WATER

Water Cycle or Hydrologic Cycle, series of movements of water above, on, and below the surface of the earth. The water cycle consists of four distinct stages: storage, evaporation, precipitation, and runoff. Water may be stored temporarily in the ground; in oceans, lakes, and rivers; and in ice caps and glaciers. It evaporates from the earth's surface, condenses in clouds, falls back to the earth as precipitation (rain or snow), and eventually either runs into the seas or reevaporates into the atmosphere. Almost all the water on the earth has passed through the water cycle countless times. Very little water has been created or lost over the past billion years.

STORAGE

Enormous volumes of water are involved in the water cycle. There are about 1.4 billion cu km (about 340 million cu mi) of water on the earth, enough to cover the United States with water 160 km (99 mi) deep. Slightly more than 97 percent of this amount is ocean water and is therefore salty. However, because the water that evaporates from the ocean is almost free of salt, the rain and snow that fall on the earth are relatively fresh. Fresh water is stored in glaciers, lakes, and rivers. It is also stored as groundwater in the soil and rocks. There are about 36 million cu km (about 8.6 million cu mi) of fresh water on the earth.

The atmosphere holds about 12,000 cu km (about 2900 cu mi) of water at any time, while all the world's rivers and freshwater lakes hold about 120,000 cu km (about 29,000 cu mi). The world's two main reservoirs of fresh water are the great polar ice caps, which contain about 28 million cu km (about 6.7 million cu mi), and the ground, which contains about 8 million cu km (about 2 million cu mi).

Almost all of the world's fresh ice is found in the ice caps of Antarctica and Greenland. These ice caps cover more than 17 million sq km (more than 6.6 million sq mi) of land to an average depth of more than 1.5 km (more than 0.93 mi). Most other glaciers, formed in mountain valleys at high latitudes, are tiny compared to the ice caps. If all of the ice in the ice caps and other glaciers melted, it would raise the sea level by about 80 m (about 260 ft).

The amount of water stored as ice on the land varies with climate. At the peak of the last ice age, about 22,000 years ago, an additional 20 million sq km (8 million sq mi) of land-including almost all of Canada, the northern fringe of the United States, northern Europe, and large tracts in Siberia-were covered with ice about 1.5 km (about 0.93 mi) thick. Because this water came from the oceans, sea level was about 120 m (about 390 ft) lower than it is today. Most water in the ice caps remains frozen for centuries and is not readily accessible.

Most groundwater is more accessible and supplies much of people's water needs in many regions of the earth. Permafrost, ground that is always frozen, forms an impermeable barrier to the flow of groundwater. Permafrost occurs in places such as northern Canada and Siberia where the annual average temperature is below 0° C (below 32° F).

Almost all groundwater fills the tiny pores and cracks in the soil and rocks. Very little is stored in subterranean caverns. Near the earth's surface, most soils and sedimentary rocks are so porous that water can occupy from 20 to 40 percent of their volume. As depth increases, the pores and open spaces in the rocks are squeezed shut. As a result, almost all groundwater is found in the top 8 to 16 km (5 to 10 mi) of the earth. Water below this depth is chemically bound in the rocks and minerals and is not readily available, but it can be released as a result of geologic processes such as volcanic eruptions.

EVAPORATION

Evaporation is the process by which liquid water changes to water vapor and enters the atmosphere as a gas. Evaporation of ice is called sublimation. Evaporation from the leaf pores, or stomata, of plants is called transpiration. Every day about 1200 cu km (about 290 cu mi) of water evaporates from the ocean, land, plants, and ice caps, while an equal amount of precipitation falls back on the earth. If evaporation did not replenish the water lost by precipitation, the atmosphere would dry out in ten days.

The evaporation rate increases with temperature, sunlight intensity, wind speed, plant cover, and ground moisture, and it decreases as the humidity of the air increases. The evaporation rate on the earth varies from almost zero on the polar ice caps to as much as 4 m (as much as 13 ft) per year over the Gulf Stream. The average is about 1 m (about 3.3 ft) per year. At this rate, evaporation would lower sea level about 1 m per year if the water were not replenished by precipitation and runoff.

