# 5

# WEATHER IN RELATION TO PHYSICAL CHARACTERISTICS

All of the matter and energy in the physical and biological system in which we live has, theoretically, potential ecological significance. Of greatest interest to the ecologist is the matter and energy distribution within the earth-atmosphere interface, or biosphere, which supports life. Most of this energy originates outside of the atmosphere, such as the radiant energy from the sun. Some comes from within the earth; geothermal energy is an example. The analytical ecologist is interested in the physical and biological interaction between matter and energy in the biosphere. Before analyzing some of these interactions, let us review both the relationships between the sun and earth and the weather in relation to physical characteristics at the earth's surface.

## 5-1 THE DISTRIBUTION OF SUNLIGHT

One of the more precise physical relationships in the universe is the position of the sun relative to the earth. This precision is manifested by the regularity with which the earth revolves around the sun and rotates on its axis. The calendar does not represent this relationship perfectly; the addition of a day in February every four years is a correction factor for this.

The ecological role of sunlight is significant. Different day lengths affect the growth and reproduction of plants and animals. Sunlight generates different thermal relationships in the atmosphere that result in weather patterns. It is a source of energy for the process of photosynthesis upon which all life depends. It alters the thermal regime at the earth's surface, causing changes in physical conditions as well as in the behavior of plants and animals. Many more effects can also be recognized, of course. Before considering its effect on plants and animals, let us consider how it is related to physical characteristics on the earth, such as topography over daily and seasonal time periods.

The times at which the sun rises and sets for different latitudes are available in tabular form. Differences within a one-hour time zone can be corrected for in order to determine solar time. Such tables are not suitable for direct entry into a computer program. Sunrise and sunset times can be calculated on the basis of the spatial relationships between the sun and earth, however. An equation can be used to store this information in a computing system, which can then calculate the times at which the sun rises and sets, the length of daylight, and other solar considerations in an ecological analysis.

The sunrise time, sunset time, hours of daylight, altitude of the sun at solar noon, and the solar insolation in langleys per minute for any slope aspect, slope angle, and time can be calculated from inputs of date (Julian Calendar), latitude, slope aspect, slope angle, time of day (0 to 2400 hours), and transmittance of the atmosphere (Robbins, unpublished data, BioThermal Laboratory).

A similar type of program that calculates additional factors pertaining to the spectral characteristics of radiation has been described by McCullough and Porter (1971). Their program generates clear-day direct and diffuse components of natural terrestrial radiation for any time of the day, elevation, terrestrial latitude, and time of year. It computes radiation spectra for large zenith angles in which atmospheric curvature and refraction are important, irradiation patterns at latitudes $>66° 30'$ (polar zones), the variation of the diffused spectral components of solar radiation with the elevation and reflectivity of the underlying surface, and diffused ultraviolet radiation spectra where ozone absorption of the scattered radiation must be accounted for. These outputs are generated from eight inputs, including time of day, day of year, latitude, longitude, sea level, meteorological range (visibility), atmospheric pressure (i.e., elevation), reflectivity of the underlying earth's surface, and total precipitable water vapor.

There are data in the literature that are useful in evaluating the outputs of these two programs. Sellers (1965), for example, shows the distribution of solar radiation throughout the United States at different times of the year (Figure 5-1). Variations in the radiation values shown are due to differences in latitude, altitude, distribution of water, and topographical effects on weather patterns, and so forth. Note the large difference between January and June. Other data are found in textbooks on meteorology and in numerous research reports in meteorological journals.

The outputs from these two programs are not perfect representations of these parameters at every point on the earth's surface. The programs are useful for setting an ecological "stage" with a few principal characters. The interactions between sunrise and sunset time, length of daylight, animal movements, breeding conditions, plant productivity, thermal energy balance, and other significant components of the ecosystem might be considered initially. Since the equipment necessary to make these fairly complex programs workable is seldom available to students, it is suggested that simpler approximations be made that can be

