# INDICATORS OF CONDITION AND TREND ON HIGH RANGE-WATERSHEDS

*of the*

# INTERMOUNTAIN REGION

Agriculture Handbook No. 19



UNITED STATES DEPARTMENT OF AGRICULTURE
Forest Service

# INDICATORS OF CONDITION AND TREND ON HIGH RANGE-WATERSHEDS OF THE INTERMOUNTAIN REGION

By

LINCOLN ELLISON, Forest Ecologist, A. R. CROFT, Forester
and REED W. BAILEY, Director, Intermountain Forest
and Range Experiment Station, Forest Service

Agriculture Handbook No. 19

U. S. Department of Agriculture August 1951

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C.—Price 30 cents

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# THE PROBLEM OF JUDGING CONDITION AND TREND

High mountain lands of the Intermountain West have great significance and importance to its people, even though they make up only a small fraction of its total area. From these highlands the accumulation of winter snow yields yearlong stream flow, the lifeblood of the Intermountain country. They provide summer grazing for domestic herds and for wild game. They furnish timber for local sawmills. And finally, their forests, streams, and rugged landscape provide an opportunity for enjoyment and inspiration to all.

The vegetation of these high mountain lands plays a particularly important role in regulating stream flow. Grasslands, brush fields, and forests hold the soil in place and keep it open and porous, so that even the most violent summer rains are safely absorbed. When the vegetal cover is intact, overland flow is virtually unknown. On the other hand, if the vegetal cover is greatly reduced, dashing rains wear away the soil, etching rills and gullies into the watershed slopes. In many years this deterioration of the upper slopes is reflected only in the sediment that collects in canals and reservoirs. But in those years when the most intense storms occur, the eroded slopes discharge the flood waters almost as fast as they fall. These pour down the gullies, uniting to gut the larger channels and finally, spewing mud and boulders out of the canyon mouth, wreak havoc on whatever—farm, dwelling, or town—may lie in their way.

Thus the condition of the plant cover on these range-watershed lands, through its influence on soils and stream flow, is vital to the welfare of people of the Intermountain region (fig. 1). This "condition" is the character of the vegetal cover and the soil, under man's use, in relation to what it ought to be. Change in condition is referred to as "trend."

Condition and trend are recognizable by certain signs, or "indicators," that can be seen in the soil and vegetation. These indicators tell much about changes that have taken place in the past or that are taking place at present. Often they suggest what may be expected in the way of trend and condition in the future.

Judgment of condition and trend depends upon ability to recognize indicators and understand their significance. By proper interpretation of indicators constructive changes in management may be planned, and on the same basis the effectiveness of management may be evaluated later. On the other hand, unless indicators of downward trend are recognized accurately and unless management is geared to correct the causes of downward trend, costly and even irreparable damage may be done to the range-watershed resource.

This publication is intended to help the range manager judge condition and trend accurately in the course of range inspection. In order to make best use of the evidence on the ground, he has three major needs: First, a technical foundation of ecological principles

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FIGURE 1.—The welfare of all people dwelling in the Intermountain valleys is ultimately dependent on the condition of their mountain watersheds.

underlying the concepts of condition and trend; second, an understanding of condition and trend as they relate to the normal and to objectives in management; and third, a knowledge of indicators of condition and trend, their meanings and their limitations. The three major divisions of this publication are intended to serve these needs, in the order given.

In preparing this publication many well-known ecological facts and principles have been drawn upon, but no attempt is made to cite the many references that would be necessary to review the ecological literature. These facts and principles are presented in the light of the authors' own experience with indicators on range-watersheds of the Intermountain region.

# THE RANGE-WATERSHED COMPLEX

A *complex,* by definition, is "a whole made up of interrelated parts." The range [1] is such a complex, or whole, or system. It is made up of

[1] The term "range-watershed" is frequently shortened to "range" in this publication. It will be understood when "range" is used alone that watershed as well as forage aspects of the land are implied.

parts so closely interrelated, and normally so well integrated or adjusted to one another, that what affects one affects all. This principle is of basic importance to judgment of range condition and trend, and indeed to all range management.

The range-watershed complex is not necessarily considered as a large area or even a single watershed. For purposes of judging condition and trend, the term will refer to a smaller area of essentially homogeneous character—a flat, a single hillside within narrow elevational limits, or that part of a hillside upon which slope steepness and exposure are essentially uniform.

## Components of the Range-Watershed Complex

The ultimate parts of the range-watershed complex are numberless. For convenience they are grouped into five classes—animals, vegetation, soil, climate, and topography—and these classes are spoken of as "components" of the complex.

### Animals

Animals as components of the range-watershed complex include not only domestic livestock and game, but the entire fauna above and below ground, varying from large animals down to forms of microscopic size.

Doubtless the greatest single influence on western range lands in historic times has been the introduction of large numbers of domestic animals. These have utilized vegetation more closely and consistently than the original native animals, and in many places have so reduced the cover as to cause rapid soil erosion. Moreover, the presence of domestic animals and occupancy by man has often forced native wild animals to change their habits. It is reasonably certain, for example, that deer and elk have been forced to graze some ranges much more heavily than they did naturally, especially in winter and spring.

Grazing animals exert three important influences on the range that are relevant here. These influences are removal of herbage, trampling of soil, and dissemination of seed.

Although any grazing is sometimes thought of as being injurious, it is not necessarily so. Under certain conditions grazing has a stimulating effect on growth, and as a general rule, if the grazed plants are given sufficient opportunity to make substantial regrowth, foliage removal is not injurious. Injury done the individual plant by close or repeated cropping is mainly in reducing its photosynthetic area and draining its food reserves. Heavy grazing affects the vegetation as a whole by handicapping preferred species, thus favoring less palatable species, and by reducing the amount of foliage cover and litter, thus creating a drier microclimate at the ground surface and inducing soil erosion. Certain palatable species are better adapted than others, by growth form, rapidity of development, or otherwise, to grazing. Other species escape grazing at a time unfavorable to them because they are palatable only late in the season after their growth cycle is complete. Species so adapted tend to increase in the plant cover as the more palatable plants decrease.

Heavy trampling not only damages plants but it may damage the soil as well. Its effects are especially marked in the compaction of fine-textured soils when wet. Rain water is then likely to flow off the surface, carrying topsoil with it, instead of soaking into the ground and replenishing the soil moisture supply. Soil displacement by heavy trampling, too, may be an important form of accelerated erosion, particularly on steep slopes when the soil is very dry or very wet.

The influence of animals in disseminating seed, while probably universal, is most evident where the range has been heavily grazed and trampled. Common dandelion and annuals like tarweed, lambsquarters, and knotweed are plants that have followed the white man's flocks and herds, first becoming established along trails and on bedgrounds where the native cover had been most reduced. On the other hand, through their dissemination and perhaps burial of seed, grazing animals have been a constructive factor in the invasion and spread of perennial herbs and grasses which have helped check erosion on lands denuded by earlier overgrazing.

The relations of other components of the range-watershed complex to animals are so well known that they need only be suggested here. Vegetation, either as forage or cover, is often the reason for the presence of animals on a particular part of a range. Slope and exposure determine distribution of animal life markedly, so that various intensities of grazing and trampling—and ultimately of range condition—are directly related to topography. Climate and soil, through their effects on vegetation and topography, influence all animal life.

The relation of one kind of animal to another deserves special mention. On many ranges there is question of competition between livestock and game. Animals other than domestic livestock may be responsible for unsatisfactory condition, or, on the other hand, they may be blamed for a condition for which they are not responsible. The better one understands interrelations among animals, therefore, and the interrelations of animals and the rest of the range-watershed complex, the sounder his judgment of range condition or trend is likely to be.

## Vegetation

Vegetation is the total aggregate of plants. The term properly includes all kinds of plants: Minute bacteria, lowly molds and fungi, lichens, algae, mosses, herbs, grasses, shrubs, and forest trees. The smaller forms are known to be of great importance to the larger and more familiar ones, chiefly through their action on soil or as parasites. The range manager's most direct concern, of course, is with herbaceous and woody plants which, as they grow together, form the basic units of vegetation, commonly called "stands," "communities," or "associations."

Three characteristics of high-mountain vegetation are particularly noteworthy from the standpoint of judging range condition and trend.

First, on range in good condition, is the tendency of vegetation, with the litter it produces, to form an effective protecting cover against soil erosion. Partly this effectiveness results from an amount of cover that tends to be greater on high-mountain range than on lowland range, and partly it results from a high degree of vegetal dispersion Even on dry uplands where crownspread cover and herbaceous litter are less than—for example—on wet meadows, bare spaces are neither large nor permanent if the range is in good condition. Whatever bare ground may be present is dispersed irregularly in small spots throughout the stand; likewise vegetation and litter are thoroughly dispersed, with the result that their influence usually extends over the bare spots, shading them part of the day and tending to shelter them from direct impact of wind and rain. Although a well-dispersed cover may not be complete, it can be completely effective. Even where bare spaces are not entirely sheltered and tend to give rise to runoff and erosion on a small scale, they are isolated from one another, held apart in a mesh of vegetation that prevents the runoff from combining and increasing to cause erosion of seriously destructive proportions.

A second characteristic of vegetation on high-mountain range in good condition is that it usually consists of many kinds of plants. Even so small an area as a square rod may contain 20 or 30 different forage species (fig. 2). This diversity in kinds of forage plants is of special significance in management. It means that many different degrees of palatability are represented in the stand, many different patterns of seasonal development, many variations in growth form. Hence, the better the plants are known—not only their names but their habits of growth, flowering, and reproduction, their palatabilities, and the time and intensity of their utilization—the better for management. While a large number of species may seem to make judgment of trend

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Figure 2.—A dense cover of vegetation, consisting of a mixture of perennial species, characterizes herbaceous mountain range in reasonably good condition. Such vegetation provides effective protection to the soil as well as palatable forage.

difficult, this very complexity of vegetation suggests that a rather high degree of precision in judgment of trend may be expected as the ecology of mountain plant communities becomes better understood.

A third characteristic of high-mountain vegetation in good condition is dominance by plant species of perennial life form. Annuals, if present at all, make up only a small part of the stand. Where annuals are conspicuous in high-mountain vegetation, the range is not in good condition.

Vegetation is influenced by other elements of the range-watershed complex than grazing animals. These influences may affect vegetal composition, or changes in composition, in such a way as to be confused with the influence of grazing. A slight difference in exposure, elevation, or degree of slope, may make a material difference. Some species may be abundant or scarce, or may be reproducing aggressively or hardly reproducing at all, because of weather. Certain species are naturally restricted to certain types of soil; the character of soil surface, as a result of past erosion, may prevent invasion of desirable species; or the soil may be so thin that only certain species can survive in it. And finally, different species of plants interact upon one another in marked degree, partly in competitive, partly in commensal relations, to produce trends. These facts emphasize the necessity to consider the range-watershed complex as a whole rather than as vegetation alone.

## Soil

Soil has been defined as a natural body on the surface of the earth in which plants grow, composed of organic and mineral materials. The phrase *a natural body* should be taken to mean that soil is something with a definite form that is the result of a process of development, not just an amorphous mass of dirt. The distinction is important to an understanding of the range-watershed complex and to interpretation of condition and trend.

Soil has two features of particular significance in range-watershed management. One is that the soil itself, and the substratum upon which it rests, constitute a reservoir for water storage. This reservoir makes possible development of all higher vegetation, including forest trees and range forage plants, and prolongs discharge of water into streams. The second feature of particular significance is that the normal soil surface is highly permeable to water. Because of this fact large volumes of snow melt and sudden dashing rains are readily absorbed by mountain soils with normal protective cover. Where protective cover has been reduced, as it has in most of the Intermountain region, the urgent task of management is to restore it. Rehabilitation has the multiple objective of stopping accelerated soil erosion and of increasing the impaired soil's permeability to water, thereby augmenting water storage (which in turn permits growth of more luxuriant vegetation) and improving the character of stream flow.

The typical soil profile of well-drained high-mountain grassland, as revealed in a trench or fresh road cut, is rather simple (fig. 3). At the surface is a layer of litter made up of recognizable stems and leaves. Beneath the surficial layer, processes of decay are active, and plant parts


FIGURE 3.—Profile of a deep, mountain grassland soil that has developed on gently sloping terrain. Dark soil with high organic content and crumb structure near surface changes gradually downward, becoming lighter in color and more blocky. The most marked profile change is between soil mantle and parent material about halfway between surface and pick. Pick handle is 15 inches long.

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are less recognizable in a brief transition to mixed organic and mineral matter. In the profile below the litter layer, for a depth of perhaps 6 to 12 inches, are concentrated innumerable roots and rootlets. Here the soil is darker and of better tilth than that into which it grades beneath. Lower down, roots are fewer, the proportion of organic matter is less, soil is lighter in color and more compact, and rocks are larger and more numerous. The lowest part of the profile is, as a rule, essentially all rock or rock fragments. This is the "parent material," so-called because the soil above it—the "soil mantle"—has been developed from material of this sort. Although clear-cut horizons are seldom distinguishable within the soil mantle, the contrast between mantle and parent material is commonly fairly sharp (fig. 4).

The character of a mountain soil profile is often greatly modified by normal soil movement, and compared with some lowland soils, mountain soils are "young." In terms of human life, however, even a soil as shallow as the one shown in figure 4, is really very old, probably representing development over many centuries. Normal soil movement is accomplished mainly by two very slow, persistent processes—creep, in which the whole soil mass moves downward, and surficial erosion. Normally, on sites where a soil mantle has been developed, these processes are much too slow to be extensively perceptible. This last fact is basic to judgment of condition and trend whenever the question arises of differentiating normal from accelerated erosion.

Soil is not something that has always existed as we now see it: it is the result of an age-long development that might almost be called a process of growth. Beginning with a parent material of mineral matter, the combined action of all environmental factors produces the soil mantle.

Climate is responsible for the earliest disintegration of rock, for the physical weathering that results from freezing and thawing. The action of climate is responsible for chemical changes also, dissolution of certain minerals, their transportation through the soil in solution, and their deposition at new levels in new combinations. These influences, both physical and chemical, are greatly modified by topographic situation and by the reactions of plants and animals.

Vegetation has an exceedingly important influence on soil, from assisting disintegration of the original rock by means of the expansion of roots to supplying organic reagents that take part in chemical changes. Furthermore, a stand of vegetation, by furnishing dead parts of plants as food materials and by modifying climate near the soil surface, encourages a rich flora of microscopic plants—algae, fungi, and bacteria. These are minute individually, but they teem in millions to the cubic inch in a fertile topsoil, and are among the most potent agents of the biotic community in developing soil and in maintaining its fertility and tilth.

Organisms other than plants should be mentioned as influencing soil formation. Burrowing mammals like pocket gophers play an obvious role in mixing and aerating the soil, bringing subsoil to the surface and carrying topsoil and organic matter below. Less conspicuous, but possibly even more important in transforming organic matter, turning over the soil, and riddling it with tunnels that permit aeration and promote percolation of water, are the myriads of smaller forms—insects, mites, mollusks, millipedes, worms, etc.—that are constantly at

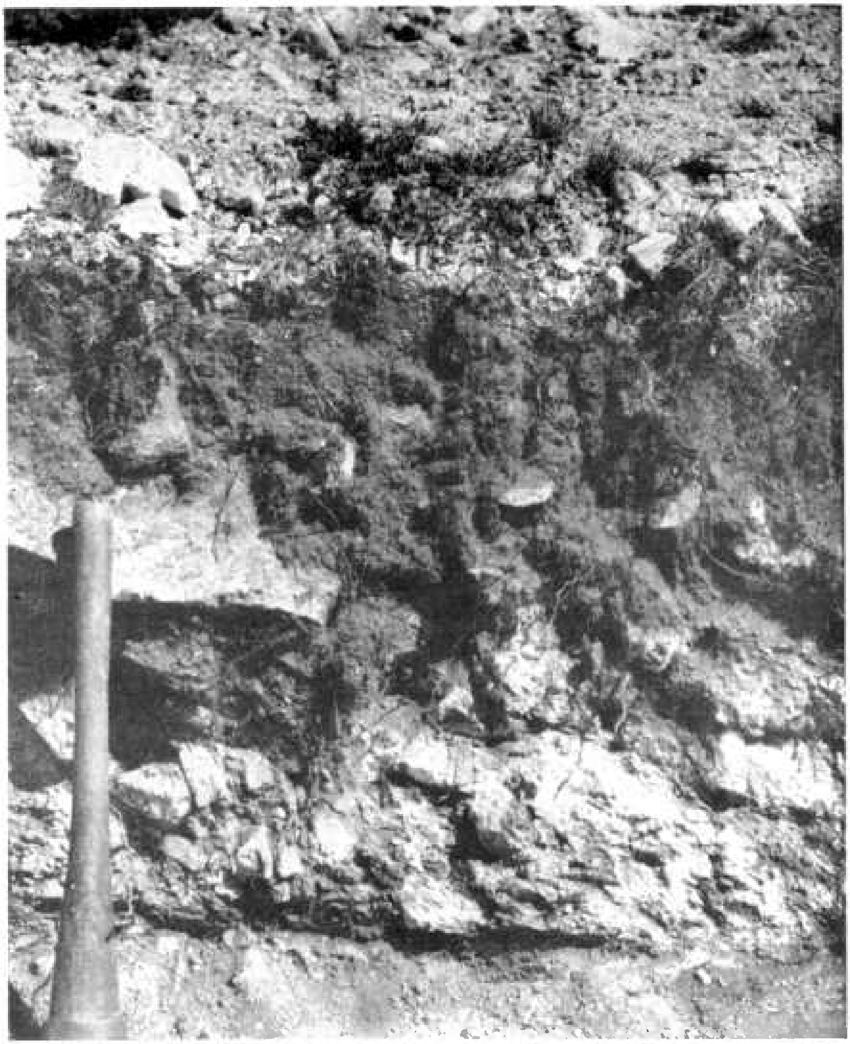

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FIGURE 4.—Profile of shallow soil underlain by rock parent material on a steep mountain slope. Gravel on surface has recently been washed down from an area of accelerated erosion above, as indicated by partly buried vegetation. Pick handle is 15 inches long.

work. Some evaluation of these organisms has been made in agricultural and forest soils, and though little is yet known about them on high mountain range land, their importance there is probably also very great.

