Water resources

Article by:

Berner, Elizabeth K. Department of Geology and Geophysics, Yale University, New Haven, Connecticut.

Publication year: 2014

DOI: http://dx.doi.org/10.1036/1097-8542.801450 (http://dx.doi.org/10.1036/1097-8542.801450)

Content

The Earth's water supply and its natural distribution. Although water is a renewable resource, which is continually being replaced by precipitation, it is not evenly distributed and is scarce in many areas.

Water reservoirs

Water is stored on the Earth's surface in a number of places called reservoirs (**Table 1**).

Table 1 - World water*

Location	Surface area, km^2	Water volume, $10^3 km^3$	Percent of total
World ocean	362,000,000	1,400,000	95.96
Mixed layer		50,000	
Thermocline		460,000	
Abyssal		890,000	
Glacial ice	18,000,000	43,400	2.97
Groundwater		15,300	1.05
Lakes, fresh	855,000	125	0.009
Rivers		1.7	0.0001
Soil moisture		65	0.0045
Atmosphere†		15.5	0.001
Biosphere		2	0.0006
TOTAL	510,000,000	1,459,000	100

*SOURCE: E. K. Berner and R. A. Berner, *Global Environment: Water, Air and Geochemical Cycles*, Prentice Hall, 1996; National Research Council (NRC), *Global Change in the Geosphere—Biosphere*, National Academy Press, 1986; R. L. Nace, Terrestrial water, in AccessScience@McGraw-Hill, http://www.accessscience.com.DOI 10.1036/1097–8542.685800, last modified July 15, 2002 (surface area).†As liquid water.

Oceans

By far the largest reservoir is the ocean, which contains 96% of the Earth's water and occupies more than two-thirds of the Earth's surface. Ocean water, being saline, is not generally available for human consumption, although it can be used for some purposes, mainly thermoelectric power. *See also:* **Hydrosphere (/content/hydrosphere/330800)**; **Ocean (/content/ocean/757648)**

Glaciers

Freshwater makes up only about 4% of the Earth's water. The largest freshwater reservoir is glacial ice, at 3%. Most of this ice (about 85%) occurs as continental glaciers in Antarctica and less than 10% in the Greenland ice sheet. Alpine or mountain glaciers, which occur in mountain valleys on the continents, contain a small part of the total ice. *See also:* **Hydrology (/content/hydrology/329800)**

Groundwater

The largest reservoir of available freshwater is groundwater (1.05% of total water), which is stored in the pores and spaces in rocks, sand, gravel, and soil under the Earth's surface. The top plane of the groundwater is referred to as the water table, below which all the spaces are filled with water. About half of the groundwater occurs quite near the Earth's surface (<0.8 km) and this is an important source of water for human consumption. Although shallow groundwater is continually being refilled by precipitation trickling down to the water table, the rate of recharge is very slow and often takes hundreds or thousands of years. This makes many groundwater aquifers a nonrenewable resource. The rest of the groundwater, while at greater depths, does not occur much deeper than a few kilometers, where the pressure of the overlying rock becomes so great that pore space disappears. Deep groundwater is harder to recover and is more likely to be saline. A smaller amount of water occurs in the soil above the water table, where both air and water fill the pore spaces; this water is referred to as soil moisture and is tightly held in the pores. *See also:* **Aquifer (/content/aquifer/045600)**; **Artesian systems (/content/artesian-systems/052500)**

Lakes, rivers, and other reservoirs

Freshwater lakes and rivers on the Earth's surface contain only 0.01% of the Earth's water. This water is generally available for human consumption. There is also an even smaller reservoir of water in the atmosphere (0.001%), where the water occurs as water vapor gas. The smallest reservoir of water occurs in the biosphere, within plants and animals (0.0006%).

