in Nebraska, with an average of about 200 feet. Depth to water ranges from 0 to 500 feet, with an average depth of about 100 feet. Ground water generally flows from west to east and discharges naturally to streams and springs and by evapotranspiration in areas where the water table is near the land surface. Pumping from numerous irrigation wells across the area also contributes to ground-water withdrawal. Currently, precipitation is the principal source of recharge to the aquifer. The location is:



High Plains ground water is utilized primarily to grow crops for the nation; irrigation accounts for 94 percent of the ground-water use. The second largest ground-water use, 418 million gallons per day (MMgal/day), is for domestic drinking water. Almost 2 million people rely on the High Plains aquifer for their drinking water. Surface water is used for drinking water primarily in the larger cities near the periphery of the High Plains aquifer (Cheyenne, Wyoming, and Lubbock, Odessa, and Amarillo, Texas). Other utilization of aquifer water includes livestock (222 MMgal/day), mining (210 MMgal/day), and industry (155 MMgal/day). The irrigation results in a typical High Plains scene:

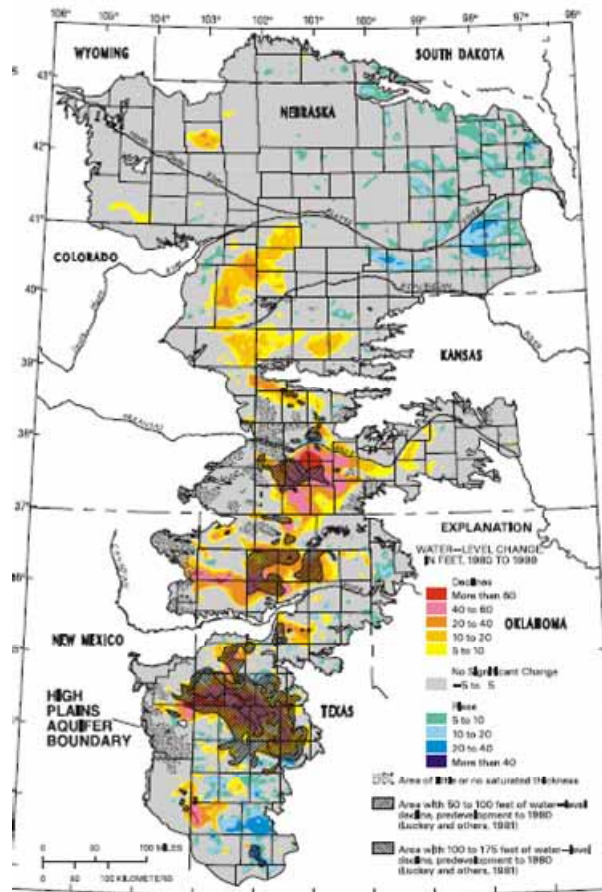


The USGS has made statements like:

“Regional variability of water-level changes in the High Plains aquifer results from large regional differences in climate, soils, land use, and ground-water withdrawals for irrigation. Withdrawals greatly exceeded recharge in many areas, causing large water-level declines. Water levels have declined more than 100 feet since irrigation began (1940's) in parts of Kansas, New Mexico, Oklahoma, and Texas. In some areas, because of water-level declines, irrigation has become impossible or cost prohibitive.”

In response to this belief, the U.S. Geological Survey, in cooperation with numerous federal, state, and local water-resource agencies, began a groundwater monitoring program in 1988 to assess annual water-level change in the aquifer using water-level measurements from more than 7,000 wells.

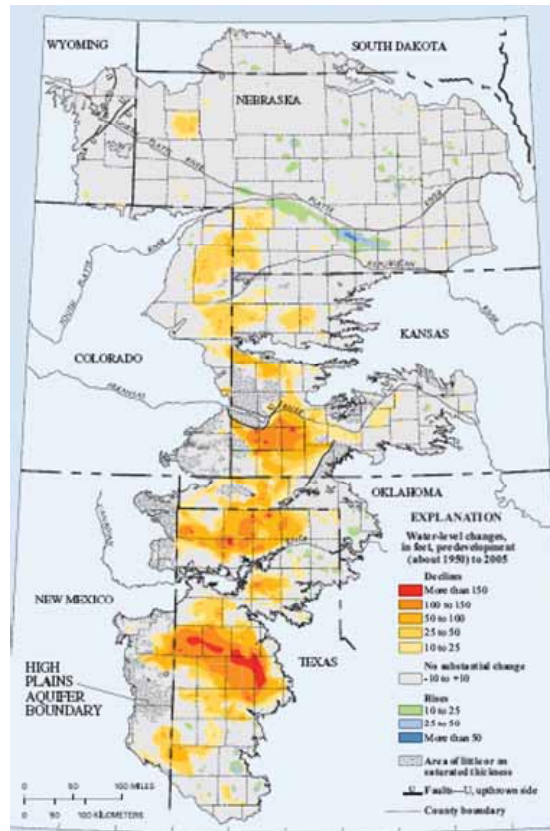
**Changes in water level measured during 1980 - 1999**



