Water resources

Contributed by: Elizabeth K. Berner

Publication year: 2017

Key Concepts

- The ocean holds 96 percent of Earth's water, but that water is not drinkable.
- Glacial ice is the largest freshwater reservoir, containing 3 percent of Earth's water.
- Groundwater is the largest reservoir of freshwater that is available for human use. Lakes, rivers, and other freshwater reservoirs contain only 0.01 percent of Earth's water.
- Water continually moves between reservoirs in the hydrologic cycle, or water cycle. Yet, the amount of water in each reservoir has remained roughly constant over geologic time.
- The result of uneven distribution of net precipitation and rivers around the world is that many areas do not have adequate water resources.
- Contamination from nitrogen and phosphorus, along with acid precipitation, have decreased water quality in freshwater lakes..

The Earth's water supply and its natural distribution. Freshwater is a renewable resource, and it is continually being replaced by precipitation, but it is not evenly distributed and is scarce in many areas. The uses of water worldwide are for agriculture, for domestic purposes such as drinking and sanitation, and for industrial purposes, primarily hydropower (**Fig. 1**). The natural hydrologic cycle constantly moves the world's supplies of water through a variety of reservoirs over many thousands of years. The accessibility and usefulness of the water resources varies considerably with geography and climatological conditions, however, and may be further complicated by factors such as pollution. *See also:* HYDROLOGY.

Global uses for water

Water designated for human consumption is unsafe in many places, particularly in the developing countries. Many diseases in developing countries are water-related, and 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.

Fig. 1 **Furrow irrigation using a gated-pipe-supply system. (Credit: Jeff Vanuga/USDA Natural Resources Conservation Service)**

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 polycyclic aromatic compounds and polychlorinated biphenyls). *See also:* DAM; POLYCHLORINATED BIPHENYLS; WATER POLLUTION; WATER POWER.

Agriculture uses water primarily for irrigation. 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. *See also:* IRRIGATION (AGRICULTURE).

Desalinization of salt water currently supplies only a fraction of freshwater needed worldwide. It is expensive since it requires a lot of energy. Thus, it is used primarily for drinking water in water-scarce areas. *See also:* WATER DESALINATION.

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.
†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; OCEAN.

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:* GLACIOLOGY.

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; ARTESIAN SYSTEMS; GROUNDWATER HYDROLOGY.

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.

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. 2**). 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.

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.

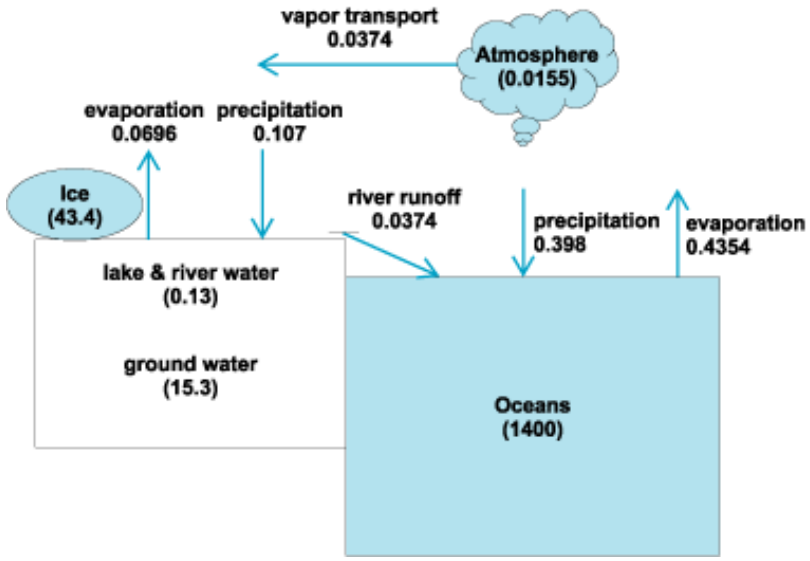

Fig. 2 **Water cycle. Volumes of reservoirs in parentheses (in 10^6 km^3); fluxes in 10^6 km^3/yr. (Data source: E. K. Berner and Robert A. Berner, Global Environment: Water, Air, and Geochemical Cycles, Prentice Hall, Upper Saddle River, NJ, 1996)**

The 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.

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

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	Brama-putra	Asia (India)	603
6	Missis-sippi	United States	580
7	Yenisei	Asia (Russia)	560
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	Ir-rawaddy	Asia (Burma)	428
15	Macken-zie	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.

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.

Use problems

The result of the uneven distribution of net precipitation and rivers around the world 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 flow of the Nile is reduced to zero.

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.

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

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.

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.

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.

Use problems

One major problem with freshwater lake quality has been contamination 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. *See also:* ACID RAIN.

Elizabeth K. Berner

Keywords

water; reservoirs; hydrologic cycle; ocean; rivers; lakes; groundwater

Test Your Understanding

1. Water, in both liquid and frozen form, covers 75 percent of Earth's surface. Yet, only a small fraction of that water is available for human use. Explain why.
2. How does water move in different forms through the hydrologic cycle?
3. What are the two largest rivers, and where do they occur?
4. Critical Thinking: Depletion in which type of freshwater reservoir—groundwater, lakes, or rivers—poses the greatest problem, and why?
5. Critical Thinking: How might increasing the development of genetically engineered crops impact the world's demand on water resources? Explain your answer.

Additional Readings

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

M. Black, *The Atlas of Water*, 3d ed., University of California Press, 2016

E. K. Berner and R. A. Berner, *Global Environment: Water, Air and Geochemical Cycles*, 2d ed., Princeton University Press, 2012

J. Holden (ed.), *Water Resources: An Integrated Approach*, Routledge, 2014

K. Jacobs et al., Linking knowledge with action in the pursuit of sustainable water-resources management, *PNAS*, 113(17):4591–4596, 2016 DOI: http://doi.org/10.1073/pnas.0813125107

M. Konar et al., Water resources sustainability in a globalizing world: who uses the water?, *Hydrol. Process.*, 30(18):3330–3336, 2016 DOI: http://doi.org/10.1002/hyp.10843

L. W. Mays, *Water Resources Engineering*, 2d ed., Wiley, 2011

Pacific Institute: Sustainable Water Management

United Nations: UN Water

U.S. Geological Survey: Water Resources of the United States