ASSIGNMENT 1
The Water Cycle

- Evaporation
- Condensation
- Sublimation
- Desublimation
- Precipitation
- Snowmelt runoff
- Streamflow
- Infiltration
- Seepage
- Groundwater flow
- Groundwater storage
- Volcanic steam
- Ice and snow
- Precipitation
- Fog and dew
- Evapotranspiration
- Surface runoff
- Plants
- Animals
- Freshwater
- Oceans
- Vents and volcanos

- Atmosphere
- Seepage
- Spring
The Water Cycle

Viewed from space, one of the most striking features of our home planet is the water, in both liquid and frozen forms, that covers approximately 75% of the Earth’s surface. Geologic evidence suggests that large amounts of water have likely flowed on Earth for the past 3.8 billion years—most of its existence. Believed to have initially arrived on the surface through the emissions of ancient volcanoes, water is a vital substance that sets the Earth apart from the rest of the planets in our solar system. In particular, water appears to be a necessary ingredient for the development and nourishment of life.

Water, Water, Everywhere

Water is practically everywhere on Earth. Moreover, it is the only known substance that can naturally exist as a gas, a liquid, and solid within the relatively small range of air temperatures and pressures found at the Earth’s surface.

Earth is a water planet; three-quarters of the surface is covered by water, and water-rich clouds fill the sky. (NASA.)
In all, the Earth’s water content is about 1.39 billion cubic kilometers (331 million cubic miles), with the bulk of it, about 96.5%, being in the global oceans. As for the rest, approximately 1.7% is stored in the polar ice caps, glaciers, and permanent snow, and another 1.7% is stored in groundwater, lakes, rivers, streams, and soil. Only a thousandth of 1% of the water on Earth exists as water vapor in the atmosphere.

Despite its small amount, this water vapor has a huge influence on the planet. Water vapor is a powerful greenhouse gas, and it is a major driver of the Earth’s weather and climate as it travels around the globe, transporting latent heat with it. Latent heat is heat obtained by water molecules as they transition from liquid or solid to vapor; the heat is released when the molecules condense from vapor back to liquid or solid form, creating cloud droplets and various forms of precipitation.

<table>
<thead>
<tr>
<th>Estimate of Global Water Distribution</th>
<th>Volume (1000 km³)</th>
<th>Percent of Total Water</th>
<th>Percent of Fresh Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans, Seas, and Bays</td>
<td>1,338,000</td>
<td>96.5</td>
<td>-</td>
</tr>
<tr>
<td>Ice Caps, Glaciers, and Permanent Snow</td>
<td>24,064</td>
<td>1.74</td>
<td>68.7</td>
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<tr>
<td>Groundwater</td>
<td>23,400</td>
<td>1.7</td>
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<tr>
<td>Fresh</td>
<td>(10,530)</td>
<td>(0.76)</td>
<td>30.1</td>
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<tr>
<td>Saline</td>
<td>(12,870)</td>
<td>(0.94)</td>
<td>-</td>
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<tr>
<td>Soil Moisture</td>
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<td>0.05</td>
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<td>Ground Ice and Permafrost</td>
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<tr>
<td>Lakes</td>
<td>176.4</td>
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<td>-</td>
</tr>
<tr>
<td>Fresh</td>
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<td>(0.007)</td>
<td>0.26</td>
</tr>
<tr>
<td>Saline</td>
<td>(85.4)</td>
<td>(0.006)</td>
<td>-</td>
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</tbody>
</table>

Water vapor—and with it energy—is carried around the globe by weather systems. This satellite image shows the distribution of water vapor over Africa and the Atlantic Ocean. White areas have high concentrations of water vapor, while dark regions are relatively dry. The brightest white areas are towering thunderclouds. The image was acquired on the morning of September 2, 2010 by SEVIRI aboard METEOSAT-9. [Watch this animation (23 MB QuickTime) of similar data to see the movement of water vapor over time.] (Image ©2010 EUMETSAT.)
Atmosphere 12.9 0.001 0.04
Swamp Water 11.47 0.0008 0.03
Rivers 2.12 0.0002 0.006
Biological Water 1.12 0.0001 0.003
Total 1,385,984 100.0


For human needs, the amount of freshwater on Earth—for drinking and agriculture—is particularly important. Freshwater exists in lakes, rivers, groundwater, and frozen as snow and ice. Estimates of groundwater are particularly difficult to make, and they vary widely. (The value in the above table is near the high end of the range.)

Groundwater may constitute anywhere from approximately 22 to 30% of fresh water, with ice (including ice caps, glaciers, permanent snow, ground ice, and permafrost) accounting for most of the remaining 78 to 70%.

A Multi-Phased Journey

The water, or hydrologic, cycle describes the pilgrimage of water as water molecules make their way from the Earth’s surface to the atmosphere and back again, in some cases to below the surface. This gigantic system, powered by energy from the Sun, is a continuous exchange of moisture between the oceans, the atmosphere, and the land.

Studies have revealed that evaporation—the process by which water changes from a liquid to a gas—from oceans, seas, and other bodies of water (lakes, rivers, streams) provides nearly 90% of the moisture in our atmosphere. Most of the remaining 10% found in the atmosphere is released by plants through transpiration. Plants take in water through their roots, then release it through small pores on the underside of their leaves. In addition, a very small portion of water vapor enters the atmosphere through sublimation, the process by which water changes directly from a solid (ice or snow) to a gas. The gradual shrinking of snow banks in cases when the temperature remains below freezing results from sublimation.

Together, evaporation, transpiration, and sublimation, plus volcanic emissions, account for almost all the water vapor in the atmosphere that isn’t inserted through human activities. While evaporation from the oceans is the primary vehicle for driving the surface-to-atmosphere

Earth’s water continuously moves through the atmosphere, into and out of the oceans, over the land surface, and underground. (Image courtesy NOAA National Weather Service Jetstream.)

Courtesy National Oceanic and Atmospheric Administration
portion of the hydrologic cycle, transpiration is also significant. For example, a cornfield 1 acre in size can transpire as much as 4,000 gallons of water every day.

After the water enters the lower atmosphere, rising air currents carry it upward, often high into the atmosphere, where the air is cooler. In the cooler air, water vapor is more likely to condense from a gas to a liquid to form cloud droplets. Cloud droplets can grow and produce precipitation (including rain, snow, sleet, freezing rain, and hail), which is the primary mechanism for transporting water from the atmosphere back to the Earth's surface.

When precipitation falls over the land surface, it follows various routes in its subsequent paths. Some of it evaporates, returning to the atmosphere; some seeps into the ground as soil moisture or groundwater; and some runs off into rivers and streams. Almost all of the water eventually flows into the oceans or other bodies of water, where the cycle continues. At different stages of the cycle, some of the water is intercepted by humans or other life forms for drinking, washing, irrigating, and a large variety of other uses.

Groundwater is found in two broadly defined layers of the soil, the "zone of aeration," where gaps in the soil are filled with both air and water, and, further down, the "zone of saturation," where the gaps are completely filled with water. The boundary between these two zones is known as the water table, which rises or falls as the amount of groundwater changes.

The amount of water in the atmosphere at any moment in time is only 12,900 cubic kilometers, a minute fraction of Earth's total water supply: if it were to completely rain out, atmospheric moisture would cover the Earth's surface to a depth of only 2.5 centimeters. However, far more water—in fact, some 495,000 cubic kilometers of it—are cycled through the atmosphere every year. It is as if the entire amount of water in the air were removed and replenished nearly 40 times a year.

Water continually evaporates, condenses, and precipitates, and on a global basis, evaporation approximately equals precipitation. Because of this equality, the total amount of water vapor in the atmosphere remains approximately the same over time. However, over the continents, precipitation routinely exceeds evaporation, and conversely, over the oceans, evaporation exceeds precipitation.

In the case of the oceans, the continual excess of evaporation versus precipitation would eventually leave the oceans empty if they were not being replenished by additional means. Not only are they being replenished, largely through runoff from the land areas, but over the past 100 years, they have been over-replenished: sea level around the globe has risen approximately 17 centimeters over the course of the twentieth century.

This map shows the distribution of water vapor throughout the depth of the atmosphere during August 2010. Even the wettest regions would form a layer of water only 60 millimeters deep if it were condensed at the surface. (NASA image by Robert Simmon, using AIRS & AMSU data.)
Sea level has risen both because of warming of the oceans, causing water to expand and increase in volume, and because more water has been entering the ocean than the amount leaving it through evaporation or other means. A primary cause for increased mass of water entering the ocean is the calving or melting of land ice (ice sheets and glaciers). Sea ice is already in the ocean, so increases or decreases in the annual amount of sea ice do not significantly affect sea level.

Sea level has been rising over the past century, partly due to thermal expansion of the ocean as it warms, and partly due to the melting of glaciers and ice caps. (Graph ©2010 Australian Commonwealth Scientific and Research Organization.)

Throughout the hydrologic cycle, there are many paths that a water molecule might follow. Water at the bottom of Lake Superior may eventually rise into the atmosphere and fall as rain in Massachusetts. Runoff from the Massachusetts rain may drain into the Atlantic Ocean and circulate northeastward toward Iceland, destined to become part of a floe.

Blackfoot (left) and Jackson (right) glaciers, both in the mountains of Glacier National Park, were joined along their margins in 1914, but have since retreated into separate alpine cirques. The melting of glacial
of sea ice, or, after evaporation to the atmosphere and precipitation as snow, part of a glacier.

Water molecules can take an immense variety of routes and branching trails that lead them again and again through the three phases of ice, liquid water, and water vapor. For instance, the water molecules that once fell 100 years ago as rain on your great-grandparents’ farmhouse in Iowa might now be falling as snow on your driveway in California.

The Water Cycle and Climate Change
Among the most serious Earth science and environmental policy issues confronting society are the potential changes in the Earth’s water cycle due to climate change. The science community now generally agrees that the Earth’s climate is undergoing changes in response to natural variability, including solar variability, and increasing concentrations of greenhouse gases and aerosols. Furthermore, agreement is widespread that these changes may profoundly affect atmospheric water vapor concentrations, clouds, precipitation patterns, and runoff and stream flow patterns.

For example, as the lower atmosphere becomes warmer, evaporation rates will increase, resulting in an increase in the amount of moisture circulating throughout the troposphere (lower atmosphere). An observed consequence of higher water vapor concentrations is the increased frequency of intense precipitation events, mainly over land areas. Furthermore, because of warmer temperatures, more precipitation is falling as rain rather than snow.

Global climate change will affect the water cycle, likely creating perennial droughts in some areas and frequent floods in others. (Photograph ©2008 Garry Schlatter.)

One expected effect of climate change will be an increase in precipitation intensity. A larger proportion of rain will fall in a shorter amount of time than it has historically. Blue represents areas where climate models predict an increase in intensity by the end of the 21st century, brown represents a predicted decrease. (Map adapted from the IPCC Fourth Assessment Report.)

In parts of the Northern Hemisphere, an earlier arrival of spring-like conditions is leading to earlier peaks in snowmelt and resulting river flows. As a consequence, seasons with the highest water demand, typically summer and fall, are being impacted by a reduced availability of fresh water.

Courtesy National Oceanic and Atmospheric Administration
Warmer temperatures have led to increased drying of the land surface in some areas, with the effect of an increased incidence and severity of drought. The Palmer Drought Severity Index, which is a measure of soil moisture using precipitation measurements and rough estimates of changes in evaporation, has shown that from 1900 to 2002, the Sahel region of Africa has been experiencing harsher drought conditions. This same index also indicates an opposite trend in southern South America and the southern central United States.

While the brief scenarios described above represent a small portion of the observed changes in the water cycle, it should be noted that many uncertainties remain in the prediction of future climate. These uncertainties derive from the sheer complexity of the climate system, insufficient and incomplete data sets, and inconsistent results given by current climate models. However, state of the art (but still incomplete and imperfect) climate models do consistently predict that precipitation will become more variable, with increased risks of drought and floods at different times and places.

**Observing the Water Cycle**

Orbiting satellites are now collecting data relevant to all aspects of the hydrologic cycle, including evaporation, transpiration, condensation, precipitation, and runoff. NASA even has one satellite, Aqua, named specifically for the information it is collecting about the many components of the water cycle.

Aqua launched on May 4, 2002, with six Earth-observing instruments: the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU), the Humidity Sounder for Brazil (HSB), the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E), the Moderate Resolution Imaging Spectroradiometer (MODIS), and Clouds and the Earth’s Radiant Energy System (CERES).
References


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*Courtesy National Oceanic and Atmospheric Administration*
Estimated Use of Water in the United States in 2010

By Molly A. Maupin, Joan F. Kenny, Susan S. Hutson, John K. Lovelace, Nancy L. Barber, and Kristin S. Linsey
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Abstract

Water use in the United States in 2010 was estimated to be about 355 billion gallons per day (Bgal/d), which was 13 percent less than in 2005. The 2010 estimates put total withdrawals at the lowest level since before 1970. Freshwater withdrawals were 306 Bgal/d, or 86 percent of total withdrawals, and saline-water withdrawals were 48.3 Bgal/d, or 14 percent of total withdrawals. Fresh surface-water withdrawals (230 Bgal/d) were almost 15 percent less than in 2005, and fresh groundwater withdrawals (76.0 Bgal/d) were about 4 percent less than in 2005. Saline surface-water withdrawals were 45.0 Bgal/d, or 24 percent less than in 2005. Updates to the 2005 saline groundwater withdrawals, mostly for thermoelectric power, reduced total saline groundwater withdrawals to 1.51 Bgal/d, down from the originally reported 3.02 Bgal/d. Total saline groundwater withdrawals in 2010 were 3.29 Bgal/d, mostly for mining use.

Thermoelectric-power and irrigation remained the two largest uses of water in 2010, and total withdrawals for both were notably less than in 2005. Withdrawals in 2010 for thermoelectric power were 20 percent less and withdrawals for irrigation were 9 percent less than in 2005. Similarly, other uses showed reductions compared to 2005, specifically public supply (–5 percent), self-supplied domestic (–3 percent), self-supplied industrial (–12 percent), and livestock (–7 percent). Only mining (39 percent) and aquaculture (7 percent) reported larger withdrawals in 2010 compared to 2005. Thermoelectric power, irrigation, and public-supply withdrawals accounted for 90 percent of total withdrawals in 2010.

Withdrawals for thermoelectric power were 161 Bgal/d in 2010 and represented the lowest levels since before 1970. Surface-water withdrawals accounted for more than 99 percent of total thermoelectric-power withdrawals, and 73 percent of those surface-water withdrawals were from freshwater sources. Saline surface-water withdrawals for thermoelectric power accounted for 97 percent of total saline surface-water withdrawals for all uses. Thermoelectric-power withdrawals accounted for 45 percent of total withdrawals for all uses, and freshwater withdrawals for thermoelectric power accounted for 38 percent of the total freshwater withdrawals for all uses.

Irrigation withdrawals were 115 Bgal/d in 2010 and represented the lowest levels since before 1965. Irrigation withdrawals, all freshwater, accounted for 38 percent of total freshwater withdrawals for all uses, or 61 percent of total freshwater withdrawals for all uses excluding thermoelectric power. Surface-water withdrawals (65.9 Bgal/d) accounted for 57 percent of the total irrigation withdrawals, or about 12 percent less than in 2005. Groundwater withdrawals were 49.5 Bgal/d in 2010, about 6 percent less than in 2005. About 62,400 thousand acres were irrigated in 2010, an increase from 2005 of about 950 thousand acres (1.5 percent). The number of acres irrigated using sprinkler and microirrigation systems continued to increase and accounted for 58 percent of the total irrigated lands in 2010.

Public-supply withdrawals in 2010 were 42.0 Bgal/d, or 5 percent less than in 2005, and represented the first declines in public-supply withdrawals since the 5-year reporting began in 1950. Total population in the United States increased from 300.7 million people in 2005 to 313.0 million people in 2010, an increase of 4 percent. Public-supply withdrawals accounted for 14 percent of the total freshwater withdrawals for all uses and 22 percent of freshwater withdrawals for all uses excluding thermoelectric power. The number of people that received potable water from public-supply facilities in 2010 was 268 million, or about 86 percent of the total U.S. population. This percentage was unchanged from 2005. Self-supplied domestic withdrawals were 3.60 Bgal/d, or 3 percent less than in 2005. More than 98 percent of the self-supplied domestic withdrawals were from groundwater sources.

Self-supplied industrial withdrawals were 15.9 Bgal/d in 2010, a 12 percent decline from 2005, and continued the downward trend since the peak of 47 Bgal/d in 1970. Total self-supplied industrial withdrawals were 4 percent of total withdrawals for all uses and 8 percent of total withdrawals for all uses excluding thermoelectric power. Most of the total...
self-supplied industrial withdrawals were from surface-water sources (82 percent), and nearly all (93 percent) of those surface-water withdrawals were from freshwater sources. Nearly all of the groundwater withdrawals for self-supplied industrial use (98 percent) were from freshwater sources. Total aquaculture withdrawals were 9.42 Bgal/d in 2010, or 7 percent more than in 2005, and surface water was the primary source (81 percent). Most of the surface-water withdrawals occurred at facilities that operated flowthrough raceways, which returned the water to the source directly after use. Aquaculture withdrawals accounted for 3 percent of the total withdrawals for all uses and 5 percent of the total withdrawals for all uses excluding thermoelectric.