Besides the part it plays in formation of soil, vegetation augments the efficiency of soil and its rocky substratum as a reservoir for water. While plants themselves use up a portion of the soil moisture, they make soil receptive to infiltration of water so that, as compared with bare ground, relatively little water is lost as overland flow. Effective precipitation is thereby increased. The accumulation of organic matter from dead plant parts in the soil, furthermore, increases the soil's capacity to retain water and to support vegetation.

Vegetation has a protective function that is especially important to mountain soils because of the continual tendency for soil displacement on sloping ground. Climatic forces may be considered destructive to soil as well as constructive: frost loosens, rain washes, and wind blows the soil. Vegetation tends to modify climatic influences and prevent loss. The litter of dead plant parts on the soil surface and the cover provided by branches and foliage hinder freezing and check blowing and washing. At the same time, a fibrous interlocking system of roots and other underground parts binds the soil firmly so that displacement is held to a minimum. All these influences of vegetation constitute what is referred to in this publication as "vegetal control" over soil surface and microclimate.

The influence of topography upon soil formation is readily perceived in differences in depth of soil mantle on slopes of varying steepness. Mountain topography induces wide variation in rate of both normal and accelerated erosion. Part of this influence is exerted through the influence of topography upon local climate and vegetation.

A characteristic of high-mountain lands having topography gentle enough to be accessible to domestic livestock is, normally, the almost universal presence of a soil mantle. On the other hand, most terrain that is so rough and rocky as to be nongrazable—e.g., steep rock slopes or talus—does not possess a true soil mantle. The loose rocks and rock waste present on such sites form a mineral mantle, whether its components be coarse or fine—rock, sand or clay—that has not been stabilized sufficiently long to be modified into soil under the influence of climate and organisms. When the term "soil" is used in this publication, it applies only to the former kind of substratum, where the mineral mantle has been modified, by the combined action of climate and organisms, into a well-defined body markedly different in character from purely mineral materials.

The normal existence of a soil mantle on practically all grazable terrain is the basis for all indicators of range condition and trend that relate to soil. The soil mantle itself is an indicator of a long period of essential stability. In view of this stability, signs of recent disturbance such as active gullies, wind-scoured depressions, and topsoil remnants indicate that the slow, constructive process of soil development has been superseded by rapid, destructive processes of accelerated erosion. Conversely, healing of erosion scars indicates that the erosive process is being halted and soil development may again take place.

## Climate

Under "climate" are included all the atmospheric factors of radiation, precipitation, wind, evaporation, etc., that exist in the range-watershed complex.

A distinction must be made between climate and weather because the two bear differently upon range condition and trend. The climate of a given locality is a persistent feature continuing for hundreds, and probably thousands, of years at about the same level. Weather, on the other hand, changes from day to day and year to year. Variations in temperature, rainfall, wind, sunshine, and so on, make different kinds of weather, but it should be emphasized that these variations are themselves part of one climate. They are as much a part of that climate as the characteristic maximum and minimum temperature or the average annual rainfall; and like other features of climate, they influence development of vegetation and animals, evolution of topography, and formation of soil.

The climate of high range lands is alpine or subalpine. Average precipitation is adequate for luxuriant plant growth. An important characteristic of precipitation at high elevations is its winterlong accumulation in the form of snow, which is the source of most of the yearlong stream flow. For a period in early spring the moisture supply of the soil mantle is invariably replenished to maximum capacity. Thus, even though winter precipitation may be greatly below normal, the vegetation begins growth each spring with about the same amount of soil moisture. However, dry summers occur in which plant growth is markedly curtailed. On sunny or windy sites, too, the advantages of high average precipitation tend to be offset by high rates of evaporation.

A second important characteristic of mountain precipitation of the Intermountain region is the occurrence of high-intensity summer storms. Although these storms contribute only a minor part of total precipitation, they are responsible for most of the soil erosion and for summer floods.

Low temperatures prevail in the mountains, and the growing season is short. This season nearly coincides with the period of grazing, and the disadvantage of a short growing season is thereby intensified. A double burden is laid upon vegetation, for plants that maintain themselves under grazing must recover their food reserves and still complete their seasonal growth cycle, all in a few weeks. Although temperatures are low, freezing of the soil is slight because of insulation by the deep snow cover. Shallow frost heaving is common in spring and fall, with resulting injury or death to seedlings.

Three climatic levels may be distinguished, of which the first and most extensive is an *over-all climate* characteristic of the region. It is this climatic level with which human beings are most concerned, but for plants of a particular site, rooted as they are in one place, the over-all climate is modified by local topographic factors. This *local climate,* induced by topography, is at a second, less extensive level. Examples of differences in local climate are the contrasts to be found on a south slope as compared with a north slope, or on a ridgetop as compared with a valley.

Finally, at the third and least extensive level, is a *microclimate.* Microclimate is that climate at the surface of the ground and most immediately under the influence of vegetation. It is a modification of the local climate by vegetation as local climate is a modification of over-all climate by topography. Microclimate includes all the atmospheric conditions beneath a vegetal canopy. In a timber stand the microclimate may extend for more than 100 feet above the ground surface; in an herbaceous stand it may be only a few inches in depth.

Living plants and the litter that accumulates on the soil surface alter the microclimate by casting shade and obstructing movement of wind. These influences result in lowered light intensity, more equable temperature, higher atmospheric humidity, and reduced evaporational loss from the soil, as compared with open spaces free of vegetation. The difference in an herbaceous stand can be appreciated on almost any clear day by placing one hand under vegetation and the other, at the same time, on exposed bare ground.

In combination with the influences of vegetation on soil and soil moisture previously described, the altered climate under vegetation favors a different and more luxuriant population of animals and plants than could endure if the protecting vegetation were not there. The site can be occupied by species of plants that are too demanding in their requirements to withstand the rigors of climate in the open. Successful reproduction of desirable herbaceous species may not occur where the sheltering influence of vegetation is lacking. The process and rate of soil development also are influenced by the altered climate under vegetation and the organisms that flourish in it. Near the ground level even lowly herbaceous vegetation may do an important job of air conditioning.

Microclimate is of more practical significance than either local climate or over-all climate, because it is the one climatic level that can be influenced through manipulation of grazing. If the vegetation is allowed to grow tall, casting plenty of shade and litter, the establishment of seedlings of the more moisture-demanding species in the stand is encouraged.

## Topography

Topography, or configuration of the land surface, includes degree of slope, direction of slope, and position of any part of the land surface in relation to adjacent parts.

The effect of topography upon climate is perhaps its most obvious influence, for everyone has experienced the difference in temperature and humidity of different exposures on a hot summer day. Topography has much to do with air movement, distribution of rainfall, and accumulation of snow, as well as with temperature and humidity, from place to place. Its effect upon season is manifest not only by a progressively later season with increase in altitude, but by variations in season at the same altitude. Thus at a time when midsummer has arrived on south-facing slopes, as attested by vegetation already brown and dried, the local season may be early spring on nearby snowbank areas. These variations may give rise to abrupt differences in range condition, for the attractiveness of small spots of lush, early-season forage often results in heavier and more continuous grazing, and more severe compaction of the soil by trampling, than prevail over the range generally.

Topography also modifies the character of vegetation of mountain range watersheds through the kind of local climate it creates and through the relation of land surface to the water table. The natural instability of surface on some very steep slopes, too, favors dominance by plants adapted to such sites.

Distribution of animals, variations in the intensity of grazing and trampling, and resulting changes in range condition, are closely related to character of topography.

The influence of topography upon soil formation is partly a result of its influence upon local climate and upon the type of vegetation the site supports, and in places upon drainage. At any one spot, normal rates of soil accumulation and of soil loss are materially affected by the topographic situation of that spot, and thus depth of soil mantle is very closely correlated with character of topography.

In these ways and others, topography influences climate, vegetation, and soil; but these also influence topography. The influence of vegetation on topography is subtly manifest by the even, rounded contours of slopes that have been densely vegetated for centuries. These surfaces, comparatively gentle elevations and depressions, are made possible by vegetal stabilization and chemical weathering of irregular rock materials, and they reflect the age-long concurrent development of vegetation and soil. They reflect, in fact, the concurrent development of slope surface with vegetation and soil. This influence of vegetation on topography is more dramatically apparent on such slopes after its vegetal cover has been destroyed: the once-smooth surface is quickly cut up into a miniature badland by gully systems.

As another example of interrelation, the contrasting climates and corresponding contrasts in vegetation and soil of north and south exposures produce marked differences in length and steepness of slope: south-facing slopes tend to be long and gentle, north-facing slopes short and steep. This difference results from differences in rate of normal geologic erosion on the constrasting exposures. The erosion rates relate to character of vegetation and soil, and these in turn to local climate. There is thus an interlocking organization of cause and effect, with many reciprocal relations, between these components of the range-watershed complex.

While most indicators of range condition and trend relate directly to vegetation or soil, certain indicators are topographic. The rounded surfaces of vegetated slopes have indicator significance. So also have the gullies that dissect them. A flood plain or an alluvial fan is a topographic phenomenon indicating an area of deposition. If either is incised by a gully, the indication is clear that a process of deposition has been superseded by a process of erosion. Where this has happened it is well to look to the condition of the cover in the drainage basin as a possible cause of abnormal runoff.

Topographic factors must be taken into account in judging condition and trend, as well as in other phases of range management. "Key areas," for example, are often determined by the influence of topography on the distribution of animals, or by its influence on erosion potential. Again, in making comparisons between ranges under differing management, judgment must be weighted by considering to what degree the sites are comparable. For comparability, sites should be essentially similar in topography.

## Interrelations Between Components of the Range-Watershed Complex

The fact that management practices modify not only forage but set in motion an array of interrelated forces, gives rise to the term range-watershed *complex*. The term *complex* is used to emphasize the significant interrelations that exist on the range and to mark a difference from the oversimplified concept of range condition as being essentially only forage production. Emphasis on the range-watershed complex as a whole does not depreciate the products of management—forage and water—with which the range manager is most directly concerned, but serves to put these products in true relation to the environment that produces them.

The concept of the range as a complex or system made up of interrelated parts aids an understanding of how invasion of an aggressive species of plant may result in alterations of soil and microclimate so far-reaching as to affect the entire population of plants and animals. The wholesale invasion of a new species of animal might result eventually in just as complete a total change. In the closely integrated complex any change may be almost automatically transmitted through a chain of action and interaction to produce far-reaching changes in the complex as a whole. This, in general terms, is the essence of ecological succession.

## HOW THE RANGE-WATERSHED COMPLEX CHANGES

The range-watershed complex is never static, but constantly undergoes change. Normally the change is very slow and is marked by the progressive invasion of certain species and elimination of others. Such orderly change is called "succession." It is necessary in consideration of condition and trend to distinguish two kinds of succession, primary and secondary.

Primary succession begins by the invasion of vegetation on bare areas not formerly occupied by plants and continues by normal development of vegetation and soil toward a climax determined predominantly by over-all and local climate. Examples are successions on talus slopes, on bare rock surfaces such as might be produced by glacial scouring, on glacial moraines, or in lakes.

Secondary succession begins by the invasion of vegetation on bared areas formerly occupied by plants, and hence possessing a soil, or it may consist of successive changes resulting from some disturbance, like the replacement of brush fields (that have followed fire) by coniferous forest. Secondary succession may be favorable or unfavorable to grazing; and grazing itself may set a secondary succession in motion (fig. 5).

Succession involves more than a sequence of changes in dominant vegetation. Parallel successional changes also take place in the understory vegetation, in the population of other organisms—of small mammals and insects, for example—and in microflora of the soil. Moreover, the physical environment itself undergoes change—soil, microclimate, and even microtopography. Thus succession is change in the complex as a whole, and change in dominant vegetation is but the mark of this total succession.

### Primary succession

The range-watershed complex is rooted in the past. The complex as a whole, and each of its component parts, is the product of slow successional change over a long period of time—change that is still going on, except as it may be disrupted by secondary succession or destructive change. Various stages in successions of several different types may be observed readily in the mountains. Perhaps the type most

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FIGURE 5.—Small bushes in grassland near edge of dense stand of Rothrock sagebrush (*Artemisia rothrockii*, right) indicate succession from grassland to sagebrush. Most bushes in the dense stand are 30 years old or more, while most in the grassland are 10 years old or less. Invasion of sagebrush into this once fairly moist swale was caused by overgrazing which exposed the soil and made the site abnormally dry.

characteristic of mountain slopes is that which begins on loose rock.

The initial stage may be a cliff disintegrating into fragments of rock that accumulate in all sizes at its base, forming a long talus slope. At this stage the complex is relatively simple. It has little or no soil; its vegetation is represented only by pioneer lichens and mosses; and its animal life is represented only by a few insects that feed or breed on these plants, and an even fewer number that prey in turn upon them. In time a little soil, formed by pioneer plants or blown or washed in from elsewhere, accumulates between the rock fragments, and larger plants—forbs, grasses, shrubs, and trees—become established in the interspaces. As centuries pass, the spaces between fragments of rock fill up with an accumulation of finer materials, rock fragments disintegrate into smaller pieces, and a more luxuriant vegetation and a more varied fauna develop. Spreading foliage shelters rock surfaces that were formerly exposed, litter accumulates on them, and the cover of soil and vegetation gradually becomes more and more complete (fig. 6).

The more luxuriant the vegetation becomes, the more completely it controls the microclimate and deepens the soil; new species of plants and animals enter the complex, and old ones give way. On some sites an aspen forest may invade and be succeeded by a conifer forest. Or, on other sites, succession may proceed from scattered trees and brush, with an herbaceous understory, to a dense stand of grasses and forbs (broadleaved herbs) as a soil profile characteristic of grassland is developed.

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Figure 6.—Talus slope on which soil is being formed and vegetation, consisting of several species of forbs, grasses, and shrubs, is developing. This succession has proceeded so far in middle distance that a complete cover of soil and vegetation has developed there. Trees in background are part of another succession on a different site.

If the succession can continue sufficiently long under constant external conditions, a status is reached in which comparatively little further change takes place. The character of soil, of microclimate, and of plants and animals—in a word, the character of the complex—remains about the same indefinitely. This is the climax. Even the climax, however, is not static. Like the stages that lead up to it, a certain turnover in biota and soil is constantly going on; the slow, continual loss of soil is made up by the continual formation of new soil; plants and animals die and are replaced; fluctuations in external influences occur, and the complex adjusts itself to them.

## Balance in the complex

In all stages of primary succession the many elements making up the range-watershed complex are in essential equilibrium with one another. From the time talus reaches its angle of repose and soil begins to accumulate between the rock fragments, until the climax is attained, each element of the complex is in essential balance—or adjustment, or harmony—with every other element. Changes are exceedingly slow. As one element changes the others also change, and they change in such a way that harmony within the whole is preserved.

Nowhere is successful balance within the complex more clearly manifest than on steep slopes (fig. 7). Here, under the influence of a particular climate, parent material, and topography, a soil has de-

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FIGURE 7.—Grass-covered slopes of 90 percent, 20 percent steeper than the angle of repose of the loose parent material. Salmon River, Idaho.

veloped and deepened over hundreds of years, while vegetation and animal life have undergone parallel successional development. The steeper the slope the more certain it is that soil and vegetation must have developed interdependently. Lacking soil, vegetation could not have clothed the slope; lacking vegetation, soil could not have been formed and retained in place. They must have grown up together; for at any stage in development either would have been impossible without the other. Proof is provided by the fact that if present vegetation is removed the soil erodes rapidly, and in time the smooth surface of the slope becomes gashed with gullies.

The significance of balance to range condition, particularly on range with steep slopes, is intensified by considering fluctuations in weather. The fact that development of soil and vegetation requires a span of time to be reckoned in thousands of years, a period long enough to include all extremes of weather, not only the most violent storms but prolonged dry spells, indicates in itself that an essential balance has persisted through many environmental changes.

Figure 8, derived from records at a valley station, illustrates the recurrence of periods of dry and wet years as a normal feature of climate. Note that although a cyclic tendency is suggested, there seems to be no permanent trend, no true climatic shift during the half-century.