The 100” decline is actually only in small localized regions. For some 99% of all water-level changes between 1980 to 1999, the data show a range from a rise of 34 feet to a decline of 67 feet. The average area-weighted water level in the High Plains aquifer declined 3.2 feet from 1980 to 1999 compared to a decline of 9.9 feet from predevelopment to 1980. In the areas with from 50 to 175 feet of water-level decline from predevelopment to 1980, the average water level decline from 1980 to 1999 was 26 feet or about 1.4 feet per year. This does not equate to the headlines of a 100’ loss of water across the aquifer.

The most recent data available shows the change from predevelopment to 2005 as follows:

**Changes in water level  
measured during from  
Predevelopment to 2005**



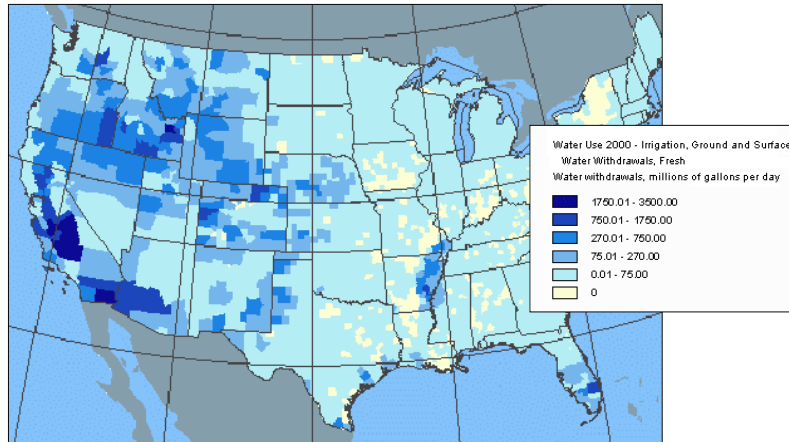
Total water in storage in the aquifer in 2005 was about 2,925 million acre-feet, which was a decline of about 253 million acre-feet (or 9 percent) since predevelopment. Comparing the data in the two charts above it seems that:

1. The decline in water level in the aquifer does not correspond to the highest number of corn irrigated acres. In fact, in Nebraska, the aquifer water level seems to be rising.
2. The data for 2005 seems to show more intense water level changes in localized areas but not across the aquifer. Why does water not flow within the aquifer?