To summarize, the main freshwater resources available for humans on the Earth's surface are groundwater and lake and river water, which together only constitute about 1.1% of the Earth's total water. *See also:* **Groundwater hydrology (/content/groundwater-hydrology/301300)**

Hydrologic cycle

Water does not permanently remain in any one reservoir on the Earth but is continually in motion through the hydrologic or water cycle (**Fig. 1**). Residence time is the length of time water spends in a particular reservoir before being removed through the water cycle. The ocean has a residence time of 36,000 years, the time it would take river flow to replace the water in the ocean. *See also:* **Atmospheric general circulation (/content/atmospheric-general-circulation/059500)**

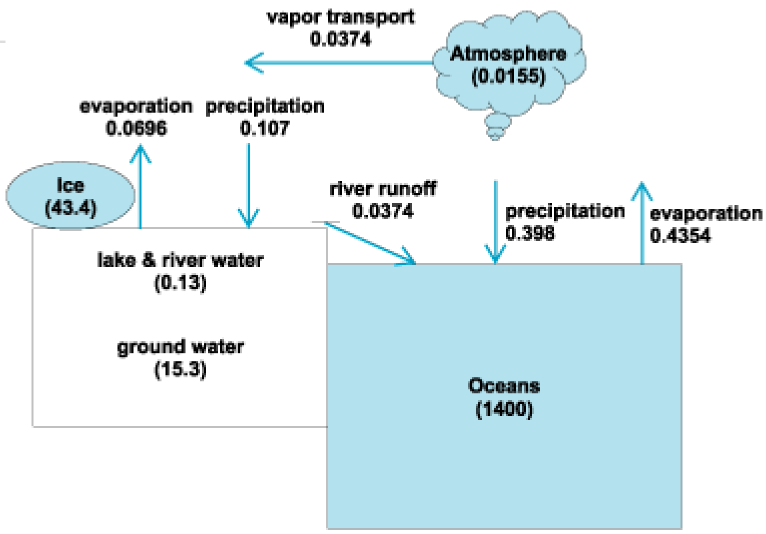

Fig. 1 Water cycle. Volumes of reservoirs in parentheses (in 10^6 km^3); fluxes in 10^6 km^3/yr. (*Data source: E. K. Berner and Robert A. Berner, Global Environment: Water, Air, and Geochemical Cycles, Prentice Hall, Upper Saddle River, NJ, 1996*)

The water cycle is driven by solar energy. Water is evaporated from the oceans to the atmosphere in the form of water vapor gas (a flux of 435,400 km^3/year). Part of this water vapor cools and is precipitated back to the oceans in the form of rain (398,000 km^3/year). Some water vapor (37,400 km^3/year) is transported through the atmosphere to the continents where it joins water vapor evaporated from the land (69,600 km^3/year). The vapor cools and precipitates out as rain or snow (107,000 km^3/year). Much of this precipitation runs along the Earth's surface to rivers, which flow to the oceans. A small amount of precipitation trickles down to join the groundwater.

The flow of water in rivers to the ocean, which can be estimated reliably, is about 37,400 km^3/year. The water vapor flux from the oceans to the land is set equal to the river flux from the land to the oceans.

The total amount of water on the Earth's surface in the various reservoirs remains roughly constant over time. The general belief is that the amount of water on or near the Earth's surface has not changed greatly since 3.8 billion years ago.

Rivers

The rivers with the greatest volume of water discharged to the oceans are listed in **Table 2**. The first 13 rivers make up about 38% of the total water discharge to the oceans, which is approximately 37,400 km^3/yr. The Amazon River of Brazil and central South America alone comprises 17% of the total. There are three American rivers that are among the world's 17 largest rivers: the Mississippi, St. Lawrence, and Columbia rivers. *See also:* **River (/content/river/591000)**

Table 2 - Major world rivers by discharge to ocean

	River	Location	Discharge, km^3/yr
1	Amazon	South America	6300
2	Zaire (Congo)	Africa (Congo)	1250
3	Orinoco	South America	1100
4	Yangtze (Chiang)	Asia (China)	900
5	Bramaputra	Asia (India)	603
6	Mississippi	United States	580
7	Yenisei	Asia (Russia)	560

Table 2 - Major world rivers by discharge to ocean

8	Lena	Asia (Russia)	525
9	Mekong	Asia (Vietnam)	470
10	Ganges	Asia (India)	450
11	St. Lawrence	North America	447
12	Parana	South America	429
13	Irrawaddy	Asia (Burma)	428
15	Mackenzie	North America (Canada)	306
17	Columbia	United States	251
	TOTAL all rivers		37,400

SOURCE: E. K. Berner and R. A. Berner, *Global Environment: Water, Air, and Geochemical Cycles*, Prentice Hall, Upper Saddle River, NJ, 1996.

