Appendix A
The Hydrologic Cycle

The unending circulation of the earth's water through the atmosphere, land, and oceans, has no beginning or end, but we can think of it as beginning with the waters of the oceans. Water from the surface is evaporated into the atmosphere, is lifted, and is eventually condensed and falls back as precipitation.

The precipitation that falls as rain, hail, dew, snow, or sleet on lands within mining permit boundaries is of particular concern to the inspector.

Some of the precipitation, after wetting the foliage and ground, runs off over the surface. It is this runoff that sometimes causes erosion and is the main contributor to floods. Of the precipitation that soaks into the ground, some is available for plant growth, some is evaporated, and some reaches the deeper zones and slowly percolates back to the surface through springs and seeps. This water maintains streamflow during dry periods. The streams eventually flow back to the oceans, where the cycle begins anew.

Precipitation Interception

Water is delivered to the land as rain, hail, snow, and sleet. What happens to it after that depends on its state, rate of delivery, and on the character of the plants, soil, and underlying material. Its fate, in turn, largely determines the severity of floods and erosion, the quantity and quality of water supplies, and the production of vegetative cover.

Only a part of the rain or snow from each storm event reaches the soil without interference. Vegetation interposes leaves, branches, and litter, affecting the quantity, distribution, and kinetic energy of precipitation that reaches the soil surface. Rain and snow are affected differently in some respects. Part of each passes through the canopy of vegetation without being caught, but if the canopy is dense, a large part strikes leaves or branches. Leaf cover can be seasonal so interception can also be largely seasonal, particularly in temperate regions of the world.

Of the part thus intercepted some spills from drip points, some flows to the ground along stems, and some is held and evaporates without ever having reached the land surface. Rain wets the vegetative surface it strikes. It can form only a thin water layer before it starts flowing toward the ground. Snow may wet the surfaces it strikes, but whether it does or not, it can pile up to a considerable depth. A good deal more snow than rain can thus be intercepted by vegetation.

The quantity of precipitation that is intercepted by vegetation and then evaporated depends on the kind and size of storm, the kind and extent of vegetative cover, and the temperature and humidity of the ambient air. It represents, however, a fairly constant percentage of annual precipitation under the same vegetation conditions. Where interception has been measured, it generally has been found to be between 5 and 15 percent of the annual precipitation.

Vegetation and its debris act to disperse the energy of falling rain, hail, or sleet and thus constitute a first line of defense against runoff and erosion.

Infiltration

Rain that reaches the soil surface is wholly or partly absorbed by the soil in the process of infiltration. How much of it enters the soil depends upon the rate of rainfall and the infiltration rate of the soil. Runoff or surface flow results when water is delivered to the soil faster than it can be absorbed. Surface flow is generally undesirable because it may erode the soil and because it may produce flash floods during storms. Because of the damaging consequences of surface-flowing water, many land management practices are designed to induce as high an infiltration rate as possible.

Infiltration rate is controlled by a combination of factors—some natural and some the result of modifications imposed by use of the land. Infiltration rate is naturally greater in sandy soil than in clay. Ordinarily, the finer the soil texture, the lower the rate of infiltration. But the effect of texture is modified greatly by the aggregation of the soil particles and by the structure of the soil. A surface soil that is well supplied with organic matter is ordinarily far more receptive to water than a soil consisting mainly of mineral material. Maintaining an organic-reinforced open structure is one of the objectives of mulching.

Percolation

Water entering the soil either increases the moisture content of the soil or drains through it. If the soil is dry, water entering it wets successively deeper horizons to field capacity, which is the moisture content to which a soil must be raised before water can drain through it. Until the entire soil profile has been wetted to field capacity, water movement is basically downward. When field capacity is reached, additional waters entering the soil will move laterally in the saturated zones to emerge in springs and seeps. When little or no lateral movement occurs, these waters simply raise the elevation of the water table.

Water draining through the soil feeds streams longer and more evenly than water flowing over the soil. For maximum water control the best reclamation practices are those that induce the most water to enter the soil, except where the lateral movement of subsurface water might endanger the stability of fragile natural slopes or constructed embankments.