Total mining withdrawals in 2010 were 5.32 Bgal/d, or about 1 percent of total withdrawals from all uses and 3 percent of total withdrawals from all uses excluding thermoelectric. Mining withdrawals accounted for the largest percentage increase (39 percent) in water use between 2005 and 2010 among all the categories. Groundwater withdrawals accounted for 73 percent of the total mining withdrawals, and the majority of the groundwater was saline (71 percent). The majority (80 percent) of surface-water withdrawals for mining was freshwater.

Livestock withdrawals in 2010 were 2.00 Bgal/d, or 7 percent less than in 2005. All livestock withdrawals were from freshwater sources, mostly from groundwater (60 percent). Livestock withdrawals accounted for about 1 percent of total freshwater withdrawals for all uses excluding thermoelectric power.

In 2010, more than 50 percent of the total withdrawals in the United States were accounted for by 12 States. California accounted for about 11 percent of the total withdrawals and 10 percent of freshwater withdrawals in the United States, predominantly for irrigation. Texas accounted for about 7 percent of total withdrawals, predominantly for thermoelectric power, irrigation, and public supply. Florida accounted for 18 percent of the total saline-water withdrawals in the United States, mostly from surface-water sources for thermoelectric power. Oklahoma and Texas accounted for about 70 percent of the total saline groundwater withdrawals in the United States, mostly for mining.

**Introduction**

This report, “Estimated use of water in the United States in 2010,” is the 13th in a series of U.S. Geological Survey (USGS) Circular reports that have been published every 5 years since 1950. The 60-year span of national reports represents the longest compilation record of water-use data by a Federal agency in the United States. Estimates of withdrawals enable the depiction of trends in total water use for the Nation among different geographic areas, categories of use, and sources over time. The USGS is dedicated to providing reliable scientific information that accurately describes current and historic conditions and enables a better understanding of the Earth’s precious water resources. Water-use information complements and supports surface-water and groundwater availability studies and water budgets that are critical to these studies. This information is also essential to accurately understand how future water demands will be met while maintaining adequate water quality and quantities for human and ecosystem needs.

The National Water Use Information Program (NWUIP) is the USGS program (http://water.usgs.gov/watuse/) that facilitates the 5-year compilation of water use and over time has met various challenges in estimating water use in the United States. The program, however, has reduced some data collections over time to address limitations of available resources for analysis and limitations of capabilities for accurate interpolations. The National Water Census (NWC) is a recent USGS program, implemented as part of the SECURE (Science and Engineering to Comprehensively Understand and Responsibly Enhance) Water Act (Subtitle F of Public Law 111–11, the Omnibus Public Land Management Act) to study national water availability and use by integrating diverse research and building new water accounting tools, such as decision support capacity. These tools and research are designed to enable water managers to accurately assess water availability at regional and national scales (http://water.usgs.gov/watercensus/). To meet NWC goals of building water budget assessments at regional and national scales, accurate and complete water-use estimates are necessary. The NWUIP is working closely with the NWC to provide water-use data for accurate water budget assessments in the NWC study areas. To meet these goals, several water-use specific research studies supported by the NWC were begun, some are completed, and some are ongoing. Each study specifically addresses a water-use data collection challenge, such as improvement in the dissemination of information on data inventories, collection of more accurate information, use of better methods for analysis, and upgrade of data dissemination tools.

NWUIP-supported projects with direct relevance to water use were conducted concurrently with the NWUIP 2010 compilation efforts and focused on the three largest categories of water use, irrigation, thermoelectric power, and public supply. For irrigation water use, methods and documentation were synthesized into a national report using the 2000 and 2005 compilation data and suggested improved estimation methods (Dickens and others, 2011). Additionally, methods were developed to assist in estimating irrigation water use in humid Eastern States, using two predictive models that use climate, soils, and crop data to explain the potential for irrigation (Levin and Zarriello, 2013). For thermoelectric power, linked heat and water budget models were developed for 1,290 thermoelectric powerplants in the United States (Diehl and others, 2013). This project entailed a indepth inventory of powerplants and associated information. Data from this project considerably improved
The Boise River Diversion Dam in Ada County, Idaho, was completed in 1909 and diverts water into the New York Canal, the primary irrigation canal for Ada and Canyon Counties. Photo by Jeff Woody, used with permission.

the NWUIP understanding of the cooling systems used at individual powerplants as well as provided a more complete inventory of powerplant locations and net power generation. On the basis of the water budget models, Diehl and Harris (2014) reported powerplant-specific estimates of withdrawals and consumptive use. For public supply, the U.S. Environmental Protection Agency (EPA) provided a public-supply dataset from the Safe Drinking Water Information System (SDWIS). These data included site-specific well, surface-water intake, and distribution-system information, which was filtered through a USGS database (Price and Maupin, 2014) and enhanced for quality control using associated USGS data. These data were disseminated as State datasets to each USGS Water Science Center to help construct a site-specific database capable of storing public-supply withdrawal, distribution, use, and return data for each State.

Data dissemination capabilities and data-collection efforts have improved over the course of each 5-year compilation. The online resource, “USGS Water Use Data for the Nation” (http://waterdata.usgs.gov/nwis/wu), provides the best available county water-use data (1985–2010). These county-level estimates are the foundation for the statewide totals presented in each 5-year compilation report and are stored, updated, and disseminated using the USGS National Water Information System (NWIS) database. Data are retrievable as county, State, and national totals for each category of use as reported in the 5-year compilation reports. Because data are updated periodically and revised during interim years, the Web site will enable quick and easy access to the most current water-use data.

Factors such as demographics, new manufacturing and cooling-system technologies, economic trends, legal decisions, and climatic fluctuations have varying effects on water use. Between 2000 and 2010, population growth in the U.S. was 9.7 percent, lower than the 13.2 percent growth for the 1990–2000 period (U.S. Census Bureau, 2011). More population growth was recorded in Southern and Western States (14.3 and 13.8 percent, respectively) between 2000 and 2010 compared to Midwestern States (3.9 percent) and Northeastern States (3.2 percent). Southern and Western States accounted for more than 84 percent of the total U.S. population growth from 2000 to 2010. Population growth puts additional pressure on existing public utilities and increases demand on sometimes already limited water supplies. In parts of the United States, communities have sought additional water sources or instituted water-conservation measures to meet increasing demands. New cooling-system technologies and wastewater management practices at thermoelectric powerplants and industrial facilities are examples of water-saving practices that are being implemented. Powerplants have reduced the demand for cooling water by implementing more efficient cooling systems, such as changing to recirculating systems or building new plants with dry-cooling systems. Industrial facilities are
using more efficient water-conserving manufacturing technologies, driven by higher costs for water and energy. Industrial manufacturing has declined with more goods being produced outside of the United States. Increases in industrial reuse and recycling of wastewater help to reduce withdrawals from the available resources and treated discharges to surface waters over time.

Climate fluctuations affect water use, particularly for irrigation, power generation, and public supply. In 2010, the contiguous United States (CONUS) experienced average annual air temperatures slightly above normal and precipitation above the long-term average. An abnormally cold winter with abundant moisture resulted in record-breaking precipitation in the East and Northeast for December–February. While the East enjoyed an abnormally warm spring, the Western United States experienced below normal temperatures. The summer of 2010 was the fourth warmest on record for the CONUS, but was the ninth wettest in 116 years in the Upper Midwest and Great Lakes. The West and Southeast had below-normal precipitation during the summer. The fall of 2010 was warmer than normal, but the Upper Midwest and Northeast continued to receive above-average precipitation, while Florida suffered through the second driest September–November period on record (National Oceanic and Atmospheric Administration National Climatic Data Center, 2010).

Cooling-system technology in thermoelectric power-plants has dramatically improved in recent years, causing large changes in withdrawals between 2005 and 2010. Improvements driven by the Clean Water Act and other economic factors have changed the way industrial facilities use, reuse, and recycle water, resulting in reduced discharges to wastewater-treatment plants or surface-water bodies. Cooling water is essential for producing most of the thermoelectric power in the United States, and an increase in electric energy use has resulted in additional demands for water. Limitations on water supplies have led to the use of less water-intensive cooling technologies for producing thermoelectric power in newer powerplants.

Purpose and Scope

This report presents average daily withdrawals (in millions of gallons per day) for calendar year 2010, by source (groundwater and surface water) and quality (fresh and saline) for the 50 States, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands (hereafter referred to as “States” for brevity). Withdrawals are reported by category of use: public supply, domestic (including self-supplied domestic and deliveries from public supply), irrigation, livestock, aquaculture, self-supplied industrial (referred to as “industrial” for brevity), mining, and self-supplied thermoelectric power (referred to as “thermoelectric power” for brevity). Saline water is defined as water containing dissolved solids of 1,000 milligrams per liter or more. All withdrawals for the public supply, domestic, irrigation, and livestock categories are reported as totals, although in some areas water is treated to reduce salinity for these uses. Aquaculture totals include a small amount of saline surface-water withdrawals for two States. Both freshwater and saline-water withdrawals are reported for industrial, mining, and thermoelectric-power uses.

Total water withdrawals in the United States for 2010 were estimated for eight categories of use: public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power (fig. 1). The three largest categories were thermoelectric power, irrigation, and public supply, cumulatively accounting for 90 percent of the national total. The remaining categories of industrial, aquaculture, mining, domestic, and livestock together were just about 10 percent of total water withdrawals estimated in this report.

Total State populations and withdrawals by source for 2010 are listed in table 1. Total freshwater and saline-water withdrawals were estimated to be 355,000 million gallons per day (Mgal/d), or 397,000 thousand acre-feet per year (acre-ft/yr). Freshwater withdrawals of 306,000 Mgal/d made up 86 percent of the total, and saline-water withdrawals made up the remaining 48,300 Mgal/d (14 percent). Most saline-water withdrawals were seawater and brackish coastal water used for thermoelectric power. Total surface-water withdrawals were estimated to be 275,000 Mgal/d, or 78 percent of the total. About 84 percent (230,000 Mgal/d) of total surface-water withdrawals were freshwater. Total groundwater withdrawals were 79,300 Mgal/d, of which 96 percent (76,000 Mgal/d) was freshwater.

Total withdrawals by category and State are listed in table 2A, in million gallons per day, and in table 2B, in thousand acre-feet per year. Withdrawals for thermoelectric power (161,000 Mgal/d) are mostly derived from freshwater sources and accounted for 38 percent of the total freshwater withdrawals and about 91 percent of total saline-water withdrawals. Irrigation withdrawals totaled 115,000 Mgal/d and accounted for 38 percent of total freshwater withdrawals. Total withdrawals for public supply (42,000 Mgal/d) represented nearly 14 percent of the total freshwater withdrawals.

In 2010, more than 50 percent of the total withdrawals in the United States were accounted for by 12 States: California, Texas, Idaho, Florida, Illinois, North Carolina, Arkansas, Colorado, Michigan, New York, Alabama, and Ohio. California accounted for 11 percent of the total withdrawals for all categories and 10 percent of total freshwater withdrawals for all categories nationwide. Texas accounted for about 7 percent of total withdrawals for all categories, predominantly for thermoelectric power, irrigation, and public supply. Florida had the largest saline withdrawals, accounting for 18 percent of the total in the United States, mostly saline surface-water withdrawals for thermoelectric power. Oklahoma and Texas accounted for about 70 percent of the total saline groundwater withdrawals in the United States, mostly for mining.

Water withdrawals by category and State are listed for surface water in tables 3A and 3B and for groundwater in tables 4A and 4B. In 2010, more surface water than groundwater was withdrawn for all uses except domestic, livestock, and mining. Thermoelectric power accounted for 51 percent of the total fresh surface-water withdrawals and irrigation accounted for 29 percent. The largest surface-water withdrawals in the Nation were in California, where irrigation accounted for 76 percent of total fresh surface-water withdrawals. Large quantities of fresh surface water were also withdrawn for thermoelectric power in Illinois, Texas, Michigan, and Alabama. Large saline surface-water withdrawals for thermoelectric power occurred in Florida, California, Maryland, and New York, which cumulatively accounted for 57 percent of the national total saline surface-water withdrawals.

Of the total fresh groundwater withdrawals (76,000 Mgal/d), irrigation accounted for 65 percent, primarily in California, Arkansas, Texas, and Nebraska. Fresh groundwater irrigation withdrawals in these four States cumulatively accounted for 42 percent of the national total fresh groundwater withdrawals. Nearly all groundwater withdrawals (96 percent) were from freshwater, and irrigation used greater than three times more fresh groundwater than public supply, which was the next largest use of groundwater in the Nation. The largest withdrawals of saline groundwater occurred in Oklahoma and Texas.

The geographic distribution of total withdrawals in the United States is shown in figure 2. The geographic distribution of total surface water and groundwater, and total freshwater and saline-water withdrawals by State is shown in figure 3.
Figure 1. Total water withdrawals by category, 2010.
Figure 2. Total water withdrawals by State and barchart showing categories by State from west to east, 2010.
Figure 3. Surface-water and groundwater, and freshwater and saline-water withdrawals, 2010.
Public Supply refers to water withdrawn by public and private water suppliers that provide water to at least 25 people or have a minimum of 15 connections. Public-supply water is delivered to users for domestic, commercial, and industrial purposes, and also is used for public services and system losses.

Approximately 42,000 Mgal/d (table 5), or 47,100 thousand acre-ft/yr (table 2B), of water were withdrawn for public supply in 2010. This amount is 5 percent less than the estimated amount of water withdrawn for public supply in 2005. Public supply represents about 14 percent of total freshwater withdrawals and 22 percent of all withdrawals excluding thermoelectric power. In some States, public-supply water sources include desalinated seawater or brackish groundwater that has been treated to reduce dissolved solids. A combined total of 23.5 Mgal/d saline surface-water withdrawals for public-supply use were identified in Florida, the U.S. Virgin Islands, Massachusetts, and Texas. A combined total of 317 Mgal/d saline groundwater withdrawals for public-supply use were identified in Florida, California, Texas, Virginia, and Utah. Because these saline withdrawals were identified for only seven States and represent less than 1 percent of total public-supply withdrawals, they are not listed separately in table 5 but were included in the calculations.

An estimated 268 million people relied on public-supply water for their household use in 2010. This number represents about 86 percent of the total U.S. population. About 35 percent of all public-supply withdrawals were in the four States with the largest populations: California, Texas, New York, and Florida (fig. 4). Sixty-three percent of water withdrawn for public supply in 2010 was from surface sources, such as lakes and streams; the other 37 percent was from groundwater.

Five States—California, Texas, New York, Pennsylvania, and Illinois—each withdrew more than 1,000 Mgal/d of surface water for public supply in 2010 and together accounted for 40 percent of the total surface-water withdrawals for public supply. In 36 States, including Puerto Rico and the U.S. Virgin Islands, surface-water sources provided more than half of the total public-supply withdrawals.

Three States—California, Florida, and Texas—each withdrew more than 1,000 Mgal/d of groundwater for public supply in 2010 and accounted for 38 percent of total groundwater withdrawals for public supply. States that relied on groundwater for 75 percent or more of their public-supply withdrawals were Hawaii, Florida, Idaho, Mississippi, Nebraska, and Iowa.

Most of the public-supply withdrawals are delivered to customers for domestic, commercial, and industrial needs. Part of the total is used for public services, such as public pools, parks, firefighting, water and wastewater treatment, and municipal buildings, and some is unaccounted for because of leaks, flushing, tower maintenance, and other system losses. Domestic deliveries represent the largest single component of public-supply withdrawals, averaging 57 percent of the total nationally. Estimates of public-supply deliveries to domestic use, representing indoor and outdoor water uses at occupied residences, are identified in table 5. Estimates for commercial and industrial deliveries, public use, and system losses were not available for all States and, therefore, are included in table 5 as an aggregate number.

Methods for estimating public-supply withdrawals, source of water, population served, and domestic deliveries varied by State. Common sources of information about withdrawals by source included data collected from water suppliers by State water regulatory agencies or through surveys. Estimates of the population served by public supply were derived using various sources, including reports from State agencies, the EPA SDWIS database, U.S. Census data, and information on service connections from public suppliers. Methods for estimating domestic deliveries included surveys of public-supply sales information, calculations using coefficients for per capita use, and development of average percentages of deliveries to various customer categories.
Figure 4. Public-supply withdrawals by source and State, 2010.
Domestic water use includes indoor and outdoor uses at residences. Common indoor water uses are drinking, food preparation, washing clothes and dishes, and flushing toilets. Common outdoor uses are watering lawns and gardens or maintaining pools, ponds, or other landscape features in a domestic environment. Domestic water is either self-supplied or provided by public suppliers. Self-supplied domestic water use is typically withdrawn from a private source, such as a well, or captured as rainwater in a cistern. Domestic deliveries are provided to homes by public suppliers. Figure 5 illustrates the proportions of total domestic water from public-supply deliveries and self-supply domestic withdrawals.

Table 6 lists the estimated self-supplied and public-supplied population in each State, as well as the amounts used by each segment of the population for domestic needs and the respective per capita use in gallons per day (gallons per capita daily, gpcd). Domestic self-supplied withdrawals and public-supplied deliveries also are combined in table 6 to show the total estimated domestic use in 2010 and the weighted per capita use in gallons per day calculated for all domestic use.