Size and distribution

The amount of river runoff from the continents is determined by the difference between precipitation and evaporation, or net precipitation in the river basin. Ultimately, the amount of precipitation is determined by the atmospheric circulation of water vapor. Evaporation rates depend upon temperature, and decrease with increasing distance from the equator. Most of the world's large rivers occur in two belts where precipitation exceeds evaporation, an equatorial belt from 10°N latitude to 10°S latitude and a temperate belt from 30 to 60°N and S latitude.

The two largest rivers, the Amazon and the Congo rivers, occur in the equatorial belt. The temperate belt has two major rivers, the Mississippi in the United States and the Yangtze in China. Although precipitation in the subarctic regions (60°N–70°N) is low, there is also low evaporation, resulting in net precipitation and a number of large rivers such as the Yenisei and the Lena in northern Russia and the Mackenzie in the Canadian Arctic. The 20–30°N and S belt, between the equatorial and temperate zones, has many deserts and few rivers because of descending dry air from the overall atmospheric circulation.

Usage problems

The result of the uneven distribution of net precipitation and world rivers is that many areas do not have adequate water resources. For example, large parts of the flow of the Amazon and Congo rivers, which account for 18.5% of the total global river flow, are geographically inaccessible to populated areas. The remote northern rivers of North America and Eurasia (Mackenzie, Lena, and Yenisei) are also inaccessible. In total, about 20% of world river flow is geographically inaccessible to populated areas and thus not available for human use.

The western part of the United States is semiarid to arid, with precipitation generally declining as one moves west from the Mississippi River. The Colorado River, for example, flows through a generally arid region. Water is allocated by law to various states and withdrawn from the Colorado along its U.S. route until there is almost no flow by the time the river reaches Mexico. The water that remains contains high concentrations of dissolved minerals because of irrigation use and evaporation from large reservoirs behind dams, and therefore Mexico's share of the Colorado River must be desalinated. There are disputes over Colorado River water between California, Arizona, Nevada, and Mexico. The northwestern United States is an exception to the generally dry western United States, with a major river, the Columbia, fed by heavy precipitation in the coastal mountain ranges.

Rivers in other dry parts of the world, such as the Nile in Egypt, have had their flow greatly reduced due to dams and irrigation. At times, the Nile is reduced to zero flow.

Lakes

Freshwater lakes only make up 0.009% of the worlds water by volume (125,000 km^3), but they are important water resources. The world's major freshwater lakes are listed in **Table 3** in order of surface area.

Table 3 - Major world freshwater lakes

	Lake	Location	Area, km^2	Maximum depth, m	Length, km
1	Superior	United States–Canada	82,103	406	563
2	Victoria	Africa	69,485	82	402
3	Huron	United States–Canada	59,570	229	331
4	Michigan	United States	57,757	281	494
5	Tanganyika	Africa	32,893	1470	676
6	Baikal	Russia	31,500	1620	636
7	Great Bear	Canada	31,329	446	306
8	Nyasa	Africa	28,879	695	579
9	Great Slave	Canada	28,570	614	480
10	Erie	United States–Canada	25,667	64	388
11	Winnipeg	Canada	24,390	18	428
12	Ontario	United States–Canada	19,011	244	311

SOURCE: U.S. Geological Survey.

Size and distribution

The American-Canadian Great Lakes (Superior, Michigan, Huron, Erie, and Ontario) are among the world's major lakes. They contain approximately 25,500 km^3 of water, or one-fifth of the world's freshwater, and are connected with the water finally flowing eastward from Lake Ontario into the St. Lawrence River and on to the Atlantic. The Great Lakes were formed when the last Pleistocene glacier melted about 15,000 years ago and owe their origin to glacial features: glacial erosion, deposits of sand and gravel left by the melting ice, and the general downwarping of the Earth's crust by the weight of glacial ice in north central North America. In addition to the Great Lakes, there are large numbers of small glacial lakes in Canada, Minnesota, Michigan, western New York, and New England. The Finger Lakes in upstate New York are conspicuous examples of glacial erosion. Two other large glacial lakes and many smaller lakes occur in northwestern Canada, including Great Bear Lake and Great Slave Lake, and Lake Winnipeg in central Canada. *See also:* **Lake (/content/lake/368800)**