PRECIPITATION

Precipitation occurs when water vapor in the atmosphere condenses into clouds and falls to the earth. Precipitation can take a variety of forms, including rain, snow, ice pellets, and hail. About 300 cu km (about 70 cu mi) of precipitation falls on the land each day. Almost two-thirds of this precipitation reevaporates into the atmosphere, while the rest flows down rivers to the oceans. Individual storms can produce enormous amounts of precipitation. For example, an average winter low-pressure system drops about 100 cu km (about 24 cu mi) of water on the earth during its lifetime of several days, and a severe thunderstorm can drop 0.1 cu km (0.02 cu mi) of water in a few hours over a small area.

RUNOFF

Water that flows down streams and rivers is called surface runoff. Every day about 100 cu km (about 24 cu mi) of water flows into the seas from the world's rivers. The Amazon River, the world's largest river, provides about 15 percent of this water. Runoff is not constant. It decreases during periods of drought or dry seasons and increases during rainy seasons, storms, and periods of rapid melting of snow and ice.

Water reaches rivers in the form of either overland flow or groundwater flow and then flows downstream. Overland flow occurs during and shortly after intense rainstorms or periods of rapid melting of snow and ice. It can raise river levels rapidly and produce floods. In severe floods, river levels can rise more than 10 m (more than 33 ft) and inundate large areas. Groundwater flow runs through rocks and soil. Precipitation and meltwater percolate into the ground and reach a level, known as the water table, at which all of the spaces in the rocks are filled with water. Groundwater flows from areas where the water table is higher to areas where it is lower. The speed of flow averages less than 1 m (less than 3.3 ft) a day. When groundwater reaches streams, it supplies a base flow that changes little from day to day and can persist for many days or weeks without rain or meltwater. During periods of sustained drought, however, the water table can fall so low that streams and wells dry out.

EFFECTS OF HUMAN ACTIVITY

Human beings have been altering the water cycle for thousands of years. Irrigation channels are constructed to bring water to dry land. Wells are dug to obtain water from the ground. Excessive pumping from wells has drastically lowered the water table, depleting some ancient water supplies irreversibly and causing the intrusion of salt water into groundwater in densely populated low-lying coastal regions. Levees are built to control the course of rivers, and dams are built to render rivers navigable, store water, and provide electrical power. Evaporation of water behind dams is a serious source of water loss. Increasing urbanization has led to more severe flooding because rainwater reaches streams more rapidly and in greater quantity from areas where the ground has been paved.

As human population continues to grow, effective use and management of the planet's water resources have become essential. Careful management of waterworks has alleviated many problems, but limits to the water supply place limits on the sustainable population of an area and can play an important part in the politics of some regions, as in the Middle East.

ICE

INTRODUCTION

Ice, water in the solid state. (Frozen forms of other substances, such as carbon dioxide, are also known as ices.) Ice is colorless and transparent; it crystallizes in the hexagonal system. Its melting point is 0° C (32° F); pure water freezes at 0° C also, but ice will form at 0° C only if the water is disturbed or contaminated with dust or other objects.

PROPERTIES

One important property of ice is that it expands upon freezing. At 0° C it has specific gravity 0.9168 as compared to specific gravity 0.9998 of water at the same temperature. As a result, ice floats in water. Because water expands when it freezes, an increase of pressure tends to change ice into water and therefore lowers the melting point of ice. This effect is not very marked for ordinary increases of pressure. For instance, at a pressure 100 times the normal atmospheric pressure, the melting point of ice is only about 1° C (about 1.8° F) less than at normal pressure. At higher pressures, however, several allotropic modifications, or allotropes (different forms of the same element that exist in the same physical state) of ice are formed. These are designated Ice II, Ice III, Ice V, Ice VI, and Ice VII. Ordinary ice is Ice I. These allotropes are denser than water and their melting points rise with increased pressure. At about 6000 atm (about 6200 kg per sq cm, or about 88,200 lb per sq in) the melting point is again 0° C and at a pressure of 20,000 atm (about 20,700 kg per sq cm, or about 294,000 lb per sq in) the melting point rises above 80° C (176° F).

The expansion of water when it freezes has important geological effects. Water that enters minute cracks in rocks on the surface of the earth creates an enormous amount of pressure when it freezes, and splits or breaks the rocks. This action of ice plays a great part in erosion.