An estimated 44.5 million people in the United States, or 14 percent of the population, provided their own water for domestic use in 2010. These self-supplied withdrawals were estimated at 3,600 Mgal/d (4,040 thousand acre-ft/yr), or about 1 percent of total withdrawals for all uses in 2010. Nearly all (98 percent) of these self-supplied withdrawals were from fresh groundwater sources. Self-supplied domestic withdrawals are rarely metered or reported; typically this usage is calculated by multiplying an estimate of the population not served by public supply by a coefficient for daily per capita use. For some States, these coefficients were county-specific averages derived from observed residential water use and population estimates in nearby areas served by public suppliers. Other States used the same coefficient for all counties, commonly one used by State regulatory or planning agencies. Self-supplied domestic per capita use ranged from 48 gpcd in Wisconsin to 189 gpcd in Nevada. Generally, per capita use is least in the Northern and Eastern States and greatest in the Mountain and Western States where outdoor watering is more common. The national average self-supplied domestic per capita use in 2010 was 81 gpcd (table 6).

The majority of people in the United States used water provided by public suppliers. Domestic deliveries by public water suppliers totaled 23,800 Mgal/d in 2010 and represented water provided to 268 million people at single-family and multifamily dwellings. Per capita water use for domestic deliveries ranged from 51 gpcd in Maine to 167 gpcd in Utah. The national average was 89 gpcd for public-supplied domestic water use. This per capita usage is less than the rate of 101 gpcd observed in 1995 and 100 gpcd in 2005. Domestic deliveries from public supply were not compiled nationally in 2000. Combined self-supplied domestic withdrawals and public-supply deliveries totaled 27,400 Mgal/d in 2010, and the national average per capita usage was 88 gpcd. The corresponding average per capita use for total domestic use in 2005 was 98 gpcd. The geographic distribution of total domestic water use by State is shown in figure 6A. Self-supplied domestic population in each State, in thousands of people and as a percentage of total State population, are shown in figure 6B. Self-supplied domestic populations were largest in Pennsylvania, North Carolina, and Michigan. States with the largest percentages of their population that were self-supplied were Maine, Alaska, and the U.S. Virgin Islands.
Figure 6A. Domestic withdrawals and deliveries by State, 2010.
Figure 6B. Self-supplied domestic population and percentage of total population by State, 2010.
Irrigation water use includes water that is applied by an irrigation system to sustain plant growth in all agricultural and horticultural practices. Irrigation also includes water that is used for pre-irrigation, frost protection, application of chemicals, weed control, field preparation, crop cooling, harvesting, dust suppression, and leaching salts from the root zone. Estimates of irrigation withdrawals include water that is lost in conveyance prior to application on fields as well as water that may subsequently return to a surface-water body as runoff after application, water consumed as evapotranspiration (ET) from plants and ground surfaces, or water that recharges aquifers as it seeps past the root zone. Irrigation of golf courses, parks, nurseries, turf farms, cemeteries, and other self-supplied landscape-watering uses also are included in the estimates. Irrigation water use includes self-supplied withdrawals and deliveries from irrigation companies or districts, cooperatives, or governmental entities. Some irrigation water is reclaimed wastewater from nearby treatment facilities or industries although these quantities are not included in irrigation withdrawals reported here. All irrigation withdrawals are considered freshwater. Irrigated acres are reported by three types of irrigation methods: sprinkler, microirrigation, and surface (flood) systems.

Irrigation withdrawals and irrigated acres by type of irrigation system are listed by State in table 7. For 2010, total irrigation withdrawals were 115,000 Mgal/d, or 129,000 thousand acre-ft/yr, which accounted for 38 percent of total freshwater withdrawals and 61 percent of total freshwater withdrawals for all categories excluding thermoelectric power. Total irrigation withdrawals were 9 percent less than in 2005. Withdrawals from surface-water sources were 65,900 Mgal/d, which accounted for 57 percent of the total irrigation withdrawals, and were almost 12 percent less than in 2005. Groundwater withdrawals for 2010 were 49,500 Mgal/d, or 6 percent less than in 2005.

About 62,400 thousand acres were irrigated in 2010, an increase of about 950 thousand acres (1.5 percent) from 2005. About 31,600 thousand acres (51 percent) were irrigated with sprinkler systems, 26,200 thousand acres with surface (flood), and 4,610 thousand acres with microirrigation systems. The national average application rate for 2010 was 2.07 acre-feet per acre, or 11 percent less than the 2005 average of 2.32 acre-feet per acre.

The geographic distribution of total, surface-water, and groundwater withdrawals for irrigation is shown in figure 7. The majority of total U.S. irrigation withdrawals (83 percent) and irrigated acres (74 percent) were in the 17 contiguous Western States (west of solid line in figure 7), which are typical of areas where average annual precipitation is less than 20 inches and generally insufficient to support crops without supplemental water. Surface water was the primary source of water in the arid West, except in Kansas, Oklahoma, Nebraska, Texas, and South Dakota, where more groundwater was used. The 17 Western States cumulatively accounted for 93 percent of total surface-water irrigation withdrawals and 69 percent of total groundwater irrigation withdrawals.

Because the 17 Western States accounted for the majority of total irrigation withdrawals, changes in those States had a great effect on the overall total. Total irrigation withdrawals declined noticeably in Nebraska, Montana, Idaho, Colorado, and California. Groundwater irrigation withdrawals declined in the West and increased in the East, and surface-water irrigation withdrawals declined in both regions. Total irrigated acres increased in both regions—1 percent (568 thousand acres) in the West, and 2 percent (381 thousand acres) in the East. In the West, the total number of acres irrigated by the less-efficient surface-irrigation methods decreased by about 500 thousand acres, and the number of acres irrigated by more efficient sprinkler (including microirrigation) methods increased by about 1,080 thousand acres.

Average application rates are calculated as a function of total irrigation withdrawals and total irrigated acres. The highest application rates are found in arid Western States, where more surface water than groundwater is used for irrigation and water typically is conveyed longer distances in canals between the points of diversion and use. Among the Western States, cumulatively, more lands were irrigated with sprinkler (including microirrigation) systems than surface methods, and land using the microirrigation system are increasing at a faster rate than the other two types of systems. Several States that used the large quantities of water for irrigation in 2010, such as California, Idaho, Colorado, Texas, and Nebraska, showed declines in application rates from 2005 levels, and in all of these States the number of acres irrigated by sprinkler or microirrigation systems increased in 2010.

Sources of data for irrigation withdrawals and irrigated acres included State and Federal crop reporting programs, irrigation districts, canal companies, incorporated management areas, and satellite data depicting 2010 cropland landscapes. Withdrawals also were estimated using information on irrigated crop acreages by crop type and specific crop water-consumption coefficients, or irrigation-system application rates, as well as soil moisture balance models. Estimation methods varied from one State to the next and sometimes between geographic areas within a State. Estimation methods ideally included adjustments for climate, system efficiencies, conveyance losses, and other irrigation practices such as pre-irrigation, salt leaching, or frost protection. Other methods for estimating irrigation withdrawals included extrapolation of sample data on crop water-application rates or power-consumption coefficients.
Figure 7. Irrigation withdrawals by source and State, 2010.
Livestock

Livestock water use is water associated with livestock watering, feedlots, dairy operations, and other on-farm needs. Livestock includes dairy cows and heifers, beef cattle and calves, sheep and lambs, goats, hogs and pigs, horses, and poultry. Other livestock water uses include cooling of facilities for the animals and products, dairy sanitation and wash down of facilities, animal waste-disposal systems, and incidental water losses. All withdrawals were considered freshwater and self supplied. The livestock category excludes on-farm domestic use, lawn and garden watering, and irrigation water use.

Livestock withdrawals for 2010 are listed by State in table 8. During 2010, withdrawals for livestock use were an estimated 2,000 Mgal/d, or 2,240 thousand acre-ft/yr (table 2B). Livestock withdrawals were about 1 percent of total freshwater withdrawals and about 1 percent of total freshwater withdrawals for all categories excluding thermoelectric power. Groundwater was the source for 60 percent of total livestock withdrawals. Estimated total livestock withdrawals for 2010 were 7 percent less than in 2005.

The geographic distribution of total, surface-water, and groundwater livestock withdrawals is shown in figure 8. Texas, California, Iowa, Nebraska, and Kansas each used more than 100 Mgal/d for livestock and together accounted for 41 percent of total livestock withdrawals in 2010. Texas, Iowa, Nebraska, Kansas, and California each used more than 80 Mgal/d of groundwater for livestock and accounted for 42 percent of groundwater withdrawals for this use. Texas and California each used more than 100 Mgal/d of surface water for livestock, and accounted for 29 percent of surface-water withdrawals for livestock.

Few State agencies require livestock operations to report water withdrawals; therefore, most estimates of livestock withdrawals were derived using animal population data and water-use coefficients, in gallons per head per day for each animal type. Animal population data generally are available from State agricultural agencies and the NASS. Coefficients vary by State and, for many States, were provided by agricultural extension agents or water-permitting agencies. Coefficients may reflect facility maintenance needs and effects of climate on animal watering. Many of the 2010 withdrawals for livestock were estimated according to methods described by Lovelace (2009a), using livestock population data compiled for the NASS 2007 Census of Agriculture (Robert Hunt, National Agricultural Statistics Service, written commun., 2013) and water-use coefficients.
Figure 8. Livestock withdrawals by source and State, 2010.
Aquaculture water use is water associated with raising organisms that live in water—such as finfish and shellfish—for food, restoration, conservation, or sport. Aquaculture production occurs under controlled feeding, sanitation, and harvesting procedures primarily in ponds, flowthrough raceways, and, to a lesser extent, cages, net pens, and closed-recirculation tanks. All withdrawals were considered self supplied.

Total withdrawals for aquaculture during 2010 are listed by State in table 9 at 9,420 Mgal/d, or 10,600 thousand acre-ft/yr (table 2B). Surface water was the source for about 81 percent of the withdrawals for this category. Much of the surface water was used for flowthrough raceways and was returned to the source after use. A combined total of 14.2 Mgal/d saline surface-water withdrawals, less than 0.2 percent of total aquaculture withdrawals, were reported in Rhode Island (8.80 Mgal/d) and Texas (5.37 Mgal/d); these amounts are not shown separately in table 9 but are included in the total. Aquaculture withdrawals were 3 percent of total withdrawals and 5 percent of total withdrawals for all categories excluding thermoelectric power. Estimated aquaculture withdrawals in 2010 were 7 percent more than in 2005.

The geographic distribution of total, surface-water, and groundwater withdrawals for aquaculture is shown in figure 9. Idaho, North Carolina, California, and Oregon used the most water for aquaculture, about 63 percent of the total and about 74 percent of the surface-water withdrawals for aquaculture. Alaska, Louisiana, Arkansas, California, and Mississippi combined accounted for 60 percent of the total groundwater withdrawals for aquaculture.

Several sources of information were used to estimate 2010 aquaculture withdrawals. Some estimates were derived from State permits that reported water withdrawals or return flows for aquaculture facilities. The EPA Permit Compliance System database also was a source of return-flow data that were used to estimate water withdrawals. Individual aquaculture operations, State regulatory agencies, State offices of the NASS, and Cooperative Extension Service offices also provided information that was used to estimate aquaculture withdrawals in some States.

Many of the 2010 withdrawals for aquaculture were estimated by multiplying the number of aquaculture farms in operation in each county during 2007 by the average groundwater and surface-water withdrawal rates for aquaculture farms in the county. For the purpose of these estimates, the change in the number of aquaculture farms in each county from 2002 to 2007 was assumed to be representative of withdrawal changes from 2005 to 2010. The average groundwater and surface-water withdrawal rates for each county were calculated by dividing the estimated groundwater and surface-water withdrawals for aquaculture in 2005 in the county by the number of aquaculture farms in operation in the county in 2002. The numbers of aquaculture farms in operation in 2002 and 2007 in each county were provided by the NASS (Robert Hunt, National Agricultural Statistics Service, written commun., 2013). In counties where no aquaculture operations existed in 2002, but one or more farms existed in 2007, the State average groundwater and surface-water withdrawal rates per farm were multiplied by the number of farms in the county.
### Figure 9. Aquaculture withdrawals by source and State, 2010.

#### EXPLANATION

Water withdrawals, in million gallons per day

- **0 to 10**
- **11 to 50**
- **51 to 100**
- **101 to 500**
- **501 to 2,760**

#### Maps

- **Total withdrawals**
- **Surface-water withdrawals**
- **Groundwater withdrawals**

#### Alaska, Hawaii, Puerto Rico, U.S. Virgin Islands

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#### Figures

- **Total withdrawals**
- **Surface-water withdrawals**
- **Groundwater withdrawals**
Industrial withdrawals provide water for such purposes as fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product; or for sanitation needs within the manufacturing facility. Some industries that use large amounts of water produce such commodities as food, paper, chemicals, refined petroleum, or primary metals. Water for industrial use may be delivered from a public supplier or be self supplied. In this report, industrial use refers to self-supplied industrial withdrawals only. Withdrawals were reported as freshwater or saline water. As in the 2000 and 2005 reports, public-supply deliveries for industrial and consumptive uses were not reported for 2010.

Industrial withdrawals are listed by State in table 10. For 2010, withdrawals were an estimated 15,900 Mgal/d, or 17,900 thousand acre-ft/yr (table 28). Industrial withdrawals were about 4 percent of total withdrawals and about 8 percent of total withdrawals for all categories excluding thermoelectric power. Surface water was the source for 82 percent of total industrial withdrawals, and 93 percent of the surface-water withdrawals for industrial use was freshwater. More than 98 percent of the groundwater withdrawals for industrial use also was freshwater. For 2010, total industrial withdrawals were 12 percent less than in 2005.

The geographic distribution of total, total surface-water, and total groundwater withdrawals for industrial use is shown in figure 10. Indiana, Louisiana, and Texas accounted for 35 percent of total industrial withdrawals, and Indiana and Louisiana accounted for 33 percent of the total fresh surface-water withdrawals. Texas accounted for 65 percent of the saline surface-water industrial withdrawals, mostly from areas along the Gulf coast. The largest fresh groundwater industrial withdrawals were in California, which accounted for 14 percent of the total national fresh groundwater industrial withdrawals. Most of the saline groundwater industrial withdrawals were in Utah.

Sources of data for industrial withdrawals included information obtained directly from facilities or State and Federal permit programs that require reporting of industrial withdrawals or return flows. Industrial withdrawals also were estimated using industry-group employment data and per employee water-use coefficients. A notable improvement from historical estimation methods include additional facility information provided to each USGS Water Science Center that included information about the type of business, number of employees, the location of the facilities, as well as economic indicators of the size of the business. These data were derived from a commercial database and were kept confidential.
Figure 10. Industrial withdrawals by source and State, 2010.
Mining water use is water used for the extraction of minerals that may be in the form of solids, such as coal, iron, sand, and gravel; liquids, such as crude petroleum; and gases, such as natural gas. The category includes quarrying, milling of mined materials, injection of water for secondary oil recovery or for unconventional oil and gas recovery (such as hydraulic fracturing), and other operations associated with mining activities. All mining withdrawals were considered to be self supplied. Water withdrawals were reported as freshwater or saline water. Dewatering was not reported as a mining withdrawal unless the water was used beneficially, such as dampening roads for dust control.

Mining withdrawals during 2010 are listed by State in table 11. During 2010, an estimated 5,320 Mgal/d, or 5,960 thousand acre-ft/yr (table 2B), were withdrawn. Mining withdrawals were about 1 percent of total withdrawals and about 3 percent of total withdrawals for all categories excluding thermoelectric power. Groundwater was the source for 73 percent of total withdrawals for mining. Seventy-one percent of the groundwater withdrawn for mining was saline. Eighty percent of the surface-water withdrawn was freshwater. Saline groundwater withdrawals and fresh surface-water withdrawals together represented 74 percent of the total withdrawals for mining.

Total mining withdrawals in 2010 were 39 percent more than in 2005. Groundwater withdrawals were 54 percent more, and surface-water withdrawals were 9 percent more. Freshwater withdrawals in 2010 were only 1 percent less than in 2005, but saline-water withdrawals were 97 percent more than in 2005. Some of the increase in saline withdrawals was attributed to increased accounting of water produced as a byproduct during oil and gas extraction and then re-injected for secondary oil and gas recovery.

The geographic distribution of total, total freshwater, and total saline-water withdrawals is shown in figure 11. Oklahoma and Texas accounted for 46 percent of the total withdrawals for mining. Nevada and Texas accounted for 41 percent of fresh groundwater withdrawals, and Oklahoma and Texas accounted for 79 percent of saline groundwater withdrawals. Minnesota, Indiana, Texas, and Iowa accounted for 46 percent of fresh surface-water withdrawals. Utah and Alaska accounted for almost 100 percent of saline surface-water withdrawals.

Sources of data used to estimate water use for mining included surveys of mining operations and State and Federal agencies that collect water withdrawal, discharge, or mineral production data for mining operations. Many of the 2010 withdrawals for mining were estimated according to methods described by Lovelace (2009b), using mineral production data and water-use coefficients, in gallons per weight or volume of minerals produced. Production data for nonfuel minerals, including metals and nonmetallic minerals, were provided by the USGS Minerals Information Team (Robert Callaghan, U.S. Geological Survey, written commun., 2012). Production or water-injection data for fuel minerals, including coal, petroleum, and natural gas, were obtained from the Energy Information Administration and various State agencies.
Figure 11. Mining withdrawals by water quality and State, 2010.
Thermoelectric Power

Water for thermoelectric power is used in generating electricity with steam-driven turbine generators. Thermoelectric-power withdrawals were compiled by cooling-system type. Once-through cooling systems circulate water through heat exchangers and then return the water to the source. Recirculation cooling systems circulate water through heat exchangers, then cool the water using ponds or towers, and then the water is recirculated. Water withdrawals for a recirculation system are used to replace water lost to evaporation, blowdown, drift, and leakage. Thermoelectric-power withdrawals were reported as freshwater or saline water, as well as by cooling system. Net power generation is also reported by cooling system.