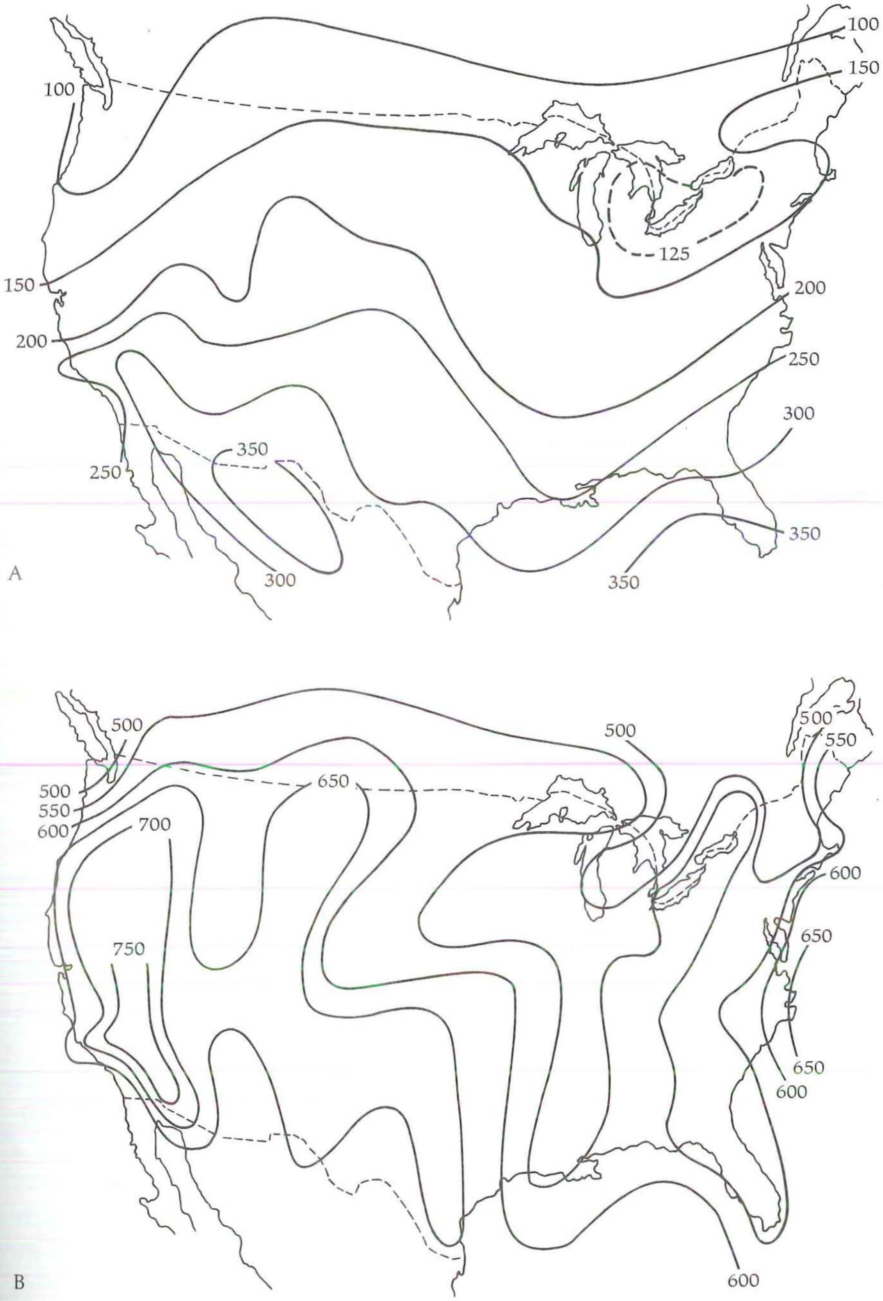



FIGURE 5-1. The average solar radiation on a horizontal surface in the United States in (A) January and (B) July. The units are langleys per day. (From Sellers 1965.)

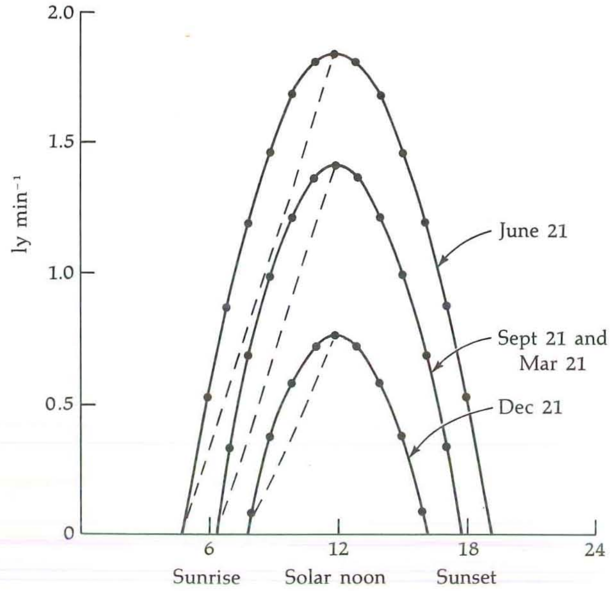



FIGURE 5-2. Sunrise, sunset, and solar radiation values for a latitude of 42°26′ N (Ithaca, N.Y.). The dashed lines are linear approximations of the radiation curve (see text).

handled by desk-top computing systems or calculators, or can even be done without the aid of a machine. For example, solar radiation curves can be approximated by a linear regression equation (Figure 5-2). This obviously results in potentially large errors. The student of analytical ecology is urged to consider the interreactions between solar radiation and an organism, however, and the linear approximation is quite adequate for working out the mechanisms of a predictive solar radiation curve in relation to the biological response of an organism. In other words, extensive detail in part of the total organism-environment relationship is undesirable until all parts of the relationship have been considered.

THE ATMOSPHERE. The atmosphere is divided into several general regions (Figure 5-3). These include the troposphere, the stratosphere, the mesosphere, the thermosphere, and the exosphere. The *troposphere* contains the "weather" and shows a general decrease in temperature with height. Its upper limit is characterized by the maximum height of most clouds and storms. The *stratosphere* has a fairly complex temperature structure that varies geographically and seasonally. It also has wind regimes that vary seasonally and affect weather conditions at the earth's surface.

Above the stratosphere is the *mesosphere*, characterized by cold temperatures and very low atmospheric pressure. Above the mesosphere is the *thermosphere* in which theoretical radiant temperatures rise with height, although artificial satellites do not acquire such temperatures because of the rarefied air (Barry and Chorley 1970). The thermosphere includes the region in which ultraviolet radiation and cosmic rays cause ionization; this region is called the *ionosphere.* The outer limits of the atmosphere grade into a region called the *exosphere,* or outer space, with its almost total lack of atoms. The earth's magnetic field becomes more important than gravity in the distribution of atomic particles in the exosphere. A more detailed discussion of the characteristics of the atmosphere may be found in Barry and Chorley (1970).

All of the layers of the atmosphere are of interest to the ecologist since together they form the total blanket of air in the biosphere. The atmospheric components serve particular functions, including the filtering of radiant energy from the sun, insulation from heat loss at the earth's surface, and stabilization of weather and climate owing to the heat capacity of the air. Several cycles are present that relate to the movement of matter between an organism and its environment. These include the water cycle, the carbon cycle, the nitrogen cycle, the phosphorus cycle, and others.

Gases in the atmosphere include nitrogen, oxygen, argon, carbon dioxide, and water vapor, along with traces of several other elements. Oxygen is necessary for most forms of life, but other forms exist only in an anaerobic environment. In terms of quantity, carbon dioxide is the most variable of these gases. Considerations have been made for the enrichment of the atmosphere (carbon dioxide fertilization) to promote plant growth. These are discussed in Chapter 15. Water vapor condenses in the atmosphere, resulting in precipitation. Its effect on the distribution of plants and animals is obvious on both a small and a large scale. Precipitation limits visibility, too, so observations of animals are more difficult and field work is less efficiently carried out in rain or snow. Consequently, information on animals in storms is lacking, yet these extreme conditions may affect their survival and productivity.