Evaporation and Transpiration

Water held within the soil after drainage has ceased can be transpired by plants or lost by evaporation. Plants can-

not utilize all water stored in the soil; they can dry the soil only to the wilting point. The wilting point is that moisture content at which the surface tension force holding water to the soil particles equals the maximum water-absorbing force of plant roots. Just as clay soils can hold more water at field capacity than sands, so also is the wilting point of a clay higher than that of a sand. Both the upper and lower limits of the available moisture range, between wilting point and field capacity, are determined primarily by soil texture and organic matter content (Fig. 4).

Evaporation can dry soil below the wilting point. In the evaporation process, soils dry from the surface downward. All soil water lost by evaporation must rise to the soil surface and pass through it. Given sufficient time without water additions, soils may dry many feet deep. Ordinarily, evaporation significantly affects only soils near the surface.

Evaporation and transpiration together take their toll of soil water in response to a number of conditions. If the soil surface is free of plants but thickly covered with an insulating layer of litter, evaporative loss will be much less than if the vegetation-free soil is bare. A soil loses less water under a cover of shallow-rooted plants than under plants whose roots reach to the full depth of the soil. Where a water table exists a short distance below the root zone, the lower soil layers may not dry perceptibly, although large quantities of water may be withdrawn from the water table.

Evapotranspiration rates and volumes can be modified in various ways. Protective mulches can be placed on the soil surface to reduce evaporation. The loss of plant leaves can reduce transpiration to nearly zero during winter or extreme drought. Transpiration can be reduced by removing or thinning undesirable vegetation. Shallow-rooted plants can be grown on soils previously occupied by plants with deep roots. On the other hand, deep-rooted plants may be used to remove soil moisture, where an excess of moisture might be undesirable. There are, however, limitations to how far transpiration losses can be modified. It is obviously not desirable to reduce the density of plant cover so much that the soil is insufficiently protected against storm runoff and erosion.

Typical Water-Holding Characteristics of Different-Textured Soils

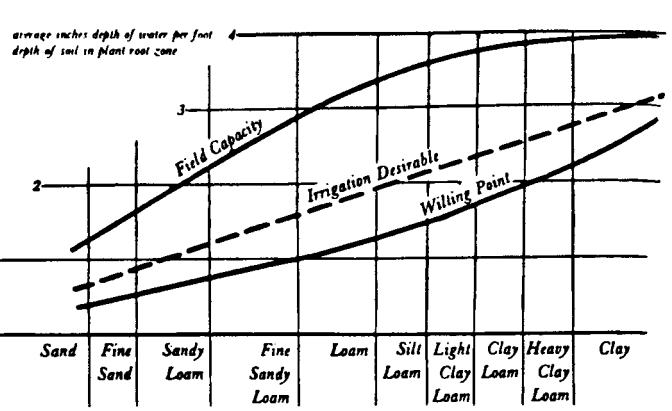

Figure 4. Typical water-holding capacities of different-textured soils.

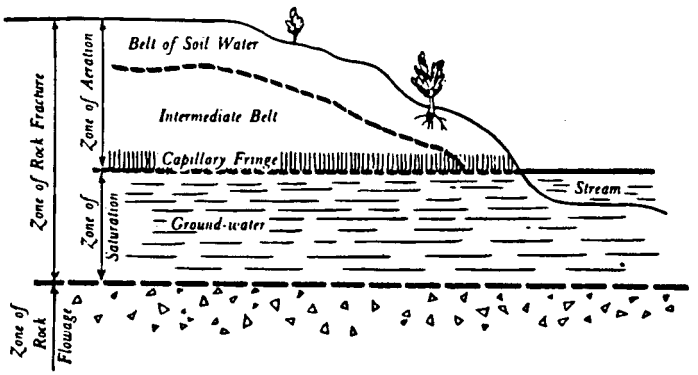

Figure 5. Schematic of groundwater zones and belts.