For 2010, public-supply deliveries to thermoelectric powerplants and consumptive use were not reported. However, 1,290 thermoelectric powerplants from the linked heat and water budget model provided monthly and annual estimates of withdrawals and consumptive use by powerplant. These data were provided as supplemental and supportive datasets for the compilation. Datasets substantially improved existing NWUIP capabilities with more accurate and complete information on thermoelectric powerplant locations, categorization of cooling-system types, and water sources. Quality-assured data for net power generation were also provided with linked information about cooling system and fuels, monthly and annual (2010) estimates of withdrawals based on the models, and associated monthly and annual estimates of consumptive use by plant (Diehl and others, 2013; Diehl and Harris, 2014). These data were used either in whole, or in part, for this compilation. Compilers in some States obtained data reported directly from thermoelectric powerplants.

Thermoelectric-power withdrawals and net power generation are listed by State in table 12. Total withdrawals for thermoelectric power for 2010 were 161,000 Mgal/d or 180,000 thousand acre-ft/yr (table 2B). Surface water was the source for over 99 percent of total thermoelectric-power withdrawals, and 73 percent of those surface-water withdrawals were from freshwater sources. Saline surface-water withdrawals for thermoelectric power accounted for 97 percent of total saline surface-water withdrawals for all uses. Total withdrawals for thermoelectric power accounted for 45 percent of total water withdrawals, 38 percent of total freshwater withdrawals, and 51 percent of fresh surface-water withdrawals for all uses. Net power generation associated with thermoelectric-power withdrawals was 3,130,000 gWh (gigawatt-hours), or about 2 percent less than in 2005. On average, 19 gal (gallons) were used to produce 1 kWh (kilowatt-hour) of electricity in 2010, compared to almost 23 gal/kWh (gallons per kilowatt-hour) in 2005.

The geographic distribution of total, total freshwater, and total saline-water withdrawals for thermoelectric power is shown in figure 12. The largest total withdrawals for thermoelectric power were in Texas, where nearly all the withdrawals were from freshwater sources. Illinois, Texas, Michigan, and Alabama, together accounted for more than 32 percent of freshwater withdrawals for thermoelectric power. Florida, California, and Maryland accounted for about 48 percent of total saline withdrawals, nearly all from surface water. Hawaii, California, and Nevada accounted for 82 percent of the total saline groundwater withdrawals. Estimated 2010 thermoelectric withdrawals were 20 percent less than estimates for 2005. Reasons for this large difference include plant closures, use of the linked heat and water budget model data, decrease in use of coal and increase in use of natural gas, and new powerplants using more water-efficient cooling technology.

Eastern States accounted for 86 percent of total thermoelectric-power withdrawals in the United States and 75 percent of the related net power generation. Hydroelectric-power generation is not included in this report but meets the demand for a significant amount of the U.S. total energy needs, predominantly in Western States. In 2010, 61 percent of the total 257,000 gWh from hydroelectric powerplants was produced by public utilities in Washington, California, Oregon, and New York (U.S. Department of Energy, 2011). Thermoelectric-power withdrawals and net power generated by cooling-system type are listed by State in table 13. Powerplants with once-through cooling systems accounted for 94 percent of total withdrawals and 47 percent of net power generated. Plants with recirculating cooling systems required much less water (6 percent) and produced the majority (53 percent) of the net power generated. Powerplants with recirculating cooling systems are found in every State but were the predominant type of cooling system at powerplants in Western inland States such as Arizona, Oklahoma, Wyoming, Utah, Colorado, Kansas, and New Mexico.

Reclaimed wastewater is a supplemental source of water for thermoelectric power, especially in areas where additional water sources are needed for plant operations, such as for air pollution control equipment, or scrubbers (Veil, 2007). Arizona (67.6 Mgal/d) and California (22.8 Mgal/d) reported substantial amounts of reclaimed water use. Reclaimed wastewater is not included in the thermoelectric-power data or national totals for this report.

Sources for thermoelectric-power withdrawals, cooling-system information, and net power generation included data collected directly from facilities, State permitting or regulatory agencies, the USDOE EIA, and a linked heat and water budget for powerplants in the United States, as mentioned previously. Using information gleaned from the NWC thermoelectric project, some powerplant’s cooling-system classifications were changed, thereby making them different from previous compilations. Similarly, net power-generation data from EIA were scrutinized for each plant to determine whether the power that was reported and used in this compilation was associated with a water use.
Figure 12. Thermoelectric-power withdrawals by water quality and State, 2010.
The USGS has conducted water-use compilations every 5 years since 1950 (http://water.usgs.gov/watuse/50years.html). A summary of population growth and withdrawal estimates by category of use and source of water is discussed in this section and shown in table 14 for each 5-year period from 1950 through 2010. These trends are shown graphically for freshwater uses in figure 13 and total uses in figure 14.

Table 14 shows withdrawals for categories of use for each compilation period. Some categories were compiled and presented differently since compilations were begun. For example, self-supplied domestic and livestock withdrawals are shown separately in table 14; however, they were combined as “rural” in the 1950 and 1955 reports. Prior to 1985, the industrial water-use category included withdrawals for commercial, mining, and aquaculture; after 1985 these categories were estimated separately. Water use at fish hatcheries was reported as commercial use in 1990 and 1995, but was included in the aquaculture category for 2000, 2005, and again in 2010. Estimates of commercial withdrawals were not compiled nationally for 2000, 2005 or 2010. Totals in table 14 represent the most current data and incorporate revisions to previously published data; therefore, percentage differences and national totals may be slightly different from previous reports.

Total withdrawals for all categories of use in 2010 were estimated to be 355 Bgal/d, a level of withdrawal not reported since before 1970. Total withdrawals in 2010 were 13 percent less than in 2005, causing an abrupt downward shift to the mostly steady trend exhibited since 1985. This downward trend was caused by significant declines in the largest categories of use, including thermoelectric power, irrigation, public supply, and industrial. Categories with larger withdrawals in 2010 than in 2005 were mining and aquaculture, but these categories are small and increased total withdrawals for those categories of use did not offset the much larger overall decrease of 54 Bgal/d from the other uses.

Although the trend in total population since 1950 has been steadily upward, the rate of increase has varied over time (table 14). Most recently, total population in the United States increased only 4 percent between 2005 and 2010, or an additional 12.3 million people. This continues the upward trend in total population growth exhibited since 1950, but at a slightly slower rate. Historically, decadal growth rates in the United States were at their highest between 1950 and 1960, with an 19 percent increase from an additional 29 million people. Then growth rates exhibited an overall steady trend between 1960 and 1990, with no more than a 27 million person per year increase in the 30 year period. The rates sharply increased with a 13.2 percent increase (32.7 million) between 1990 and 2000 and were most recently at a 9.7 percent (27.3 million) increase from 2000 to 2010. (U.S. Census Bureau, 2011). In the last decade, population growth rate recorded was much faster in Southern and Western States (14.3 and 13.8 percent, respectively) compared to Midwestern States (3.9 percent) and Northeastern States (3.2 percent).

Thermoelectric power continued to account for the largest withdrawals for any category of use at 161 Bgal/d, or 45 percent of the total withdrawals from all categories of use. Total thermoelectric-power withdrawals in 2010 were about 20 percent less than in 2005; freshwater withdrawals were 18 percent less, and saline-water withdrawals were 24 percent less. These were the largest reductions in total withdrawals between 2005 and 2010 when considering all uses and accounted for the majority of the 13 percent decline in total withdrawals for all uses. Total withdrawals for thermoelectric power in 1985 were 11 percent less than in 1980, and fluctuations in total withdrawals during the 5-year intervals between 1985 and 2005 were never more than 5 percent.

Several factors may be attributed to the 20 percent decline in total thermoelectric withdrawals. Since the 1970s, an increasing number of powerplants were built with or converted to recirculating cooling systems or dry cooling systems, which use less water than powerplants with once-through cooling systems. Withdrawals at powerplants have declined in some States due to the implementation of new rules designed to minimize adverse effects to aquatic life at powerplant intakes. The decrease in use of coal and increase in use of natural gas and new powerplants coming online that use more water-efficient cooling technology also have helped to reduce withdrawals for thermoelectric power.

The plant-specific information pertaining to cooling systems, water sources, and net power generation provided estimates of thermoelectric-power withdrawals from the linked heat and water budget models. These data were used in place of data reported to EIA if plant-reported data were not available. Finally, between 2005 and 2010, the closing of once-through plants also contributed significantly to the reduction in total withdrawals. Withdrawals in California were nearly 50 percent less between 2005 and 2010 primarily due to plant closures and upgrades to intakes and cooling systems implemented in order to comply with State regulations (California State Water Resources Control Board, 2013).

Net power generation associated with thermoelectric power was 3,130,000 GWh in 2010 (table 12), or about 2.5 percent less than the 3,200,000 GWh in 2005. Net power generation increased nearly 50 percent between 1985 (2,140,000 GWh) and 2010. On average, 19 gallons were used to produce 1 kWh of electricity in 2010, compared to almost 23 gal/kWh in 2005.

Irrigation withdrawals were 9 percent less between 2005 and 2010, from 127 Bgal/d to 115 Bgal/d, a level not reported since before 1965. This marks the second consecutive 5-year period of decline in irrigation withdrawals and placed 2010 withdrawals 23 percent less than 1980, when withdrawals peaked. However, irrigation withdrawals remained

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the second-largest category of use after thermoelectric. In 1950, irrigation withdrawals accounted for 64 percent of total freshwater withdrawals excluding thermoelectric, and in 2010 irrigation withdrawals accounted for 61 percent of total freshwater withdrawals excluding thermoelectric. Between 1985 and 2010, the majority of irrigation water was supplied by surface-water sources, ranging from 66 percent in 1985 to 57 percent in 2010. The use of more water-efficient irrigation systems continued to increase with nearly 3 percent more irrigated acres using sprinkler systems in 2010 than in 2005. Nearly 2 percent fewer irrigated acres were reported using flood (surface) irrigation systems in 2010 compared to 2005. Microirrigation systems showed the largest percentage increase between 2005 and 2010, with 14 percent more irrigated acres with this type of system. Total irrigated acres were only 2 percent more in 2010 than in 2005.

Public-supply withdrawals in 2010 were 5 percent less than in 2005, decreasing from 44.3 Bgal/d to 42.0 Bgal/d and marking the first decline since public-supply withdrawals were initially reported in 1950. Total public-supply withdrawals in 2010 were at levels not reported since prior to 2000. During decadal periods between 1950 and 1960, public-supply withdrawals increased 50 percent in conjunction with the high population growth rates during those periods. Percentage increases in public-supply withdrawals during the next three decadal periods between 1960 and 1990 averaged 23 percent, again coinciding with the rate of growth in population during the same time periods. Between 1990 and 2000, the rate of increase in public-supply withdrawals was lower at 12 percent. Between 1990 and 2010, public-supply withdrawals have been roughly 60 percent from surface water and 40 percent from groundwater sources. The percentage of the population that is served from public-supply withdrawals has increased from 62 percent in 1950 to 86 percent in 2010.

Self-supplied domestic withdrawals declined 3 percent between 2005 and 2010, from 3.71 Bgal/d to 3.60 Bgal/d. Since 1985, the rate of change in self-supplied domestic withdrawals has remained fairly steady with, at most, a 6 percent increase (1995–2000). Between 1985 and 2010, the percentage of total population that was self-supplied has continuously declined, from about 18 percent to 14 percent. The average per capita use for self-supplied domestic withdrawals decreased from 89 gallons per day in 2005 to 81 gallons per day in 2010. Estimates of self-supplied domestic withdrawals are computed either using a standard coefficient of use or a coefficient derived from data about public-supply domestic withdrawals.


[Data for 2005 and earlier from Kenny and others (2009). 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 1985–2005; percentage change is calculated from unrounded numbers. Geographic extent: 1950, 48 States and District of Columbia, and Hawaii; 1955, 48 States and District of Columbia; 1960 and 1975–2005, 50 States and District of Columbia, Puerto Rico, and U.S. Virgin Islands; 1965–70, 50 States and District of Columbia, and Puerto Rico]

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1Revised data values.
2Data not available.
3Included in self-supplied industrial category.
Figure 13. Trends in population and freshwater withdrawals by source, 1950–2010.

Figure 14. Trends in total water withdrawals by water-use category, 1950–2010.
deliveries. The national average public-supply domestic delivery per capita use declined from 105 gallons per day in 1985 to 89 gallons per day in 2010. The decline in the self-supplied domestic per capita use is most likely a function of the decline in the public-supply domestic delivery per capita use. In particular, California (7 percent self-supplied population) reported 179 gpcd for self-supplied domestic use in 2005, and 69 gpcd in 2010. Similarly, Texas (10 percent self-supplied population) and Wisconsin (30 percent self-supplied population) both reported 8 percent declines in self-supplied domestic per capita use between 2005 and 2010.

Changes in the industrial category can be compared for 1985 through 2010, which are the years this category was compiled separately for commercial, mining, and aquaculture uses. Total industrial withdrawals decreased 12 percent between 2005 and 2010, continuing the decline shown each period since 1985. Total industrial withdrawals decreased by 38 percent between 1985 to 2010, from 25.8 Bgal/d in 1985 to 15.9 Bgal/d in 2010. Groundwater provided 14 percent of the total industrial withdrawals in 1985; this proportion has been in the range of 17 to 18 percent since. Almost all of the industrial groundwater withdrawals were freshwater. Fresh surface-water withdrawals have accounted for more than 90 percent of surface-water withdrawals for industrial use since 1995 and was 93 percent in 2010.

Declines in industrial withdrawals reflects greater efficiencies in industrial processes and an emphasis on water reuse and recycling within industrial facilities, both driven by environmental regulations and limited availability of freshwater resources in some areas. The larger decline in industrial withdrawals from 2005 to 2010 compared to 2000 to 2005 (12 percent compared to 8 percent) may be due in part to lower industrial production in the major water-using industries of wood products, primary metals, paper, and chemicals, all of which had lower production following the 2008 U.S. recession (Board of Governors of the Federal Reserve System, 2014).

Livestock, mining, and aquaculture withdrawals were included with other categories prior to 1985. Livestock initially was included with rural domestic, but since 1960 has been estimated as a separate category and has consistently accounted for about 1 percent of total withdrawals excluding thermoelectric throughout the 1960–2010 period. Withdrawals for livestock decreased 7 percent from 2.15 Bgal/d in 2005 to 2.00 Bgal/d in 2010, showing the second consecutive period of decline. Livestock withdrawals in 2010 were 16 percent less than the peak year of 2000, when 2.39 Bgal/d was reported.

Mining withdrawals were 5.32 Bgal/d in 2010, or a 39 percent increase over 2005 (3.83 Bgal/d). This represented the largest percentage increase of any category of use between 2005 and 2010, but since mining is a relatively small category in terms of total withdrawals, the increase did not offset the large national decreases in total water use. Prior to 1985, mining was included in other industrial withdrawals, but since 1985 has represented from 1.6 to 2.7 percent of total withdrawals excluding thermoelectric. Trends in mining withdrawals have fluctuated between 1985 and 2010, ranging from an increase of 43 percent between 1985 and 1990, followed by a 27 percent decrease between 1990 and 1995.

Aquaculture withdrawals were 9.42 Bgal/d in 2010, or a 7 percent increase from 2005. Aquaculture was the other category along with mining that showed an increase in withdrawals between 2005 and 2010. Since 1985, aquaculture has grown from 1 percent of total withdrawals excluding thermoelectric to almost 5 percent in 2010 with the most increase change between 1995 and 2000 when the total withdrawals increased nearly 80 percent.