These properties of freezing water explain the way in which open bodies of water freeze. When the temperature of the surface of an open body of water is reduced toward the freezing point, the surface water becomes denser as it cools, and therefore sinks. It is replaced at the surface by warmer water from beneath. Eventually the entire body of water reaches a uniform temperature of 4.0° C (39.2° F), the point at which water has its maximum density. If the water is cooled further, its density decreases and finally ice is formed on the surface. Bodies of water freeze from the top down rather than from the bottom up because of these density differences.

In rivers, however, ice is sometimes formed beneath the surface. On cold winter nights the surface of a swiftly flowing stream may become cooled well below 0° C because of its contact with the air. Such "undercooled" water, mixing with the warmer layers beneath, produces a spongy mass of ice crystals known as frazil, which floats downstream. Sometimes masses of frazil lodging under surface ice in quieter water may dam a stream and cause floods. Another form of below-surface ice is anchor ice, which is formed around rocks on streambeds. During cold nights enough heat may be radiated from the rocks so that they become cool enough to freeze the water flowing around them. When the rocks are warmed by the sun in the daytime, masses of the anchor ice may detach and rise to the surface of the stream. See Snow.

ICEBERGS

Whenever glaciers or ice sheets reach the sea, the movement of the ice eventually pushes the end of the sheet into water which is deeper than the thickness of the glacier ice. Portions of the end of the glacier break off and form floating masses known as icebergs or bergs. Icebergs are often of enormous size and may reach a height of 90 to 150 m (about 300 to 500 ft) above the surface of the sea. Yet about 90 percent of the mass of an iceberg is beneath the surface. Icebergs are common in both the Arctic and Antarctic regions and are often carried into lower latitudes by sea currents, particularly in the North Atlantic Ocean. North Atlantic icebergs all come from the Great Greenland ice sheet and have been observed as far as 3200 km (about 2000 mi) from their origin. After the sinking (1912) of the steamship Titanic, 16 nations instituted an iceberg patrol of the North Atlantic, which included the U.S. Coast Guard. Now known as the International Ice Patrol, it tracks icebergs and reports their location to ships.

GLACIERS

Glacier, large, usually moving mass of ice formed in high mountains or in high latitudes where the rate of snowfall is greater than the melting rate of snow. Glaciers can be divided into four well-defined types-alpine, piedmont, ice cap, and continental-according to the topography and climate of the region in which the glacier was formed.

ALPINE GLACIERS

The snow that falls on the walls and floors of valleys in high mountain regions tends to accumulate to a great depth, because the rate of melting, particularly in wintertime, is far lower than the rate at which the snow falls. As a result, the earlier snows, compressed by later falls, are changed into a compact body of ice having a granular structure. In some areas, however, where the temperature rarely rises as high as the melting point, this accumulation of ice can be formed by the recurrent process of sublimation and recrystallization. Sublimation is a change from the solid state into vapor without an intermediate liquid stage. When the depth of the glacier reaches approximately 30 m (about 100 ft) the whole mass begins to creep slowly down the valley. This flow continues as long as a superabundance of snow falls at the top of the glacier. As the glacier flows down the valley to a lower altitude where it is not replenished by snowfall, it melts or wastes away, the meltwater forming the source of streams and rivers.

In cross section the structure of all glaciers is similar. At the top is a mantle of freshly fallen snow with a very low density of not more than 0.1. Below this is a layer in which the snowflakes have diminished in size to become granular snow, of which the density may be 0.3 or greater. This is caused either by the influence of moisture and the pressure exerted by accumulated snow, or by sublimation and recrystallization. Further recurrent action results in névé, or firn, which approaches a density of 0.5. At the base of the glacier is a layer of clear ice that may approach a density of 0.7 to 0.8 and flows like a viscous fluid.

The lower glacial ice is under such great pressure that any cracks or separations occurring in this layer are quickly healed. The upper layers, however, may suffer tensions and strains from moving over underlying obstructions or from differential movement, in which the center of the glacier moves more rapidly than its edges. These strains produce crevasses that may be many meters deep and are frequently covered by newly fallen snow. A large crevasse known as the bergschrund is usually formed in the shape of a semicircle at the head of the glacier, between the glacier itself and the headwall of the valley in which it lies.