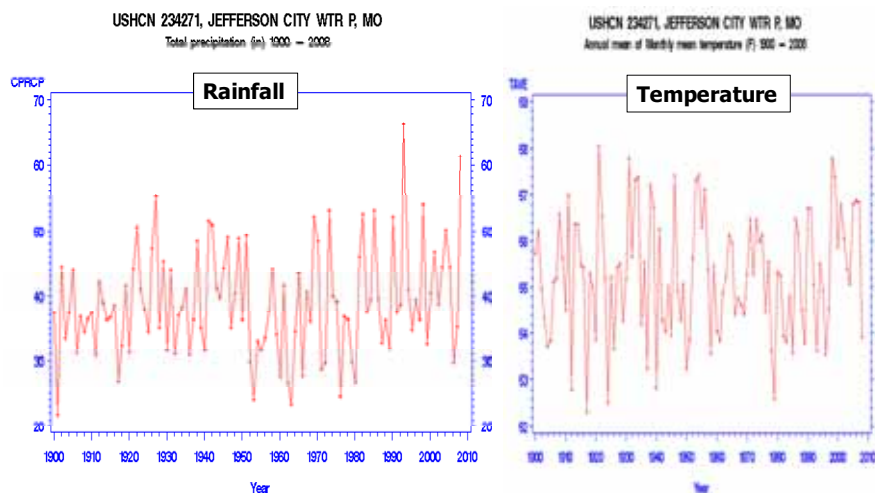
**4. Future Needs & Issues**

**More timely information** and availability of current data is important. At present, the data being used is possibly no longer relevant, or is not a clear current picture. For example, the USDA agricultural irrigation data are all from the 1990's or before. The USGS uses old data with a few references to early 2000's data, the survey of 2005 is not yet published. Many of the debates are based on old data and the present trend is unclear. For example, in recent years the number of acres irrigated has declined, or the number of acres irrigated has remained flat while the volume of water utilized has declined due to newer management techniques and better equipment – but these factors are seldom brought forth in the debate.

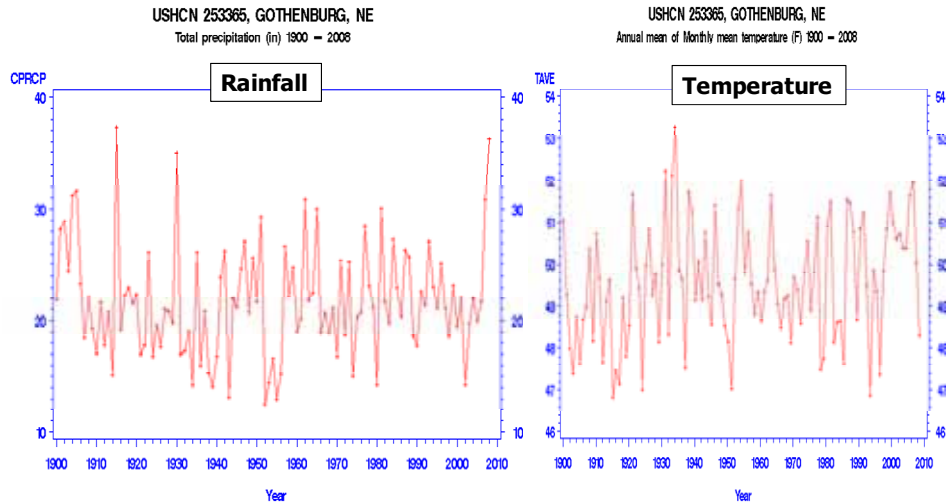
**Corn is a relatively small in terms of irrigation.** Across the US, the acres of corn irrigated represent 21% of the total irrigated area. However, the volume of water utilized in corn irrigation represents only 7% of all irrigation water. Moreover, the primary area for corn irrigation lies over the High Plains aquifer which does not correspond to the most intense water utilization for irrigation (see following chart):



Clearly, California is where the main issue exists in relation to water availability for irrigation. For CA and other localized areas, some action plan is required to deal with future needs. Historically, increased water demands were met by expanding available water supplies. Actions such as dam construction, more ground-water pumping, and inter-basin conveyance are not likely to continue on any significant scale. There are several schools of thought that even suggest the future supply of fresh water (via precipitation) will be decreased due to concepts about global warming. While we can find evidence that some warming has occurred in urban situations, we don't find any significant warming in the Mid-West, nor any relationship to rainfall patterns, over the past 100 years. For example, the following charts are just two example stations:



Source: CN Williams Jr., MJ Menne, RS Vose, DR Easterling, NOAA, National Climatic Data Center, Asheville, NC



Source: CN Williams Jr., MJ Mearns, RS Vose, DR Easterling, NOAA, National Climatic Data Center, Asheville, NC Source: CN Williams Jr., MJ Mearns, RS Vose, DR Easterling, NOAA, National Climatic Data Center, Asheville, NC

**Future water demands** will require one or more of the following solutions:

- Re-allocation of existing supplies: will likely impact agriculture with water being taken for public utilization, over irrigation.
- Change in crop water need. We see this as being very difficult since lowering transpiration has a biological limit due to the need to cool the plant. Drought tolerance genes may help to some extent but their mode of action is likely to be related to turgor pressure rather than lowering the transpiration:yield ratio. Drought tolerance will increase yield in some situations, such as minor water stress, but will not overcome major water deficit.
- Continuation of improvement in water delivery. Irrigation management, efficiency of water delivery, better equipment will all make a contribution.
- Recycling more water via advanced treatments and reverse osmosis. All industrial, process and livestock water use could be further re-cycled – often within agriculture.
- Generating more fresh-water supply will need to be considered very seriously, especially in California. Areas in proximity to the sea that require additional water can use desalination with short- and medium-distance transport in specific pipelines. This is just moving water from the largest source to an area that requires more water for utilization by all the human activities.
- In the longer-term, there may even be a need to run a pipeline from sea-side desalination plants to re-charge the central aquifer system. There is no real shortage of water in the world – just in some locations and the technology exists to fix that.