The Plant Bowen coal-fired powerplant outside Euharlee in Bartow County, Georgia. Photo by Alan Cressler, USGS.
References Cited


Glossary

The following terms are referenced in the text or are part of the water-use Circular series.

animal-specialties water use  Water use associated with the production of fish in captivity, except for fish hatcheries, and the raising of horses and such fur-bearing animals as rabbits and pets. Animal-specialties water-use estimates were included in the 1990 and 1995 water-use Circulars, but were combined with the livestock categories or aquaculture categories beginning in 2000. See also aquaculture water use, fish-farm water use, livestock water use, and rural water use.

aquaculture water use  Water use associated with the farming of organisms that live in water (such as finfish and shellfish) and offstream water use associated with fish hatcheries. See also fish-farm water use, fish-hatchery water use, animal-specialties water use, and livestock water use.

closed-loop cooling system  See recirculation cooling system.

commercial water use  Water for motels, hotels, restaurants, office buildings, other commercial facilities, military and nonmilitary institutions, and (for 1990 and 1995) offstream fish hatcheries. Water may be obtained from a public-supply system or may be self-supplied. Commercial water-use estimates were included in some previous water-use Circulars but were omitted beginning in 2000. See also fish-hatchery water use, public-supply water use, public-supply deliveries, and self-supplied water use.

cooling system  An equipment system that provides water for cooling purposes, such as to condensers at powerplants or at factories. May include water intakes, outlets, cooling towers, ponds, canals, pumps, and pipes. See also cooling-system type, industrial water use, and thermoelectric-power water use.

cooling-system type  Defined as either once-through or recirculation cooling system. See also industrial water use, once-through cooling system, recirculation cooling system, and thermoelectric-power water use.

domestic water use  Water used for indoor household purposes such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and outdoor purposes such as watering lawns and gardens. Domestic water use includes water provided to households by a public water supply (domestic deliveries from public suppliers) and self-supplied water. See also public-supply deliveries, public-supply water use, rural water use, and self-supplied water use.

fish-farm water use  Water used for the production of finfish and shellfish under controlled feeding, sanitation, and harvesting procedures for commercial purposes. Water use by fish farms is classified in the aquaculture category. See also animal-specialties water use, aquaculture water use, and fish-hatchery water use.

fish-hatchery water use  Water used for raising fish for later release and in association with the operation of fish hatcheries or fishing preserves. Fish-hatchery water use has been included in the aquaculture category since 2000. See also animal-specialties water use, aquaculture water use, and fish-hatchery water use.

freshwater  Water that contains less than 1,000 milligrams per liter (mg/L) of dissolved solids. Generally, water with more than 500 mg/L of dissolved solids is undesirable for drinking and many industrial uses. See also saline water.

industrial water use  Water used for fabrication, processing, washing, and cooling. Includes industries such as chemical and allied products, food, mining, paper and allied products, petroleum refining, and steel. Term used in previous
water-use Circulars to describe the combined public-supply deliveries to industrial users and self-supplied industrial withdrawals. Since 2000, industrial water use refers only to self-supplied industrial withdrawals. See also cooling system, cooling-system type, mining water use, public-supply deliveries, public-supply water use, and self-supplied water use.

instream use Water that is used, but not withdrawn, from a surface-water source for such purposes as hydroelectric-power generation, navigation, water-quality improvement, fish propagation, and recreation. Instream water-use estimates for hydroelectric power were included in some previous water-use Circulars but were omitted since 2000.

irrigation district A cooperative, self-governing public corporation set up as a subdivision of the State government, with definite geographic boundaries, organized, and having taxing power to obtain and distribute water for irrigation of lands within the district. Created under the authority of a State legislature with the consent of a designated fraction of the landowners or citizens. See also irrigation water use.

irrigation water use Water that is applied by a irrigation system to assist crop and pasture growth, or to maintain vegetation on recreational lands such as parks and golf courses. Irrigation includes water that is applied for pre-irrigation, frost protection, chemical application, weed control, field preparation, crop cooling, harvesting, dust suppression, leaching of salts from the root zone, and conveyance losses. See also conveyance loss, microirrigation system, sprinkler irrigation system, and surface irrigation system.

livestock water use Water used for livestock watering, feedlots, dairy operations, and other on-farm needs. Types of livestock include dairy cows and heifers, beef cattle and calves, sheep and lambs, goats, hogs and pigs, horses and poultry. See also animal-specialties water use, aquaculture water use, and rural water use.

microirrigation system An irrigation system that wets only a discrete portion of the soil surface in the vicinity of the plant by means of applicators (such as orifices, emitters, porous tubing, or perforated pipe) and operated under low pressure. The applicators may be placed on or below the surface of the ground or suspended from supports. See also irrigation water use, sprinkler irrigation system, and surface irrigation system.

mining water use Water used for the extraction of naturally occurring minerals including solids (such as coal, sand, gravel, and other ores), liquids (such as crude petroleum), and gases (such as natural gas). Also includes uses associated with quarrying, milling of mined materials, injection of water for secondary oil recovery or for unconventional oil and gas recovery (such as hydraulic fracturing), and other operations associated with mining activity. Does not include water associated with dewatering of the aquifer that is not put to beneficial use. Also does not include water used in processing, such as smelting, refining petroleum, or slurry pipeline operations. These processing uses are included in industrial water use. See also industrial water use and self-supplied water use.

offstream use Water withdrawn or diverted from a groundwater or surface-water source for aquaculture, commercial, self-supplied domestic, industrial, irrigation, livestock, mining, public supply, thermoelectric-power, and other uses. See also entries for each of these categories of use.

once-through cooling system Also known as open-loop cooling system. Cooling system in which the water is withdrawn from a source, circulated through the heat exchangers, and then returned to a body of water at a higher temperature. See also cooling system, cooling-system type, industrial water use, and thermoelectric-power water use.

public-supply deliveries Amount of water delivered from a public supplier to users for domestic, commercial, industrial, thermoelectric-power, or public-use purposes. Estimates of deliveries for each purpose were provided for 1995 and earlier years, but not for 2000. For 2005 and 2010, only domestic deliveries were estimated nationally. See also commercial water use, domestic water use, industrial water use, public-supply water use, public water use, and thermoelectric-power use.

public-supply water use Water withdrawn by public and private water suppliers that furnish water to at least 25 people or have a minimum of 15 connections. Public suppliers provide water for a variety of uses, such as domestic, commercial, industrial, thermoelectric-power, and public water use. See also commercial water use, domestic water use, industrial water use, public-supply deliveries, public water use, and thermoelectric-power water use.
**Public water use** Water supplied from a public supplier and used for such purposes as firefighting, street washing, flushing of water lines, and maintaining municipal parks and swimming pools. Generally, public-use water is not billed by the public supplier. See also public-supply deliveries and public-supply water use.

**Recirculation cooling system** Also known as closed-loop cooling system. Water is withdrawn from a source, circulated through heat exchangers, cooled, and then re-used in the same process. Recirculation cooling systems may use induced draft cooling towers, forced draft cooling towers, cooling ponds, or canals. See also cooling system, cooling-system type, industrial water use, and thermoelectric-power water use.

**Reclaimed wastewater** Wastewater-treatment plant effluent that has been diverted for beneficial uses such as irrigation, industry, or thermoelectric-power cooling instead of being released to a natural waterway or aquifer. See also water use.

**Return flow** Water that reaches a groundwater or surface-water source after release from the point of use and thus becomes available for further use. See also water use.

**Rural water use** Water used in suburban or farm areas for domestic and livestock needs. The water generally is self-supplied, and includes domestic use, drinking water for livestock, and other uses such as dairy sanitation, cleaning, and waste disposal. Term used in previous water-use Circulars. See also animal-specialties water use, domestic water use, livestock water use, and self-supplied water use.

**Saline water** Water that contains 1,000 mg/L or more of dissolved solids. See also freshwater.

**Self-supplied water use** Water withdrawn from a groundwater or surface-water source by a user rather than being obtained from a public-supply source.

**Sprinkler irrigation system** An irrigation system in which water is applied by means of perforated pipes or nozzles operated under pressure so as to form a spray pattern. See also irrigation water use, microirrigation system, and surface irrigation system.

**Standard industrial classification (SIC) codes** Four-digit codes established by the Office of Management and Budget, published in 1987, and used in the classification of establishments by type of activity in which they are engaged.

**Surface irrigation system** Irrigation by means of flood, furrow, or gravity. Flood irrigation is the application of irrigation water in which the entire soil surface is covered by ponded water. Furrow is a partial surface-flooding method of irrigation normally used with clean-tilled crops in which water is applied in furrows or rows of sufficient capacity to contain the design irrigation stream. Gravity is an irrigation method in which water is not pumped, but flows in ditches or pipes and is distributed by gravity. See also irrigation water use, microirrigation system, and sprinkler irrigation system.

**Thermoelectric-power water use** Water used in the process of generating electricity with steam-driven turbine generators. Term used in previous water-use Circulars to describe the combined public-supply deliveries to thermoelectric-power plants and self-supplied thermoelectric-power withdrawals. Since 2000, thermoelectric-power water use refers only to self-supplied thermoelectric-power withdrawals. See also cooling system, cooling-system type, public-supply water use, and self-supplied water use.

**Wastewater-treatment return flow** Term used in previous water-use Circulars to describe water returned to the hydrologic system by wastewater-treatment facilities. See also water use.

**Water use** In a restrictive sense, the term refers to water that is withdrawn for a specific purpose, such as for public supply, domestic use, irrigation, thermoelectric-power cooling, or industrial processing. In previous water-use Circulars, water use for the domestic, commercial, industrial, and thermoelectric categories included both self-supplied withdrawals and deliveries from public supply. More broadly, water use pertains to the interaction of humans with and influence on the hydrologic cycle, and includes elements such as water withdrawal, delivery, consumptive use, wastewater release, reclaimed wastewater, return flow, and instream use. See also offstream use and instream use.

**Water withdrawal** Water removed from a groundwater or surface-water source for use. See also offstream use and self-supplied water use.

**Watt-hour (Wh)** An electrical energy unit of measure equal to 1 watt of power supplied to, or taken from, an electric circuit steadily for 1 hour.
Saleh Taghvaeian
Assistant Extension Specialist

Irrigation water management begins with knowing the quantity of water available. The purpose of this publication is to provide basic information on water measurement units and convenient conversion factors. Sometimes one will want to know only the volume of water used; while, at other times one will want to know the rate of flow. Conversion factors simplify changing from one unit of measurement to another.

Water Measurement Units

There are two conditions under which water is measured—water at rest and water in motion. Water at rest is measured in units of volume. Water in motion is measured in units of flow—unit of volume for a convenient time unit. It is important that the difference between a unit of volume and a unit of flow be kept in mind.

Volume Units

Water at rest; i.e., ponds, lakes, reservoirs, and in the soil, is measured in units of volume—gallon, cubic foot, acre-inch, and acre-foot.

Cubic Foot - The volume of water that would be held in a container one foot wide by one foot long by one foot deep.
Acre-inch - The volume of water that would cover one acre (43,560 square feet) one inch deep.
Acre-Foot - The volume of water that would cover one acre one foot deep.

Flow Units

Water in motion; i.e., flowing in streams, canals, pipelines, and ditches, is measured in units of volume per unit of time—gallons per minute (gpm), cubic feet per second (cfs), acre-inches per hour and acre feet per day. Cubic feet per second, sometimes written second-feet (sec. ft. or cusec) is most commonly used for measuring flow of irrigation water moving by gravity from streams and reservoirs. Gallons per minute is most commonly used for measuring flow from pumps.

Cubic foot per second - The quantity of water equivalent to a stream one foot wide by one foot deep flowing with a velocity of one foot per second.
Gallon per minute - The quantity of water equivalent to a stream which will fill a gallon measure once each minute.

A flow of one cfs is approximately equal to either 450 gpm, one acre-inch per hour, or two acre-feet per day (24 hours).

Conversion Factors

The following equivalents are useful for converting from one unit to another and for calculating volumes from flow units.

Volume Units

One gallon
= 231 cubic inches
= 0.13368 cubic foot weighs approximately 8.33 pounds

One cubic foot
= 1,728 cubic inches
= 7.481 gallons (7.5 for ordinary calculations) weighs 62.4 pounds (62.5 for ordinary calculations)

One acre-inch
= 3,630 cubic feet
= 27,154 gallons (27,200 for ordinary calculations)
= 1/12 acre-foot weighs approximately 113.1 tons

One acre-foot
= 43,560 cubic feet
= 325,851 gallons
= 12 acre-inches weighs approximately 1,357 tons

Flow Units

One gallon per minute
= 0.00223 (approximately 1/450) cubic foot per second
= 0.00221 acre-inch per hour
= 0.00442 acre-foot per (24 hour) day
= 1 acre-inch in 1 hour and 30 seconds (1 hour for ordinary calculations)
= 1 acre-foot in 12 hours and 6 minutes (12 hours for ordinary calculations)
= 1.984 acre-feet per (24 hours) day (2 acre-feet for ordinary calculations)

One cubic foot per second
= 448.83 gallons per minute (450 for ordinary calculations)
= 1 acre-inch in 1 hour and 30 seconds (1 hour for ordinary calculations)
= 1 acre-foot in 12 hours and 6 minutes (12 hours for ordinary calculations)
= 1.984 acre-feet per (24 hours) day (2 acre-feet for ordinary calculations)

Million gallons per day (mgd)
= 694.4 gallons per minute (695 for ordinary calculations)
= 1.547 cubic feet per second (1.5 for ordinary calculations)
ASSIGNMENT 2
IV. RIPARIAN RIGHTS.

McBryde, the State, and Gay & Robinson, as owners of land in the Hanapepe Valley, may have water rights other than Terr. v. Gay, 31 Haw. 376, 395 (1930), recognized such a right and said: wuch a right and said:

‘Water for domestic purposes on a lower ahupuaa is in any event assured under Hawaiian law. Every portion of land, large or small, ahupuaa, ili or kuleana, upon which people dwelt was, under the ancient Hawaiian system whose retention should, in my opinion, continue unqualifiedly, entitled to drinking water for its human occupants and for their animals and was entitled to water for other domestic purposes. At no time in Hawaii’s judicial history has this been denied.’

This court recognized and included this right to water for domestic purposes as part of the ancient appurtenant rights.

Now, what is this Hawaiian law or ancient Hawaiian system mentioned in the decision? This acknowledgment of the right to domestic water, we believe, was a recognition of the right guaranteed in ‘Enactment of *192 Further Principles,’ enacted by the Hawaiian Government on August 6, 1850, Laws 1850, p. 202,’ the pertinent portion of which provides:

‘The people (meaning owners of land) also shall have a right to drinking water, **1342 and running water, and the right of way. The springs of water, and running water, and roads shall be free to all, should they need them, on all lands granted in fee simple: Provided, that this shall not be applicable to wells and water courses which individuals have made for their own use.’

Section 577 of RLH 1925, the effective statute then, contained the provison guaranteeing the right ‘to drinking water and to running water.’ It is crystal clear that the statute reserves to landowners the right to both ‘drinking water’ and ‘running water.’ Now, what is the right to ‘running water’ guaranteed landowners? As the right to ‘drinking water and running water’ in artificial watercourses constructed by individuals for their own use is excepted by the statute, the term ‘running water’ must mean water flowing in natural water courses, such as streams and rivers. We also believe that the right to ‘running water’ as contained therein guarantees a land owner the same flow of water in a stream or river as at the time of the mahele, without substantial diminution, or the right to flow of a stream in the form and size *193 given it by nature. This right may be in connection with his right of laundering, canoeing, swimming, bathing, etc.

We shall next consider the possible reason for the enactment of the law. We are aware that the missionaries, many of whom came from Massachusetts, not only brought the Christian religion to the Hawaiian people, but also brought with them the English common law as recognized in Massachusetts. Also, history shows that missionaries had tremendous influence among the leaders of the Hawaiian Kingdom.

In Weston v. Alden, 8 Mass. 136 (1811) the Massachusetts Supreme Court recognized the right of an owner of a parcel of land adjoining a brook to use water
from such brook for domestic use, including the watering of animals and irrigation of his land. Then, in Colburn v. Richards, 13 Mass. 420, 421 (1816), the Massachusetts court held that an owner of a parcel of land adjoining a natural watercourse had the right to use the water to irrigate his farm; however, it also held that he could not divert such water from the natural channel to the detriment of an owner of land below. In Anthony v. Lapham, 22 Mass. 175, 177 (1827), the Massachusetts court said ‘(e)very man, through whose land water passes, may use it for watering his cattle or irrigating his land, but he must use it in this latter way so as to do the least possible injury to his neighbor who has the same right.’ It is interesting to note that on this point the court as footnote 1 refers to 3 Kent’s Commentaries (13th ed.) 439, 444.

In 3 Kent’s Commentaries (13th ed.) 439, it is stated:
‘Every proprietor of lands on the banks of a river has naturally an equal right to the use of the water which flows in the stream adjacent to his lands, as it was wont to run (currere solebat), without *194 diminution or alteration. No proprietor has a right to use the water, to the prejudice of other proprietors, above or below him, unless he has a right to divert it, or a title to some exclusive enjoyment. He has no property in the water itself, but a simple usufruct while it passes along. Aqua currit et debet currere ut currere solebat is the language of the law. Though he may use the water while it runs over his land as an incident to the land, he cannot unreasonably detain it, or give it another direction, and he must return it to its ordinary channel when it leaves his estate. Without the consent of the adjoining proprietors, he cannot divert or diminish the quantity of water which would otherwise descend to the proprietors below, nor throw the water back upon the proprietors above * * *.’

In Tyler v. Wilkinson, 4 Mason 397, 400 (1827), in a case involving water rights of the Pawtucket River, which forms a **1343 boundary between the States of Massachusetts and Rohode Island, Justice Story stated:
‘Prima facie every proprietor upon each bank of a river is entitled to the land, covered with water, in front of his bank, to the middle thread of the stream, or, as it is commonly expressed usque filum aquae. In virtue of this ownership he has a right to the use of the water flowing over it in its natural current, without diminution or obstruction. But, strictly speaking, he has no property in the water itself; but a simple use of it, while it passes along. The consequence of this principle is, that no proprietor has a right to use the water to the prejudice of another. It is wholly immaterial, whether the party be a proprietor above or below, in the course of the river; the right being common to all the proprietors on the river, no one has a right to diminish the quantity which will, according to the natural current, *195 flow to a proprietor below, or to throw it back upon a proprietor above . . . . The natural stream, existing by the bounty of Providence for the benefit of the land through which it flows, is an incident annexed, by operation of law, to the land itself. When I speak of this common right, I do not mean to be understood, as holding the doctrine, that there can be no diminution whatsoever, and no obstruction or impediment whatsoever, by a riparian proprietor, in the use of the water as it flows . . . . There may be a diminution in quantity, or a retardation or acceleration of the natural current indispensable for the general and valuable use of the water, perfectly consistent with the existence of the common right. . . . The maxim is applied, sic utere tuo, ut non alienum laedas.’