Lake Baikal in Russian Asia is the world's largest lake by volume (23,000 km^3) because it is also the deepest at 1620 m. It alone contains about one-fifth of the Earth's fresh lake water. Lake Baikal occurs in a rift valley, a narrow downdropped valley with steep faults on either side. This type of geologic setting contributes to its great depth. A number of large, deep African lakes, such as Lake Tanganyika and Lake Nyasa, are also formed in rift valleys. Lake Tanganyika, which is almost as deep as Lake Baikal, also contains a large volume of freshwater at 20,850 km^3.

Lake Chad in central Africa used to be one of the world's largest freshwater lakes by surface area although it was very shallow (5–8 m). However, a combination of extensive use for irrigation and long-term drought have reduced its size by 90% from 25,750 km^2 in the 1960s to 2150 km^2 in 2001.

There are several very large saline lakes. In fact, the world's largest lake, the Caspian Sea (at 371,000 km^2) at the border between Asia and Europe, is saline. It was named a “sea” because of its salinity. The Aral Sea is another large saline lake, although it has been shrunk extensively by the use of its water for irrigation; its original size was 67,340 km^2 and it is now about half that large. In addition, the salty beds left behind the dried-up lake are exposed to the wind, resulting in dust storms that cause severe air pollution. The largest American saline lake, the Great Salt Lake in Utah, which is more saline than seawater, is the remnant of an originally freshwater glacier lake.

Usage problems

One major problem with freshwater lake quality in the United States has been contamination of lakes with nitrogen and phosphorus. This causes overgrowth of algae and green murky water as well as loss of oxygen in the bottom water when the algae die and decay. Phosphorus has been removed from detergents, improving lake water quality, but there remains an ongoing problem with phosphate and nitrogen from sewage effluent and lawn and agricultural runoff.

Acid lakes, particularly in the northeastern United States and in Scandinavia, result from the production of air pollution upwind from the lakes. Sulfuric acid pollution comes from coal burning power plants and nitric acid from automotive pollution and power plants. The air pollution is carried by the atmospheric circulation to susceptible lakes and then falls as acid rain.

United States water use

Freshwater use in the United States, which totaled 345 billion gallons/day in 2000, is shown in **Fig. 2**. The two largest uses, at about 40% each, are irrigation of crops and thermoelectric power generation. Public water supply accounts for 12%, followed by industry at 6%. The last four uses are less than 1% each: aquaculture, domestic (well) water, mining, and livestock.

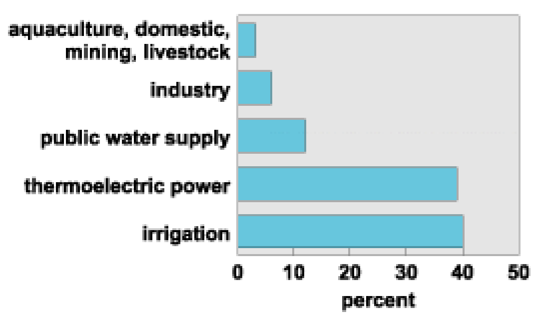

Fig. 2 Freshwater use in the United States in 2000. (*Data source: U.S. Geological Survey Cir. 1268, 2004*)

The sources of freshwater are surface water (76%) and groundwater at (24%). The largest use of groundwater is for irrigation, which has increased to 42% of the total water use or 58 billion gallons/day. Groundwater also makes up 37% of the public water supply. These two uses make up most of the total groundwater withdrawal.

The largest withdrawal of groundwater occurs in three states, California, Texas and Nebraska, where groundwater is used primarily for irrigation. The Ogallala Aquifer, which lies under the High Plains states and is a big groundwater source, was drawn down by more than 100 ft from 1940 to 1980 in southwest Kansas, Texas, and the Oklahoma panhandle. However, better conservation methods have since been implemented, such as more efficient irrigation to reduce water loss.