The ionosphere is affected by magnetic storms on the sun, with an increase

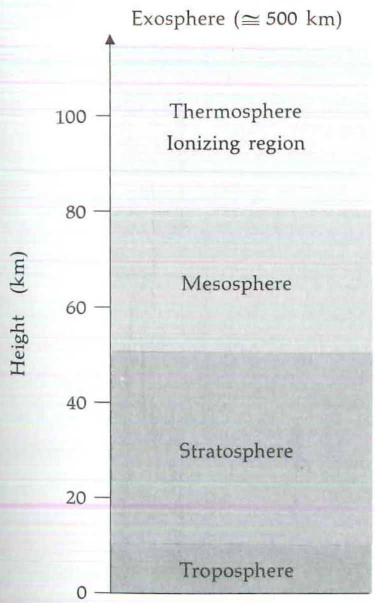



FIGURE 5-3. Atmospheric layers; each grades into the next without a sharp line of demarcation between them.

in the number of free electrons present during periods of intense activity. Population cycles have been attributed to these storms and subsequent electrical activity in the ionosphere, although there is considerable controversy over the validity of such correlations. Personal observations by the author indicate that white-tailed deer seem to respond to unidentified factors, with an increase in nervousness, activity, and physiological parameters such as heart rate. The possible interactions between the energy from the sun, cosmic rays, ionization in the thermosphere, electrical activity at ground level, and physiological processes in plants and animals need further analyses through basic investigations of atmospheric physics, physiology, neurology, and behavior.

## 5-2 ATMOSPHERIC WATER

Atmospheric water is found in gaseous form or droplet form. The quantity of water present in gaseous form is expressed as vapor pressure. When the vapor pressure is maximum for the temperature of the atmosphere, the air is said to be saturated. Thus the maximum vapor pressure of the air is called its saturation pressure, and the actual quantity of vapor present (vapor pressure) is a function of the temperature of the atmosphere. Relative humidity is equal to the vapor pressure divided by saturation pressure times 100. Students are reminded that relative humidity is *temperature dependent,* a fact often overlooked in ecological analysis. This will be discussed again in Chapter 6.

Clouds form as condensation takes place around hygroscopic nuclei in the atmosphere. These particles can be dust, smoke, sulphur dioxide, salts (NaCl), or similar microscopic substances (Barry and Chorley 1970). Clouds have distinct characteristics that are classified in an internationally adopted system according to the shape, structure, vertical height, and altitude of the cloud. Cloud types can be identified through a "keying out" process similar to a taxonomic key for plants and animals (Table 5-1). Clouds reflect and absorb solar radiation and are good absorbers and emitters of infrared radiation. They are also the centers of considerable electrical activity, as well as the source of precipitation.

## 5-3 PRECIPITATION

Precipitation consists of all liquid and frozen forms of water, including rain, sleet, snow, hail, dew, hoarfrost, fog-drip, and rime (Barry and Chorley 1970). Rain and snow are the only forms that contribute significantly to the precipitation totals, but some of the other forms, such as dew and hail, can have significant ecological impact. The analytical ecologist is interested in the functional relationships between precipitation and organisms, and this demands an understanding of the energy and matter relationships between them rather than the mere correlation of observed responses of organisms in different precipitation regimes.

RAIN. A basic analysis of the functional relationships between precipitation and organisms permits these mechanisms to be related to other interactions

**TABLE 5-1** A KEY FOR THE IDENTIFICATION OF CLOUD FORMATIONS
(Beginning with couplet number one, select the most appropriate choice and go to the numbered couplet indicated until a cloud formation has been identified.)

| | | |
|---|---|---|
| 1 | Clouds piled up, puffy, currents | 2 |
| | Clouds formed without vertical movement | 3 |
| 2 | Clouds, puffy, changing shape | cumulus, 13 |
| | Strong vertical development | cumulonimbus, 15 |
| 3 | Cloud veils or sheets | 4 |
| | More or less broken | 7 |
| 4 | Large halo present | cirrostratus |
| | No halo effect | 5 |
| 5 | Sun visible through veil | altostratus, 12 |
| | Sun not visible, heavy veil | 6 |
| 6 | Low uniform sheet, no rain | stratus |
| | Low heavy sheet, rain streaks | nimbostratus |
| 7 | High ice clouds, usually thin wispy streaks | cirrus, 16 |
| | Heavier clouds, patchy or irregular masses | 8 |
| 8 | Patches or layers of puffy or roll-like gray or whitish clouds, corona often | 9 |
| | Irregular masses in a rolling or puffy layer, gray with darker shading | stratocumulus, 18 |
| 9 | White to light gray roll-like, or roll-like in combination with patchy or wispy, high ice clouds | cirrocumulus |
| | Patches or layers of puffy or roll-like gray or whitish clouds, corona often, middle water and ice clouds | altocumulus, 10 |
| 10 | White to gray roll-like middle water and ice clouds | 11 |
| | Patchy to nearly continuous gray middle water and ice clouds | altocumulus perlucidus |
| 11 | White to light gray clouds, roll-like or less distinctly so | altocumulus translucidus |
| | Gray, roll-like clouds | altocumulus translucidus undulatus |
| 12 | Darker clouds, but sun appears to be behind frosted glass | altostratus opacus |
| | Lighter clouds, sun appears to be behind frosted glass | altostratus translucidus |
| 13 | Irregular patches broken by strong winds | cumulus fractus |
| | Bulky patches, white to gray | 14 |
| 14 | White to light gray, low water clouds, may be towering | cumulus humilis |
| | Darker gray low water clouds, becoming more dense | cumulus congestus |
| 15 | Low vertical water clouds to towering water to ice clouds, often anvil shaped | cumulonimbus capillatus |
| | Dense clouds with vertical development indicated by ventral projections, seldom seen | cumulonimbus capillatus mammatus |
| 16 | Thin wispy streaks, broken pattern | 17 |
| | Heavier streaks, almost patches, white, high ice clouds | cirrus densus |
| 17 | Streaks broken, not spreading over sky | cirrus filosus |
| | Streaks broken, spreading over sky | cirrus cinus |
| 18 | Low water clouds, light gray | stratocumulus translucidus |
| | Low water clouds, dark gray | stratocumulus opacus |