Perhaps the most important point regarding transpiration is that it is a natural process that occurs wherever there is vegetation. While transpiration and evaporative water losses can sometimes be reduced by treating the soil and its cover, they cannot be eliminated.

Subsurface Water

Water that has infiltrated into the soil is known as subsurface water. It may be evaporated from the soil; it may be absorbed by the plant roots and then transpired; or it may percolate downward to groundwater reservoirs and move laterally into streams. Subsurface water occurs in that zone between the ground surface and the lower limits of porous, water-bearing rock formations. This zone is designated as the zone of fractured rock and is subdivided into the zone of aeration and the zone of saturation (Fig. 5).

The zone of aeration is further divided into three belts—the belt of soil water, the intermediate belt, and the capillary fringe. The belts vary in depth and are not sharply defined by physical changes in the soil. Indeed, depending upon differences between inflow and outflow rates, the belt boundaries on any given site will fluctuate. In natural soils generally there is a gradual transition from one belt to another; however, on reclaimed mines the transition may be sharp. In considering the movement of water through the soil profile, however, it is desirable to delineate zones or belts that have different effects on the subsurface movement of water.

The upper belt, or belt of soil water, consists of the topsoil and subsoil from which water is returned to the atmosphere by evaporation and transpiration. As water passes through the surface and enters this belt, it is acted upon by gravity and molecular attraction. Gravity tends to pull the water downward. Molecular attraction tends to hold the water in a thin film over the surfaces of soil particles and in the very minute spaces between the particles. Only when sufficient water has entered this belt to satisfy the storage requirements due to molecular attraction does water start to percolate downward under the force of gravity.

The belt of soil water is of particular importance to reclamation because it furnishes the plant-available moisture

necessary for vegetation to grow. The depth of the belt of soil water varies with the soil type and the vegetation rooting depth, and its thickness may vary from a few feet to several tens of feet. Water passing downward from the belt is beyond the reach of plant roots and is no longer available to support plant growth. However, the roots of some plants extend to the water table, especially if the water table is not too far down.

Water passing through the belt of soil water enters the intermediate belt and continues its movement downward by gravitational action. Like the belt of soil water, the intermediate belt holds water suspended by molecular attraction. In this belt, however, suspended water can be considered dead storage, since it is not available for use. In the hydrologic cycle, this belt serves only to provide a passage for water from the belt of soil water to the capillary fringe. The intermediate belt may vary in thickness from zero to several hundred feet; its thickness has a significant effect on the time it takes water to pass through the belt and reach the water table or to exit as seeps or springs.

The capillary fringe lies immediately below the intermediate belt and above the zone of saturation. It contains water that is held above the zone of saturation by capillary force. The amount of water held and the thickness of the capillary fringe depend on the type of material in which the capillary fringe is located. In silty material it may extend 2 feet or more above the zone of saturation. In a coarse, gravelly material it may extend less than an inch. As in the intermediate belt, water is stored in the capillary fringe. Water moved by gravity from the surface to the zone of saturation passes through the capillary fringe.

Groundwater

The zone of saturation, or groundwater, forms a natural reservoir that feeds springs, streams, and wells. Water moving by gravity through the three belts of the zone of aeration enters the upper surface of the zone of saturation, which is referred to as the water table. With the possible exception of some with entrapped air, all the pores and spaces in this zone are filled with water. The depth of the zone depends on the local geology. It may include loose, unconsolidated deposits of sand and gravel, as well as porous rock formations such as sandstone and limestone. Its lower limit is that point where the rock formation becomes so lacking in pores and joints and cracks that water cannot penetrate it. The zone of saturation may vary in thickness from a few feet to hundreds of feet.

The zone of saturation is extremely important because it provides water for wells and the normal, relatively uniform flow of streams. It receives water during wet periods so that the water table rises as water drains into it from above. It can thus store huge supplies of water which, because of the slowness of its lateral movement through the zone, is discharged at a slow and relatively uniform rate.