Persistence of a soil and plant cover on steep slopes through the centuries during which similar fluctuations undoubtedly occurred is proof that the complex is resilient enough to absorb these natural impacts rather than be destroyed by them. During these many centuries the various components of the complex have undoubtedly had to adjust themselves to changes other than those in weather—fire, and changes in grazing use by wildlife, for example. That a soil mantle and

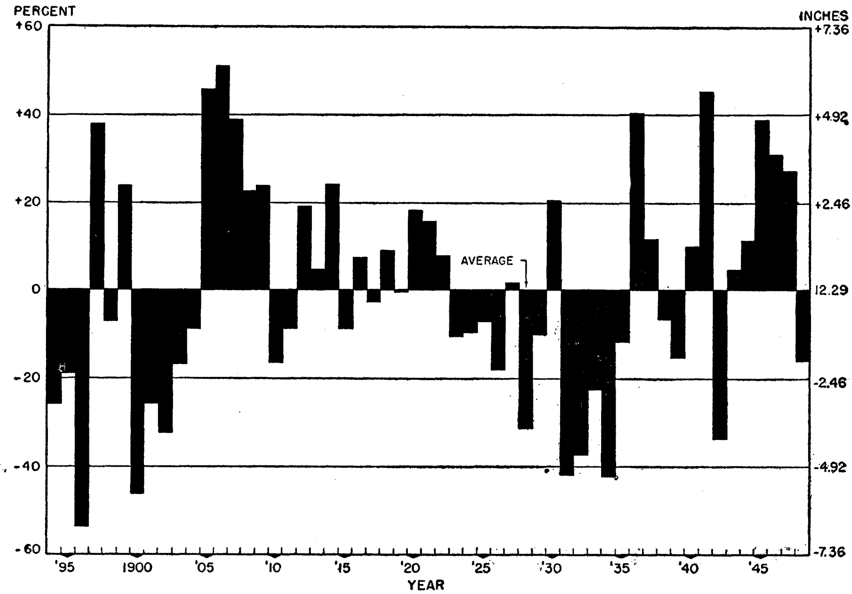


FIGURE 8.—Deviations from average annual precipitation at Manti, Utah, elevation 5,575 ft., 1894-1948 (U. S. Weather Bureau records).

vegetal cover have persisted is the best possible evidence that the adjustments have been made successfully and hence that balance between the various components has been maintained throughout.

Thus an intact soil mantle is a record of a long period of balance. This fact has a basic value in judgment of range condition, even where the soil mantle may no longer be intact. Areas of partly eroded soil or subsoil are evidence that a complete soil mantle once existed (fig. 9). Evidence that the soil mantle has been recently destroyed is proof that some powerful stress, of greater magnitude than normal stresses of the environment, has been placed upon it.

## Secondary succession

Examples of secondary succession—orderly change in which a soil mantle, or at least part of the mantle, is present—may be seen wherever vegetation has been disturbed. The most familiar example, perhaps, is the reinvasion of abandoned cropland by shrubs or trees. Fire, as well as the plow, prepares the way for secondary successions: sagebrush or other shrubs may come in on burns, and be succeeded in time by conifers. The sequential changes in plant composition that take place, either as a direct result of disturbance or as release from disturbance, along highways, railroad rights-of-way, or from flooding, draining, mowing, or heavy grazing, are all examples of secondary succession.

If one were able to reconstruct the past, he would find an example of secondary succession on practically every area of high mountain range in the Intermountain region. Vegetation has improved general-

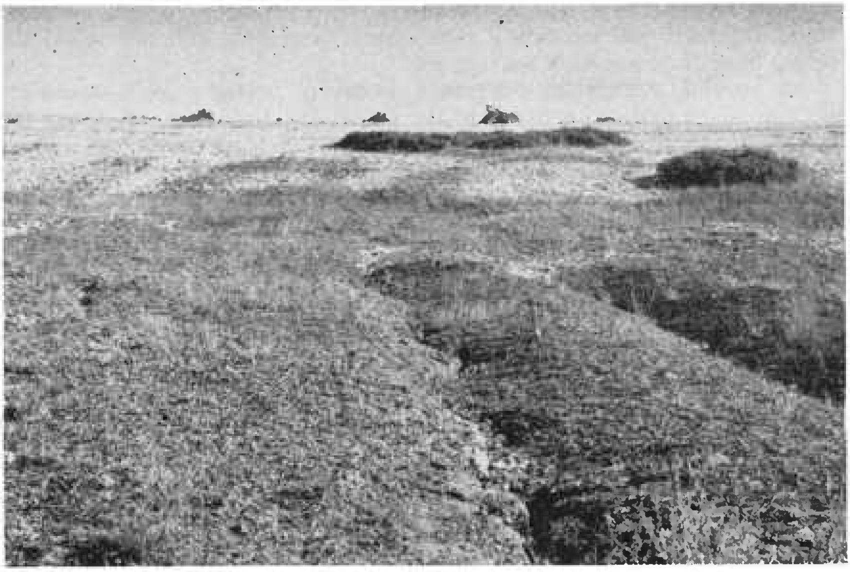

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FIGURE 9.—An eroding slope with erosion pavement and soil remnants in background, gullies and exposed subsoil in foreground. These indicators suggest that the soil mantle originally extended over the entire slope, even where no soil is now evident.

ly, both in kind and in amount, where management has replaced the exploitative grazing practices of early days. Although permanent plot and photographic records attest the improvement that has occurred in many places, there are no records on most of the range. These changes are recognizable today only in the indicator aspects of vegetation and soil—healed gullies, former wind-scoured depressions now clothed with vegetation, etc.

Many secondary successions under grazing are undesirable trends, usually resulting from differences in palatability of different species to a given kind of grazing animal. The most palatable species are grazed closest and are handicapped; the least palatable species are passed by and, in relation to the others, are encouraged. The result is a trend toward a stand containing a smaller proportion of palatable plants and a larger proportion of unpalatable plants. Other factors than palatability may play a part in secondary succession due to grazing—growth form, physiological requirements, and season of development in relation to time of grazing, may be just as important. As a result, some fairly palatable species—e.g., dandelion, which happens to be undesirable for other reasons—may actually increase on overgrazed range.

There are two important differences between primary and secondary succession. First is a matter of time. A complete primary succession on high mountain range land involves development of a soil mantle and requires a very long time, probably thousands of years. Any substantial segment, such as development from one well-marked stage to another, is probably to be reckoned in centuries at least. Secondary succession, on the other hand, taking place where soil is already in existence, is relatively rapid, and recognizable changes may take place in a very few years or decades. Hence, to achieve short-term objectives, such a betterment of range condition within a lifetime, management must depend upon secondary successional processes, and not upon the slow changes of primary succession.

A second important difference between primary and secondary succession is that, whereas primary succession follows a relatively set course determined by all the natural factors of a given site, secondary succession may take many courses, depending on the kind of disturbance or pressure applied. Vegetal composition may be changed by grazing, first in one direction and then another in a great variety of ways, depending on the kind of animals and the season and intensity of grazing.

These differences should not obscure an essential similarity between primary and secondary succession, however, which is that in both, change is orderly. In secondary succession, as well as in primary succession, vegetal control of the soil surface is maintained. If some soil loss does occur, increase in vegetation is so rapid that the loss is soon checked.

## Destructive change

When vegetal control is lost and erosion sets in at a rate that is accelerated rather than normal, the principal changes are no longer evolutionary, but revolutionary in character. The constructive development of soil, vegetation, and animal life that took place under prevailing topography and climate, is overwhelmed by destructive processes, and the orderly connotations of the term "succession" no longer apply. Instead, the term "destructive change" is used in this publication to describe changes that occur when accelerated erosion is involved.

Destructive change from overgrazing comes about in several ways. One is the effect of decrease in cover through excessive cropping of foliage. Besides the loss of established vegetation, the soil is abnormally exposed to the influence of sun, wind, and water, with corresponding chances for intensified erosion. The new, drier microclimate handicaps seedlings of most species. Another way that damage is done is by impairing the tilth of surface soil. Surface soil is normally porous in spring as a result of frost action and of alternate wetting and drying. In this condition water is readily absorbed. However, if its tilth is destroyed by trampling, the soil fails to absorb water quickly, and, in event of a violent storm, overland flow and erosion are almost certain to occur. Still another way that damage is done is by actual displacement of soil in trampling.

Accelerated erosion is conspicuous where gullies have been cut into the soil, or where the soil has been stripped down to a heavy erosion pavement (fig. 9). But erosion may be very rapid and still not be recognized, particularly on slopes where replacement from above makes up the quantity displaced below. On some soils, too, rills and even small gullies cut during storms are soon obliterated as the soil dries and sloughs down. Finally, erosion may be accelerated well above the normal rate and still be scarcely perceptible because the individual displacements are so slight.

These facts indicate the need for close observation of the soil surface, particularly during and immediately after storms. Accelerated erosion ought to be recognized early, not only so that damage can be prevented, but so that the most economical remedial measures may be applied. It is known that accelerated erosion, when well advanced, may continue under its own momentum until all the soil is lost, even though grazing is eliminated. The range area shown in figure 10 has not been grazed for 20 years, yet the cover-effectiveness of vegetation had been so completely reduced by the time protection was given that soil losses have continued. Thus, although simple management practices may suffice to check accelerated erosion in its early stages, in advanced stages costly artificial procedures are the only ones likely to be effective.

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FIGURE 10.—Deterioration on this area had gone so far 20 years ago when livestock were removed that vegetation has not yet increased to the point where it can stabilize the soil. Present vegetation (e.g., the low, tufted mint, *Monardella odoratissima*) is characteristic of sites naturally much drier than this, and indicates a radical alteration in microclimate here.

## Change and management

The foregoing ecological concepts have important bearing on judgment of condition and trend. The concept of balance, a normal state of integration between components of the range-watershed complex in which orderly successional change may take place, is basic to an understanding of range condition. Equally basic to an understanding of trend is the distinction between succession and destructive change. Appraisal of trend is simply the recognition of the nature, rapidity, and direction of ecological change.

The three kinds of change that have been distinguished relate differently to range-watershed management. Primary succession, a knowledge of which is fundamental to an understanding of the complex and its ultimate potentialities, ordinarily has little direct application to management. The changes involved in primary succession are too slow to be manipulated readily.

Secondary succession is utilized in management, for most management problems at the present time consist, essentially, in changing undesired to desired trends. A knowledge of the forage preferences of different animals, of seasonal changes in palatability, and of growth requirements of both desirable and undesirable species in the stand provides an important basis for using particular methods of grazing to solve particular problems.

Destructive change is also a matter of great concern in management. Unlike secondary succession, destructive change has no positive application: the problem in management is everywhere the same, to stabilize the eroding soil as quickly as possible so that constructive trends can take over.

# FUNDAMENTALS FOR JUDGING CONDITION AND TREND

Judgment of range condition in any one place depends, first and foremost, upon whether all components of the range complex are in essential balance. When these components are well integrated, orderly change or succession is possible; balance, therefore, does not rule out change.

## CONDITION

Range condition has been called "range health." The parallel is apt. Like health, condition is relative, and when a particular piece of range is described as being in "good condition" or "poor condition" the description is always relative to a standard or ideal for that kind of range—its full potentiality in soil stability and in amount and quality of forage.

An essential of satisfactory condition is successful balance within the range-watershed complex. Normal soil stability or, put another way, an amount of vegetal cover adequate to protect the soil from accelerated erosion, is a practicable index of such balance. Figure 2 (p. 5) illustrates this aspect of satisfactory condition. Foliage, together with litter on the ground, protects the soil and assures stability necessary for continuing normal development.

But stability alone is not enough to define satisfactory condition. A second requirement is that the vegetation include a large proportion of desirable forage species. In figure 2, for example, the mixture of several forbs and grasses of varying degrees of palatability meets this second requirement for that particular area.

Unsatisfactory condition results when any one of the requirements for satisfactory condition is lacking. Most important is lack of normal soil stability. The elements of unsatisfactory condition—in fact, of extremely unsatisfactory condition—may be illustrated with another picture taken in the same type as figure 2, and on the same hillside, but on an area that has been overgrazed for many years (fig. 11). Here, in the first place, balance between soil and vegetation has long been upset. Vegetal cover and litter are scanty. Sizable bare spaces have developed and coalesced, and as a result of exposure fine soil particles have been lost, leaving an erosion pavement. Rapid movement of surface soil is indicated by the accumulation of fine materials and even gravel against the uphill side of grass tufts. Another indication that balance has been lost lies in the absence of grasses in young and intermediate age classes; microclimate at the unshaded surface of the ground is probably inhospitable to seedlings. Finally, there is a contrast in species composition—against a mixture of many species, some of high forage value, the almost exclusive presence on the overgrazed range of a single coarse, rather unpalatable grass.

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FIGURE 11.—A stand reduced by selective grazing almost entirely to one rather unpalatable grass. Absence of young and middle-aged plants emphasizes the very unsatisfactory condition indicated by bare soil and trampling displacement.

For purposes of this publication range condition may be divided into four broad classes, as follows:

1. Soil stable under a normal or near-normal amount of vegetal cover; a high proportion of desirable forage plants: *satisfactory condition.*
2. Soil stable under a normal or subnormal amount of vegetal cover; a low proportion of desirable forage plants: *unsatisfactory condition.*
3. Soil unstable under a subnormal amount of vegetal cover; a high proportion of desirable forage plants: *unsatisfactory condition.*

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4. Soil unstable under a subnormal amount of vegetal cover; a low proportion of desirable forage plants: *very unsatisfactory condition.*

The first of these classes does not occur widely on high range-watershed lands of the Intermountain region today. The second may be encountered in meadows and level uplands where the erosion potential is not great; it is also rather common in forest types, particularly aspen, where the overstory provides litter for soil protection. The third is almost never met with now, although after the first impact of excessive use it may have been fairly common on sloping lands. The fourth is very common, especially in herbaceous types on well-drained, sloping lands in the alpine and subalpine zones.

Within each of these broad classes further division may some day be made within major vegetal types. For example, under the first broad class, all degrees of desirability in species composition can be conceived, depending on the combinations of species that are possible and the relative abundance of each in the stand. Similarly, within the last many rates of soil loss are possible, ranging from slow to fast, but all in excess of the normal rate. Such refined classification, both in regard to vegetal composition and soil erosion, will probably be found feasible when specific complexes have been carefully studied.

## The normal a basis for judgment of range condition

In deciding on the condition of a particular piece of range, judgment must spring from an understanding of the normal for such a situation—not normal in the sense of usual or prevailing, but in the sense of natural, undisturbed, or pristine. For most practical purposes the best available approximation to this undisturbed state is given by relic areas that have never been grazed by domestic livestock, excessively grazed by game, or otherwise disturbed.

This should not be interpreted to mean that an undisturbed, pristine range is the objective in management. The pristine serves only as a guide to indicate what species and what volume of herbage the site is capable of supporting, the normal character of litter cover, and the normal appearance of surface soil. It gives the essential characteristics of the range likely to be achieved under successful management, but not necessarily details such as a desired species composition.

For any piece of range there are certain limits within which condition must be judged. These limits are imposed primarily by site factors of climate and topography and by status in primary succession. Stages in secondary succession resulting from grazing are sometimes used as degrees of condition. Stages in primary succession cannot be used in this way, however, for the reason that well-marked stages in primary succession are separated by immense spans of time—hundreds or thousands of years rather than decades as in secondary succession. Each particular stage of primary succession itself determines a potential that may be achieved within a reasonable time, and it is with respect to this potential that condition should be evaluated. Comparison can justly and practicably be made only between ranges of similar potentiality. Condition of a wet meadow, for example, should be judged by the soil stability, herbage production, and species composition of such a meadow, not by those characteristic of a dry upland site. Similarly, north slopes should not be compared with south slopes, aspen forest with open grassland, nor conifer forest with aspen.

An important feature of the normal is that fluctuations in weather are part of normal climate. Fluctuations in weather must be accepted as normal events, and effort must be made to distinguish the effects of grazing from them in judging range condition. Variations in amount of rainfall and in the monthly pattern of distribution of rainfall cause natural variations in volume of vegetal production and response of different plants. Probably they also cause variations in the normal rate of erosion. On high mountain range-watershed lands these variations are of a minor order compared with the changes that take place in the long process of soil development and primary plant succession. This long process has included many of the same extremes of weather we experience today, and probably even greater ones.

It follows that variations in weather alone cannot account for such indicators of accelerated erosion as incision of a soil mantle by an active gully system. Soil mantle and gully system cannot both be normal; the two are irreconcilable. The same may be said for occurrence of bare soil surfaces unsheltered by vegetation, wind-scoured depressions, observed movement of soil, soil displacement by trampling, pedestaling of plants by sheet erosion, and widespread accumulation of gravel at the soil surface to form erosion pavement. On high mountain range land none of these indicators is compatible with development of a soil mantle.

## TREND

Trend is change in condition. When a trend takes place, some kind of change in every component of the complex may be expected to occur. For the purpose of using the indicators of trend described in this publication, however, it will be necessary only to consider changes in soil and vegetation.

In speaking of trend, one must distinguish between those cumulative changes that produce a real difference in condition and changes that are mere fluctuations. A large crop of seedlings of certain desirable perennial species, for example, may reflect only a temporarily favorable combination of circumstances. One would be surer of an upward trend if he found, in addition to the seedlings, plants of successively older age classes.