In Wright v. Haward, 19 1 Simons & Stuart 190, 203 (1823), the English Chancery Court said:
'Prima facie, the proprietor of each bank of a stream is the proprietor of half the land covered by the stream, but there is no property in the water. Every proprietor has an equal right to use the water which flows in the stream; and, consequently, no proprietor can have the right to use the water to the prejudice of any other proprietor. Without the consent of the other proprietors, who may be affected by his operations, no proprietor can either diminish the quantity of water, which would otherwise descendent to the proprietors below, nor throw the water back upon the proprietors above.'

Mason v. Hill, 5 Barn. & Adol, 110 Eng.Rep. 692 (1833), is a case where the issue was whether the defendants by diverting water, for a period of less than twenty years, had acquired right to the water by first appropriation so that the plaintiff who had been denied flow of water in a natural water course which flowed through his field could recover damages. The English court said ‘2 Blackstone’s Commentaries, p. 18, ‘Water is a movable wandering thing, and must of necessity continue common by the law of nature; so that I can only have a temporary, transient, usufructuary property therein; wherefore if a body of water runs out of my pond into another man’s I have no right to reclaim it.’ (p. 700) Then it said:

‘From these authorities, it seems that the Roman law considered running water, not as a bonum vacans, to which the first occupant may acquire an exclusive right, but that it is public and common in this sense only, that all may reasonably use it who have a right of access to it, that none can have any property in the water itself, except in that particular portion which he may have abstracted from the stream, and of which he had the possession; and during the time of such possession only.

**1344 We think that no other interpretation ought to be put upon the passage in Blackstone, and that the dicta of the learned Judges above referred to, in which water is said to be publici juris, are not to be understood in any other than this sense; and it appears to us there is no authority in our law, nor, as far as we know, in the Roman law (which, however, is no authority in ours), that the first occupant (though he may be the proprietor of the land above) has any right by diverting the stream, to deprive the owner of the land below, of the special benefit and advantage of the natural flow of water therein.’ 110 Eng.Rep. 692 at 701.

In Embrey v. Owen, 6 Exc. 353, 155 Eng.Rep. 579, 585 (1851) the English court said:

‘The right to have the stream to flow in its natural state without diminution or alteration is an incident *197 to the property in the land through which it passes; but flowing water is publici juris, not in the sense that it is a bonum vacans, to which the first occupant may acquire an exclusive right, but that it is public and common in this sense only, that all may reasonably use it who have a right of access to it, that none can have any property in the water itself, except in the particular portion which he may choose to abstract from the stream and take into his possession, and that during the time of his possession only: see 5 B. & Ad. 24. But each proprietor of the adjacent land has the right to the usufruct of the stream which flows through it.’

The court also said that the principle of law was established by Wright v. Haward, supra, Mason v. Hill, supra, Wood v. Waud, supra, and cases decided by American courts. It also cites 3 Kent’s Commentaries 439-445.

In Miner v. Gilmour, XII Moore P. C. 131, 14 Eng.Rep. 861, 870 (1858), a case from Canada involving claims of water rights between owners of property on the opposite banks of a river, the English court in applying the doctrine of riparian rights said '(i)t did not appear that, for the purposes of this case, any material distinction exists between the French and English law.'

[18] It would appear that in the light of history and historical background of the Hawaiian Kingdom, the provision of the law enacted on August 6, 1850 which reserves to property owners the ‘right to drinking water and running water,’ was a codification or statutory enactment of the doctrine of riparian rights recognized as part of the common law by the English and Massachusetts courts.

[19] [20] We therefore hold that under the statute a proprietor *198 of land adjoining natural water courses has riparian water rights. thus, McBryde, the State, and Gay & Robinson, as owners of parcels of land adjoining the Hanapepe River or Koula Stream have such rights-the
right to use water flowing therein without prejudicing the riparian rights of others and the right to the natural flow of the stream without substantial diminution and in the shape and size given it by nature. This right is incapable of measurement into number of gallons per day. Of course, the riparian right appears only to land adjoining a natural watercourse for its use.

FOOTNOTES

19 It is interesting to note the similarity of the courts' holding, 3 Kent Commentaries at 439 and Tyler v. Wilkinson, supra, which are all contemporaneous.

20 Then at page 586 it quotes extensively from 3 Kent's Commentaries, 13th ed., at 439, in fact the entire section on Running Water excepting the first paragraph. The quotation which appears there is the same as the text in 3 Kent's Commentaries, 13th ed.

21 On this point it should be noted that the rule of McNaughten's Case, 10 Clark & Fin. 200, 210, 8 Eng.Rep. 718 (1843), which recognized insanity as a defense in a criminal case, was codified in the Hawaiian Kingdom in 1850. See HRS s 703-4.

HISTORICAL INFORMATION

Ahupuaa means 'a land division usually extending from the uplands to the sea . . .' Pukui & Elbert, Hawaiian Dictionary (1971). An ili has been interpreted to mean a 'land section, next in importance to ahupuaa and usually a subdivision of an ahupuaa.' Id. Kuleanas are small parcels of land within an ahupuaa. Id at 165. Konohiki means 'a head man of an ahupuaa land division' id. at 153.

The term mahele means to divide or apportion. Id. at 202. When used in the context of land titles, reference is usually to the Great Mahele of 1848, which accomplished the division of the undivided interest in land between the King on one hand and the chief and konohikis on the other. Wells H. Hutchins, The Hawaiian System of Water Rights at 23 (1946)
Supreme Court of Illinois.

John Evans, appellant,
v.
Henry W. Merriweather, appellee.

December Term, 1842.

*492 Appeal from Greene.

**1 The language of all the authorities is, that water flows in its natural course, and should be permitted to flow, so that all through whose lands it naturally flows may enjoy the privilege of using it. The property in the water, by virtue of the riparian ownership, is in its nature usufructuary, and consists, in general, not so much of the fluid itself as of the advantage of its impetus. A riparian proprietor, though he has an undoubted right to use the water of a stream, for hydraulic and manufacturing purposes, must so use it as to do no injury to any other riparian proprietor.*

Each riparian proprietor is bound to make such a use of running water as to do as little injury to those below him as is consistent with a valuable benefit to himself.

Where the stream is small, and does not furnish water more than sufficient to supply the natural wants of the different proprietors living on it, none of the proprietors can use the water for either irrigation or manufactures.

Where the water of a stream is not wanted to supply natural wants, and there is not sufficient for each proprietor living on the stream to carry on his manufacturing purposes, and there is no contract or grant, neither proprietor has a right to use all the water; all have a right to participate in its benefit, and an action will lie against a party who diverts or consumes the whole of the stream.

Where all have a right to participate in a common benefit, and no one can have an exclusive enjoyment, no rule, from the very nature of the case, can be laid down, as to how much each may use, without infringing upon the rights of others. In such cases, it must be left to the jury to determine whether the party complained of has used, under all the circumstances, more than his just proportion.

Where an upper riparian proprietor forbade his workmen to divert a stream, upon which his steam mill was situated, and one of them built a dam across it, near the mill, and diverted it for the use of the mill, and the proprietor lived only about half a mile off, and was often at the mill: Held, that a jury might fairly infer that he was conversant with the manner with which his mill was supplied with water, and that he either countermanded his instructions or acquiesced in the construction of the dam, after it was erected.

Where a party avails himself of the illegal act of his servant, the law presumes he authorized it.

Where the damages are small, and justice, upon the whole, has been done, the Supreme Court ought not to remand a cause to see if a jury, upon another trial, would not give less, even if the true principles which govern the case were not correctly given to the jury.

**2 This cause was heard in the court below at the April term, 1839, before the Hon. Wm. Thomas and a jury. Verdict and judgment were rendered for the plaintiff for $150 damages. The defendant appealed to this court.

Attorneys and Law Firms


This was an action on the case, brought in the Greene Circuit Court, by Merriweather against Evans, for obstructing and diverting a water course. The plaintiff obtained a verdict, and judgment was rendered thereon. On the trial the defendant excepted to the instructions asked for and given, at the instance of the plaintiff. The defendant also excepted, because instructions that were asked by him, were refused. After the cause was brought into this court, the parties agreed upon the following statement of facts, as having been proved on the trial, to wit: “It is agreed between the parties to this suit, that the following is the statement of facts proved at the trial in this case, and that the same shall be considered as part of the record by the court, in the adjudication of this cause. Smith and Baker, in 1834, bought of T. Carlin six acres of land, through which a branch ran, and erected a steam mill thereon. They depended upon a well and the branch for water in running their engine. About one or two years afterwards, John Evans bought of T. Carlin six acres of land, on the same branch, above and immediately adjoining the lot owned by Smith & Baker, and erected thereon a steam mill, depending upon a well and the branch for water in running his engine. About one or two years afterwards, John Evans bought of T. Carlin six acres of land, on the same branch, above and immediately adjoining the lot owned by Smith & Baker, and erected thereon a steam mill, depending upon a well and the branch for water in running his engine.

“Smith & Baker, after the erection of Evans’ mill, in 1836 or 1837, sold the mill and appurtenances to Merriweather, for about $8,000. Evans’ mill was supposed to be worth $12,000. Ordinarily there was an abundance of water for both mills; but in the fall of 1837, there being a drought, the branch failed, so far that it did not afford water sufficient to run the upper mill continually. Evans directed his hands not to stop, or divert the water, in the branch; but one of them employed about the mill did make a dam across the branch, just below Evans’ mill, and thereby diverted all the water in the branch into Evans’ well. Evans was at home, half a mile from the mill, and was frequently about his mill, and evidence was introduced conducing to prove that he might have known that the water of the branch was diverted into his well. After the diversion of the water into Evans’ well, as aforesaid, the branch went dry below, and Merriweather’s mill could not and did not run, in consequence of it, more than one day in a week, and was then supplied with water from his well. Merriweather then brought this suit, in three or four weeks after the putting of the dam across the branch for the diversion of the water, and obtained a verdict for $150. This suit, it is admitted, is the first between the parties litigating the right as to the use of the water. It is further agreed, that the branch afforded usually sufficient water for the supply of both mills, without materially affecting the size of the current, though the branch was not depended upon exclusively for that purpose. Furthermore, that at the time of the grievances complained of by the plaintiff below, the defendant had water hauled in part for the supply of his boilers. That the dam was made below the defendant’s well, across the branch, which diverted as well the water hauled and poured out into the branch above the well, as the water of the branch, into the defendant’s well.

Upon this state of facts, the question is presented, as to what extent riparian proprietors, upon a stream not navigable, can use the water of such stream? The branch mentioned in the agreed statement of facts, is a small natural stream of water, not furnishing, at all seasons of the year, a supply of water sufficient for both mills. There are no facts in the case showing that the water is wanted for any other than milling purposes, and for those purposes to be converted into steam, and thus entirely consumed. In an early case decided in England, it is laid down that "A water course begins ‘ex jure naturæ,’ and having taken a certain course naturally, can not be diverted.“ The language of all the authorities is, that water flows in its natural course, and should be permitted thus to flow, so that all through whose land it naturally flows, may enjoy the privilege of using it. The property in the water, therefore, by virtue of the riparian ownership, is in its nature usufructuary, and consists, in general, not so much of the fluid itself, as of the advantage of its impetus. A riparian proprietor, therefore, though he has an undoubted right to use the water for hydraulic or manufacturing purposes, must so use it as to do no injury to any other riparian proprietor. Some decisions, in laying down the rights of riparian proprietors of water courses, have gone so far as to restrict their right in the use of
water flowing over their land, so that there shall be no diminution in the quantity of the water, and no obstruction to its course. The decisions last referred to can not, however, be considered as furnishing the true doctrine on this subject. Mr. Justice Storey, in delivering the opinion of the court, in the case of Tyler v. Wilkinson, says, "I do not mean to be understood as holding the doctrine that there can be no diminution whatever, and no obstruction or impediment whatever, by a riparian proprietor in the use of water as it flows; for that would be to deny any valuable use of it. There may be, and there must be, of that which is common to all, a reasonable use. The true test of the principle and extent of the use is, whether it is to the injury of the other proprietors or not. There may be diminution in quantity, or a retardation or acceleration of the natural current, indispensable for the general and valuable use of the water, perfectly consistent with the use of the common right. The diminution, retardation, or acceleration, not positively and sensibly injurious, by diminishing the value of the common right, is an implied element in the right of using the stream at all. The law here, as in many other cases, acts with a reasonable reference to public convenience and general good, and is not betrayed into a narrow strictness, subversive of common use, nor into an extravagant looseness, which would destroy private rights." The same learned judge further says, "That of a thing common by nature, there may be an appropriation by general consent or grant. Mere priority of appropriation of running water, without such consent or grant, confers no exclusive right." This doctrine is fully sustained by English and American cases. In the case of Arnold v. Foot, it was held, where a defendant had diverted the water from a spring rising on his land, to irrigate his meadow, "that he had a right to use so much as is necessary for his family and his cattle, but he has no right to use it for irrigating his meadow, if thereby he deprive the plaintiff of the reasonable use of the water in its natural channel."

**5 Each riparian proprietor is bound to make such a use of running water as to do as little injury to those below him as is consistent with a valuable benefit to himself. The use must be a reasonable one. Now the question fairly arises, is that a reasonable use of running water by the upper proprietor, by which the fluid itself is entirely consumed? To answer this question satisfactorily, it is proper to consider the wants of man in regard to the element of water. These wants are either natural or artificial. Natural are such as are absolutely necessary to be supplied, in order to his existence. Artificial, such only as, by supplying them, his comfort and prosperity are increased. To quench thirst, and for household purposes, water is absolutely indispensable. In civilized life, water for cattle is also necessary. These wants must be supplied, or both man and beast will perish.

The supply of man’s artificial wants is not essential to his existence; it is not indispensable; he could live if water was not employed in irrigating lands, or in propelling his machinery. In countries differently situated from ours, with a hot and arid climate, water doubtless is absolutely indispensable to the cultivation of the soil, and in them, water for irrigation would be a natural want. Here it might increase the products of the soil, but it is by no means essential, and can not, therefore, be considered a natural want of man. So of manufactures, they promote the prosperity and comfort of mankind, but can not be considered absolutely necessary to his existence; nor need the machinery which he employs be set in motion by steam.

From these premises would result this conclusion: that an individual owning a spring on his land, from which water flows in a current through his neighbor’s land, would have the right to use the whole of it, if necessary to satisfy his natural wants. He may consume all the water for his domestic purposes, including water for his stock. If he desires to use it for irrigation or manufactures, and there be a lower proprietor to whom its use is essential to supply his natural wants, or for his stock, he must use the water so as to leave enough for such lower proprietor. Where the stream is small, and does not supply water more than sufficient to answer the natural wants of the different proprietors living on it, none of the proprietors can use the water for either irrigation or manufactures. So far, then, as natural wants are concerned, there is no difficulty in furnishing a rule by which riparian proprietors may use flowing water to supply such natural wants. Each proprietor in his turn may, if necessary, consume all the water for these purposes. But where the water is not wanted to supply natural wants and there is not sufficient for each proprietor living on the stream, to carry on his manufacturing purposes, how shall the water be divided? We have seen that, without a contract or grant, neither has a right to use all the water; all have a right to participate in its benefits. Where all have a right to participate in a common benefit, and none can have an exclusive enjoyment, no rule, from the very nature of the case, can be laid down, as to how much each may use without infringing upon the rights of others. In such cases, the question must be left to the judgment of the jury, whether the party complained of has used, under all the
circumstances, more than his just proportion.

**6 It appears, from the facts agreed on, that Evans obstructed the water by a dam, and diverted the whole into his well. This diversion, according to all the cases, both English and American, was clearly illegal. For this diversion, an action will lie. It, however, was contended that Evans forbade the construction of the dam, by which the water was diverted into his well. If a servant do an act against the consent of the master, the latter is not liable. In this case, however, a jury might fairly infer from the fact, that as Evans lived near the mill and was frequently at it, he must have been conversant with the manner in which his mill was supplied with water, and that he either countermanded the instructions or acquiesced in the construction of the dam, after it was erected. Having availed himself of the illegal act of his servant, the law presumes he authorized it. Having arrived at the conclusion that an action will lie in behalf of Merriweather against Evans, for obstructing and diverting the water course mentioned in the plaintiff’s *497 declaration, I have not deemed it necessary to examine the instructions given by the court, to see if they accord with

the principles above laid down. Having decided that the plaintiff below has a right to recover on the facts, whether the instructions were right or wrong would not vary that result. It is possible that if the true principles which govern this action had been correctly given to the jury, the damages might have been either less or more than the jury have given; but in this case, as the damages are small, the court ought not, where justice has upon the whole been done, to send the case back, to see if a jury, upon another trial, would not give less.

For these reasons I am of opinion that the judgment ought to be affirmed, with costs.

*Judgment affirmed.*

**All Citations**

3 Scam. 492, 4 Ill. 492, 1842 WL 3800, 38 Am.Dec. 106

Footnotes

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As to diversion of surface water, see Laney v. Jasper, 39 Ill., 46, and Bailey's note.

1 CATON, Justice, did not hear the argument in this case, and gave no opinion; and DOUGLASS, Justice, having been of counsel, likewise gave no opinion.

1 Bulstrode, 339.

2 2 Barn & Cres., 510; Angell on Water Courses, 11.