It is a growing fashion to talk about the world shortage of water – which is a strange statement when the planet is 70% covered with a water volume in excess of 330 million cubic miles. The current situation is more about cost than it is about water. It really becomes a question of what value society puts on having water available to facilitate processing and the provision of useful products. Given the price that people pay for bottled water (another form of re-distribution) it seems that pipeline delivery of desalinated water should be quite acceptable.

## 5. References

- Connor, R., Faurès, J-M., Kuylenstierna, J., Margat, J., Steduto, P., Vallée, D., and van der Hoek, W. (2009). Chapter 7: Evolution of Water Use. In, *Water in a Changing World*. 3<sup>rd</sup> U.N. World Water Development Report. United Nations Educational, Scientific and Cultural Organization (UNESCO) Natural Sciences, Paris, France.
- Gleick, P. H., (1996). Water resources. In *Encyclopedia of Climate and Weather*, Ed. Schneider, S.H., Oxford University Press, New York, pp.817-823.
- Hoekstra, A. Y., and Chapagain, A.K. (2007). Water Footprints of Nations: Water use by people as a function of their consumption pattern. *Water Resources Management*, 21, 35-48.
- NCDC (2009). National Climatic Data Center, NOAA Satellite and Information Service. <http://www.ncdc.noaa.gov/oa/ncdc.html>
- NebGuide (1996). Evapotranspiration (ET) or Crop Water Use. University of Nebraska, Cooperative Extension Institute of Agriculture and Natural Resources, NebGuide G90-992-A
- Reilly, T.E., Dennehy, K.F., Alley, W.M., and Cunningham, W.L. (2008). *Ground-Water Availability in the United States: U.S. Geological Survey Circular 1323*, 70pp. Denver, CO.
- USDA (2004). *Farm and Ranch Irrigation Survey (2003)*. Volume 3, Part 1, Special Studies of 2002 Census of Agriculture, AC-02-SS-1. U.S. Department of Agriculture, National Agricultural Statistics Service.
- USGS (2006). *Water-Level Changes in the High Plains Aquifer, Predevelopment to 2005 and 2003 to 2005*. Scientific Investigations Report 2006–5324.
- USGS (2009). United States Geological Survey. <http://www.usgs.gov>
- USGS (2009B). USGS reports on estimated water use in the U.S. <http://water.usgs.gov/watuse/>
- WW2010 (2009). Weather World 2010 Project at the University of Illinois. [http://ww2010.atmos.uiuc.edu/\(Gh\)/home.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/home.rxml)

## APPENDIX

One estimate of global water distribution:				
Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of freshwater	Percent of total water
Oceans, Seas, & Bays	321,000,000	1,338,000,000	--	96.5
Ice caps, Glaciers, & Permanent Snow	5,773,000	24,064,000	68.7	1.74
Groundwater	5,614,000	23,400,000	--	1.7
Fresh	2,526,000	10,530,000	30.1	0.76
Saline	3,088,000	12,870,000	--	0.94
Soil Moisture	3,959	16,500	0.05	0.001
Ground Ice & Permafrost	71,970	300,000	0.86	0.022
Lakes	42,320	176,400	--	0.013
Fresh	21,830	91,000	0.26	0.007
Saline	20,490	85,400	--	0.006
Atmosphere	3,095	12,900	0.04	0.001
Swamp Water	2,752	11,470	0.03	0.0008
Rivers	509	2,120	0.006	0.0002
Biological Water	269	1,120	0.003	0.0001
<b>Total</b>	<b>332,500,000</b>	<b>1,386,000,000</b>	<b>-</b>	<b>100</b>

Source: Gleick, P. H., 1996: Water resources. In Encyclopedia of Climate and Weather, ed. by S. H. Schneider, Oxford University Press, New York, vol. 2, pp.817-823.