### Trend when soil is stable

On most sites in the mountains a prerequisite for stable soil is a fairly dense cover of vegetation and litter. On some sites, however, particularly where slope is slight and soil is not greatly exposed to drying and blowing, a sparse cover may suffice to hold it. These two circumstances present two rather different problems in judging trend by means of indicators.

With normal or near-normal cover there are no known indicators with which, merely by inspection, change in *amount* of vegetation can be detected. Records on permanent plots over a period of years are especially needed to detect such trends. Changes in *proportion* of species in the stand are more easily detected, both by permanent plot records and by indicators. Evidence of increase in desirable species is evidence of improvement, while increase of undesirable species is of course the reverse.

When amount of cover is abnormally low, evidence of change in amount of vegetation is usually easier to detect. Scanty cover usually means either that fairly large bare surfaces exist or that annuals and early-season perennials predominate. In either case, the extent to which perennials have recently invaded bespeaks an increase in amount of protective cover. Rate of invasion is indicated by age classes, and with this the residue of litter from past years and extent of current utilization are likely to be correlated. A circumstance that indicates increase in vegetal cover is evidence of a formerly unstable surface that has become stabilized, e. g., healed gullies or other types of erosion surface that have been reclaimed by perennial vegetation. Perhaps it is too much to infer that this increase in vegetation is continuing currently, but the indication is at least one of upward trend in the recent past.

### Trend when soil is eroding

While soil is eroding the amount of vegetation does not necessarily decrease, though it may. Ultimately, of course, very little vegetation will remain if the soil is destroyed, but for long periods while erosion is going on the amount of vegetation may appear essentially constant, or it may even increase. Similarly vegetal composition may or may not improve. Far from being rare, such paradoxical combinations of trends are common on herbaceous subalpine slopes in the Intermountain region.

There can be no question but that net trend is downward when soil is eroding and either amount or quality of vegetation is decreasing. There may be a question, however, when the two trends are in different directions. In such a case, since one cannot add unlike things, a precise judgment is not possible.

It is possible, of course, to describe the trends rather precisely in separate terms and suspend judgment as to net trend. Such a description may be cumbersome and difficult for some people to understand, but it is capable of giving a better picture of what is happening than any single term. In reaching a decision about net trend, however, it it not so necessary to be precise as it is to weigh the facts realistically. Whether loss of soil be fast or slow, so long as the rate is greater than normal, the basic resource is being destroyed. This is a fact of tremendous weight. Any increase in vegetation is important in cutting down the rate of loss, but no increase in vegetation can compensate for soil that is gone. In the authors' opinion, therefore, the prudent judgment is that trend is downward unless evidence to the contrary is very strong.

## Relation Between Condition, Trend, and Utilization

It is necessary to distinguish sharply between condition and trend. Condition is the status of the range. Trend is the way in which that status is changing. Utilization is one of the most important causes of trend, and hence ultimately of condition. The relations between these three are, very simply, that *utilization* (together with other influences of the animals besides cropping) may set an upward or downward *trend* in motion, and if it does a different *condition*, or status of the range, will result.

# OBJECTIVES

## The Primary Objective

Mountain range-watersheds are multiple-use lands, yielding a variety of products and services. Since a stable soil is basic to them all, the primary objective in management is to maintain and improve those soils that are stable and to stabilize those that are now eroding. An axiom of sound management is that *stable soil is prerequisite to satisfactory condition on any area where a soil mantle has been developed.* This principle is applicable to range anywhere and relates to any normal vegetal cover; it does not change with site or with type of vegetation. If the cover is lost, the soil is lost; and with the soil gone there will no longer be a resource. If the soil is partly lost and then stabilized, which is the best that can be done now with many high range-watershed slopes, the resource will be but partly restored. Full restoration of soil will probably require centuries. The practical objective, therefore, is to develop and maintain a cover adequate to assure soil stability as quickly as possible.

How is one to know what adequate protective cover is on any particular site? Comparable natural areas, if any can be found, may tell him. The grazed range itself provides valuable opportunities to develop guides. If one makes it a point to be out on the range during and immediately after torrential storms (and during is better than after), he can see which kinds and amounts of cover appear adequate to protect the soil, and which plainly are not.

Criteria of inadequate cover are surface washing during storms or evidences of runoff afterward—at the least rill marks, pedestaled pebbles, and tiny alluvial deposits. If water does not run over the surface, the cover may be presumed adequate to protect the soil against storms of that particular intensity and duration. A satisfactory cover for that kind of site, in other words, must be at least similarly dense and well dispersed. Further observation during still more intense storms may cause upward revision of these preliminary standards of cover adequacy. Improvement in range-watershed management is greatly dependent on standards built up from widespread observation of this kind.

If the soil is stable, maintenance of that stability and improvement of soil and vegetation often may be achieved simply by manipulating the grazing. Even when the soil is eroding, simple management practices may increase the amount of vegetation so as to bring about stabilization, if certain requirements can be met. These requirements are that most of the topsoil is intact, that slopes are not particularly steep, and that a sufficient stand of erosion-preventing perennials remains to provide a seed source. When these requirements cannot be met, artificial planting will be necessary. Where much soil has been lost and erosion is rapid, still more costly measures must be taken—not only reseeding, but artificial mulching or contour trenching.

### SECONDARY OBJECTIVES

Secondary objectives are products of the land. So far as range-watershed management is concerned these objectives are a full, continuing supply of desirable forage and well-regulated stream flow.

The vegetal types most desirable from the standpoint of water yield are those that use up least water in transpiration. Nevertheless, irrespective of the water it consumes, a certain minimum cover must be maintained to protect the soil and hold it firmly in place. Although it appears probable that shallow-rooted species consume less soil water than deep-rooted species, too little is yet known about water consumption and soil protection requirements to permit recommending one type over another.

With forage the situation is different: certain types and subtypes are known to be more desirable than others. The secondary objective in management is therefore to develop that combination of species which, within the productive potential of the site, is most desirable as forage. As part of this objective, management will naturally attempt to reduce the undesirable species.

In general, a mixture of many species is better than predominance by one or two. And, as a matter of practical necessity, until nutritive values of more forage plants are known, the most palatable species are regarded as being highest in forage value. In making this approximation to forage value one is not concerned with pleasing the palates of the animals, but simply with providing a large volume of herbage they will eat readily with a minimum of travel and trampling.

## INDICATORS

An indicator is a sign in the vegetation, soil, or topography, which may be used to interpret condition or trend in the complex. Stated another way, an indicator is a clue to events that have happened, are happening, or will happen on the range-watershed. This publication emphasizes indicators associated with soil and vegetation on range-watershed slopes where grazing use is taking place. Indicators that do not exist on the range itself, like downstream channel cutting and flood deposits, will not be considered here, even though they are valid evidence of events that have happened on the watershed.

The indicators described here are mostly of wide application and are not restricted to any single plant community, type, or subtype. They apply particularly to herbaceous vegetation in the subalpine zone, but most of them are applicable in greater or less degree in other zones. Naturally they must be employed with caution on range at a distance from the subalpine zone, for with increasing distance the basic premises about the character of the normal complex become increasingly different.

Absence of an indicator may, in itself, have indicator value. The absence of rill marks and recent cutting in gullies, for example, may indicate that accelerated erosion has been checked. As a rule, however, absence of an indicator is very weak evidence and depends for its validity upon the support of independent, positive evidence. For this reason one cannot give the same weight to the positive and negative aspects of an indicator. Thus, absence of rill marks or fresh gully cutting may mean, not that accelerated erosion has been checked, but only that storms of sufficient intensity to produce these effects have not occurred for some time.

As a matter of fact, few indicators have absolute value which permits them to be used mechanically. To interpret a single indicator correctly it is usually necessary to have additional evidence. Several indicators are usually observable on any range, and each may have a bearing on condition or trend. For the sake of brevity it is necessary to treat the indicators as if they occurred alone rather than in combination with other indicators as they naturally occur. This treatment may seem to give each indicator an arbitrary and absolute significance. In application, however, no one indicator should be accepted at the full value ascribed to it here without due consideration, from evidence of associated indicators, of the extent to which that value actually applies.

Consideration of each indicator in the following pages will, so far as possible, cover four points in the following order: (1) Definition of the indicator; (2) how to recognize it in the field; (3) what it indicates as to range condition; and (4) what it indicates as to range trend.

## COVER

Cover includes both vegetation and litter as they overlie the surface of the ground. It is made up of the spreading crowns of living plants and the dead organic matter that accumulates on the ground surface. That litter lying in openings rather than under foliage, and thus complementing crownspread cover, is the part of the litter cover that is most important from the standpoint of condition and trend.

Amount and character of cover naturally vary greatly according to kind of vegetation. In a closed coniferous forest, cover may really be complete, even though the understory vegetation is sparse, because litter forms a continuous carpet an inch or more deep. It differs from the litter of dry grassland in being formed primarily from the coniferous overstory, and owes little to the foliage of herbs, grasses, and shrubs, which are usually sparse. Grassland other than wet meadow, in contrast, seldom forms a complete cover. The volume of herbage may be great in a normal stand, but if one looks vertically downward, he will usually find many openings among the leafage. In some of these litter is thin and broken, with a certain amount of bare soil exposed. It is necessary to pay particular attention to these openings in evaluating cover, in order to give proper weight both to litter and to bare ground. The eye tends to be unduly impressed by foliage, which is high lighted, and to ignore the many small openings between leaves and between plants, which are overshadowed. When quantitative estimates of cover are made, as a proportion of the total ground surface, the same consideration should be given to bare surface and to litter as to leafage.

A characteristic of normal cover is a high degree of dispersion, which, for effective soil protection is as important as a large amount of cover. Figure 12, *A* shows a thin cover of poor-quality vegetation, but it happens to be fairly well dispersed and holds the soil much more efficiently than the patchy vegetation in figure 12, *B,* which gives only localized protection.

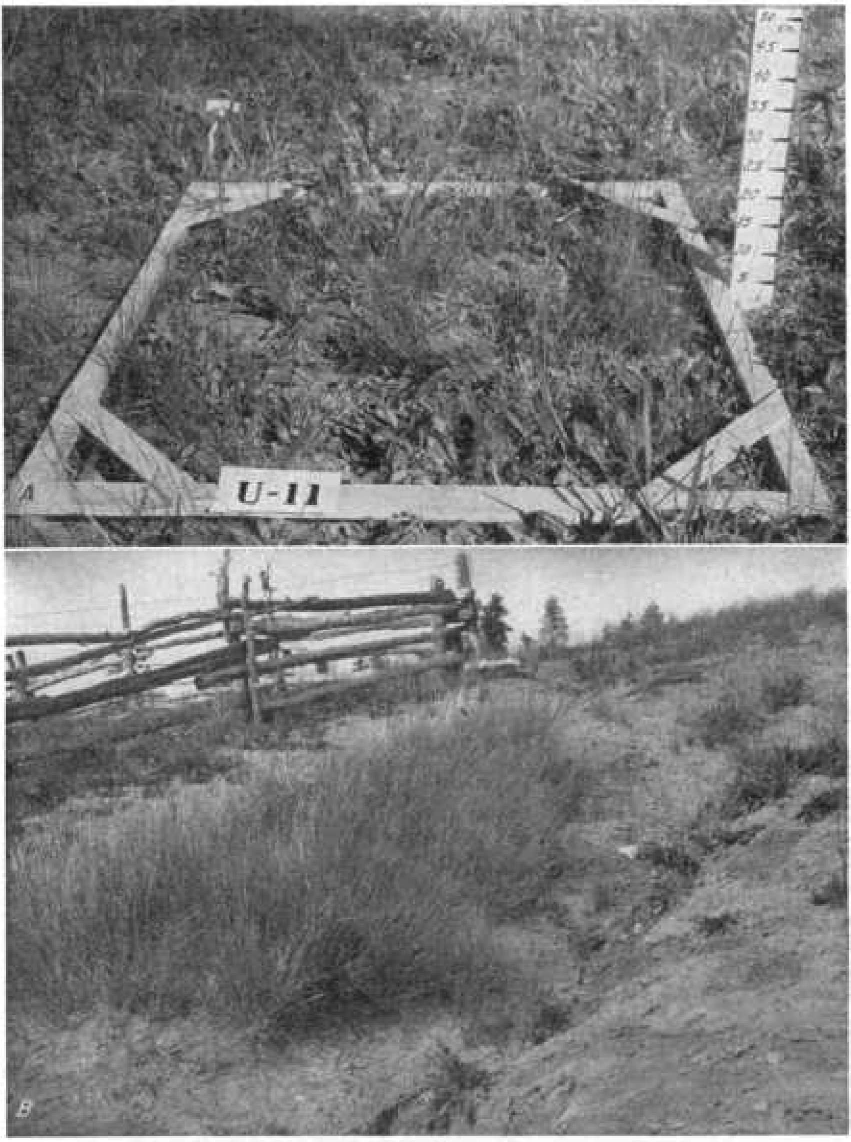


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FIGURE 12.—*A*, Well-dispersed vegetation and litter, with small, scattered openings, tend to provide better soil protection than *B*, poorly dispersed vegetation. Although growing in dense patches, this cannot protect adjacent bare surfaces against erosion.

*Condition.*—On mountain range-watersheds in satisfactory condition cover of perennial plants is essentially complete, even though small openings are a normal feature of many herbaceous types on slopes and other fairly dry situations. On many subalpine slopes of moderate steepness, a cover of well-dispersed vegetation and litter together should amount to between 50 and 75 percent. To the casual eye either of these amounts of cover appears practically complete. While obviously only approximate for general application, these figures may serve as a useful rule of thumb for moderate slopes until more specific values are determined. On wet meadows in satisfactory condition, on the other hand, under the most critical inspection leafage cover is often 100 percent, particularly when the growing season is well advanced. If openings between the leaves exist, these are covered by litter so that total cover is still 100 percent; no bare ground can be seen.

When cover of perennial plants is less than that normal for the site, even though it may not permit accelerated erosion, unsatisfactory condition is indicated on two counts. First, reduced cover reflects reduced volume of forage, and second, it is associated with a microclimate that is drier than normal. A drier microclimate will lead to, if it has not already brought about, a change toward dominance by more xeric (drought-resistant) species than are normal for the site. In other words, a material reduction both in quantity and quality of forage commonly accompanies a material reduction in cover.

On most range-watershed lands of the Intermountain region any material reduction in cover of herbaceous types is accompanied by accelerated erosion. Condition in this case is still more unsatisfactory than that described in the last paragraph. Many degrees of unsatisfactoriness are possible. The incipient stages of accelerated erosion on slopes, when cover is just beginning to break, are detectable only during infrequent torrential storms of very great intensity—perhaps once in 20 years or more. At the other extreme, when little cover is left, accelerated erosion may be seen after every storm of moderate intensity; the signs are freshly made several times each summer in most years. For such an extreme in unsatisfactory condition the indicator "bare soil surface" is more appropriate than "cover."

*Trend.*—Changes in amount of cover are a very important element in range trend, whatever the condition may be. A desirable change usually involves increasing cover; an undesirable change, decreasing cover. Increase or decrease of cover may be inferred from several other indicators—"soil remnants," "vegetal composition," "age classes," "invasion of bared surfaces," and "vegetation in gullies," presented later.

Amount of cover by itself is not an indicator of change, but of condition. Where the amount of cover is slight, and consequently the soil is abnormally exposed, trend is almost certainly downward (see "bare soil surface").

## Bare Soil Surface

"Bare soil surface" means a soil surface that is not sufficiently covered with vegetation and litter for protection against accelerated erosion. The term has reference either to generally scanty cover (fig. 13) or to abnormally large spaces devoid of a vegetal cover (fig. 14, *B* and *C*).

Since some bare spots may be found even on virgin range, and larger bare spots, more conspicuous but of a temporary nature, may occur as a result of burrowing by animals, one needs to have some conception of the normal to use this indicator. In general, bare spots that occur normally on mountain range land are small and well dispersed. At the other extreme, when plant cover is very greatly reduced it is not difficult to detect that the soil is so bare that vegetal control of the surface is lacking. Rill marks after every rainstorm, wind-scouring

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FIGURE 13.—Bare soil surface. Although plants are distributed fairly uniformly, the stand is so thin that vegetal control is far below normal. Pedestaling of the older plants indicates continuing loss of soil. The species present reflect harshness in the site and soil instability: Yarrow *(Achillea lanulosa)*, the plant with white flowers, can spread in this eroding soil by vegetative means; dandelion *(Taraxacum officinale)* and slender wheatgrass *(Agropyron trachycaulum)* are aggressive seeders capable of reproducing on a bared surface of this character.

after every dry spell, and almost complete mortality of seedlings, indicate that vegetal control is inadequate. But with range in less extreme degrees of deterioration, lack of control becomes increasingly hard to detect. Even though plant cover may fall considerably short of normal, its ineffectiveness may be apparent only for short periods after occasional severe storms.

*Condition.*—No bare ground should be visible on wet-meadow range in good condition, and that which may be present on drier uplands and slopes should not be evident upon casual inspection. Closely examined, uplands and slopes in good condition may show small and well-dispersed bare spots, aggregating no more than 30 to 50 percent of the surface. If the proportion of bare soil is very much greater than 50 percent, there is cause for alarm.