The top of the zone of saturation is generally called the water table. The action of gravity tends to make the water table a level surface. However, because movement of water is relatively slow through soil and rock formations, the frequent additions and withdrawals do not usually permit the water table to become a truly level surface.

During periods of low flow, the level of the water surface in a stream may drop below the level of the water table (Fig. 6). Groundwater will then seep into the stream and the slope of the water table will dip toward the stream in the direction of groundwater flow. When the stream is flowing at a level above the water table, seepage moves in the opposite direction and the water table rises. Because of the constant changes resulting from increased supply to groundwater or the increased demand from groundwater, the level of the water table is constantly changing.

Geologic formations also affect the water table. Where there are layers of impervious material, it is possible to have water tables at different elevations (Fig. 7). Water may be confined in a permeable layer between two impervious layers. Such confined waters may be under hydrostatic pressure. Occasionally pressures are sufficient to cause the water to rise in a well above the land surface, creating a flowing well.

Conditions differ greatly under different geologic formations, but in the hydrologic cycle the principal functions of the ground water zones are as follows:

- Zone of aeration—receives and holds water available for plant use in the belt of soil water and allows the downward movement of excess water.
- Zone of saturation—receives and stores water, and provides a natural regulated discharge to wells, springs, and streams.

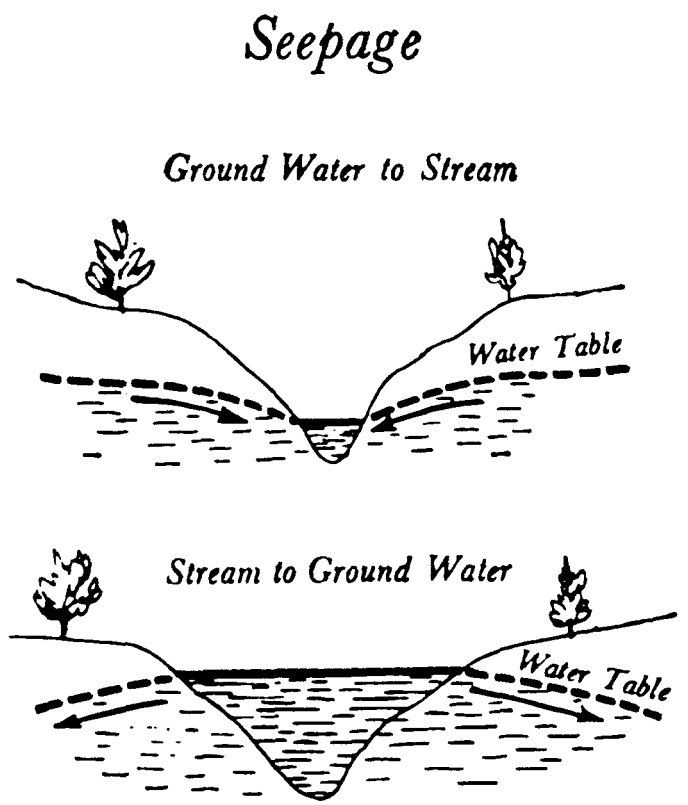

Figure 6. Seepage between the water table and stream.

Runoff

Broadly speaking, runoff is composed of water from both surface flow and subsurface flow.. It is an extremely important segment of the hydrologic cycle, since, on the average, about 20 percent of all precipitation is carried to the ocean by streams and rivers. When precipitation does not have an opportunity to infiltrate the soil and flows across the land surface in very thin layers, it is referred to as sheet flow. Eventually, most of the surface runoff enters stream channels which carry it to the ocean. Once in channels, the surface flow is referred to as streamflow.

Inspectors are directly concerned with the surface flow portion of runoff. They need to understand the factors that affect the volume and rate of surface flow so that they can recognize situations and land management practices that are beneficial as well as those that may lead to disastrous effects during periods of high flow.

The amount and the rate of precipitation affect the volume and peak flow of a stream. Similarly, temperature may influence runoff. During periods of low temperatures, precipitation may accumulate in the form of ice or snow. This is particularly important in areas high in latitude or elevation. Rapid temperature rises often result in exceedingly rapid snowmelt. This in turn may cause high rates of surface runoff, particularly when the soil is frozen.