3 4 Mason, 400.

1 Angell on Water Courses, 23.

2 12 Wend., 330.
This is a water rights case involving a non-navigable watercourse. It presents a confrontation between the past and the present. Plaintiffs are the owners of a 140-year-old water-powered gristmill. They emphasize the natural flow theory. Defendants are upper riparians using water to irrigate their farms. They emphasize the reasonable use theory of water rights.

The plaintiffs, Willie and Arlene Gilbert, own property commonly known as Howard’s Mill located on Kirkland’s Creek, a non-navigable stream in Early County which goes into the Chattahoochee River. They acquired a partial interest in the property in 1974. The other interest was acquired at the same time by their daughter and son-in-law. In 1977, they purchased the other interest and now own the fee. Until August 31, 1978, the Gilberts owned and operated a water-powered gristmill on their property. They also rented boats for profit and permitted fishing and swimming in the 40-acre pond. (On August 31, 1978, the mill was destroyed by fire.)

On July 7, 1978, the Gilberts filed a complaint against Sanford Hill,1 who is an owner of property that is upper riparian in relation to the Gilbert’s property, *404 alleging that since 1975 he has been diverting and using water from Kirkland’s Creek for irrigation, and that he also has been trespassing and pumping water out of their millpond. This allegation of trespass by Hill for the purpose of taking water from the pond apparently was not pursued by the Gilberts. The Gilberts characterized Hill’s diversion of waters from Kirkland’s Creek for irrigation as both a nuisance and a trespass and sought injunctive relief as well as actual and punitive damages and attorney fees.

The testimony at a hearing on July 18, 1978, revealed to plaintiffs that other upper riparian owners also had irrigated with water from the creek. The plaintiffs subsequently added four defendants: George Edgar Pyle, Jimmy Doster, Philip Buckhalter and Vinson Evans.2 Following discovery, the trial court made an extensive examination of our water law and granted the plaintiffs’ motions for summary judgment as to liability against all defendants, holding that the defendants’ use of the water for irrigation constituted a diversion, a trespass, a nuisance and an unreasonable use as a matter of law, and enjoining any future use.3 The issue of damages was reserved for trial. The defendants appeal.

1. Over 100 years ago, when this court first considered riparian rights in *405 Hendrick v. Cook, 4 Ga. 241 (1848), several bedrock principles were established. First, the court firmly rejected the doctrine of appropriation and instead applied riparian principles to the dispute.7 And in stating the principles of riparian rights, the court also adopted the doctrine of reasonable use. As stated by the court (4 Ga. at 256): “Each proprietor of the land on the banks of the creek, has a natural and equal right to the use of the water which flows therein as it was wont to run, without diminution or alteration. Neither party has the right to use the water in the creek, to the prejudice of the other. The plaintiff cannot divert or diminish the quantity of water which would naturally flow in the stream, so as to prejudice the rights of the defendants, without their consent . . . Each riparian proprietor is entitled to a reasonable use of the water, for domestic, agricultural and manufacturing purposes; provided, that in making such use, he does not work a material injury to the other proprietors.” (Emphasis supplied.) The court also held that an injury to one’s riparian rights gave rise to an action for damages for trespass even in the absence of proof of actual damage.6

Subsequently, two statutes were enacted and codified in the Code of 1863. Section 2206 of the Code of 1863 appears today almost verbatim at Code s 85-1301: “Running water, while on land, belongs to the owner of the land, but he has no right to divert it from the usual channel, nor may he so use or adulterate it as to interfere *406 with the enjoyment of it by the next owner.” (Emphasis supplied.) (See also Code s 85-1305.) Section 2960 of the Code of 1863 now appears at Code s
105-1407: “The owner of land through which nonnavigable watercourses may flow is entitled to have the water in such streams come to his land in its natural and usual flow, subject only to such detention or diminution as may be caused by a reasonable use of it by other riparian proprietors; and the diverting of the stream, wholly or in part, from the same, or the obstructing thereof so as to impede its course or cause it to overflow or injure his land, or any right appurtenant thereto, or the pollution thereof so as to lessen its value to him, shall be a trespass upon his property.” (Emphasis supplied.) The words “subject only to such detention or diminution as may be caused by a reasonable use of it by other riparian proprietors” first appear in the Code of 1933, s 105-1407, and appear to have been taken from White v. East Lake Land Co., 96 Ga. 415, 416, 23 S.E. 393 (1895). See also Pool v. Lewis, 41 Ga. 162(1) (1870).

Thus it is clear that under both court decisions and statutes, Georgia’s law of riparian rights is a natural flow theory modified by a reasonable use provision. Kates, Georgia Water Law 1969, p. 63 (1969); Agnor, Riparian Rights in Georgia, 18 Ga.B.J. 401, 403 (1956). The reasons for the rule and its contradictory reasonable use provision were well stated by the court in Price v. High Shoals Mfg. Co., 132 Ga. 246, 248-249, 64 S.E. 87, 88 (1909): “Under a proper construction (of the pertinent Code sections), every riparian owner is entitled to a reasonable use of the water in the stream. If the general rule that each riparian owner could not in any way interrupt or diminish the flow of the stream were strictly followed, the water would be of but little practical use to any proprietor, and the enforcement of such rule would deny, rather than grant, the use thereof. Every riparian owner is entitled to a reasonable use of the water. Every such proprietor is also entitled to have the stream pass over his land according to its natural flow, subject to such disturbances, interruptions, and diminutions as may be necessary and unavoidable on account of the reasonable and proper use of it by other riparian proprietors. Riparian proprietors have a common right in the waters of the stream, and the necessities of the *407 business of one can not be the standard of the rights of another, but each is entitled to a reasonable use of the water with respect to the rights of others.” (Emphasis supplied.)

In this case, the trial court found that irrigation with modern equipment was a “diversion” which is entirely prohibited by Georgia law, Code ss 85-1301, 105-1407, supra; i.e., the trial court found that irrigation with modern equipment constituted a trespass as a matter of law. We disagree. The use of water for agricultural purposes was recognized as a reasonable use along with domestic use in the first reported Georgia case on riparian rights. Hendrick v. Cook, supra. We realize, of course, that irrigation was not involved in that case. We also recognize that “There does not seem to be a Georgia case dealing with the consumption of water for irrigation . . . It is generally stated that a reasonable amount of water may be diverted for irrigation, under the general right of use for domestic and agricultural purposes.” Agnor, supra, 405-406; Kates, supra, 35-36; see also 1 Clark, Waters and Water Rights 373, s 54.3(F); see also 45 Am.Jur.2d 951, 954, Irrigation, ss 7, 14.

The first question, then, is whether the use of water for irrigation is a diversion under our laws and thus is prohibited. We find that it is not. When our riparian rights statutes were enacted, irrigation apparently was practiced only moderately here and in other “humid” states. Thus the General Assembly would not have contemplated prohibiting the use of water for irrigation in enacting these laws. This conclusion is buttressed by the absence of any litigation in Georgia on this topic. Additionally, the legislation largely tracks the case of Hendrick v. Cook, supra, and its progeny, and the court therein specified that a reasonable use of riparian water could be made for agricultural purposes. This use for agricultural purposes would have been primarily by some form of irrigation.

[3] In prohibiting “diversion”, Code ss 85-1301, 105-1407, we do not find that the General Assembly intended to prevent the use of riparian water for irrigation, even though irrigation is accomplished by removing water from its natural watercourse. Rather we *408 think the General Assembly intended to prohibit the diversion of water from a watercourse for other purposes, such as to drain one’s own property (see Goodrich v. Ga. R. & Bkg. Co., 115 Ga. 340, 41 S.E. 659 (1902)) or to create a new watercourse on the diverter’s property (see McNabb v. Houser, 171 Ga. 744, 156 S.E. 595 (1930)). That this latter use would have been of some concern to the General Assembly is evidenced by the adoption of the natural flow theory, which recognizes that the mere presence of a watercourse on one’s property generally enhances it. Rest. Torts 2d, Chapter 41, Topic 3, Introductory Note, p. 212.

Finally, Georgia’s Water Quality Control Act (Ga.L.1977, p. 368) exempts farm uses, including irrigation, from its permit requirements. Code Ann. s 17-510.1. This, we think, is a legislative recognition that irrigation is not a
prohibited “diversion” but is rather a permitted use where it is reasonable. See Code Ann. s 17-517. Hence we find that irrigation is not per se a diversion of water prohibited by law.

In sum, we find that the right of the lower riparian to receive the natural flow of the water without diversion or diminution is subject to the right of the upper riparian to its reasonable use (Rome R. Co. v. Loeb, 141 Ga. 202, 206, 80 S.E. 785 (1913)), for agricultural purposes, including irrigation.

2. In addition to holding that the use of water for irrigation was a prohibited diversion, the trial court also ruled that the uses at issue here were unreasonable as a matter of law. The trial court granted summary judgment as to liability based on several findings of fact as to which we find a conflict in the evidence.

First, the trial court made findings of fact as to the defendants’ combined capacity to irrigate and actual volume of irrigation. These figures came from defendants’ answers to interrogatories. Four of the defendants (all except Evans) stated they had used more than one piece of irrigation equipment. The trial court apparently added together the capacity of each item to determine total capacity, but the record shows that three defendants who used more than one unit did not use them in the same years; as to those pumps and travelers used by the remaining defendant in conjunction with each other, their capacity would be the capacity of the less capable piece of equipment in the system, not the total of their capacities; and there is no evidence to support the finding that the five defendants’ combined capacities were in use at any one time; i. e., these answers only stated the capacity of the equipment, not the dates, times or durations which it was operated. (F/F # 9 and # 10).

Regarding the effect of the complained of irrigation, in light of the foregoing we find an issue of fact as to whether it substantially altered and diminished the natural flow of the stream. (F/F # 4 and # 5). Defendant Hill, who formerly operated the mill, testified that before the irrigation began the mill would at times be unusable due to a shortage of water. Thus we also find an issue of fact as to whether the normal and natural flow of the stream is sufficient and adequate to power the plaintiffs’ gristmill at all times (F/F # 6), as to whether the irrigation caused the mill to be shut down (F/F # 7) and as to whether it was the cause of cessation of pond fishing and boating (F/F # 8).

Finally, we do not find that the record supports the conclusion that the uses complained of were unreasonable as a matter of law. Whether the use of water for irrigation is reasonable or unreasonable presents a triable question. White v. East Lake Land Co., supra, 96 Ga. at 417, 23 S.E. 393; Price v. High Shoals Mfg. Co., supra, 132 Ga. at 249, 64 S.E. 87. It was error to grant summary judgment to the plaintiffs.

3. In its detailed analysis of Georgia water law, the trial court had to apply Hendrix v. Roberts Marble Co., 175 Ga. 389, 394, 165 S.E. 223, 226 (1932), to the effect that “... riparian rights are appurtenant only to lands which actually touch on the watercourse, or through which it flows, and that a riparian owner or proprietor can not himself lawfully use or convey to another the right to use water flowing along or through his property ...” Thus Hendrix held water could only be used on riparian lands. Yet four years later, in reversing the denial of an injunction against the use of water on non-riparian land, the court did not rely heavily on Hendrix, supra. Instead the court (Russell, C. J., writing the opinion in both cases) based its decision more on general riparian water law principles than on the non-riparian use. Robertson v. Arnold, 182 Ga. 664, 671, 186 S.E. 806 (1936). To the extent that Robertson v. Arnold might reflect ambivalence as to the rule announced in Hendrix, that concern is well-founded.

A major study of Georgia water law concluded that “Another disadvantage of this doctrine is that it permits the use of stream water only in connection with riparian land.” Institute of Law and Government, University of Georgia Law School, A Study of the Riparian and Prior Appropriation Doctrines of Water Law (1955), p. 104. Likewise, the American Law Institute now recommends allowing use of water by riparian owners on non-riparian land, Rest. Torts 2d s 855, as well as allowing non-riparian owners to acquire a right to use water from riparian owners. Id., s 856(2), (see also 7 Clark, Waters and Water Rights 71-72, s 614.1 (1976)). The Restatement relies on two principles: that riparian rights are property rights and as such could normally be transferred, and that water law should be utilitarian and allow the best use of the water. Id., Comment b. Also, the Institute considers the acquisition of water rights by condemnation a “grant of riparian right.” Id., comment c.

Georgia recognizes the power to condemn riparian rights; in fact, this court relied on that principle in affirming an injunction in *411
749(2), 49 S.E. 779 (1905) (see also the second City of Elberton v. Hobbs, 121 Ga. 750, 49 S.E. 780 (1905)). City of Elberton, in turn, was relied on by the court in Hendrix for the proposition that water could not be used on non-riparian lands. In our view, City of Elberton is not good authority for that rule; rather, it established that the right to use water on non-riparian lands can be acquired by condemnation. We agree with the American Law Institute that the right to use water on non-riparian land should be permitted and if that right can be acquired by condemnation, it can also be acquired by grant. Thus we find that the right to the reasonable use of water in a non-navigable watercourse on non-riparian land can be acquired by grant from a riparian owner. The contrary conclusion in Hendrix v. Roberts Marble Co., supra, will not be followed.

4. In summary, the grant of summary judgment, and the permanent injunction based thereon, against each of the defendants must be reversed. On remand, the issues must be tried in accordance with the foregoing decision, looking always to see if, insofar as injunctive relief is concerned, all the uses of the creek and pond can be accommodated.10

Judgment reversed.

Footnotes
1 Sanford Hill and several others (who are not involved in this litigation) were the grantors of the property when it was conveyed in 1974.
2 Vinson Evans owns non-riparian property which he admits having irrigated with the alleged permission of a riparian owner. The evidence does not show that he owns any riparian property. The second and fourth findings of fact by the trial court must be reversed to the extent that they imply he is an upper riparian landowner to the plaintiffs.
3 The trial judge noted that the authorities point out conflicts as well as gaps in our water law. He observed that “Water rights are becoming more and more important with advancing techniques for its withdrawal and use, and there is a need for the courts or the legislature, or both, to further amplify and clarify equitable water rights between parties, particularly as those rights apply to irrigation.”
4 In the continental United States, the eastern or “humid” states apply the doctrine of riparian rights with some legislative modifications, while the western or “semi-arid” states apply the doctrine of prior appropriation or hybrid riparian-appropriation doctrines. See 1 Clark, Waters and Water Rights 29-32, s 4.1 (1967).
5 The facts in Hendrick involved raising the water level in the watercourse rather than diverting the water from the watercourse, but the court included diversion, albeit in dicta, in its discussion of riparian rights.
6 Whether a per se violation will authorize an injunction where water is in short supply, and the lower riparian is not using it, we do not here decide.
7 Defendant Pyle did apparently own several pieces of equipment at one time, but it was not shown that he used them simultaneously. Note: F/F refers to the trial court’s findings of fact.
8 See also Burns & Ledbetter, Inc. v. Primark Marking Co., 244 Ga. 341, 343, 260 S.E.2d 58 (1979).
9 It should be noted that the use of water in steam locomotives was a non-riparian use of that water unless the railroad right of way was considered riparian land wherever it went. See, for example, Goodrich v. Ga. R. & Bkg. Co., supra, where such use apparently was approved.
10 Kates, supra, 35-36; Oostanaula Mining Co. v. Miller, 145 Ga. 90, 88 S.E. 562 (1916). It would be inappropriate for us to undertake at this time to give other instructions as to how the case should be tried. However, lest the trial court feel that we have not provided sufficient guidance for such trial, we refer also to Rest. Torts 20 s 850A, p. 220. While we cannot and do not here approve all that is said therein, we refer to it for whatever help it may be.
Case reserved from superior court, Tolland county.