For a given site the greater the proportion of area in bare soil surface, the more unsatisfactory the condition. The process of enlargement of bare spaces on a level, turfy, subalpine range is illustrated in figure 14. The turf in *A* is almost solid, forming an effective protective cover. The turfs in *B* and *C* are in progressively less satisfactory condition because of smaller amounts of cover coupled with greater exposure of bare soil. This change has resulted from elimination of the more palatable broadleaved species present in *A* and even some of the relatively unpalatable grass. A slight accumulation of gravel on the surface of the bared soil in *C* indicates that erosion has taken place; the closed character of the depression, that fine soil particles were carried away by wind. The hummocked appearance of the grass is due to deposition of part of this fine material, as well as to erosion from the bare spaces.


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FIGURE 14.—Stages in the formation of bare spaces in subalpine meadow turf: *A*, Almost solid cover; *B*, openings in the cover, some species eliminated.

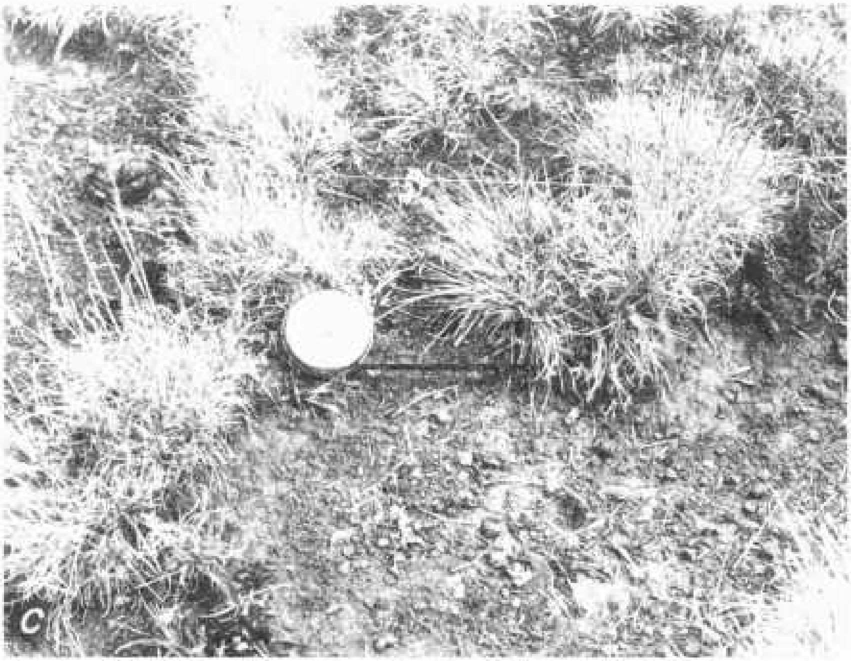

FIGURE 14 Continued.—*C*, Enlarged bare spaces and greatly reduced protective influence of vegetation.

Figure 13 illustrates bare soil surface on a moderate slope. The species present are aggressive perennials that characteristically invade a harsh, eroding surface. With so much bare soil, rapid erosion is to be expected here during storms merely of moderate intensity. Pronounced pedestaling, especially of the older grasses, shows that soil has been eroding rapidly, and the evidence of drainage that this erosion has been by water.

In short, on high range-watershed lands a soil surface unprotected by vegetation and litter is unnatural in the highest degree. It is a powerful indicator of unsatisfactory condition.

*Trend.*—As long as bare spots occur generally over a range, with vegetation insufficient to protect the soil against accelerated erosion, it is certain that wind or running water will eat away the soil and that an unfavorable microclimate will continue to handicap plant establishment. Such bare soil surfaces are, therefore, almost conclusive evidence of downward trend, and they set the stage for more positive and extreme indicators of soil erosion such as wind-scoured depressions, erosion pavement, and gullies. The larger the eroding bare areas, for a given site, the more rapid the rate of downward trend.

## Observed Movement of Soil

This indicator is the visible displacement of part of the soil mantle. The agent of displacement may be wind, running water, or hoofs of animals. Soil movement may be observed during windy weather, heavy rainstorms, or at times when animals are traversing slopes having loose soil.

In the extreme, visible displacement by wind takes the form of dust clouds, but it is important to detect displacement by wind in early, less obvious stages—the blowing of soil particles from bare spaces underfoot, undercutting on the windward side of grass tufts, and accumulation of particles in vegetation. Soil displacement by water is obvious in the dramatic violence of muddy torrents and in discharging flood deposits, but the displacement to be watched for is the cutting of tiny rills and deposition of small alluvia on slope surfaces. In the early stages of accelerated erosion few or none of these rills and alluvia even reach main stream channels. As used here, observed soil movement refers to displacement on the watershed itself, where cause and effect are nearest together. Mud that discolors the water of a main stream channel may be misleading. It may not relate to range condition or come from the watershed slopes at all. It may relate to improper road drainage, to caving stream banks, or to stream cutting of a landslide that has blocked the channel.

A small amount of soil displacement takes place normally: throughout the ages of successional change, many small, imperceptibly slow movements of soil have occurred. For short periods in certain places movement has been rapid or extensive—as, for example, after some fires —when control of the surface by vegetation has been temporarily relaxed. But since soil development is extremely slow, and since a soil mantle—the net excess of development over loss—is normal on mountain range-watershed slopes, it follows that such obvious soil movement must be rare. Hence, when the surface is disturbed so that widespread soil movement may be detected, the probability is great that soil loss is abnormal. When such loss continues year after year, the probability becomes a certainty.

*Condition.*—Observed soil movement on high range-watersheds is accelerated erosion in process and indicates unsatisfactory condition. Indeed, it is itself an unsatisfactory condition—soil instability. The less wind, rain, or trampling with which it is associated, the more serious the condition.

*Trend.*—Observed soil movement on disturbed surfaces means that soil is being destroyed and indicates that soil trend is downward. As with condition, the less force producing movement, the more rapid the trend.

## Trampling Displacement

By trampling displacement is meant evidence that surface soil has been moved downslope under the hoofs of grazing animals. It is soil displacement in a consistent direction. The displacement that occurs on level ground as a result of trampling, a churning of the soil into dust or mud, is not covered by this term.

Trampling displacement is a form of erosion similar to displacement by water, in that movement of soil is consistently downhill, but it tends to be less definitely channeled. Like erosion by water, trampling displacement becomes more and more clearly marked as steepness of slope increases, other things being equal. It occurs most readily when soil is very wet or very dry, and least readily when soil is merely moist.

Almost any grazing on slopes is bound to cause soil displacement, if only as part of the normal process of mantle creep. Some slopes, because of their steepness and character of soil, are particularly susceptible, and on certain ones a person cannot walk without displacing soil markedly. It may well be doubted whether on slopes of such instability there should be grazing by domestic livestock.

*Condition.*—Widespread trampling displacement is evidence of soil instability and therefore of unsatisfactory condition.

Evidence of trampling displacement takes two forms. In the case of excessive trailing the surface is imprinted with nearly level terraces, like contour lines (fig. 7, p. 17). The banks above these terraces are often steep, exposing plant roots.

Displacement that is not concentrated in trails, but is more generally distributed over the slope, is marked by soil accumulations on the upslope side of perennial plants (fig. 11, p. 23) and irregularities in the form of mounds or ridges downslope from each hoofprint. Such general displacement is less easily observed than terrace trails, but is probably more serious. Terrace trails suggest a measure of stability, by virtue of which the range has reached a compromise, if only a temporary one, with an abnormal concentration of grazing animals. With general displacement, however, no compromise is reached, not even temporarily, except where surface soil may accumulate above an obstruction.

*Trend.*—Terrace trails may relate to excessive trampling many years ago rather than to excessive trampling at the present time, and hence may not bear strongly on current trend. In contrast, evidence of general displacement over the slope by trampling relates directly to a current cause, and is an indicator of downward trend. Like other evidence of accelerated erosion, such trend is particularly important because it is away from a balanced range-watershed complex.

## Soil Remnants

Soil remnants are relics of surface soil. They are miniature mesas remaining in position after the soil which formerly lay between them has been eroded away. They owe their persistence to the persistence of protecting vegetation, and this is said to be "pedestaled" because of its position atop the soil remnants (fig. 15).

A former continuity of surface from remnant to remnant is sometimes suggested by a similarity in level. Sometimes it is suggested by the repeated appearance of similar parts of the soil profile in each elevated section, alternating with its absence in the depressions. "Islands" of soil above a common level of erosion pavement, as in figures 9 and 10, pages 19 and 21, suggest the former existence of a continuous mantle. In the places pictured, erosion has proceeded so far that the remnants are really remnants of subsoil. In some instances plants are unable to protect the soil remnants fully, and when the remnants are lost the plants remain for a time with elevated root crowns and exposed roots.

Elevated islands and soil pedestals are often caused by joint erosion and deposition. Erosion of the nearby soil surface lowers the general level. At the same time, deposition of a portion of the disturbed soil particles in the protecting vegetation, commonly by wind but sometimes in other ways, builds up the level of the islands. A vertical section made with knife or shovel through the island can often reveal this fact, with the deposited soil lying above the root crown of the plants

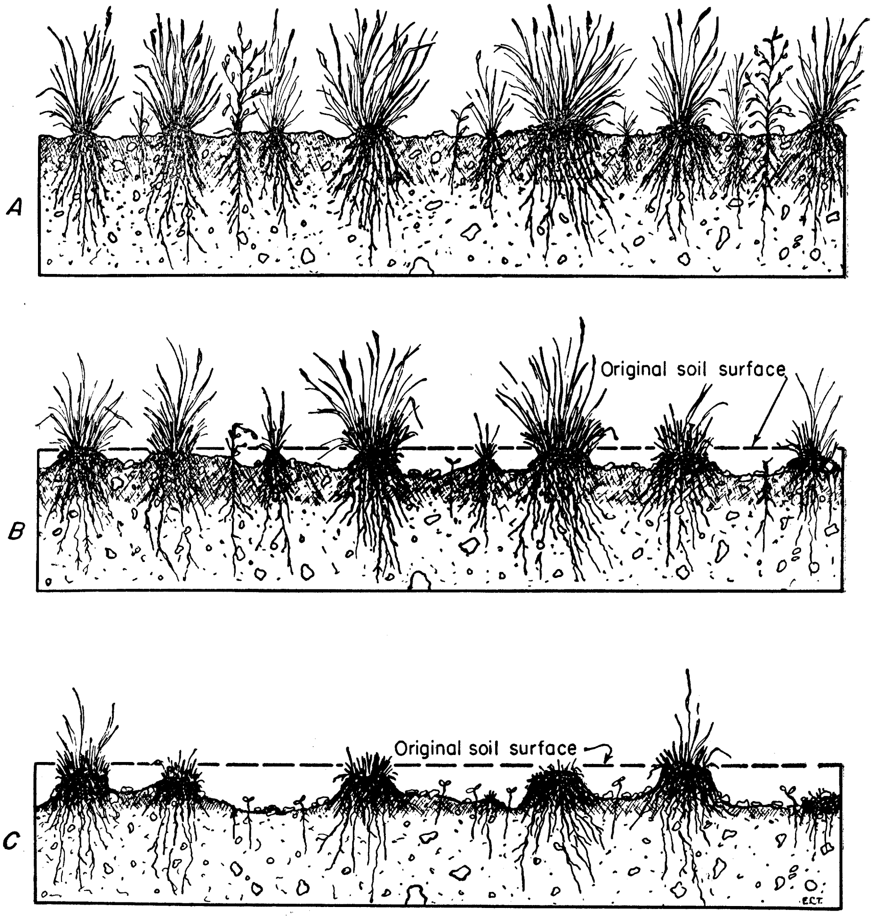


FIGURE 15.—Formation of soil remnants. *A,* Thinned stand of plants and scarcity of litter permit erosion by sheet wash and raindrop splash; *B,* more soil has been carried away, plants are left on pedestals, and small stones accumulate at surface; *C,* plants are weakened and dying not only because of heavy grazing but because of drying from root exposure and undercutting by erosion. Accumulation of stones on surface shows development of an erosion pavement.

(fig. 21, p. 46). Having taken the precaution to make such a section, one is not likely to overestimate the amount of erosional loss, as he may if he simply measures the difference between the level of the island and that of the eroded surface. On the other hand, the height of pedestals, after making any necessary allowance for deposition, usually provides an underestimate of total loss. For, on most range where pedestaling is common, accelerated erosion is not new; soil has been slipping away for several decades, and the height of pedestals represents only the latest decrement in the process.

A special type of soil remnant is formed by the impact of raindrops and sheet flow of water over bared surfaces. Small rocks and pebbles lying on the surface protect the underlying soil, while that round about

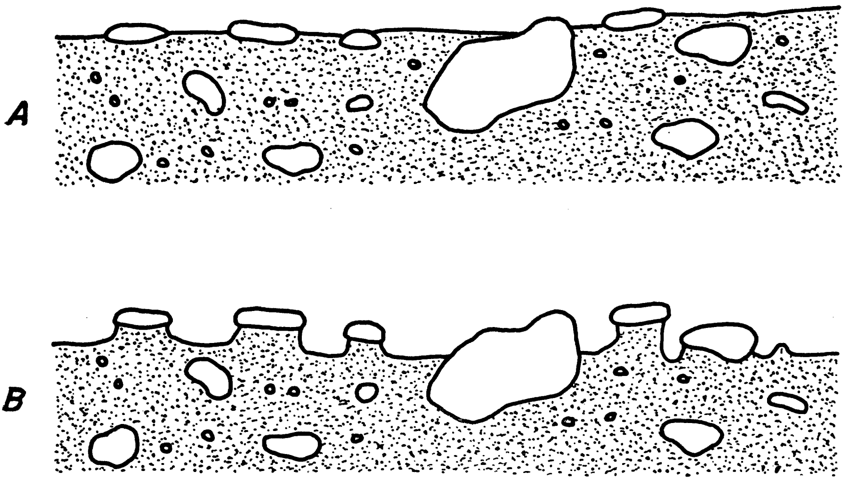


FIGURE 16.—Where soil is bared, *A*, raindrop splash and flow of water over the surface remove fine soil particles and leave small stones perched on pedestals, *B*, a special type of soil remnant.

is carried away. The result is that the pebbles appear elevated on low pedestals of soil above the surrounding surface (fig. 16). Close observation is usually necessary to discover these because, as one looks down from above, the pedestal is concealed until the pebble is carefully removed. This indicator is especially valuable in giving convincing evidence of current accelerated erosion during storms that are of such moderate intensity or duration as not to form gullies or alluvial deposits.

*Condition.*—Soil remnants reflect a state of deterioration, and their position in the soil profile indicates how serious the loss of soil has been. Least serious loss is indicated when interspaces, as well as remnants, are still essentially topsoil. When the remnants are still topsoil but subsoil is exposed in the interspaces, loss is much greater, and likelihood of getting vegetation readily established to stabilize the interspaces is less. When the remnants themselves are nothing but raw subsoil, and the interspaces are reduced to erosion pavement, the job of rehabilitation is likely to be very difficult indeed.

Soil remnants are a result of accelerated erosion. If the remnants are abundant or conspicuous, or if pedestaled pebbles can be found, erosion is undoubtedly current. Hence soil remnants indicate very unsatisfactory condition, especially when sides of the remnants are vertical and depressions between them are still not clothed with vegetation.

*Trend.*—Soil remnants with plant roots exposed or vertical sides are a result of recent soil erosion. They indicate rapid downward trend. If the remnants themselves are not adequately sheltered by vegetation, downward trend is even more marked. Remnants with sloping sides, or with sides vegetated by mosses and lichens or small seed plants, indicate less recent soil erosion. To this extent they suggest that a degree of stability is being reached. This may be misleading, however, if torrential storms have not occurred for some time. The more completely sides of remnants are occupied by vegetation, the better the evidence of a current trend toward restored stability. When the sides are strongly sloped and well covered with perennials, and when successful colonization of the depressed interspaces has occurred, the indication is that stabilization has been taking place in recent years, and improvement may be continuing.

Pedestaled pebbles indicate erosional loss during the current season, and hence unqualified downward trend.

## Erosion Pavement

Erosion pavement is the name given a concentration of gravel and rock at the soil surface as a result of blowing or washing away of finer particles of soil (figs. 14, *C*, and 15). As used here the term means a concentration caused by accelerated erosion, in distinction to one caused by normal geologic erosion.

It is sometimes difficult to tell whether the erosion pavement has been produced by accelerated or by normal processes. One criterion of a pavement produced by accelerated erosion is that beneath it the lower portion of a true soil profile, characteristic of normal soil development for the site, remains. If there is no evidence of such a truncated profile, and the material beneath the surface consists of slightly altered mineral matter and fragmented rocks, the pavement is probably normal. Evidence of abnormal pavement is provided by associated signs of accelerated erosion, either on the area in question or on essentially similar sites elsewhere. These signs include soil remnants and elevated root crowns.

There are circumstances in which gravel may be spread over the soil surface giving an appearance of erosion pavement. Figure 4 (p. 9) provides an example. Here some disturbance of the slope above has caused gravel to wash down, partly burying the plants. Soil loss, as it would be revealed by formation of erosion pavement, is clearly not indicated here.