Glaciers are usually bordered at their sides by zones of rock debris that have fallen from the sidewalls of the valley as a result of frost-wedging action. These zones of rock fragments are called lateral moraines. At the lower end of the glacier the moraines increase in size. When two glaciers from neighboring valleys meet, the moraines at their adjoining sides coalesce to form a medial moraine in the middle of the resulting glacier. As the ice melts at the lower end of a glacier, rock and debris that have been plowed up by its progress over the valley floor, in addition to rock material that may have fallen into crevasses, are deposited in a series of semicircular hillocks called the terminal moraines.

As a glacier moves down its valley, it eventually reaches a point at which the ablation, or melting and evaporation, from the surface exceeds the amount of snow falling on it. At this point, often called the névé, or firn, line, the surface of the glacier is névé rather than snow.

The speed at which glaciers flow varies within wide limits. Most glaciers move downward at the rate of less than 1 m (less than 3 ft) per day, but observation of the Black Rapids Glacier in Alaska, during 1936-37, showed that it was moving more than 30 m (more than 100 ft) per day. This is the swiftest advance ever recorded for any glacier in the world and was probably due to the extremely heavy snowfalls that had occurred in the area some years earlier.

With variations in climate, glaciers shrink and expand to a marked extent. An excess of precipitation creates a situation analogous to a river flood and causes the glacier to increase in size. Similarly, when precipitation decreases, the glacier shrinks.

Glaciers of the alpine type are found in high mountain ranges throughout the world, even in the tropics. In the United States, alpine, or valley, glaciers exist on the slopes of Mount Rainier, Mount Baker, and Mount Adams, in Washington, Mount Hood in Oregon, and Mount Shasta in California. The Hubbard Glacier in Alaska is one of the longest alpine glaciers in the world. Glaciers of the northwest U.S. were observed in 1955 to be advancing for the first time since the middle of the 19th century.

PIEDMONT GLACIERS

When a number of alpine glaciers flow together in the valley at the foot of a range of mountains, they frequently form extensive glacier sheets known as piedmont glaciers. Glaciers of this type are especially common in Alaska. The largest of the piedmont glaciers in North America is the Malaspina Glacier in Alaska, which has an area of approximately 3900 sq km (approximately 1500 sq mi). The lower portion of this glacier is almost flat and is covered with so much soil and rock debris that it supports a thick forest.

ICECAP GLACIERS

The glacier system that covers a large portion of the Norwegian island group of Svalbard, in the Arctic Ocean, is unusual in form, being a type intermediate between the alpine glacier and the Greenland glacier described below. The entire center of each island is covered with an ice sheet that overlies a high plateau. At the edges of the plateau the sheet breaks up into a series of alpine glaciers that move down steep valleys, sometimes reaching the sea.

CONTINENTAL GLACIERS

Covering almost the entire extent of Greenland is a huge glacial blanket over 1.8 million sq km (over 700,000 sq mi) in area and more than 2700 m (more than 9000 ft) in maximum thickness. This gigantic glacier flows slowly outward from two centers, one on the southern part of the island and one in the north. Because of its thickness the Greenland ice sheet rises far above both the valleys and hills of the land beneath it, and the underlying rock is exposed only near the seacoast, where the glacier breaks up into tongues of ice somewhat resembling valley glaciers. From the ends of these tongues, where they reach the sea, large and small fragments of ice break off during the summer, forming icebergs. A glacier of a similar type covers the whole of the Antarctic continent and has an area of about 13 million sq km (about 5 million sq mi). Continental glaciers covered much of North America during the Pleistocene Epoch of the Quaternary period, which ended about 10,000 years ago.

GLACIAL EROSION

As a glacier moves down a valley, or cross-country in the case of a large ice sheet, it sculpts the land in a characteristic manner. Rocks in its path are plowed out of the way, and rocks beneath it are broken up by frost action and then carried away. The rocks embedded in the bottom of the glacier abrade and scour the rocks beneath.

At the head of a valley in which a glacier is formed, the headwalls are eroded into a characteristic semicircular form called a cirque. Progressive erosion of headwalls occurring simultaneously on several sides of a mountain produces what is called a horn. Valleys down which glaciers have traveled are eroded to a U shape rather than the V shape caused by stream erosion. Frequently the valley is excavated so deeply that the mouths of tributary valleys are left high above the new valley floor as hanging valleys. Fjords are glaciated valleys that have been partly flooded by the sea. Alaska's Columbia Glacier, near Valdez, began retreating so rapidly in the 1980s that it is expected to reveal a fjord up to 40 km (25 mi) long by the end of the next few decades.