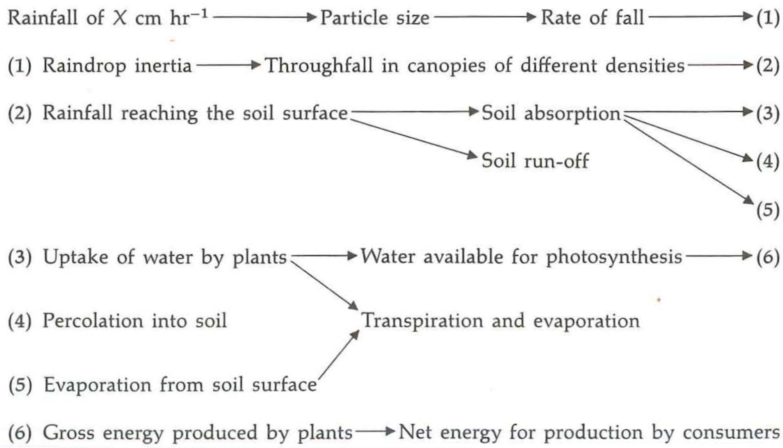
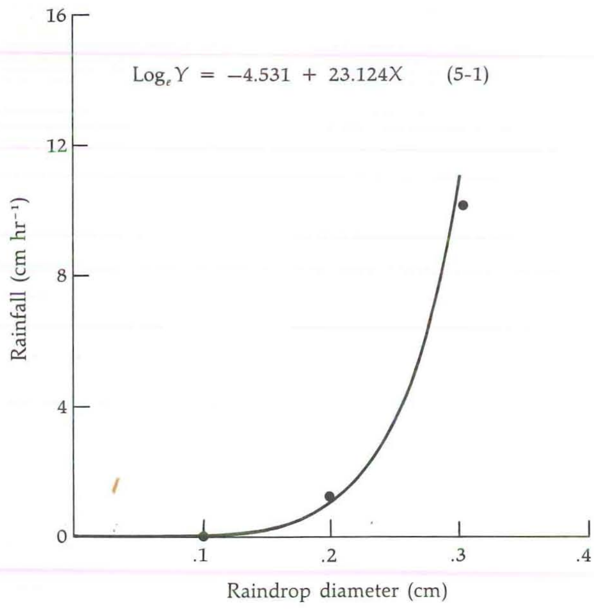



FIGURE 5-4. A flow sheet showing the relationships between rainfall per hour, raindrop characteristics, soil absorption, plant productivity, and consumer energy for production.

between organisms and environment. This is illustrated in Figure 5-4, in which the amount of rainfall in cm $hr^{-1}$ is the beginning point for calculating the mass transport of water within a plant community, relating this movement to the feedback interactions between evaporation from the surface of the soil and evapotranspiration and to plant production.

FIGURE 5-5. There is a predictable relationship between rainfall intensity and the diameter of the raindrops. (Data from Barry and Chorley 1970.)

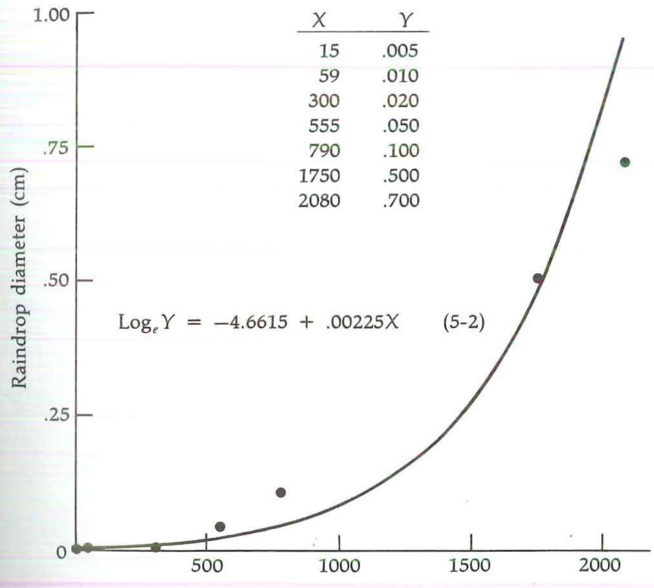


How can the flow sheet in Figure 5-4 be useful? What kinds of relationships exist that make such an analysis work? Some basic data have been reported by meteorologists that can be used to develop a series of calculations representing the relationships between rainfall in cm hr $^{-1}$ and subsequent soil water, plant uptake of water, evapotranspiration, and plant production. For example, there is a relationship between precipitation intensity and raindrop size; a greater amount of rainfall per unit time is more dependent on the size of the raindrops than on the number of raindrops. Barry and Chorley (1970) point out that the most frequent diameter of drops in a rainfall of 0.1 cm hr$^{-1}$ is 0.1 cm; in 1.3 cm hr$^{-1}$ it is 0.2 cm; and in 10.2 cm hr$^{-1}$ it is 0.3 cm. These data can be expressed in equation form [equation (5-1) in Figure 5-5]. This relates to the number/volume ratio of drops, too, as a drop having a diameter of 0.1 cm has a volume of 0.000524 cc, and 19,083,970 drops are necessary for 1 cm of water to cover an area of one square meter. This is a volume of 10 liters.

Once the particle size has been established, the rate at which the drops fall can be calculated from data in Taylor (1954). He presents data that show how a larger drop falls at a faster rate than a smaller one, and this relationship, plotted in Figure 5-6, can be approximated by equation (5-2) relating the $X:Y$ values.