*Condition.*—Erosion pavement—due to accelerated erosion—is an indicator that soil has been lost, and hence that the site has deteriorated from its original state. For a given soil, progressive deterioration is marked by progressive increase of gravel at the surface (fig. 17, *A*). Whether amount of loss has been great or little cannot be told solely from amount of gravel, however. One needs also to know the proportion of gravel in the normal profile of that particular soil from the surface downward. In soils that have little gravel in the profile, erosion pavement means severe soil loss.

Microclimate on erosion pavement is hot and dry, and if the surface is frequently disturbed by trampling, small, xeric pioneer seed plants are the usual vegetation. When trampling disturbance is lessened, species of increasingly mesic (moisture-demanding) character may become established and help in checking soil loss. Establishment of the more mesic species gives some measure of improvement over the condition when they were absent and more active erosion was taking place.

*Trend.*—Erosion pavement provides some protection for the soil surface, and as it is formed the rate of accelerated erosion is slowed. Soil loss continues even after pronounced pavement has formed, however, because frost action and burrowing or trampling by animals bring


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FIGURE 17.—*A*, Erosion pavement far advanced on steep slope in background and in process of formation, foreground. Stones first appear in gully bottoms (lower left). Other indicators of very unsatisfactory condition and downward trend are bare soil surface and pedestaled grasses. *B*, Pebbles still showing from a partial erosion pavement formed at some previous time. Present amount of vegetal cover indicates that erosion has been greatly slowed, or perhaps stopped so that an upward trend may be in progress.

soil particles to the surface between the stones, and some of this fine material is later washed or blown away. Close inspection after rainstorms often reveals evidence of this removal of fine soil material in the pedestaling of pebbles. For this reason most erosion pavement indicates downward trend.

Erosion pavement alone never indicates upward trend. A stand of vegetation over erosion pavement, particularly vegetation of relatively mesic character, may indicate upward trend (fig. 17, *B*). If the vegetation provides sufficient cover so that the pavement could not have been formed under it, undoubtedly it has invaded since the original pavement was formed. Erosion is less rapid than it was before. When vegetation is so dense that soil loss no longer occurs, an upward trend is clearly indicated.

## Lichen Lines

Lichens grow on the above-ground portion of fixed rocks, usually most abundantly on the shaded side and near ground level where moisture is greatest. They grow very slowly. If surface soil is eroded its former level can sometimes be traced, often from one rock to another, by the abrupt break between the level of great lichen density and the relative scarcity, usually absence, of lichens below. These abrupt breaks are known as "lichen lines."

Very little is known about the process of lichen colonization on rock surfaces of our western mountains, and it is therefore difficult to estimate the time period that lichen lines represent. It is certain, however, that lichen growth is sufficiently rapid to keep pace with normal surficial erosion. Probably, too, lichens can establish themselves and grow rapidly enough to keep pace with slightly or even moderately accelerated sheet erosion. Well-marked lichen lines therefore reflect a very rapid rate of accelerated erosion at some former time.

The lichen pattern on the rock in the foreground of figure 18 suggests that: (1) Only an inch or two of the rock extended above the original soil level; (2) lichen growth may have kept pace with the

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FIGURE 18.—Lichen lines on the northern and eastern faces of three large limestone rocks on subalpine range. The lower edges of the lichen concentrations indicate that the original soil surface was at least 3 inches (left) to 6 inches (right) above the present one.

earliest accelerated soil loss; and (3) a very rapid loss of from 3 to 6 inches of topsoil followed. At present soil erosion, although from other evidence probably still accelerated, has evidently slowed greatly from this rapid rate because the soil surface is now partly protected by vegetation and rock fragments.

Lichen lines are best defined on slightly elevated terrain, particularly on ridgetops or the shoulders of ridges. They are seldom well defined on slopes, even where erosion is obviously greatly accelerated, because soil losses alongside any particular rock tend to be made up by deposition from farther upslope.

*Condition.*—Lichen lines provide a fairly accurate measure of the amount of accelerated soil loss that has taken place at a particular spot, and thus an estimate of range deterioration. The weakness of such an estimate is that it tends to be highly localized, since lichen lines are seldom widely evident.

The information that lichen lines give as to condition is only relative. Thus, in figure 18 it is reasonably certain, from the rather slight evidence of current accelerated erosion, that vegetal cover at present is greater than it was while the soil below the lichen lines was being lost. This does not tell us, however, whether condition is satisfactory at present. Indeed, from other evidence—rather scanty cover and poor species composition—we know it is not.

*Trend.*—Lichen lines give an indication of current range trend only indirectly. That they exist above the present soil surface indicates rapid soil loss at some time in the past. If signs of current accelerated erosion are strong, continuing loss up to the present is suggested. If they are not marked, however, the collective evidence indicates that vegetation has increased on the formerly eroding surface since the soil below the lichen lines was lost, and that more recent trend has been toward stability.

## Active Gullies

Gullies are channels cut into the soil mantle by running water (fig. 19). They are said to be "active" when their sidewalls are unstable—that is, when their sidewalls are clothed with insufficient vegetal cover to protect the soil—or when there is evidence of recent cutting in the bottom. Rill channels are active gullies so small as to be obliterated easily by trampling or slight natural soil movement. "Gullies" therefore include channels very much smaller than the one in figure 19. If vegetation occurs only in its bottom, the gully is probably active. Only when vegetation clothes the sidewalls may the gully be considered healed. Vegetation in gullies will be treated in some detail later.

The term "gullies" as here used does not refer to main downstream channels, but rather to channels on the range-watershed itself. Cutting or deposition in downstream channels should call attention to the possibility of unsatisfactory condition on the watershed above. On the watershed itself gullies should lead the observer to see less obvious signs he might otherwise miss. For a gully denotes a concentration of erosive power, and is obvious when many of the tributary surfaces that feed it may be difficult to see.

Gullies are caused by rapid surface drainage of water which, under normal conditions, would enter and filter through the soil. Rills are formed and gully cutting begins as the infiltration capacity of the soil

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FIGURE 19.—A deep and active gully extending through the soil mantle and shaly subsoil. The steep, active tributary gullies at the left indicate that the gully system is being enlarged. Note the similarity in level of the land surface on each side, suggesting former continuity and indicating that this gully is a topographic abnormality.

is reduced by heavy forage utilization and trampling. Gullies are also formed by improper road drainage, breaking of diversion ditches, etc. Like downstream channels, such gullies may give an erroneous impression of range condition unless they are shown to relate to the soil-vegetation balance on the range-watershed proper.

Once formed, gullies intensify the rapidity with which moisture drains out of the soil mantle. More rapid drainage promotes more rapid soil erosion, excavation of plant roots, loss of moisture through exposure of a larger soil area to evaporation, and, in turn, still more rapid drainage. With each torrential storm a gully system becomes entrenched more deeply and becomes more effective as a collector and conductor of runoff. It is easy to understand, therefore, why an active gully system, once established, tends to perpetuate itself and grow. Even after vegetation on the watershed slopes has improved materially, rainstorm runoff from the raw gully sidewalls, or snow melt in spring, may continue to cut out the bottom and keep the gully open.

Rill marks are of special interest because they reflect current soil loss and because they are among the signs by which soil erosion may be detected before a system of large gullies has been formed. Rill marks can be seen most easily right after a storm, for the smaller ones are easily obliterated in a few days by trampling, frost heaving, or even alternate wetting and drying of the soil. The next storm creates a new set, and these in turn are obliterated. This unspectacular process can go undetected, frequently on a wide scale and over a long period of time, until much soil is lost. Much of what is referred to as "sheet erosion" is really rill erosion. An established gully system comes into existence when certain rills cut deeply and entrench themselves so that their channels are not filled and blocked by ordinary movements of surface soil.

The real significance of rill marks or of gullies on mountain range land lies in the fact that they are incised *into a soil mantle.* They occur naturally and normally on loose material where a soil mantle has never developed, as on areas of rock waste in very rugged terrain—which is why soil development has not occurred on such areas. But where a soil mantle has been developed, rills and gullies are abnormal in the highest degree. Here they indicate the sudden domination of one process, soil development, by a wholly different process, accelerated erosion.

*Condition.*—A gully, whether active or healed, represents range deterioration—both because of the soil that has been lost and because of accelerated drainage of soil water and drying of the soil mantle. An active gully, which has resulted from range deterioration, indicates very unsatisfactory condition on at least part of the area it drains. Rill marks indicate very unsatisfactory condition of the site on which they occur. The more gullies or rill marks per unit area, and the deeper and more active they are, the more serious the unsatisfactory condition.

*Trend.*—Active gullies indicate downward trend. Whatever the source of water that forms them, the soil mantle in which gullies are entrenched continues to deteriorate. Some gullies, originally excavated by summer storms, are currently kept open by snow melt each spring; these do not necessarily indicate downward trend on the slopes above. If the water runs off these slopes, downward trend is indicated there.

Rill marks are of particular importance for, in contrast to many indicators, they relate to current causes rather than to causes in the indeterminate past. They testify to the inadequacy of present vegetal cover in protecting the soil surface, and are therefore an unmistakable indicator of downward trend.

## WIND-SCOURED DEPRESSIONS

Wind-scoured depressions are shallow basins in bared surface soil between patches of vegetation, from which wind has carried away the finest soil particles.

The action of wind may be recognized by a residue of fine gravel or sand particles, too large to be blown away, resting on the scoured surface of depressions. Fresh evidences of wind-scouring are lines etched in the surface, paralleled by tiny, streamlined ridges of fine soil material in the lee of pebbles. The depressions usually have no outside drainage. In extreme cases the soil surface is merely a series of such shallow depressions separated by low ridges of vegetation (fig. 20). The depressions may be fairly symmetrical or they may be irregular, a few inches or a few feet across.

Wind-scoured depressions develop when the soil is exposed to wind as a result of thinning of the plant cover. Figure 14 (p. 33) portrays the process that leads to development of wind-scoured depressions like those in figure 20. Such scouring is caused by winds of moderate intensity such as may occur on almost any day of the snow-free season, as well as by stronger winds. A fine-textured soil in an exposed situation, and

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FIGURE 20.—Large and severely eroded wind-scoured depressions, some of which are surfaced with a light erosion pavement, on level mountain range. Exposure of roots by wind erosion is killing the grass on the windward (left) side of the hummocks. Deposition of fine soil particles is responsible for the gentler slope on the leeward side.

one that is repeatedly pulverized by trampling, is most liable to this kind of erosion.

*Condition.*—Wind-scoured depressions indicate unsatisfactory range condition, and the greater the extent of barrenness, and the fresher the evidence of scouring, the more unsatisfactory the condition. Depending on its natural abundance in the soil, the amount of gravel that has accumulated on the surface indicates something as to the severity of erosion.

*Trend.*—If the surface of wind-scoured depressions is exposed bare soil, and especially if it is plainly scoured or etched, rapid and recent downward trend is indicated and further soil loss is to be expected. If the surface is covered with erosion pavement, soil loss is probably continuing, but its rate is less because the gravel affords some protection to finer materials. In this case evidence of wind scouring may be difficult to detect, but past action of wind in excavating the depressions may be inferred when aeolian deposits are close by and where there is but little evidence of drainage between depressions. Checking of erosion is chiefly to be judged by evidence of vegetal invasion. If vegetation covers the surface of the depressions, soil loss may have been stopped completely.

## AEOLIAN DEPOSITS

Aeolian deposits are eroded soil materials laid down by wind. They represent the depositional end of the process that begins with wind erosion.

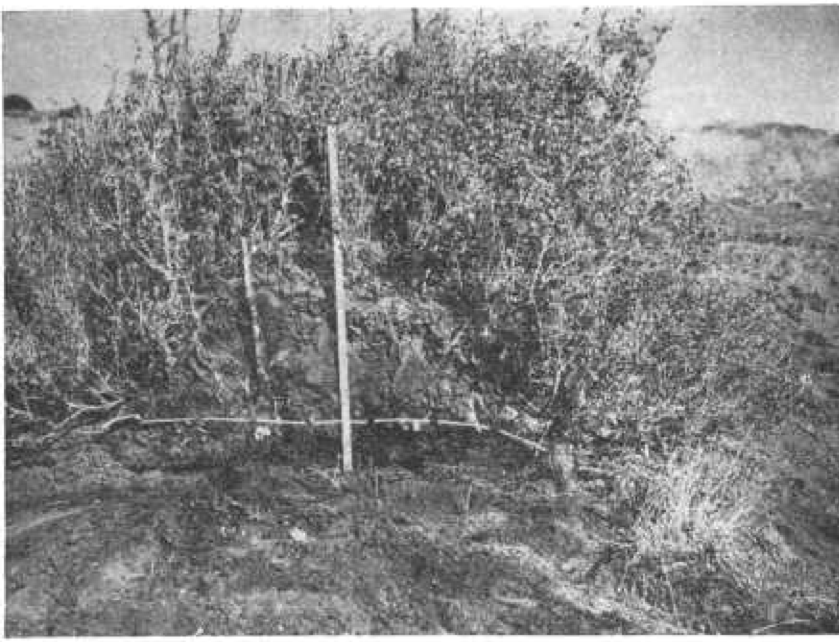

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FIGURE 21.—Wind-deposited soil built up in a currant bush. Original surface level is indicated by white line. Vertical bar is one meter (39.4 inches) long.

Aeolian deposits are confined almost exclusively within, or to the leeward of, patches of vegetation that catch moving soil particles and protect accumulating material. Such deposits are composed of fine, even-textured particles and usually contain no rocks. However, especially in large deposits that accumulate in shrubs (fig. 21), rodents sometimes bring some rocks to the surface which become mixed with the fine-textured, blown material. Aeolian deposits are very common in grass clumps on deteriorated range. They consist of fine material lying above the root crown. If the residual soil beneath the root crown contains much gravel, the zone of contact may be clearly marked.

It is advisable to cut a vertical section in hummocked grasses or shrubs so as to see how much of the difference in soil level is due to erosion of the adjacent surface and how much to deposited soil in the vegetation. In figure 21 the difference in level is a result both of erosion and of deposition.

Relative age of deposits may sometimes be judged by the degree of decomposition of buried plant parts. Thus the original soil level along the white line in figure 21 is marked by an accumulation of leaves and twigs that are still recognizable. One may reasonably conclude that the deposit is recent and reflects accelerated rather than normal erosion. The age of the deposit might be estimated more exactly by counting growth rings of buried living stem branches.

*Condition.*—Crowns and stems of plants buried by even-textured material are evidence of deposition by wind, and indicate disturbance of balance between vegetation and soil in the vicinity. They therefore indicate range deterioration. When it appears from the character of deposit that accelerated erosion is still in progress, unsatisfactory condition is indicated. Thus the occurrence of aeolian deposits in young plants is more reliably indicative of current disturbance, and of unsatisfactory condition at the present time, than their occurrence in old ones.

*Trend.*—Aeolian deposits indicate downward trend. If the deposits are found in small, young plants of a stand, as well as in large, old ones, downward trend is probably current. On the other hand, if they are found only in large, old plants, and not in young ones, downward trend has probably been checked. Small deposits close to the ground surface are a more sensitive indicator of current soil instability than deposits upon an already large accumulation well above the erosion level, as in the currant bush shown in figure 21. If the duff that has accumulated under shrubs is partly intermingled with fine soil, probably deposition is still occurring, but if a deep and distinct layer of duff is found, with no evidence of current deposition, downward trend has probably been checked.

## Alluvial Deposits

Alluvial deposits consist of soil material that has been dislodged, transported over the watershed surface by running water, and laid down again. They have the form of fans or cones at the end of small gullies or rill channels, or of accumulations on the uphill side of clumps of vegetation, logs, or litter.

The small alluvial deposits in figure 22, formed by ponding of overland flow above and to the left of the two gopher mounds, were produced by a rather low-intensity rain falling on a partly denuded slope. The fine rill marks on this slope were nearly obliterated by the time the picture was taken. The coarser the material of which an

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Figure 22.—Small alluvial deposits of fine sediment where water running over the surface from the upper left was ponded by two crescent-shaped pocket gopher mounds.

alluvial deposit is composed, the more violent the overland flow that produced it. The flow that deposited the fine mud in figure 22, for example, was much gentler than the one that laid down the gravel in figure 4 (p. 9).

As used here the term "alluvial deposits" refers to deposits on the surface of the range watershed rather than at the remote mouths of major stream channels. These large downstream flood deposits may or may not relate to unsatisfactory range condition; they do indicate disturbance of some sort on the watershed. Only a small part of these deposits is topsoil, even when they are caused by unsatisfactory range condition. The great bulk of it is canyon fill, usually containing a high proportion of rock and gravel.

*Condition.*—Alluvial deposits, since they result from soil erosion associated with inadequate cover, indicate soil deterioration on the watershed above.

Like gullies, erosion pavement, and aeolian deposits, alluvial deposits may relate to unsatisfactory condition in the past rather than the present. Their bearing on current condition is directly proportional to their recency. If an alluvial deposit is fresh, without a vegetal cover, it points unmistakably to unsatisfactory condition on the tributary slopes. If it is vegetated with annuals, short-lived perennials, or young woody plants, the probability of unsatisfactory condition still is great. But if the deposit has long-lived vegetation well established upon it, one may conclude either that the erosion which made it possible has been checked or that intense rainstorms have been lacking.