Action by Charles T. Mason and others, owners of mills and mill privileges on the Fenton river, against James Hoyle, the owner of a mill situated above the plaintiffs' mills on said stream, to restrain his unlawful detention of the waters therein, to their injury. The superior court reserved the case for the advice of this court, on the following finding of facts: “Plaintiffs have been for many years severally the owners and occupiers of lands, mills, and mill privileges situated on Fenton river, in the town of Mansfield. The plaintiff Mason, during all that time, has owned and operated a saw-mill, grist-mill, and wagon-shop, with machinery driven wholly by water-power, under a head and fall of about eight feet, supplied from a small pond owned by him, covering not over an acre and a half; and raised by a dam across the bed of the stream. About eighteen inches only upon the top of this pond, when full, is available for power. When the flow of water into the pond is scant, but adequate for the purpose, the ordinary practice at this mill has been to run the machinery until the pond is drawn down some six or eight inches from the top, and then cease running till it fills again, when the use is resumed as before. This privilege is an ancient one. The mill and privilege of the plaintiff Smith is on the same stream, at a considerable distance below that of Mason, and is and has long been used for the manufacture of silk, by means of machinery driven by water-power alone, under a head and fall of seven feet, supplied from a small pond over the bed of the stream, which has capacity to run the machinery only a few hours without supply from the stream above. The mill and privilege of the plaintiff Williams is situated only a few rods below that of Smith, on the same stream, and is also used for the manufacture of silk. The machinery is driven by water-power only, under a head and fall of six and a half feet, supplied by a pond over the bed of the stream, covering less than an acre. A regular supply of water from the stream above is indispensable for the successful conduct of the business. This privilege is so situated that a larger pond or reservoir would not be possible. It would be possible for the other plaintiffs to build larger dams and make new reservoirs to store the surplus water for use in times of drought, but the expense of doing so would make it of doubtful expediency as an investment. All these privileges depend wholly upon Fenton river for power. The machinery and business at each is and has been such that the ordinary flow of the stream, during the dry seasons of the year, as they ordinarily occur, would (except for the acts of the defendant mentioned hereafter) have been ample to continue the business, and meet its ordinary demands. The defendant Hoyle, since the year 1875, has been owner and possessor of land, mills, and mill privileges in the town of Willington, on the same stream, next above the mill of the plaintiff Mason, and about four hundred and fifty rods therefrom, which are and long have been used for the manufacture of woollen goods. The privilege consists of a head and fall of twenty feet, the water being drawn onto the wheel directly from a small pond near the mills, which is supplied by means of a canal or ditch connecting with a larger pond or reservoir, owned by him, about a quarter of a mile above, on the same stream, where there is an additional fall, when the reservoir is full, of about eleven feet; and some five acres are covered with the water. The dam at the reservoir was repaired and enlarged by the defendant about the year 1881. In addition to water-power, the defendant has at his mills a steam-boiler and engine, capable of driving his machinery independently of the water-wheel, but it is so arranged that it may be used with facility, and without detriment to the business, in connection with the water-power. As a usual thing, for eight or nine months of each year, extending from September or October to May or June following, there has been flowing in the river an ample supply of water for all the privileges and mills thereon, and during such periods there has been no complaint, or ground of complaint, against the defendant, or any other mill-owner, as to the mode of using the water; but during the remaining three or four months, between May and October, (subject to a few exceptions in extraordinary seasons,) the supply of water has been comparatively small. And during such dry seasons the amount of machinery to be driven at the defendant’s mill has been and is greatly disproportionate to the diminished capacity of the stream, and it has been impossible for the defendant, at such times, to run all his machinery by water-power alone, except for a small part of the time.
The mill and privilege now owned by the defendant was owned and occupied by other parties, for the same purposes, many years before the defendant obtained the same. These prior owners and occupants, during the season of deficient supply of water, as a general rule, used steam and water power in connection; and in this way the water naturally flowing in the stream was allowed to pass regularly to the several privileges of the plaintiffs, furnishing a supply sufficient to meet the ordinary demands of their business; so that no complaint was made by them, or either of them. But about the year 1881 the defendant adopted a practice in this respect different from that of his predecessors, and during the season of the year when the water supply has been inadequate for his use he has been in the habit of shutting his gates, wholly or partially, so that the water would accumulate in his reservoir, meanwhile running his machinery wholly by steam-power from two to five days, until there was an accumulation of water in his reservoir sufficient to run by water-power alone continuously for five or six hours; and, after so running, he would return again to the exclusive use of steam, and continue, as before, the alternative use of steam and water power. By these means the defendant has detained, for periods varying from two to five days in the week, and for many weeks, during the dry season of each year, substantially all the natural flow of the stream, except so much as he required daily for washing wool and cloth, and for his boiler, (which usually has been much less than the natural flow of the stream;) and then, by the use of water-power alone, for periods of five or six hours a day, once or twice during the week, and sometimes oftener, the water has flowed from his wheel in quantities far in excess of the natural flow of the stream during such seasons, which has resulted in quickly filling the small ponds of the plaintiffs, and then running to waste over their several dams. The defendant, however, has not let down at such times more water than was required to run all his own machinery In this way each of the plaintiffs has suffered great inconvenience, damage, and loss. The defendant, in this matter, has not acted maliciously, but from a belief that he had a lawful right to make such use of the water. The plaintiffs have repeatedly informed him of their annoyance and injuries, and remonstrated against his mode of using the water. There are several small water privileges on the same stream above the defendant’s mills, and some below the plaintiffs’; and, as to these, the court finds that for many years it has been and still is the usual practice of each of the proprietors, (including also the plaintiffs,) whenever the head of water in their several ponds has been insufficient to enable them to run their machinery to advantage, to shut the gates of their ponds, and hold back the natural flow, until there had accumulated a sufficient supply for effective use, and in no case except that of the defendant was there any evidence of resulting damage; and, in relation to this practice, the court further finds that, owing to the small capacity of the ponds, or condition of the dams, or other circumstances, there has never been in any of these cases any long-continued detention of the natural flow of the stream. And, on the other hand, owing to the small amount of machinery to be driven when the use of the water-power has been resumed, in no case has there been precipitated upon the mill-owners below any such unusual quantity as to cause it to run to waste, or occasion in any way loss or inconvenience, as in the case of the defendant.”

Opinion

*787 PARDEE and CARPENTER, JJ., dissenting.

Attorneys and Law Firms

*788 B. H. Bill and J. M. Hall, for plaintiffs.

J. L. Hunter, for defendant.

LOOMIS, J.

The rule that now obtains in all jurisdictions, as recognized by all the authorities, is that the use made by mill-owners of a stream must, in its relation to other mill-owners on the same stream, be a reasonable use. The rule is obviously one that applies solely to the relation of the several occupants of the stream among themselves. Where one mill-owner is the sole occupant, there is in law no limitation upon his use. The rule being that of reasonable use, the application of the rule becomes a matter for each particular case. The question, while in some sense a mixed question of law and fact, is yet essentially a question of fact. Whether the use be reasonable must depend less upon any general rule than upon the particular circumstances. But there are certain conditions essential to a reasonable use so long recognized by common consent, or so obviously just, that we may safely generalize with regard to them. Snow v Parsons, 28 Vt. 459. In the first place, the use must be as
near as possible an equal use, or, rather, an equal opportunity to use. “Equity delighteth in equality.” Every owner improving a mill privilege has a right to consider the law as protecting him against any unfair use by any other owner who may establish a mill above him. The term “unfair use” is the equivalent of “unreasonable use.” When the owner above him has established his mill, he is bound, not merely by this obvious rule of the stream, but by another more general rule of universal application, that no one may so use his own as to injure the property of another. This golden rule of the law is not, of course, to be taken literally; for where there is a concurrent use of water, and at the same time a deficiency, the use of one will, to some extent, injure another. In the next place, a reasonable use is one adapted to the character and capacity of the stream. Indeed, there is no other factor of so much importance that comes into the question as that of the capacity of the stream; and, in determining this capacity, its condition throughout the year is to be considered. If, for instance, there is an ample supply of water for nine months of the year, and a scarcity for three, this scarcity, if it occurs so regularly that it can be anticipated, is to be treated as *789 a fixed quantity in the estimate, and as so far reducing the capacity of the stream. We will discuss this point more fully in another connection. In the next place, a reasonable use must permit the water to flow in its accustomed way, so far as this can be done, and a beneficial use, though a limited one, be made of the reduced stream, each riparian mill-owner having his fair proportion. It is the right of every mill-owner, large or small, on the stream, that the water be allowed to run in its usual way, except where detained by another to secure his fair proportion of beneficial use. A policy of the state may come in to affect the question. It is for the public interest that all our streams be improved as far as they can be. This rule has sometimes been applied to favor the larger mill-owner, but it should have regard also to small mill-owners, who are the great majority of those in such business, or who incline to go into it. These men of moderate capital, investing their means in mills upon our lesser streams, should be protected against such a use of the streams by mills disproportioned to their capacities as would practically deprive them of water and ruin their privileges. And, where the water is sufficient only for a few hours’ use in a day, it is a reasonable demand of these lesser mills that they should be allowed water enough to run a part of every day, rather than it should be detained by any larger mill in such a way as to compel them to crowd into a single day or night all the work of a week. There would be no way in which the lesser mills could hold their own against the disproportionately large ones, with reservoirs of great capacity, but to enlarge their own reservoirs and ponds to an equal capacity; thus compelling all to enlarge their works in a manner not demanded by the capacity of the stream, and involving an unnecessary and perhaps ruinous expenditure. If a large mill-owner has made a reservoir which it requires several days to fill in the dry season, he has no more right, on that account, to detain the water for a week, to fill it, than he would have to detain it a month. His rights are not measured at all by the capacity of his reservoir, for he may be able to double or fourfold its capacity, and the law will not allow him to establish for himself the rule that shall decide his rights between himself and another. The question is not as to the capacity of the reservoir, but what is a fair use of the water between him and his neighbor below? Where the reservoir, as in the case at bar, is simply to store the water, and not to furnish the head and fall, he can as well use the water when it is a half or a quarter filled as the lower owner can use it when his smaller pond is wholly filled. A reservoir used to store surplus water, when the supply is abundant, for use at a time when it is deficient, is a great benefit to all the lower proprietors; but, if used to detain the water in the dry season, it may occasion great injury, as in this case.

These principles seem in the highest degree reasonable and just. In their application, the particular circumstances of each case must determine the result. What may be a reasonable use in one case may be an unreasonable one in another, even where the general facts are similar. The question is so largely one of fact that, like decisions in the case of wills, one decision can rarely afford a decisive guide for another. But we believe that most of the principles we have laid down accord well with the best-considered cases. A seeming conflict is often occasioned by applying some general principle to the case in hand, without stating the implied qualifications necessary to adapt it to other cases. For instance, in many cases we find the general proposition, upon which the defendant in this case relies, that the upper mill proprietor may detain the water in times of drought until he can advantageously and profitably use it to propel his machinery.

***While it is true that a right to use implies a right to detain, yet the word “reasonable” must qualify both the use and the detention. Nothing can be more unjust and unsafe than to limit one man’s rights by the selfish convenience or business of another. ***“Every riparian proprietor has a right to use the water of a river or running
stream for the purpose of working, operating, and propelling artificial works erected upon its banks. Priority of occupation secures to the first occupant the exclusive right to the use of the water to the extent of his occupation; * * * but his right is limited to using the water in a reasonable and proper manner for the propelling, working, and operating of a mill of such magnitude only as is adapted and appropriate to the size and capacity of the stream, and quantity of water flowing therein. He cannot lawfully detain the water in his pond an unreasonable length of time, nor discharge it thencefrom in such quantities that it will run to waste, and be lost by the riparian proprietors below; but he is bound to use the water in such way and manner that every riparian proprietor at points further down the stream will have the enjoyment and use of it substantially according to its natural flow, but still subject to such disturbance and interruption as is necessary and unavoidable in and by the reasonable and proper use of it for the propelling, working, and operating of a mill of suitable magnitude, adapted and appropriate to the size and capacity of the stream, and the quantity of water flowing therein; and if it appear, from all the evidence in the case, that the defendant’s mill is not adapted and appropriate to the size and capacity of the stream, and is disproportionately large and extensive, or if the defendant used the water in an unreasonable manner, and the plaintiff was in either of these ways, or by either of these means, interrupted or disturbed in the operation of his mill, he is entitled to a verdict commensurate to the injury sustained.” SHAW, C. J., in commenting upon this charge, says: “The court are of the opinion that the law was rightly stated by the judge at the trial; that it was laid down with fullness and accuracy, and with proper qualifications. Every man has a right to the reasonable use and enjoyment of a current of running water, as it flows through or along his own land, for mill purposes, having a due regard to the like reasonable use of the stream by all other proprietors above and below him.” ***

But the general principle stated by us at the outset of the discussion, to the effect that, to justify a detention of the water by the upper proprietor long enough to make an advantageous use of it, his machinery, or so much of it as he operates, must be adapted to the fixed character of the stream (if it has any) as to deficiency of water during the dry seasons, apparently conflicts with the rule laid down in many cases, that the adaptation referred to must be to the usual quantity of water in the stream, or other equivalent expressions, by which we have no doubt was meant, as applicable to those cases, the medium average flow between a high and low stage of water. But in none of the cases where the rule has been applied, so far as we have examined them, did the seasons of great scarcity of water occur with such regularity, year after year, as in the case at bar. Hence there was nothing to require the mill-owner to take notice of anything more than the average flow*** [I]n the case at bar the finding is that, “as a usual thing, for eight or nine months of each year, extending from September or October to May or June following, there has been flowing in the river an ample supply of water for all the privileges and mills thereon, and during such periods there has been no complaint, or ground of complaint, against the defendant, or any other mill-owner, as to the mode of using the water; but during the remaining three or four months, between May and October, (subject to a few exceptions in extraordinary seasons,) the supply of water has been comparatively small. And during such dry seasons the amount of machinery to be driven at the defendant’s mill has been and is greatly disproportionate to the diminished capacity of the stream; and it has been impossible for the defendant at such times to run all his machinery by water-power alone, except for a small fraction of the time.” And the other fact found, that five days’ detention of the water has enabled the defendant to run only five hours, shows still more forcibly the enormous disproportion of his machinery to the capacity of the stream during the dry season. Now, may we not advance a step, and adopt the principle that if seasons of great scarcity of water occur so regularly, and continue so long, as to fix the character of the stream in that regard, the upper proprietor must adapt the running of his machinery to that condition? We are not able to find any adjudicated case where the principle has been thus announced, but it seems to us in the highest degree reasonable, and it receives strong confirmation *793 from what so distinguished a jurist as Chief Justice REDFIELD says in his note to the case of Manufacturing Co. v. Manufacturing Co., supra, as found in 13 Amer. Law Reg. (N. S.) 92, as follows: “No doubt, every millowner upon a stream, where there is reason to expect a deficiency of water at times, is bound to construct his machinery with reference to such occasional emergencies. But this rule will not apply to extraordinary deficiencies, such as no one could reasonably have anticipated.” It would seem impossible to find any other intelligent basis for the required adaptation of machinery to the stream than what may reasonably be anticipated through the year. If periods of scarcity are uncertain as to their occurrence or as to time and extent, it is fair to look to the average flow, for there is, indeed, no other basis for calculation; but, in cases where there exists a more certain basis, it is a
strange doctrine that it may be disregarded. ***

If the principle we have been contending for is not sufficiently established to be accepted as controlling this case, still the fact of a regularly recurring deficiency of water is at least one important element in determining the question of reasonable use. The defendant knew the fact when he bought the property, and afterwards when, in 1881, he repaired and enlarged his reservoir, and when, with presumptive knowledge of the result to the plaintiffs, he changed the long-established mode of running the mill. And this suggests another element with which to test the reasonableness of the defendant’s use of the water. The immemorial local custom upon the stream, down to the time of the defendant’s interposition, to let the water flow to the plaintiffs’ mills without any long or injurious detention, according to the authorities in this and other jurisdictions, has an important bearing upon the question. Again, there is still another element of great significance as it exists in this case, namely, the extent of benefit to the defendant by his detention as compared with the injury to the plaintiffs. This principle is stated in Hayes v. Waldron, 44 N. H. 580; Union Mills v. Ferris, 2 Sawy. 196. It would seem impossible to find a parallel to the case at bar in the difference found to exist between the benefit to the defendant and the damage to the plaintiffs. If we take the period of greatest detention, which has often occurred, we find that the three mills belonging severally to the three plaintiffs must each be idle five days to enable the defendant to enjoy the slight benefit of a five hours’ use. This discussion, already too protracted, may suffice to show that to accede to the defendant’s claim as to the use of the stream would be to enable him to violate most, if not all, the conditions of reasonable use to which we have referred, and practically to absorb the entire beneficial use of the water during the seasons of scarcity. We advise the superior court that the defendant, upon the facts found, has unreasonably detained the water of the stream in question, and that judgment should be rendered against him in favor of the plaintiffs.

***PARDEE, J.

I am not able to concur in the foregoing determination. ***The flow during nine months of the year is to stand for the stream; the diminished flow of three months is the exception. The rule of law which permits the mill-owner to adapt his machinery to the power of the stream, and encourages him so to build as to compel it to do the greatest possible amount of work during the longest time, and therefore make the largest possible additions to the wealth of the country, has reference to this long period of fullness. Of course, this case is to stand as if the owner whose needs are the least had been sole plaintiff; and his contention is, in effect, that no owner shall be permitted so to build as to need more than himself; that, during eight or nine months of the year, the largest portion of the water shall pass unused by anybody, in order that his small wheel may have some on every day of the summer’s drought. In establishing principles which are to govern in such matters, courts are required to make them of as wide application as is possible. Upon every stream the proportion of ownership, as between large and small proprietors, may be and usually is a varying quantity. No rule of law can find a resting place upon it. Therefore, without inquiry in any case whether most proprietors are large or small, the courts have said, in reference to every stream, that an owner may adapt his machinery to its fullest capacity when in ordinary flow, and may so long detain the water in times of drought as that he may even then have some profitable use thereof. The plaintiffs and defendant were each lawfully upon the stream, with equal rights when it is in the condition of ordinary flow. In time of drought it is so small, and the disparity between the needs of the parties is so great, that the lost time cannot be equally apportioned. In this state of things that proprietor whose mill is adapted to the best and fullest use of the stream during the entire period of ordinary flow of nine months is preferred, in the eye of the law, over one whose mill allows a large portion of the water to run past unused during the same period*** The misfortune of the plaintiffs results from the fact that they are upon a stream of little value to any one in a time of drought; that there is another proprietor upon it; and that the law, in its inability to be impartial, gives the preference to the most beneficial use. The question is as to division of the use of water when drought prevails to such a degree that there is not enough for either party. Therefore there is no opportunity for the application of the rule which requires every person so to exercise his rights as not to injure those of another. Loss of time is inevitable. The only question is as to the apportionment of that loss. That they have so built that they cannot have the best use of the stream during nine months is not a reason for permitting them to deprive another of all use during three months. The plaintiffs can take nothing by any suggestion as to the custom upon this stream; for the finding is that the custom has been for each proprietor to shut his gate, and detain water sufficient for profitable use.