The rate of fall can be used to calculate the inertia of the raindrops as they strike the soil surface (Table 5-2; their weight was calculated from data shown

FIGURE 5-6. A first approximation of the relationship between raindrop diameter and the rate at which an individual raindrop falls. (Data from Taylor 1954, Table 7-1, p. 155.)




| X | Y |
|---|---|
| 15 | .005 |
| 59 | .010 |
| 300 | .020 |
| 555 | .050 |
| 790 | .100 |
| 1750 | .500 |
| 2080 | .700 |

**TABLE 5-2** THE INERTIA OF INDIVIDUAL RAINDROPS AT DIFFERENT RAINFALL INTENSITY

| *Rainfall* (*cm* $hr^{-1}$) | *Raindrop Diameter* (*cm*) | *Raindrop Weight* ($\times 10^{-3}$ *g*) | *Rate of Fall* (*ft* $min^{-1}$) | *Inertia: Raindrop Weight* (*g*) $\times$ *Rate of Fall* (*ft* $min^{-1}$) |
|---|---|---|---|---|
| 0.1 | 0.096 | 0.46 | 1031.96 | 0.478 |
| 0.2 | 0.126 | 1.05 | 1152.33 | 1.207 |
| 0.3 | 0.144 | 1.56 | 1210.09 | 1.891 |
| 0.4 | 0.156 | 1.99 | 1246.95 | 2.479 |
| 0.5 | 0.166 | 2.40 | 1273.57 | 3.050 |
| 1.0 | 0.196 | 3.94 | 1347.37 | 5.312 |
| 1.5 | 0.213 | 5.06 | 1385.46 | 7.010 |
| 2.0 | 0.226 | 6.04 | 1410.63 | 8.526 |
| 2.5 | 0.236 | 6.88 | 1429.22 | 9.836 |
| 3.0 | 0.243 | 7.51 | 1443.85 | 10.847 |
| 4.0 | 0.256 | 8.78 | 1466.00 | 12.878 |
| 5.0 | 0.265 | 9.74 | 1482.45 | 14.445 |
| 6.0 | 0.273 | 10.65 | 1495.46 | 15.932 |
| 7.0 | 0.280 | 11.49 | 1506.17 | 17.312 |
| 8.0 | 0.286 | 12.25 | 1515.24 | 18.560 |
| 9.0 | 0.291 | 12.90 | 1523.08 | 19.652 |
| 10.0 | 0.296 | 13.58 | 1529.99 | 20.776 |

*Note:* The values in this table and all subsequent tables containing calculations may vary according to the computing system used and the arrangement of program steps in relation to rounding of numbers.

in Figure 5-5; specific gravity of water = 1.0), and this inertia is of major importance in determining how much of the rainfall can penetrate a plant canopy (throughfall), how much reaches the soil surface, and the mechanical impact it has on the soil surface. The inertia can be related to throughfall if the mechanical strength of the plant canopy is known. The inertia can be related to soil disturbance if the mechanical strength of the soil surface is known. This depends on the distribution of particle size and density and the cohesiveness of the soil material.

RAINFALL IN RELATION TO SOIL AND TOPOGRAPHY. The results shown in Table 5-2 illustrate relationships between the amount of rainfall per hour and the inertia with which the drops strike a surface. The equations representing the factors and forces in the model were combined into a computing program that results in the outputs shown in the table. It is an example of a "rainfall per hour" to "inertia of the drops" conversion.

Let us expand the previous model to include soil absorption characteristics. Suppose that a rainfall of 1.3 cm $hr^{-1}$ is occurring. These raindrops strike the surface of the soil at a velocity of 1372.14 ft $min^{-1}$ (see Table 5-2). Suppose that the soil was on a slope of 45°, and its characteristics were such that there was no resistance to the flow of water across the soil surface and none of the water was absorbed (Figure 5-7). This would result in a run-off equal to the rainfall per hour, once steady-state conditions were reached. Note that an absorption coefficient of 0 was used in this example. A value at the other extreme could be used here, too (i.e., 1.00), and then all of the water striking the surface of the soil would be absorbed. The run-off would then be 0, of course.

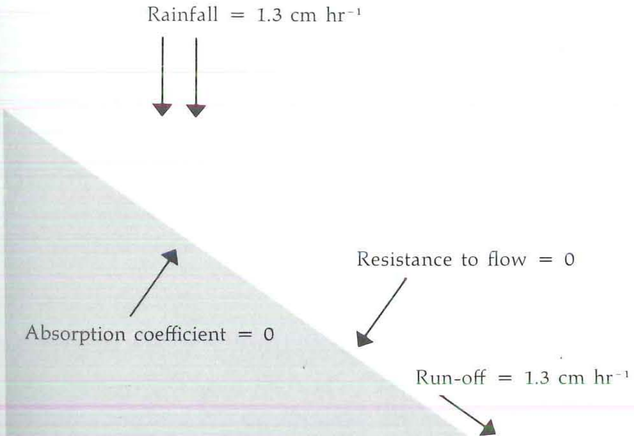
What affects the absorption coefficient of a soil? One factor is the particle size. Soils contain mixed particle sizes, of course, but before going into the details of real soils, let us consider a theoretical soil with homogenous spherical particles. If these particles were arranged as in Figure 5-8, the pore space is a constant 48% of the soil volume.

Natural soils, with particles of varying sizes and forms, are much more complex than the illustration. Calculations of the pore space of real soils can be made if enough is known about the geometry and hygroscopic characteristics of different soil types. The alternative method for determining pore space is measurement by displacement.

The absorption characteristics of a soil interact with its resistance to water flow. If the resistance to flow is high, the water will remain on the soil for a longer time, increasing the possibility for absorption. Vegetation also affects the run-off and absorption characteristics of a soil. Decaying vegetation is absorbant, and a vegetative canopy breaks larger raindrops up into smaller ones, reducing the rate at which they fall and their inertia. Thus there is a whole series of interactions that need to be considered for the modeling of rainfall, erosion, and other mechanical effects of rain.