*Trend.*—Recent alluvial deposits indicate downward trend. As with condition, old well-vegetated deposits may or may not indicate a trend toward stabilization.

## VEGETAL COMPOSITION

Vegetal composition is the relative abundance of the various species that make up a stand.

Vegetal composition on high range-watershed land with cover adequate to protect the soil is evaluated primarily in terms of the palatabilities of the component species. Where accelerated erosion is taking place, however, vegetal composition is evaluated primarily by the effectiveness of the component species in protecting the soil.

Evaluation of vegetal composition, both as to condition and trend, must always take into account the potentiality of the site, whether it be north slope, south slope, ridgetop, or meadow. It must be based on an understanding of the normal vegetal composition and amount of cover of the particular site under consideration, gained through a study of comparable natural areas or grazed range in satisfactory condition. Relic plants, too, give valuable clues as to normal vegetal composition.

*Condition.*—Natural vegetation on high range-watersheds in good condition consists of a mixture of many species, practically all of which are perennials, and a considerable proportion of the plants are palatable.

Unsatisfactory condition with a stable soil, which is sometimes encountered in herbaceous types on level ground—particularly when subirrigated—is characterized ordinarily by a sufficiently great volume of herbage to create the needed protective cover, but usually a low volume for the site, and always an abnormally high proportion of inferior forage plants. A common characteristic of such range is dominance over extensive areas by one or a very few species that are not very palatable to the kind of livestock that has been using the range. While there are exceptions to the rule, cattle tend to favor grasses over forbs, while sheep tend to favor forbs over grasses. The result is that forbs of low value for cattle often characterize depleted cattle range and grasses of low value for sheep characterize depleted sheep range. These tend to be the more xeric species in the normal stand or introduced species, usually from a drier natural habitat. Such dominance is usually referred to as a result of "class overgrazing."

An example of this kind of change in vegetal composition is given in figure 14 (p. 33). Here, on level, dry alpine meadow, the native forbs, sedges, and grasses have been reduced by heavy sheep grazing until one relatively unpalatable grass predominates. A few forbs persist that are low in palatability and otherwise resistant to grazing. Under continued heavy sheep grazing and trampling even these forbs are eliminated.

When annual weeds form a very large proportion of the vegetation, unsatisfactory condition is indicated. If annuals are abundant and conspicuous it is practically certain that perennials have been very greatly reduced, and there is a strong likelihood of accelerated soil erosion.

A surface on which rhizomatous species are dominant may be one that has been severely eroded. Rhizomatous species usually provide better soil protection than annuals, and, because they spread underground, they are able to colonize harsh, eroding surfaces where seedlings fail. They may provide the soil stability and favorable microclimate needed for the establishment of other perennials. Some rhizomatous species like yarrow *(Achillea)* become less effective as they grow older because their crownspread becomes incomplete and produces little litter. There are exceptions, but generally speaking dominance by rhizomatous species represents an intermediate level of condition, much better than dominance by annuals, and not so good as dominance by a mixture of more mesic perennials.

Those mesic species that succeed in becoming established on areas that have been stabilized or semistabilized by rhizomatous vegetation, particularly if they are species that reproduce only from seed, usually indicate a condition that is more nearly satisfactory. Species with large, spreading crowns (e.g., lupine) obviously provide more shelter for the soil surface, plant for plant, than species with small crowns (e. g., dandelion). Fibrous-rooted grasses are more effective, as a rule, than taprooted forbs, partly because their roots promote crumb structure of the soil more efficiently, and partly because the litter they produce tends to lie longer on the ground surface. Persistent, perennial forbs and grasses are more effective in sheltering the surface and improving quality of soil than either annuals or early-season perennials with their limited root systems and usually small, early-withering tops.

*Trend.*—A mixture of desirable and undesirable species will occur either when the stand is improving or declining in value. Whichever trend is taking place can only be told by finding out which species are increasing in the stand and which are decreasing. To do this, it is necessary to ascertain their relative ages, or, if accelerated erosion has occurred, to recognize old erosion surfaces and be able to infer invasion of characteristic species on them. The presence of more mesic and more palatable species in rhizomatous patches that have stabilized the soil indicates upward trend in those stabilized patches. Of more immediate concern is the trend of the less well-vegetated openings between the patches, as revealed by evidence of plant colonization on the one hand and of soil erosion on the other. The rapidity of the apparent increase of invading species, as shown by their distribution of age classes, and particularly the rapidity of invasion of the openings, provides a rough measure of the rate of upward trend or of trend toward stability.

## Age Classes

Plants of a given species may be grouped into age classes—for example, seedling, young, middle-aged, and old plants. Members of a given age class are thus of approximately the same age, and the different classes represent broadly differing ages.

Abundance of individual plants in each of the various age classes gives a clue to recent history of that species in the stand and indicates whether the species is maintaining itself, or is increasing or decreasing. The significance of age classes to condition and trend depends, therefore, on the value of the given species, either as protective cover or as forage.

Woody plants may be grouped into age classes with relative ease by counts of growth rings or less certainly by means of size differences. Age classes of herbaceous plants are less easily defined. The size of an herbaceous plant is not always a reliable criterion of its age, but massiveness of root crown tends to be proportionate to age and is a more reliable criterion than volume of foliage. Old grass clumps have a tendency to break up into a number of smaller tufts that may be mistaken for young plants; often excavation will reveal the former continuity between tufts. Similarly, a little digging will often show that small plants which are thought at first sight to be seedlings are really attached to underground parts of old plants. Very young seedlings can usually be told by the presence of attached seed coats or by their cotyledons.

Species that reproduce vegetatively often defy estimates of age. About all that can be done is to distinguish between plants that are young and those that are much older. Young plants of rhizomatous species like penstemon *(Penstemon rydbergii)*, yarrow *(Achillea lanulosa)*, and sweet sage *(Artemisia discolor)* are taller than average and form a dense, compact growth in which other species are scarce or absent. Older plants of this type extend over a greater surface area, lack sharply defined margins, and have individual shoots that are scattered and short; and plants of other species are commonly intermingled with them.

Often on eroding range the height of soil pedestals above the general level may be still another clue to relative age of the plants upon them. The pedestals are remains of a series of erosion levels upon which plants have become established, and reflect the progressive sinking of the general soil level as erosion has continued over a period of years. Age is therefore correlated with height of pedestal (fig. 23, p. 53).

Reasoning in application of age-class indicators may be illustrated as follows. Suppose for example that the age-class distribution of three herbaceous species, in relative numbers of individuals, is as shown in the tabulation:

| Age class: | *Species A* Percent | *Species B* Percent | *Species C* Percent |
|---|---|---|---|
| Seedlings | 50 | 0 | 85 |
| Young | 30 | 0 | 0 |
| Middle-aged | 15 | 20 | 0 |
| Old | 5 | 80 | 15 |
| Total | 100 | 100 | 100 |

Species *A* has a fairly large proportion of individuals in all age classes, which indicates that it is maintaining itself successfully. This is approximately what is believed to be normal age-class distribution, with very high mortality of seedlings and young plants, progressively fewer individuals in older age classes, and progressively less difference between numbers of plants in older classes. Species *B*, on the other hand, is represented almost entirely by old plants, which would suggest that no new plants have become established for several years; and it may be inferred, if the individuals are few, that the species is dying out. The grass in figure 11 (p. 23) has an age-class distribution of this kind. Species *C* is represented by only two age classes—plants that are manifestly old, and seedlings, with no plants of intermediate age. Such a distribution is evidence that no successful establishment has occurred for a number of years. The presence of seedlings may be interpreted in two ways: either the species has begun to reproduce just this year, or it is producing seedlings year after year which for some reason never succeed in becoming established. Additional evidences is needed to settle this question.

*Condition.*—On a range in satisfactory condition, normal distributions of age classes of the desirable species would be expected, but in a heavy cover of vegetation they may be difficult to recognize. Abnormal age-class distributions of desirable species, especially when the stand is thin, indicate unsatisfactory condition. With reservations, since some undesirable species may well occur in the ideal natural stand, a normal distribution of age classes of undesirable species indicates unsatisfactory condition.

*Trend.*—In interpreting trend the question is: will future composition of the stand, as indicated by the tendency for some species to increase and others to decrease, be more desirable or less desirable than its present composition? Thus, returning to the tabulation of age classes, if species *B* were of low palatability, the evidence of its passing out of the stand would indicate a desirable trend in vegetal composition, whereas if it were a palatable species similar evidence would indicate an undesirable trend.

Heavy grazing tends to eliminate the more mesic species and to encourage species that are better able to endure drought. On average sites, therefore, evidence of increase among species characteristic of moister sites indicates improvement while evidence of increase in species characteristic of drier sites indicates depletion.

## Annual Weeds

Certain annual forbs become abundant on high mountain ranges where perennial species are greatly reduced and bare soil surface is exposed. The indicator "annual weeds" means an abundance of annuals, together with an abnormally low cover of perennials.

Among the most common annuals found on high mountain range lands are pepperweed (*Lepidium* spp.), knotweeds (*Polygonum aviculare* and *P. douglasii*), goosefoot (*Chenopodium album*), tarweed (*Madia glomerata*), and tansymustard (*Descurania incisa*). Although these are typically annuals at low elevations, completing their growth and maturing seed in a single season, some, particularly tansymustard, may become biennials at high elevations.

Annual weeds furnish little litter and have taproots rather than fibrous roots.[2] Their abundance and volume of growth vary greatly from year to year, depending largely upon early-season precipitation. In many years they complete growth, dry up, and virtually disappear before the end of summer. For these reasons annual weeds furnish an uncertain, and at best unsatisfactory, cover. Moreover some, particularly tarweed, may form heavy stands that provide severe competition and greatly retard reinvasion of perennials.

Since one of the important characteristics of normal vegetation of high range-watershed lands is that it is composed almost entirely of perennials, abundance of annuals is evidence of abnormality. An abundance of annuals reflects the fact that perennials, which in a stand of anywhere near normal abundance would suppress the annuals, have been reduced.

*Condition.*—Annual weeds, when they occur abundantly on high range-watershed land, indicate unsatisfactory condition because they provide uncertain, often scanty cover, and usually inferior forage. When the site dominated by annuals is one on which accelerated erosion occurs readily, condition is very unsatisfactory. Tarweed, which is a very strong competitor and almost completely unpalatable, is considered to indicate a poorer condition than other annuals.

The mere presence of annuals as minor constituents of a perennial stand does not necessarily indicate unsatisfactory condition. Having once been introduced, some annual species seem able to remain on the range indefinitely, perpetuating themselves by colonizing each year the more or less temporary bare spots, like gopher mounds, that occur naturally. Nor do annual weeds necessarily indicate an unproductive soil, for they thrive on fertile soil. There is reason to think that some of the annual weeds listed above are more demanding in their soil requirements than many native perennials.

The presence of annual weeds in the shadow of perennial vegetation, together with their absence in nearby bare spaces, suggests that microclimate of the bare spaces may be too severe for their survival. This may be a clue as to why perennial seedlings have not been able to colonize the bare spaces.

*Trend.*—Although any plant cover is an improvement over none, annual weeds give such inadequate protection against soil erosion that continued soil loss is almost a foregone conclusion where they are dominant. Annual weeds are therefore an indicator of downward trend. The small contributions they make to soil quality in the way of struc-

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[2] These statements apply to annual forbs rather than annual grasses. Cheatgrass (*Bromus tectorum*), a very important annual grass of valleys and foothills in the Intermountain region, is not included here because it is not common or abundant on high mountain range-watersheds.

ture and organic-matter content are offset many times by the great amount of erosion they permit.

## Invasion of Bared Surfaces

Invasion of bared surfaces means the successful establishment of vegetation on soil surfaces from which most of the original vegetation has been lost. Although this indicator includes initial invasion by annuals, it relates primarily to invasion by perennials, either on bare surfaces or on surfaces supporting annuals.

To use the indicator it is necessary to be able to recognize formerly bared surfaces after they have been partly or completely covered with vegetation. Such recognition is based on rather distinctive characteristics both of soil surface and of vegetation. Usually the two are related.

A formerly bared surface may be indicated by depressions alternating with hummocks, a result of accelerated erosion and perhaps deposition. Gullies and erosion pavement, when covered with vegetation, are special kinds of formerly bared surfaces.

Where the soil surface is uneven as a result of accelerated erosion, the vegetation is likely to be decidedly patchy. That of hummocks may consist of shrubs or tenacious mat-forming species—plants which have persisted while erosion has lowered the interspaces. The contrasting vegetation of the depressed interspaces consists of plants that have invaded, and is often markedly different from that of the hummocks. If succession is not well advanced, it consists of annuals and perennials that flourish early in the season, withering in midsummer. If succession is farther advanced, it consists of perennial grasses and herbs that grow throughout the season.

In figure 23, for example, three erosion levels are shown: (1) That upon which the larger and older *Penstemon* plant became established, perhaps 20 years ago, as indicated by its root crown about 2 inches above the white line; (2) that upon which the younger plant became established, as indicated by its root crown at the level of the white line; and (3) the present erosion surface between the two *Penstemon* patches about 2 inches below the white line. This surface is vegetated chiefly

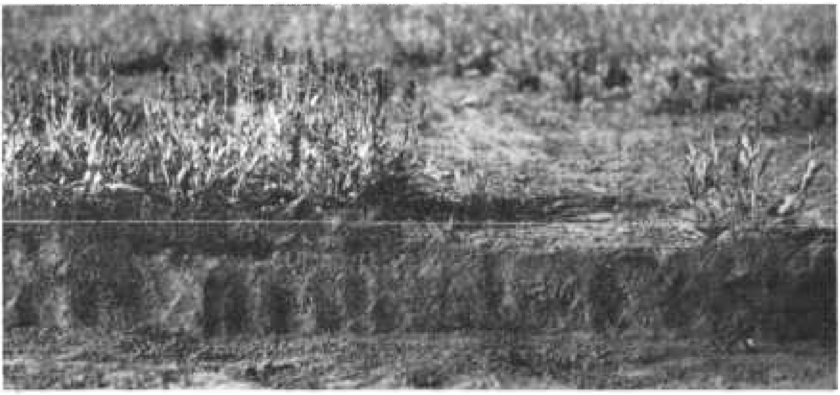

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FIGURE 23.—Patchy vegetation produced by invasion of a mat-forming *Penstemon* into deteriorated subalpine range vegetated with annuals. Two widely separated age classes of *Penstemon* and three erosion surfaces are indicated.

with annual and early-season species. A few persistent perennial grasses have become established, of which two plants may be seen between the *Penstemon* patches.

Often bare depressions, in which perennials that reproduce only by seed cannot get established, are invaded by rapidly growing rhizomatous species, like Kentucky bluegrass and yarrow. The young plants coming up at the end of the rootstocks are able to draw on the parent plant for moisture and food until they can exist independently. Figure 24 shows the invasion of a bare depression between masses of vegetation. The cracked soil surface is obviously a harsh site for seedling establishment, but the rhizomatous aster has succeeded in colonizing it vegetatively.

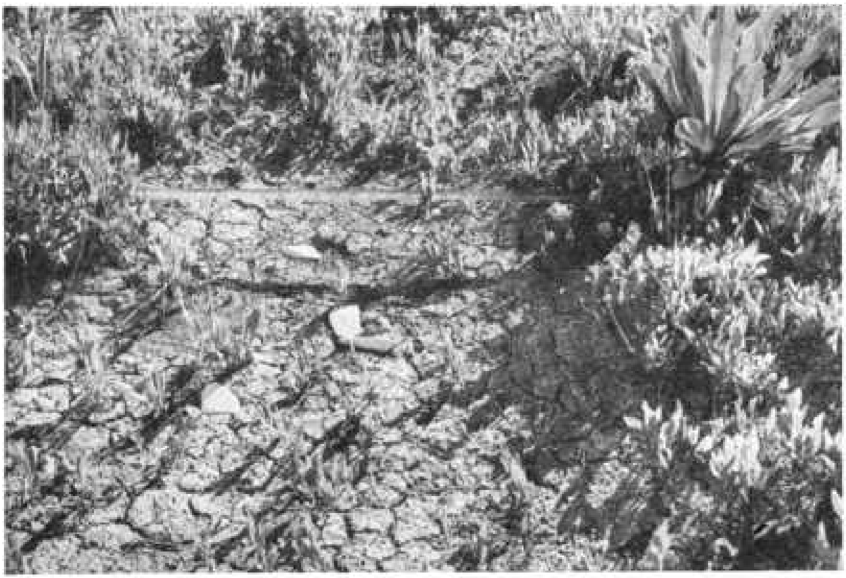

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FIGURE 24.—Rhizomatous plants like this aster invade eroded depressions that are inhospitable to seedlings. The rule is resting on the soil surface of the densely vegetated hummocks.

*Condition.*—Invasion of bared surfaces represents progress in greater or less degree toward restoration of balance between vegetation and soil. If the vegetation that has occupied formerly bared surfaces provides effective soil protection, the first requisite of satisfactory condition has been met. Condition can be considered satisfactory when the vegetation on the range as a whole is desirable as forage.