**Total water withdrawals by water-use category, 2000. (from USGS)**

[Figures may not sum to totals because of independent rounding. All values are in million gallons per day. —, data not collected]

STATE	PUBLIC SUPPLY	DOMESTIC	IRRIGATION	LIVE-STOCK	AQUA-CULTURE	INDUSTRIAL		MINING		THERMOELECTRIC POWER		TOTAL		
	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh	Saline	Fresh	Saline	Fresh	Saline	Fresh	Saline	Total
Alabama	834	78.9	43.1	—	10.4	833	0	—	—	8,190	0	9,990	0	9,990
Alaska	80.0	11.2	1.01	—	—	8.12	3.86	27.4	140	33.6	0	161	144	305
Arizona	1,080	28.9	5,400	—	—	19.8	0	85.7	8.17	100	0	6,720	8.17	6,730
Arkansas	421	28.5	7,910	—	198	134	0.08	2.78	0	2,180	0	10,900	0.08	10,900
California	6,120	286	30,500	409	537	188	13.6	23.7	153	352	12,600	38,400	12,800	51,200
Colorado	899	66.8	11,400	—	—	120	0	—	—	138	0	12,600	0	12,600
Connecticut	424	56.2	30.4	—	—	10.7	0	—	—	187	3,440	708	3,440	4,150
Delaware	94.9	13.3	43.5	3.92	0.07	59.4	3.25	—	—	366	738	582	741	1,320
District of Columbia	0	0	0.18	—	—	0	0	—	—	9.69	0	9.87	0	9.87
Florida	2,440	199	4,290	32.5	8.02	291	1.18	217	0	658	12,000	8,140	12,000	20,100
Georgia	1,250	110	1,140	19.4	15.4	622	30.0	9.80	0	3,250	61.7	6,410	91.7	6,500
Hawaii	250	12.0	364	—	—	14.5	0.85	—	—	0	0	640	0.85	641
Idaho	244	85.2	17,100	34.9	1,970	55.5	0	—	—	0	0	19,500	0	19,500
Illinois	1,760	135	154	37.6	—	391	0	—	—	11,300	0	13,700	0	13,700
Indiana	670	122	101	41.9	—	2,400	0	82.5	0	6,700	0	10,100	0	10,100
Iowa	383	33.2	21.5	109	—	237	0	32.8	0	2,540	0	3,360	0	3,360
Kansas	416	21.6	3,710	111	5.60	53.3	0	31.4	0	2,260	0	6,610	0	6,610
Kentucky	525	27.5	29.3	—	—	317	0	—	—	3,260	0	4,160	0	4,160
Louisiana	753	41.2	1,020	7.34	243	2,680	0	—	—	5,610	0	10,400	0	10,400
Maine	102	35.7	5.84	—	—	247	0	—	—	113	295	504	295	799
Maryland	824	77.1	42.4	10.4	19.6	65.8	227	8.31	0.02	379	6,260	1,430	6,490	7,910
Massachusetts	739	42.2	126	—	—	36.8	0	—	—	108	3,610	1,050	3,610	4,660
Michigan	1,140	239	201	11.3	—	698	0	—	—	7,710	0	10,000	0	10,000
Minnesota	500	80.8	227	52.8	—	154	0	588	0	2,270	0	3,870	0	3,870
Mississippi	359	69.3	1,410	—	371	242	0	—	—	362	148	2,810	148	2,960
Missouri	872	53.6	1,430	72.4	83.3	62.7	0	16.9	0	5,640	0	8,230	0	8,230
Montana	149	18.6	7,950	—	—	61.3	0	—	—	110	0	8,290	0	8,290
Nebraska	330	48.4	8,790	93.4	—	38.1	0	128	4.55	2,820	0	12,200	4.55	12,300
Nevada	629	22.4	2,110	—	—	10.3	0	—	—	36.7	0	2,810	0	2,810
New Hampshire	97.1	41.0	4.75	—	16.3	44.9	0	6.80	0	236	761	447	761	1,210
New Jersey	1,050	79.7	140	1.68	6.46	132	0	110	0	650	3,390	2,170	3,390	5,560
New Mexico	296	31.4	2,860	—	—	10.5	0	—	—	56.4	0	3,260	0	3,260
New York	2,570	142	35.5	—	—	297	0	—	—	4,040	5,010	7,080	5,010	12,100
North Carolina	945	189	287	121	7.88	293	0	36.4	0	7,850	1,620	9,730	1,620	11,400
North Dakota	63.6	11.9	145	—	—	17.6	0	—	—	902	0	1,140	0	1,140
Ohio	1,470	134	31.7	25.3	1.36	807	0	88.5	0	8,590	0	11,100	0	11,100