FIGURE 5-7. A very simple model illustrating the relationship between rainfall, absorption, resistance to flow, and run-off.

$Q_{run\text{-}off}$ = rainfall − (absorption coefficient × rainfall)



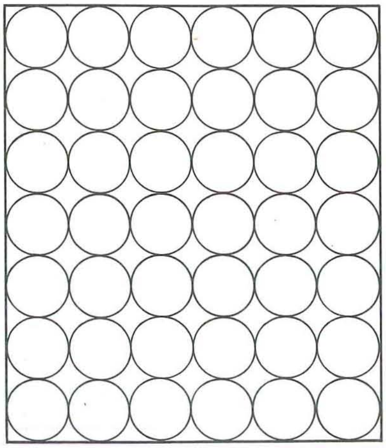


FIGURE 5-8. Spherical particles arranged in the simplest geometry.

The main point thus far is the illustration of the logic of the model-building process, showing how to proceed from the very simple to the more complex, but limiting this complexity to that which is fully understood. Real values are not necessary for building the initial model since many limits can be recognized in the natural world. Resistance to water flow, for example, must vary from no resistance to complete resistance. The effect of this variation can be analyzed within those limits, and if there is a significant ecological effect, further analyses are necessary.

SNOW. Snow is an extremely important ecological force that performs many different functions. It reduces visibility when it falls; it is a mechanical barrier, a good insulator, a source of soil moisture, and a source of run-off water. Its many different functions as a physical material, coupled with its many different interactions with organisms, compels the analytical ecologist to consider it an important component of the ecosystem. It is an interesting component of analytical models because it has so many different functions. Let us consider its physical characteristics first and relate it to organisms in later chapters.

Ice-crystals are formed in the atmosphere at temperatures below freezing by the sublimation of water vapor on hygroscopic nuclei. The ice crystals take various shapes, dependent on atmospheric conditions at the time of crystallization. New-fallen snow generally has a low density (0.05–0.10 g $cm^{-3}$) owing to the dendritic structure of the crystals. Atmospheric temperature and wind are the two primary factors that alter the density of new-fallen snow. Snow density will increase an average of 0.0065 g $cm^{-3}$ for each 1°C increase in surface air temperature at the time of deposition.

Reported density of new-fallen snow varies from 0.06 for calm conditions to 0.34 for snow deposited during gale winds. Snow density increases to 0.2–0.4 g $cm^{-3}$ as the age of the snowpack increases. As each new layer of snow is deposited, its upper surface is subjected to the weathering effects of radiation, rain, and wind, and the action of percolating water and diffusing water vapor.

The original delicate crystals become coarse grains; a developed snowpack shows distinct layers characteristic of individual snow-storm deposits and weathering effects (U.S. Army 1956; Nakaya 1954).

CONDUCTIVITY. Factors affecting the thermal conductivity of snow are: (1) the structural and crystalline character of the snowpack, (2) the degree of compaction, (3) the extent of ice planes, (4) the wetness, and (5) the temperature of the snow. Experimental work shows that the thermal properties of snow (specific heat, conductivity, and diffusivity) can be predicted from snow density measurements (Table 5-3).

Heat transfer in a natural snowpack is complicated by the simultaneous occurrence of many different heat-exchange processes. The water vapor condenses and yields its heat of vaporization ($\approx$0.600 kcal $g^{-1}$) upon reaching a cold surface. Rain or meltwater freezes within the subfreezing layers and adds the heat of fusion (0.08 kcal $g^{-1}$). These two processes tend to change and influence the conductivity and diffusivity of the snow throughout the pack and influence the heat transfer rates (U.S. Army 1956).

Temperature gradients in the snowpack are more pronounced in the winter than in the spring. When the snowpack reaches an isothermal condition at 0°C, the heat energy is dissipated in melting the snow.

## 5-4 SNOW COVER IN RELATION TO KINETIC ENERGY

WINDPACK. The wind profile that develops over different surfaces plays an important part in the characteristics of wind-packed snow (Figure 5-9). Wind flow over a snow surface has a sharp profile with high velocities very near the snow surface. The inertia of drifting snow results in a more densely packed snow layer. Vegetation interrupts the flow of air, so two separate profiles are formed. The characteristics of these wind profiles, one in and one above the vegetation, depend on the height and the density of the vegetation. The profile within the vegetation has much lower velocities resulting in a less dense snowpack. The relationships between plants, animals, and wind flow are discussed further in Chapter 6.

**TABLE 5-3** THE THERMAL PROPERTIES OF THE SNOWPACK ARE RELATED TO THE DENSITY OF THE SNOW

| *Density* ($g\ cm^{-3}$) | *Specific Heat* ($cal\ cm^{-3}\ °C^{-1}$) | *Conductivity* ($cal\ cm^{-2}\ °C^{-1}\ cm^{-1}\ sec^{-1}$) | *Diffusivity* ($°C\ cm^{-2}\ sec^{-1}$) |
|---|---|---|---|
| 1.000 (water) | 1.0000 | 0.00130 | 0.00130 |
| 0.900 (ice) | 0.4500 | 0.00535 | 0.01190 |
| 0.500 | 0.2500 | 0.00205 | 0.00820 |
| 0.350 | 0.1755 | 0.00087 | 0.00494 |
| 0.250 | 0.1250 | 0.00042 | 0.00336 |
| 0.050 | 0.0250 | 0.00002 | 0.00080 |