The physical characteristics of a watershed indicate what might be expected in total storm runoff volume and peak rate of runoff. A relatively impervious, steeply sloping watershed may shed most of the precipitation falling on it, but a level or gently sloping watershed with deep, permeable, well-protected soils may absorb essentially all of the precipitation.

In the first instance, high peak rates of flow and sharp rises and falls in flow rates would be expected. In the latter case the peak flow would be considerably less, and flow rates would change relatively slowly. However, the flow volumes produced over a long period would not necessarily be significantly different. Steep slopes produce high peak rates of runoff but have little effect on the total volume of runoff. Good vegetative cover and a layer of surface debris tend to foster infiltration, thus materially reducing the rate at which water reaches the stream channels. As surface flow volume decreases, the volume slowly passing through the soil or spoil and entering the stream as seepage flow increases.

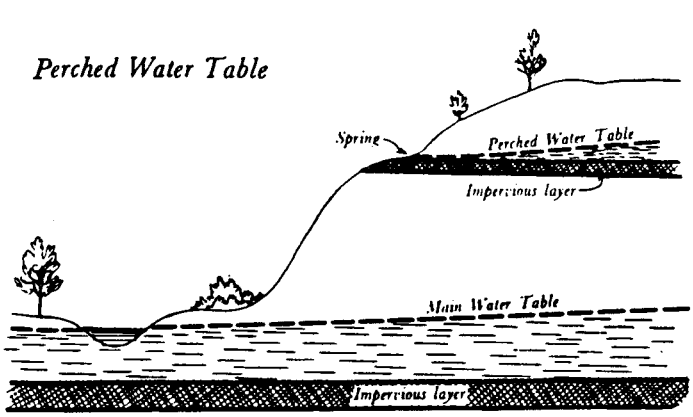

Figure 7. Diagram of main water table and a perched water table. Note that impervious layers underlie both the water tables.

Lakes, ponds, swamps, and reservoirs also act to lower peak flows and to extend flow duration in the streams they feed. Generally, there is but little loss of flow to groundwater from natural lakes and swamps since they are usually where the ground surface intersects the local water table. However, artificial impoundments, properly located, designed, constructed, and maintained, can be used effectively on surface-mined land to control or regulate runoff.

Among the many factors that affect runoff to some degree are: barometric pressure, which can affect the flow of springs and artesian wells; seepage from stream channels; and evaporation from streams. The degree to which such factors must be considered depends on the particular situation. No two streams or watersheds are alike; each has its own characteristics.

Hydrologic Balance

Although the amount of water with which we are concerned in the hydrologic cycle remains essentially constant, its distribution within any given watershed or area of interest is continually changing. The hydrologic balance within a watershed is the relationship between water input, water storage, and water output. Before mining, the hydrologic system as a whole is in balance, although some or all of the elements of the balance may be changing. Normally, precipitation is the primary mode of water input. However, there are situations where aquifers also are important means of supply. In certain cases streams originating outside the area to be mined must also be considered a source of water supply to the mined area. Waters stored on a site may be in the form of groundwater, soil moisture, or surface water. Water output is primarily in the form of streamflow or evapotranspiration, but sometimes groundwater is also important. Sometimes water is imported to the area or is consumed within the area. When that is the case, these factors must be considered in the hydrologic balance.

Surface coal mining and reclamation can affect all three phases (input, storage, and output) of the hydrologic balance in many ways. The effects may occur both on and off the mine site. Mining and reclamation can directly affect onsite groundwater storage capacity, groundwater movement, water table levels, surface drainage channels, surface water storage, and evapotranspiration. All of the changes in the hydrologic system on site can combine to cause changes in the quantity and quality of both surface and groundwater output (water yield). This can lead to adverse effects downstream, including scour and sedimentation in stream channels, disruption of aquatic habitats, and changes in both the quantity and quality of the water supplies to public or private users. The frequency, magnitude, and duration of floods may also be affected.