Oklahoma	675	25.5	718	151	16.4	25.9	0	2.48	256	146	0	1,760	256	2,020
Oregon	566	76.2	6,080	—	—	195	0	—	—	15.30	0	6,930	0	6,930
Pennsylvania	1,460	132	13.9	—	—	1,190	0	182	0	6,980	0	9,950	0	9,950
Rhode Island	119	8.99	3.45	—	—	4.28	0	—	—	2.40	290	138	290	429
South Carolina	566	63.5	267	—	—	565	0	—	—	5,710	0	7,170	0	7,170
South Dakota	93.3	9.53	373	42.0	—	5.12	0	—	—	5.24	0	528	0	528
Tennessee	890	32.6	22.4	—	—	842	0	—	—	9,040	0	10,800	0	10,800
Texas	4,230	131	8,630	308	—	1,450	907	220	504	9,820	3,440	24,800	4,850	29,600
Utah	638	16.1	3,860	—	116	42.7	5.08	26.3	198	62.20	0	4,760	203	4,970
Vermont	60.1	21.0	3.78	—	—	6.91	0	—	—	355	0	447	0	447
Virginia	720	133	26.4	—	—	470	53.3	—	—	3,850	3,580	5,200	3,640	8,830
Washington	1,020	125	3,040	—	—	577	39.9	—	—	519	0	5,270	39.9	5,310
West Virginia	190	40.4	0.04	—	—	968	0	—	—	3,950	0	5,150	0	5,150
Wisconsin	623	96.3	196	66.3	70.2	447	0	—	—	6,090	0	7,590	0	7,590
Wyoming	107	6.57	4,500	—	—	5.78	0	79.5	222	243	0	4,940	222	5,170
Puerto Rico	513	0.88	94.5	—	—	11.2	0	—	—	0	2,190	620	2,190	2,810
U.S. Virgin Islands	6.09	1.69	0.50	—	—	3.34	0	—	—	0	136	11.6	136	148
<b>TOTAL</b>	<b>43,300</b>	<b>3,590</b>	<b>137,000</b>	<b>1,760</b>	<b>3,700</b>	<b>18,500</b>	<b>1,280</b>	<b>2,010</b>	<b>1,490</b>	<b>136,000</b>	<b>59,500</b>	<b>345,000</b>	<b>62,300</b>	<b>408,000</b>

**Trends in estimated water use in the United States, 1950-2000. (USGS, 2009B)**

The water-use data are in billion gallons per day (thousand million gallons per day) and are rounded to two significant figures for 1950-80, and to three significant figures for 1985-2000; percentage change is calculated from unrounded numbers. —, not available]

	Year												Percentage change
	<sup>1</sup> 1950 <sup>2</sup>	<sup>2</sup> 1955 <sup>3</sup>	<sup>3</sup> 1960 <sup>4</sup>	<sup>4</sup> 1965 <sup>4</sup>	<sup>4</sup> 1970 <sup>3</sup>	<sup>3</sup> 1975 <sup>3</sup>	<sup>3</sup> 1980 <sup>3</sup>	<sup>3</sup> 1985 <sup>3</sup>	<sup>3</sup> 1990 <sup>3</sup>	<sup>3</sup> 1995 <sup>3</sup>	<sup>3</sup> 2000	1995-2000	
Population, in millions	150.7	164.0	179.3	193.8	205.9	216.4	229.6	242.4	252.3	267.1	285.3	+7	
Offstream use:													
Total withdrawals	180	240	270	310	370	420	440	399	408	402	408	+2	
Public supply	14	17	21	24	27	29	34	36.5	38.5	40.2	43.3	+8	
Rural domestic and livestock:													
Self-supplied domestic	2.1	2.1	2.0	2.3	2.6	2.8	3.4	3.32	3.39	3.39	3.59	+6	
Livestock and aquaculture	1.5	1.5	1.6	1.7	1.9	2.1	2.2	<sup>5</sup> 4.47	4.50	5.49	( <sup>6</sup> )	—	
Irrigation	89	110	110	120	130	140	150	137	137	134	137	+2	
Industrial:													
Thermoelectric power use	40	72	100	130	170	200	210	187	195	190	195	+3	
Other industrial use	37	39	38	46	47	45	45	30.5	29.9	29.1	( <sup>7</sup> )	—	
Source of water:													
Ground:													
Fresh	34	47	50	60	68	82	83	73.2	79.4	76.4	83.3	+9	
Saline	( <sup>8</sup> )	0.6	0.4	0.5	1.0	1.0	0.9	0.65	1.22	1.11	1.26	+14	
Surface:													
Fresh	140	180	190	210	250	260	290	265	259	264	262	-1	
Saline	10	18	31	43	53	69	71	59.6	68.2	59.7	61	+2	