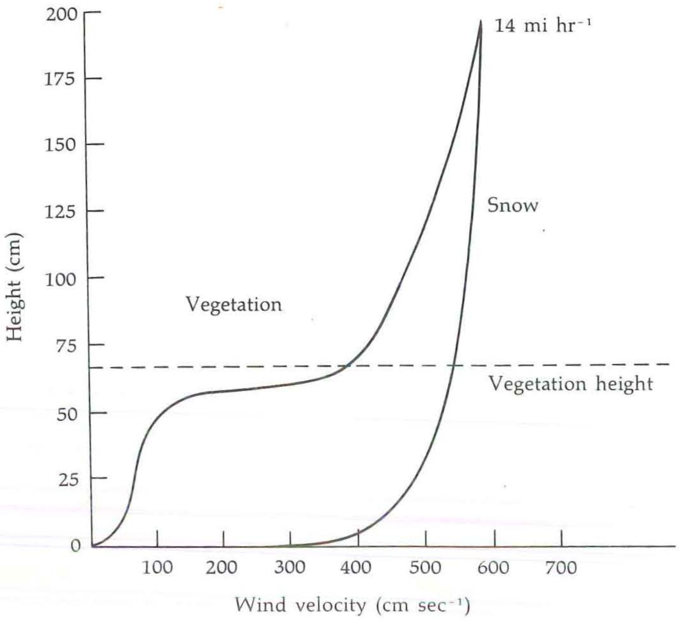



FIGURE 5-9. Vertical wind profiles over grass that is 60–70 cm in height and over a snow surface.

THE EFFECT OF WINDBREAKS. The effect of windbreaks on the distribution of snow is well known, but the turbulent flow generated by windbreaks is often described only in general terms. This is because of the difficulty in visually observing the wind and measuring the turbulence patterns. Experiments in the Thermal Environment Simulation Tunnel (TEST) in the BioThermal Laboratory, Cornell University, utilize a bubble generator that extrudes tiny neutrally bouyant bubbles that follow the movement of air as it passes through and around vegetation (Fig. 5-10).

The movement of air on the lee side of a canopy has some interesting characteristics. First, it is highly turbulent. The air is moving in three directions, including reverse flow illustrated by the trace of bubbles posterior to the deer. Second, there is a general downward trend in the flow of air behind the trees. The deer is located at a point where the wind direction is primarily vertical rather than horizontal. Third, the velocity and direction changes abruptly as the air approaches the surface, and the profile over snow shown in Figure 5-9 begins to develop.

Snowflakes follow the air flow, resulting in drift formation that is unlike snow accumulation in zero wind. Note the rounded upper surface of the drift shown in the cross-sectional drawing in Figure 5-11. The drift has an inversion that follows the pattern of air flow shown in Figure 5-10. Wind flow in the field is more complex than in the TEST, but the basic principles remain the same.

The significance of this wind flow, which is basically a kinetic-energy distribution, is discussed later. One important point to emphasize here is that cup anemometers are very unsatisfactory for measuring wind velocities in the region

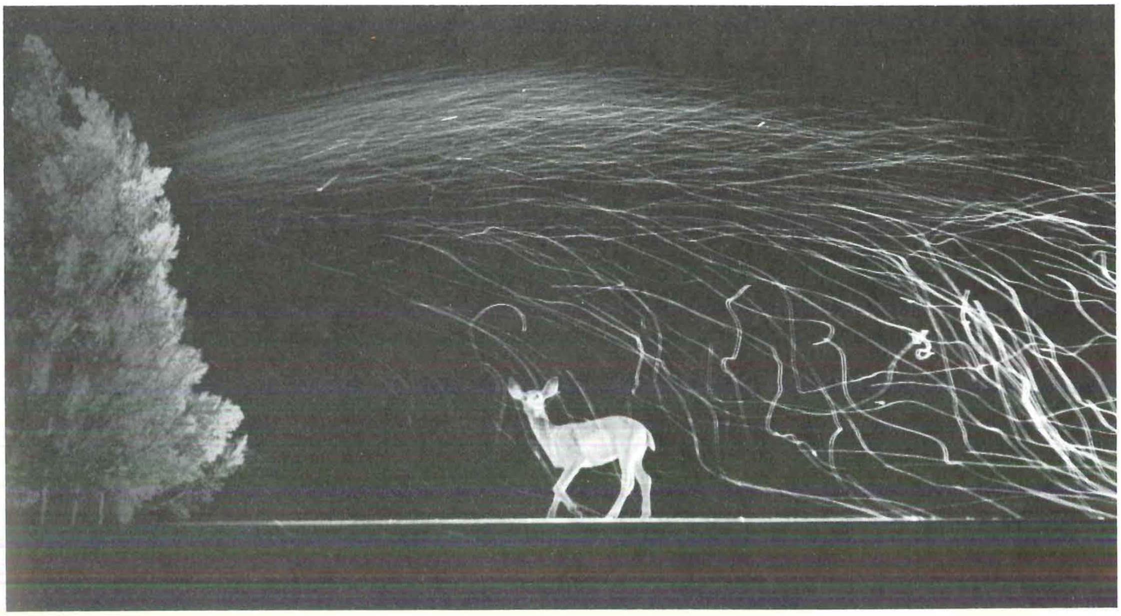
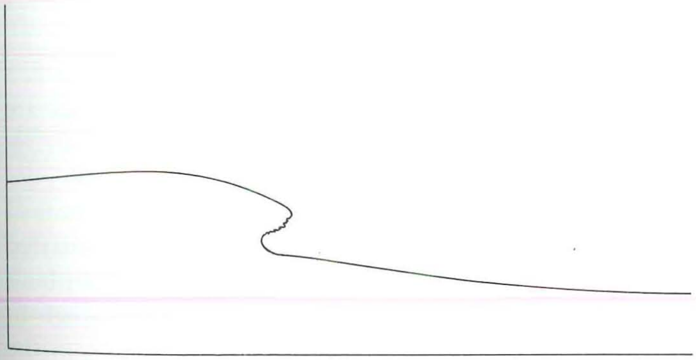


FIGURE 5-10. The movement of air on the lee side of an experimental windbreak in the Thermal Environment Simulation Tunnel.

around the deer shown in Figure 5-10 because these instruments do not respond to attack angles greater than 70° [see Hetzler, Willis, and George (1967)]. Thus a cup anemometer in a horizontal orientation just posterior to the deer at about the height of its tail would record zero velocity, but the deer would be experiencing the vertical air flow. The analytical ecologist must be aware of the importance of using instruments that measure the functional relationships between animal and environment if meaningful interpretations are to be made.

