

around the earth. At some point, the vapor-laden air may rise to a cooler region of the atmosphere where it can no longer retain its load of invisible water vapor. The vapor then gives up its latent heat of vaporization and reverts to a liquid state through *condensation*. If the temperature is low enough, it will freeze and become an ice crystal. Tiny particles called condensation nuclei facilitate the process, providing a surface on which the liquid water may form. These ever-present nuclei may consist of tiny salt crystals (borne aloft by wind during the evaporation process at sea), smoke, or dust particles from the land.

The *evaporation–condensation* process is an important factor in energy transfer at the earth's surface. Solar radiation passing through the air doesn't heat it very much. Most of the heat we feel on a warm summer day is either from sunshine falling on our bodies or reflected from the ground or other surfaces. Water vapor holds most of the heat in the lower atmosphere. The latent heat of vaporization, released to the atmosphere during cloud formation (condensation), is an important environmental factor in determining weather and climate. This kind of energy transfer can be powerful enough to drive hurricanes and other violent storms.

Even though our tiny drop of water is now visible, it would take a powerful microscope to see it—if it were alone. It is not, however; the drop is only one of billions joined to form a cloud. Droplets in clouds are so small that even though they have mass and are affected by gravity, the lightest breeze can keep them aloft indefinitely. To form rain or snow and fall as *precipitation*, many of these tiny drops must join to form drops or ice crystals large enough and heavy enough to fall from the cloud.

Before falling, the water droplet was affected mostly by thermal forces resulting from solar radiation. Once rain or snow begins to fall, the water enters the grip of the earth's gravity, and except for a possible short circuit back to the atmosphere through evaporation, gravitational forces will largely govern it until its final return to the sea.

The little particle of water has several avenues to follow once it reaches the ground. It could land on the leaf of a tree (a process called *interception*) and evaporate again to the atmosphere. It could drop on dry soil and go immediately into the ground in the process of *infiltration*. It could fall on a rock surface where it might begin to flow downhill toward a stream, initiating the process of *runoff*.

Water that falls on a running stream or on the land and immediately into a stream generally has a short journey back to the sea. Water that infiltrates the soil below the land surface, however, could go several ways. A plant could absorb it, carrying it upward. There the plant tissue could incorporate it, or the water could pass through the plant and out through the leaves, returning to the atmosphere in the process of *transpiration*. Water falling on a vegetated area may be lost to the atmosphere through transpiration

millimeters, 30 millimeters, etc.). The sketch in Figure 4.15 shows how an isohyetal map might have been constructed using the same data from the arithmetic average and the Thiessen network. Average precipitation over the whole area could be determined as follows:

1. Find average precipitation between isohyets. This would be the arithmetic average of the two isohyets; between the 1- and 2-inch isohyets the average would be 1.5 inches, between 2-inch and 3-inch isohyets the average would be 2.5 inches, and so forth.
2. Find the area on the map between two isohyets.
3. Multiply the area between isohyets by the average precipitation between them.
4. Find the sum of figures obtained in step 3 and divide it by the total area of the basin to obtain the average depth of precipitation over the basin.

The isohyetal method is the most accurate of the three, but it depends heavily on the skill of the person drawing the isohyets. The mapmaker should know the terrain within the basin and be able to interpolate the isohyets to truly reflect natural conditions in the field. In mountainous country the isohyets would approximate topographic contours, since orographic precipitation usually increases going upslope toward the mountain summit. Also, if some measuring points show unusually heavy precipitation, the isohyets can be clustered closer around such points. In the hypothetical examples shown in Figure 4.15 the averages for the three methods just happened to be close together. Ordinarily we might expect more variation in averages if we were using actual data from a real drainage basin.

There are a number of other ways to analyze precipitation data, but they are generally beyond the scope of this book. For further information on the subject of analysis, the interested reader is referred to the professional hydrology texts listed in Appendix IV.

SNOW

The foregoing sections of this chapter have used the term *precipitation* as including all forms of water falling from the sky to the earth; in reality, however, only two forms are widespread enough to be routinely measured: rain and snow. About 30 inches (760 mm) of precipitation falls on the average each year over the entire United States. Only about 4 inches (100 mm) of this average amount falls as snow; the rest is rain. Of course, not every reporting station receives both rain and snow. Some places have only rain and some have mainly snow (Figure 4.16). The southern states and the low

(PG&E). For almost 30 years PG&E has conducted cloud-seeding activities on the western slopes of the Sierra Nevada range. The company has tried to increase runoff in the rivers draining the western slope, thereby increasing the power produced by hydroelectric plants situated on the rivers.