Worldwide water use

The uses of water worldwide are 70% for agriculture, 10% for domestic purposes such as drinking water, and 20% for industry (more than half of which is used for hydropower). Countries that have scarce water include a number in the belt of low precipitation (20–30° N and S latitude) such as the northern tier of Africa (Mauritania, Algeria, Morocco, Libya, Niger, and Egypt) and the Middle East (Saudi Arabia, Palestine, Syria, and Jordan). Worldwide there are 500 million people in countries with scarce water.

Water for human consumption is unsafe in many places, particularly in the developing countries. It is estimated that as much as 80% of diseases in developing countries are water-related, and 1.7 million people, often children, die from these diseases mainly in Africa and southeast Asia. Typical diseases are diarrhea, cholera, typhoid, and malaria. The main problem is that unsafe disposal of human and animal waste contaminates water for domestic use and irrigation.

More than 50% of the water used by industry (20% of the total) is used for hydropower plants. These plants provide one-fifth of the world's electricity. Hydropower is relatively clean and nonpolluting and is renewable. Dams used for hydropower generation also store water resources for agricultural irrigation, flood prevention, and domestic use. The downside of dams is their displacement of people living in the area of the reservoir. Industrial uses of water can lead to pollution of rivers and aquifers by heavy metals (such as mercury and lead) and persistent organic pollutants (such as DDT and PCB's from electrical insulation).

Agriculture uses 70% of water worldwide, primarily for irrigation. About 65% of irrigation water is “consumed” in distribution and application and by crops and not available for reuse. Irrigation can be wasteful of water and can lead to salt buildup in soils if the soil is poorly drained. Agricultural and lawn runoff often cause overfertilization of water from nitrate and phosphate, causing algal blooms and loss of oxygen in bottom water of rivers, lakes, and estuaries. There have also been problems with agricultural pesticides polluting ground and surface water.

Desalinization of salt water currently supplies only about 0.1% of freshwater. It is expensive since it requires a lot of energy. Thus, it is used primarily for drinking water in water-poor areas. *See also:* **Water desalination (/content/water-desalination/598900)**

Elizabeth K. Berner

Bibliography

E. K. Berner and R. A. Berner, *Global Environment: Water, Air and Geochemical Cycles*, Prentice Hall, Upper Saddle River, NJ, 1996

R. Clarke and J. King, *The Water Atlas*, New Press, New York, 2004

P. H. Gleick, *The World's Water 2004–2005: The Biennial Report on Freshwater Resources (World's Water)*, Island Press, Washington, DC, 2005

P. H. Gleick, Making every drop count, *Sci. Amer.*, 284(2):40–45, 2001 DOI: 10.1038/scientificamerican0201-40 (http://dx.doi.org/10.1038/scientificamerican0201-40)

S. S. Hutson et al., Estimated use of water in the United States in 2000, U.S. Geological Survey Circ. 1268, 2004

S. L. Postel, G. C. Daly, and P. R. Ehrlich, Human appropriation of renewable freshwater, *Science*, 271:785–88, Feb. 9, 1996 DOI: 10.1126/science.271.5250.785 (http://dx.doi.org/10.1126/science.271.5250.785)

Additional Readings

S. C. Anisfeld, *Water Resources*, Island Press, Washington, DC, 2010

M. Z. Jacobson and M. A. Delucchi, Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials, *Energ. Policy*, 39(3):1154–1169, 2011 DOI: 10.1016/j.enpol.2010.11.040 (http://dx.doi.org/10.1016/j.enpol.2010.11.040)

L. W. Mays, *Water Resources Engineering*, 2d ed., John Wiley & Sons, Hoboken, NJ, 2011

S. Piao et al., The impacts of climate change on water resources and agriculture in China, *Nature*, 467(7311):43–51, 2010 DOI: 10.1038/nature09364 (http://dx.doi.org/10.1038/nature09364)

Water Resources and Freshwater Ecosystems, World Resources Institute, 2000–2001 (earthtrends.wri.org/)

Water resource information from the United States Geological Survey Water Resources Division (water.usgs.gov/)

World's water resources from the Pacific Institute (http://www.worldwater.org/)