<sup>1</sup> 48 States and District of Columbia, and Hawaii

<sup>2</sup> 48 States and District of Columbia

<sup>3</sup> 50 States and District of Columbia, Puerto Rico, and U.S. Virgin Islands

<sup>4</sup> 50 States and District of Columbia, and Puerto Rico

<sup>5</sup> From 1985 to present this category includes water use for fish farms

<sup>6</sup> Data not available for all states; partial total was 5.46

<sup>7</sup> Commercial use not available; industrial and mining use totaled 23.2

<sup>8</sup> Data not available

## Irrigation data from USGS Survey in 2000 (USGS, 2009B)

STATE	IRRIGATED LAND (in thousand acres)			WITHDRAWALS (in million gallons per day)			WITHDRAWALS (in thousand acre-feet per year)			APPLICAT ION RATE (in acre- feet per acre)	
	By type of irrigation			By source			By source				
	Sprinkle	Micro- irrigatn	Surface	Total	Ground water	Surface water	Total	Ground water	Surface water		Total
Alabama	68.7	1.3	0	70	14.5	28.7	43.1	16.2	32.2	48.4	0.69
Alaska	2.43	0	0.07	2.5	0.99	0.02	1.01	1.11	0.02	1.13	0.45
Arizona	183	14	779	976	2,750	2,660	5,400	3,080	2,980	6,060	6.21
Arkansas	631	0	3,880	4,510	6,510	1,410	7,910	7,290	1,580	8,870	1.97
California	1,660	3,010	5,470	10,100	11,600	18,900	30,500	13,100	21,100	34,200	3.37
Colorado	1,190	1.16	2,220	3,400	2,160	9,260	11,400	2,420	10,400	12,800	3.76
Connecticut	20.6	0.39	0	21	17	13.4	30.4	19	15	34	1.62
Delaware	81.1	0.71	0	81.8	35.6	7.89	43.5	39.9	8.84	48.7	0.6
DC	0.32	0	0	0.32	0	0.18	0.18	0	0.2	0.2	0.63
Florida	515	704	839	2,060	2,180	2,110	4,290	2,450	2,370	4,810	2.34
Georgia	1,470	73.8	0	1,540	750	392	1,140	841	439	1,280	0.83
Hawaii	16.7	105	0	122	171	193	364	191	216	407	3.35
Idaho	2,440	4.7	1,300	3,750	3,720	13,300	17,100	4,170	15,000	19,100	5.1
Illinois	365	0	0	365	150	4.25	154	168	4.76	173	0.47
Indiana	250	0	0	250	55.5	45.4	101	62.2	51	113	0.45
Iowa	84.5	0	0	84.5	20.4	1.08	21.5	22.9	1.21	24.1	0.28
Kansas	2,660	2.14	647	3,310	3,430	288	3,710	3,840	323	4,160	1.26
Kentucky	66.6	0	0	66.6	1.14	28.2	29.3	1.28	31.6	32.9	0.49
Louisiana	110	0	830	940	791	232	1,020	887	261	1,150	1.22
Maine	35	0.95	0.03	36	0.61	5.23	5.84	0.68	5.86	6.55	0.18
Maryland	57.3	3.32	0	60.6	29.8	12.6	42.4	33.4	14.1	47.6	0.78
Massachusetts	26.6	2.35	0	29	19.7	106	126	22.1	119	141	4.88
Michigan	401	8.67	4.87	415	128	73.2	201	144	82	226	0.54
Minnesota	546	0	26.9	573	190	36.6	227	213	41.1	254	0.44
Mississippi	455	0	966	1,420	1,310	99.1	1,410	1,470	111	1,580	1.11
Missouri	532	1.43	792	1,330	1,380	48.1	1,430	1,550	53.9	1,600	1.21
Montana	506	0	1,220	1,720	83	7,870	7,950	93	8,820	8,920	5.18
Nebraska	4,110	0	3,710	7,820	7,420	1,370	8,790	8,320	1,540	9,860	1.26
Nevada	192	0	456	647	567	1,540	2,110	635	1,730	2,360	3.65
New Hampsh	6.08	0	0	6.08	0.5	4.25	4.75	0.56	4.76	5.32	0.88
New Jersey	109	15.7	3.7	128	22.8	117	140	25.5	131	156	1.22
New Mexico	461	7.17	530	998	1,230	1,630	2,860	1,380	1,830	3,210	3.22
New York	70	8.73	1.84	80.6	23.3	12.1	35.5	26.1	13.6	39.8	0.49
North Carolina	193	3.7	0	196	65.8	221	287	73.8	248	322	1.64
North Dakota	200	0	26.7	227	72.2	73.2	145	80.9	82.1	163	0.72
Ohio	61	0	0	61	13.9	17.8	31.7	15.6	19.9	35.5	0.58
Oklahoma	392	1.5	113	507	566	151	718	635	170	804	1.59
Oregon	1,160	4.02	1,000	2,170	792	5,290	6,080	887	5,920	6,810	3.14
Pennsylvania	28.9	7.17	0	36	1.38	12.5	13.9	1.55	14	15.6	0.43
Rhode Island	4.48	0.29	0.05	4.82	0.46	2.99	3.45	0.52	3.35	3.87	0.8