PG&E is a pioneer utility company in California that serves an area stretching from the southern San Joaquin Valley to the state's northern borders. The company and its predecessors built many of the existing hydroelectric plants along the Sierran streams. Hydropower originally provided a substantial proportion of the company's electrical energy. As demand has increased with the population growth in recent years, the company has built steam-electric plants to supply additional power. For the most part these plants burn oil or gas, which the company must purchase. If PG&E can enhance runoff on mountain streams, then, it will save on alternative fuel sources. In addition, the people downstream can use the additional water for recreation, irrigation, and domestic purposes.

*Cloud Seeding at Lake Almanor.*³ One of the oldest and best-documented cloud-seeding programs in the world is the one run by PG&E at Lake Almanor in California (see map in Appendix I for location). Situated along the boundary between the Cascade range to the north and the Sierra Nevada range to the south, the Lake Almanor watershed covers about 500 square miles (1295 km²) of mountainous terrain just south of Mt. Lassen. Lake Almanor's elevation is 4500 feet (1372 m) above sea level, and although the watershed extends up the southerly slopes of Mt. Lassen, most of it lies below 7500 feet (2286 m). The wet season runs from November to May, with a substantial number of orographic storms during this period. Annual precipitation averages more than 30 inches (762 mm), with snowfall averaging about 146 inches (3710 mm) per year.

The first cloud-seeding experiments were performed in the early 1950s; as with most other experiments at that time, the results were inconclusive. In 1960 PG&E decided to change its experimental design and conduct the seeding randomly. During 1960 through 1962, eight radio-controlled, silver iodide generators were installed on ridge tops and more than 50 heated precipitation gages were placed in a 300-square-mile (777 km²) target area of the watershed. Two control areas upwind of the target area were also equipped with heated precipitation gages. The experiment continued for five seasons (November 1 to May 15) from 1962 to 1967. Analysis of the data collected over the five seasons showed a positive effect from seeding for certain storm types: orographic storms with westerly winds and cloud temperatures of -5°C (23°F) below 7500 feet (2286 m) that PG&E calls *cold westerly storms*. Since 1967, PG&E has randomly

³Material for this case history of seeding operations at Lake Almanor was supplied by Margaret Mooney, former Director of Meteorology Services, and C. A. Threlkeld, Supervising Hydraulic Engineer, Pacific Gas and Electric Company, San Francisco.

wind, all erosion is done by moving water—streams flowing over the land or waves pounding at the coasts. Erosion may be harmful when it alters the ground surface in ways that disturb the work of humans. Of particular concern is the erosion of farmland and the loss of topsoil, which contains the organic material and microorganisms essential for soil fertility. During the past half-century, the U.S. Soil Conservation Service has worked with farmers throughout the country in a massive effort to prevent the loss of topsoil by on-farm soil conservation projects focusing on erosion prevention. The major effort goes toward increasing infiltration rates into surface soil, thus preventing the rapid runoff that causes erosion.

If you were given the job of reducing erosion on a plot of bare ground, what could you do to reduce runoff and increase infiltration? Remembering the process of interception and what happens when rain falls on vegetation, you might begin by planting some kind of ground cover such as grass. You will recall that interception subjects the vegetation to the full impact of falling rain. Water dripping off trees and bushes or running down the stems of grass will hardly have the energy required to rearrange the soil's surface porosity. Further, the grass stems, trunks of bushes and trees, and ground litter all tend to slow the runoff water, reducing its momentum and carrying power and limiting its capacity to erode soil. Roots of the vegetation also tend to lock the soil into a massive unit that resists disaggregation and erosion. If you decided to plant grass, you made a wise choice in beginning to increase infiltration rates and to stabilize the soil surface in your plot.

Farmers are beginning to think more and more in this direction, too. In addition to standard soil conservation methods, some farmers are beginning to practice what is known as "conservation tillage." This method calls for reduced tillage of the soil (to prevent compaction) during planting and crop growth. After harvest, a cover of vegetative debris is left on (or just under) the soil surface. Again, the purpose is to promote infiltration and reduce opportunities for erosion.

Effect of Water Quality on Infiltration. Weathering processes at the earth's surface produce almost all the mineral grains in soil. When a crystalline rock like granite forms deep in the earth's crust, it is stable in a high-temperature, high-pressure environment. When massive earth forces lift the granite and expose it at the surface, weathering begins. Most minerals that were stable in a deep environment are no longer stable under atmospheric conditions. The major exception is quartz—silicon dioxide (SiO_2)—which makes up most of the sharp, gritty grains in soil. Most other minerals begin to change as soon as they are subjected to water and gases in the atmosphere.

One of the most interesting results of the weathering process is the group of minerals called clays; these, along with quartz, are the main constituents of surface soil. The more than one dozen kinds of clays each have distinctive