FIGURE 5-11. Cross-section of a snowdrift behind a natural windbreak, North Lansing, New York. (Moen, unpublished data.)



SNOWFALL INTERCEPTION. The interception of falling snow by vegetative cover is an important factor when predicting snow accumulation on the ground, just as it is in predicting rainfall at the soil surface. The amount of interception varies greatly, depending on the type and density of the vegetation cover and the magnitude, intensity, and frequency of storms. High winds and intense solar radiation reduce the amount of snow trapped in the canopy. A moderately dense coniferous forest, in an area with an annual precipitation of 30–50 inches, may intercept 15%–30% of the total winter precipitation. Equation (5-3) was developed for estimating the amount of interception in a coniferous tree stand in the northwestern United States (U.S. Army 1956).

$$\left\{\begin{matrix}\text{Percentage of} \\ \text{interception}\end{matrix}\right\} = \left\{\begin{matrix}0.36 \times \text{percentage} \\ \text{of canopy cover}\end{matrix}\right\} \qquad (5\text{-}3)$$

THE ROLE OF SNOW IN A PRECIPITATION-CANOPY-SUBSTRATE MODEL. The amount of information about the structural, mechanical, and thermal characteristics of snow is quite adequate for assembling initial models of the role of snow in the ecology of different organisms. The equations for snow interception by different canopies and for conductivity of snow of different densities are important for determining the amount that reaches the ground's surface and its role as a mechanical barrier and an insulator against heat loss. Students are urged to develop models that permit calculations of these functions of snow. In the absence of real data that can be used to describe some of the functions, limits can still be recognized that serve the purpose of making first approximations. For example, the aging process of snow results in a continual change in snow density, and this in turn affects conductivity. The aging process is very dependent on radiation, wind, air temperature, and precipitation, and these are not readily predicted. Their effect, however, can be approximated since the lowest snow density possible is one limit and maximum density—ice—is the other. An initial model containing changes in snow density could include an equation that describes these changes purely as a function of time. The simplest format is a linear regression equation. Initial analyses can then begin with the philosophy "What if . . . ?", and the analytical ecologist uses the outputs from such considerations in determining the *effect* of such changes on the organism(s) in question. Once this has been done, it is desirable to go back to the first approximations and improve on them so they become more and more representative of real situations in the natural world.

THE EFFECT OF SNOW DISTRIBUTION ON ANIMALS. The distribution of snow is a reflection of the distribution of kinetic energy in time and space. Animals are subject to these patterns and must be able to cope with them if they are to survive. High-density snowpacks can have opposite effects on animal life. They may pose a mechanical barrier, increasing the metabolic energy necessary for the animal to move through the snow. This is a cost to the animal that must be compensated for either by food ingested and metabolized or by reserves that have been built up during more favorable periods. Or the snowpack may be dense enough to support the weight of the animal, facilitating its movement. This results in the conservation of energy and it may also place the animal within reach of a food supply that would otherwise be too high.

The mechanical characteristics of the snowpack have a direct effect on the thermal benefit it provides such birds as grouse, which roost in the snow on cold winter nights. If the birds can penetrate the snow, they will be in a thermal regime that is very different from one above the snow surface.

Snow accumulation may directly influence the amount of available food for a wild animal. For example, the vertical distribution of potential food for deer that browse in an upland hardwood community in the Connecticut Hill Game Management Area south of Ithaca, New York, is such that one foot of snow renders 97% of it available. The zone of invading plants between a hemlock stand and an abandoned field have quite a different vertical distribution of food. One foot of snow in that habitat reduced the food supply by 25%, and two feet of snow reduced it by 40%. The marked differences between these two types of habitats indicate that the effect of one foot of snow is dependent on the vertical distribution of food, so snow depths of one foot in each of the two stands are not ecological equivalents.

The interrelationships between snowpack characteristics, forage production and availability, and animal requirements can be illustrated in a flow sheet as in Figure 5-12. The arrows indicate that there is a relationship between two or more factors, and the expression of these relationships in mathematical form will convert the picture-type model to a working model. For example, forage production over a vertical height of six feet can be expressed quantitatively. Snow depth can be expressed in relation to the removal of forage from the "available" category. Animals will eat some or all of the available forage, depending on their energy requirement. The energy requirement is in part a function of the snow depth, since it takes more energy to move through deep snow than through shallow snow.

These kinds of relationships are discussed in later chapters, especially in relation to the concept of carrying capacity. Students are urged to think about the relationships shown in Figure 5-12, progressing toward a numerical model that might be made up of dimensionless numbers at first, and then of measurements in different habitats.

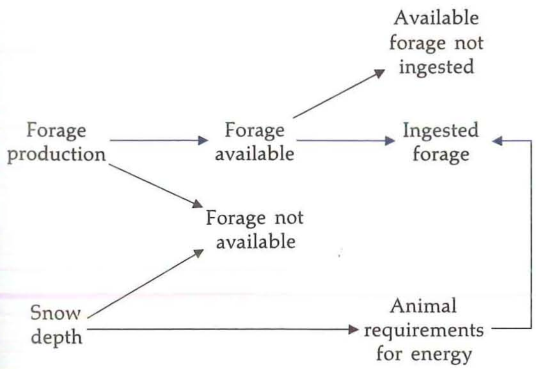



FIGURE 5-12. A flow sheet indicating the existence of interrelationships between forage availability, snow depth, and forage ingested.

Since the model-building process is such a significant part of analytical ecology, it is essential that students grasp the logic and philosophy sufficiently well to begin building meaningful models themselves. Let us turn our attention in the next chapter to weather and the processes of thermal exchange, with additional models that illustrate the process of model building and at the same time provide information on the distribution of thermal energy in the real world. Keep in mind that the process of analytical ecology results in an analysis that may be compared to dramatic art, moving from simple one-act ecological plays, each with just a few principal characters, to the more comprehensive productions that approach greater and greater realism.

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