Continued...

STATE	IRRIGATED LAND (in thousand acres)			WITHDRAWALS (in million gallons per day)			WITHDRAWALS (in thousand acre-feet per year)			APPLICAT --- RATE (in acre- --- per acre)	
	By type of irrigation			By source			By source				
	Sprinkle	Micro- irrigatn	Surface	Total	Ground water	Surface water	Total	Ground water	Surface water		Total
<b>South Carolina</b>	166	3.66	17.5	187	106	162	267	118	181	300	1.6
<b>South Dakota</b>	276	0	78.3	354	137	236	373	153	264	418	1.18
<b>Tennessee</b>	51.2	5.35	3.96	60.5	7.33	15.1	22.4	8.22	16.9	25.1	0.41
<b>Texas</b>	4,010	89.4	2,390	6,490	6,500	2,130	8,630	7,290	2,390	9,680	1.49
<b>Utah</b>	526	1.68	880	1,410	469	3,390	3,860	526	3,800	4,330	3.08
<b>Vermont</b>	4.95	0	0	4.95	0.33	3.45	3.78	0.37	3.87	4.24	0.86
<b>Virginia</b>	64.3	13.9	0	78.2	3.57	22.8	26.4	4	25.6	29.6	0.38
<b>Washington</b>	1,270	49.9	252	1,570	747	2,290	3,040	837	2,570	3,400	2.16
<b>West Virginia</b>	2.21	0	0.98	3.19	0.02	0.02	0.04	0.02	0.02	0.04	0.01
<b>Wisconsin</b>	355	0	0	355	195	1.57	196	218	1.76	220	0.62
<b>Wyoming</b>	190	4.73	964	1,160	413	4,090	4,500	463	4,580	5,050	4.36
<b>Puerto Rico</b>	15.5	33	5.35	53.8	36.9	57.5	94.5	41.4	64.5	106	1.97
<b>U.S. Virgin Isl</b>	0.2	0	0	0.2	0.29	0.21	0.5	0.33	0.24	0.56	2.8
<b>TOTAL</b>	28,300	4,180	29,400	61,900	56,900	80,000	137,000	63,800	89,700	153,000	2.48

Note: Irrigation units

Gallons is a volume applied. Acres is the area that a volume is applied to. One acre-foot is the volume of water that covers one acre to a depth of one foot: equals 43,560 cubic feet = 325,851 gallons. One acre-inch = 27,154 gal.









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