*Trend.*—Invasion of bared spaces by perennial plants indicates increasing soil stability and an increasing volume of vegetation. Invasion by palatable species is a more positive indication of upward trend than invasion by unpalatable species, because it indicates that the palatable species present on the range are capable of reproducing under current management. However, perennials low in palatability, or even annual weeds, are preferable to bare ground. Also, invasion of perennials by seed is a more favorable indication than invasion by vegetative means alone because it suggests the existence of a microclimate favorable for seed germination and seedling establishment.

In arriving at a judgment of net trend where erosion may be continuing, the rapidity of establishment of new plants, together with their value in furnishing soil protection, must be weighed against plant mortality and evidence of continuing erosion. The evidence of rapid erosion in figure 13 (p. —) is so strong, for example, and the evidence of vegetal increase so weak, that stabilization of the surface in a reasonable time is highly improbable. Occupance of erosion surfaces by annuals and early-season perennials, although preferable to bare ground, is hardly an indication of improvement. Except in very wet summers these species wither without producing much litter, and so expose the soil.

## Vegetation in Gullies

Vegetation in gullies is a kind of invasion on bare erosion surfaces in which either the gully bottoms, or the bottoms and sidewalls, become clothed with plants and litter. It is given separate treatment because it is a commonly observed type of invasion on erosion surfaces, and because vegetation in a stabilized gully helps define not only condition of the erosion surface on which it grows, but condition of all the watershed surface drained by the gully.

Gully bottoms offer favorable conditions for quick plant establishment and luxuriant growth. They may, in fact, be the only sites on badly deteriorated slopes where certain kinds of vegetation can grow at all. Bottom vegetation may persist for several seasons in truly active gullies if by chance there are no storms causing enough runoff to destroy it. Hence its presence is not a reliable indicator of soil-plant stability in the drainage above. The grass shown in figure 25 is commonly found in moist situations. It has become established in the gully bottom because of an abundant seed source nearby, favorable moisture relations in the gully, and absence of much competition. This grass, around which considerable soil has accumulated, is likely to be wiped out when a high-intensity storm occurs, for the adjacent area is too poorly vegetated to prevent surficial runoff.

Gully walls offer a less favorable environment for plants than gully bottoms. Seeds are less likely to lodge on the walls, and because the soil is drier and more unstable, seedlings have more difficulty in becoming established there. After a gully bottom has been vegetated and the flows of water in the gully have been reduced by better vegetal control on the watershed above, sloughing of the sidewalls tends to build up the bottom and lessen the sidewall slope. Vegetation spreads sideward, colonizing the moister and more stable surfaces first and the drier, more unstable parts of the slopes progressively later (fig. 26, *A*). Portions of the gully shoulders, their steepness temporarily maintained by the binding roots of plants, are the last parts of the gully walls to slough down and merge with the gentle contours of the stabilized gully (fig. 26, *B*). Mantling of gully walls by vegetation therefore indicates a much longer period of freedom from cutting than establishment of vegetation in the bottom alone, and makes it safer to infer that the trend toward stabilization is lasting.

*Condition.*—Gullies caused by accelerated erosion, no matter how well vegetated subsequently, represent deterioration in comparison with the original, intact soil mantle. Those that have raw sidewalls, even

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FIGURE 25.—Meadow barley, *Hordeum nodosum,* in a gully bottom contrasts strongly with the bare soil surface at either side. Because of the likelihood of overland flow from surfaces like these, the tenure of this grass in the gully bottom probably is temporary.

though vegetation grows along their bottoms, indicate unsatisfactory condition. If the walls are clothed with vegetation and the gully has a rounded or flat-bottomed cross section, however, balance between soil and vegetation has probably been restored on the area drained. If other evidence supports this conclusion, further judgment of condition will depend upon forage value of the vegetation in relation to what the site is capable of producing.

*Trend.*—While any vegetation is better than none, it is not safe to infer material improvement from vegetation in the bottoms of gullies with bare walls. Neither are scattered plants established on gully sides an indicator of upward trend. A fairly complete cover of vegetation on gully walls is, however, an indicator of genuine, continuing improvement, especially if the gully shoulders are well rounded, the bottom is flat, and the walls slope gently.

## RILL-CHANNEL RIDGES

Rill-channel ridges are low, narrow ridges that follow a former rill pattern. They are formed by the establishment of vegetation in rill channels and subsequent more rapid erosion of the soil on either side.

The mechanism by which these ridges form is shown diagrammatically in figure 27, in four stages. In *A* the raw channel, an inch or two deep, is cut into the soil. A few established plants are shown in surface view. In *B* plants have become established along the channel. This


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FIGURE 26.—Two stages in healing of gullies on the same slope: *A*, An early stage, with plants established in the bottom and on the lower parts of the sidewalls; *B*, a much later stage in which the gully walls are practically healed, having become vegetated except for a few sharp shoulders.

strip of vegetation diverts later flows of water to either side, forming two channels at a lower level, as in *C*, making a slight ridge of the former channel bottom. As these channels are cut deeper, and the adjacent bare surface is eroded, the little ridges of vegetation become relatively higher. They tend, also, to become broken into smaller and smaller segments by undercutting and by dying of the pedestaled plants from drought, as in *D*. The lower channels may be invaded by strips of vegetation paralleling the first, similar to the stand shown in *B*, and the process may repeat itself indefinitely. Evidence of these rill-channel ridges may consist at times only of a linear arrangement, up and down the slope, of distantly spaced, pedestaled plants (fig. 28).

*Condition.*—Rill-channel ridges indicate deteriorated range. Some idea of the extent of erosion can be obtained by imagining the tops of the ridges as former rill bottoms, and the height of the surrounding soil surface as it must have been to be drained by these. This, however, usually provides a very incomplete estimate of total soil loss. When levels of different age can be made out, it follows that this form of erosion has been going on for many years. These levels record, in a way, the sinking of the soil surface as persistent rill cutting has planed it lower and lower.

A product of continuing accelerated erosion, rill-channel ridges indicate very unsatisfactory condition.

*Trend.*—Rill-channel ridges indicate rapid downward trend. Although plants that become established in the process of ridge formation may represent some gain in total vegetal cover, this gain is trifling compared with the losses of soil that result from continued rill cutting.

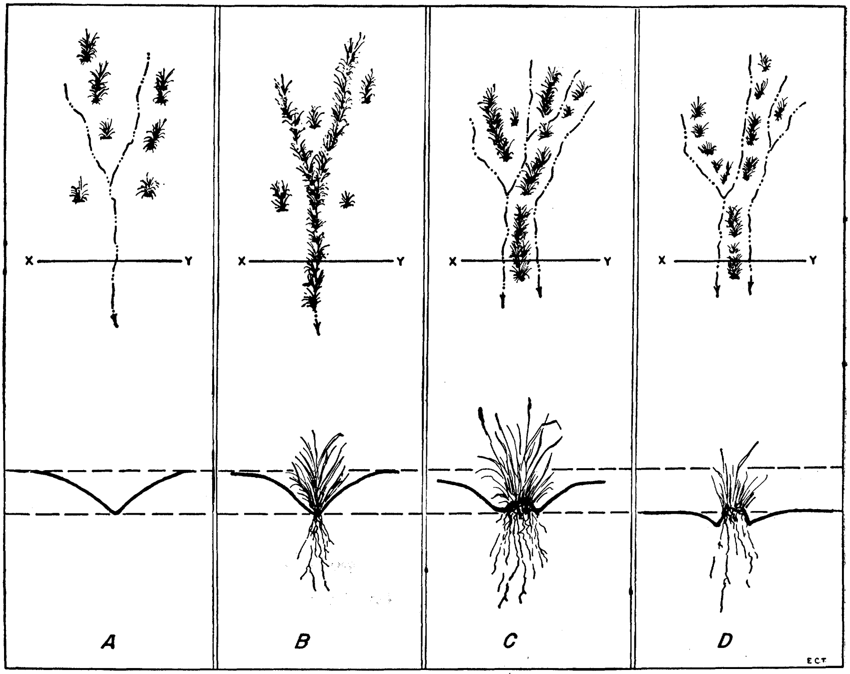


FIGURE 27.—Four stages in the formation and decadence of ridges formed by invasion of vegetation in rill channels. *A*, Raw channel cut into soil; *B*, plants established in channel; *C*, diversion of water forming new channels alongside vegetation; *D*, undercutting and pedestaling of the plants.


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FIGURE 28.—Continuous rill-channel ridges, *A*, in time may become so greatly broken that they are represented only by a linear arrangement of plants up and down slope, *B*.

## ACCESSIBILITY OF PALATABLE SPECIES

Accessibility is the extent to which plants can be reached easily by grazing animals. The premise for this indicator is the fact that, normally, palatable plants tend to occur on parts of the range where they are accessible to grazing animals, as well as where they are inaccessible. If palatable plants are found only where animals cannot easily reach them, it is probable that they have been eliminated from accessible places by grazing.

Difference in accessibility is sometimes caused by physical barriers like rock ledges or crowns of some shrubs. On cattle range the upper portions of steep slopes and areas that are distant from water may be practically inaccessible. Sometimes the barrier is not entirely physical, as when palatable forbs and grasses grow in close association with other herbaceous species that are so highly unpalatable as to repel grazing animals. On overgrazed cattle range, for example, palatable grasses may tend to be confined to the shelter of orange sneezeweed *(Helenium hoopesii)* plants.

*Condition.*—Rather uniform distribution of palatable species in both accessible and inaccessible places is a sign that composition of the vegetation has not been materially altered by grazing, or, if it has been altered, that palatable plants have succeeded in reestablishing themselves. If cover is about normal for the site, satisfactory condition is indicated. When palatable species tend to be confined to inaccessible places, on the other hand, range condition is unsatisfactory.

*Trend.*—Where numbers of young palatable plants, well beyond the seedling stage, are found in accessible places, whereas old plants of the same species are confined to inaccessible places, the indication is that this species is reinvading grazed portions of the range. This suggests that trend is upward. Where a greater proportion of large dead plants is found in accessible than in inaccessible places, without much replacement by younger plants, downward trend is indicated.

## Relics

Relics are remnants of vegetation and provide a means of visualizing its character after it has undergone modification. A relic may be a remnant of a plant community or it may be a single persistent species.

A patch of virgin vegetation isolated from the grazed range by a natural barrier, as by talus rock impassable to domestic livestock, is an example of a relic. Provided the two sites are comparable, the relic gives a picture of the grazed range in pristine condition.

A species of palatable plant found only in the shelter of shrubs is very likely a relic, restricted to inaccessible places by heavy grazing. Sometimes the palatable plant has a particularly large and decay-resistant root crown. Finding such root crowns on accessible range, and living plants confined to inaccessible places, is confirmation of the species' being a relic resulting from overgrazing. The stumps of heavily grazed shrubs provide another example of a relic (fig. 29, *B*). They indicate the existence of the shrub in a former vegetal community now largely destroyed by overgrazing. Such relics, besides being species that are infrequent on the grazed range and more abundant in protected areas, may be recognized by one or more of the following characteristics: On the grazed range they tend to be almost wholly old plants and remains of dead plants; they give little or no evidence, from survival of young plants, of reproducing successfully; and their accessible parts are grazed excessively closely.

Relics may also be a natural consequence of plant successions that do not relate to grazing. An example is sometimes provided near the


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FIGURE 29.—*A*, Patches of shrubby cinquefoil *(Potentilla fruticosa)* in a meadow; *B*, relics—heavily grazed, dead or dying stubs—of this shrub indicate its former existence on a site made abnormally dry by severe grazing, trampling, and exposure and erosion of the soil.

boundary between an aspen and a sagebrush stand, by dead and dying sagebrush bushes within the invading aspen. It is necessary, therefore, by considering associated indicators, to know the process by which a given species has become a relic in order to understand its significance.

*Condition.*—Relics due to overgrazing, reflecting as they do a depleted forage supply on the range, indicate unsatisfactory condition. Relics of normally rather unpalatable or moderately palatable species indicate a more depleted condition than relics of highly palatable species. In figure 29, *B*, for example, very unsatisfactory condition is indicated, not only by the exposure of bare soil and associated evidence of accelerated erosion—pedestaled plants and erosion pavement—but by the fact that this shrub is normally of low palatability.

*Trend.*—Relics from overgrazing indicate downward trend. In figure 29, *B*, downward trend is indicated not only by the continued destruction of this shrub but by an obviously abnormal exposure of bare soil. On the other hand, if a population of well-established young plants is found when relics of the same species are present, improvement from a more deteriorated condition is suggested. Another indicator of improvement from a deteriorated condition would be relics of an unpalatable species in a stand of relatively palatable species. The relics in this case would, of course, not bear the marks of heavy grazing.

## Hedged Shrubs

Shrubs or low trees that exhibit densely twiggy crowns, like clipped ornamental plants, are said to be hedged.

Such hedged crowns result from repeated browsing, but under certain conditions they may be caused by snow blast, that is, by wind-borne particles of ice carried at the level of snow accumulation in winter. Effects of snow blast are most evident on ridgetops and other situations greatly exposed to wind. If hedging occurs in relatively unexposed situations and only as high as animals can reach, it is probably caused by overbrowsing. When overuse is extreme, all twigs and leaves

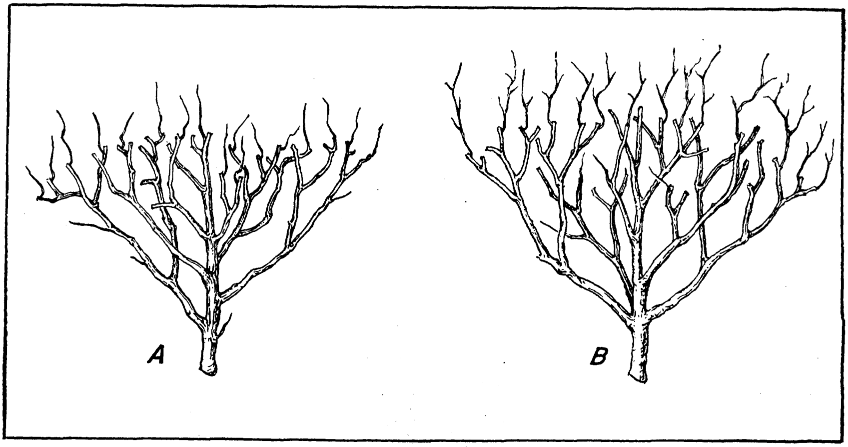


FIGURE 30.—Regrowth from hedged shrubs: *A*, Of a single season; *B*, of three or four seasons. The former suggests that overbrowsing is likely to continue; the latter that grazing pressure has been lessened.

being taken as high as animals can reach, a "highline" or "high-water mark" is produced because of the regularity of pruning up to a common level.

Severe hedging results in death of numerous branches and, if long continued, may cause death of the entire plant. Hence many dead shrubs or much dead wood in the crowns indicate that overbrowsing of the species has continued for a long time. Dead branches or dead crowns are sometimes caused otherwise than by overbrowsing, so that severe overbrowsing should not be inferred without evidence of hedging or utilization.

*Condition.*—Hedging indicates decreased productivity as compared with normal range, and hence unsatisfactory condition. The normal palatability of shrubs that are hedged by grazing suggests something of the degree of unsatisfactoriness. The lower the normal palatability to the kind of animal grazing the range, the more unsatisfactory range condition is likely to be. On the other hand, absence of hedging, if the shrub is positively known to be palatable, shows that use has not been heavy enough to inhibit normal growth.

*Trend.*—Hedging indicates downward trend. Shrubs that are hedged from overbrowsing in fall or winter show a single year's regrowth during summer. If there is only this single year's growth above the hedged surface, trend should be considered downward because these twigs are likely to be completely utilized before the next growing season, just as past years' twigs have been (fig. 30). Several years' growth above old hedged surfaces, however, suggests that grazing pressure has recently been lessened and that trend is upward.

## Current Utilization

The extent to which current growth of a species is grazed constitutes the utilization of that species for the season, and is designated as "current utilization" to distinguish it from utilization of past years.

The criterion for evaluating current utilization should be the amount of vegetation left after grazing. The objective should be to leave sufficient crownspread cover unutilized to protect the soil against erosion and provide a microclimate favorable for reproduction. This protective phase deserves the utmost consideration where an excessive area of soil surface is exposed. Heavy grazing under such conditions aggravates an already serious situation (fig. 31). Where protection is less urgent, emphasis can be transferred to the desirable forage species, which should be so utilized that they have ample opportunity to flower and produce seed. Equally important is the effect of current utilization on young plants. Sometimes utilization of young plants of desirable species, which tends to be complete because of their small size, prevents successful maintenance of those species in the stand.

Seasonlong familiarity with the range is essential so that vegetal composition, developmental characteristics of plants, and preferences of grazing animals can all be considered when judging utilization. Careful and systematic study of current utilization provides first-hand knowledge of forage preferences. Animals usually change their forage preferences during a season, and these changes need to be understood to interpret trends correctly. Observations made only near the end of the grazing season may be misleading, particularly on heavily grazed range; moderately palatable plants are then often found to be cropped about as closely as the most desirable species (fig. 32).

A knowledge of forage preferences of all species in the stand is important in appraising condition, trend, and utilization. For most purposes this knowledge need not be precise—perhaps no more than a listing of the various species in approximate order of the use they receive—but it should be fitted to each particular range on the basis of first-hand observation. This knowledge will indicate which species are the important ones. It is on these species that more detailed observa-

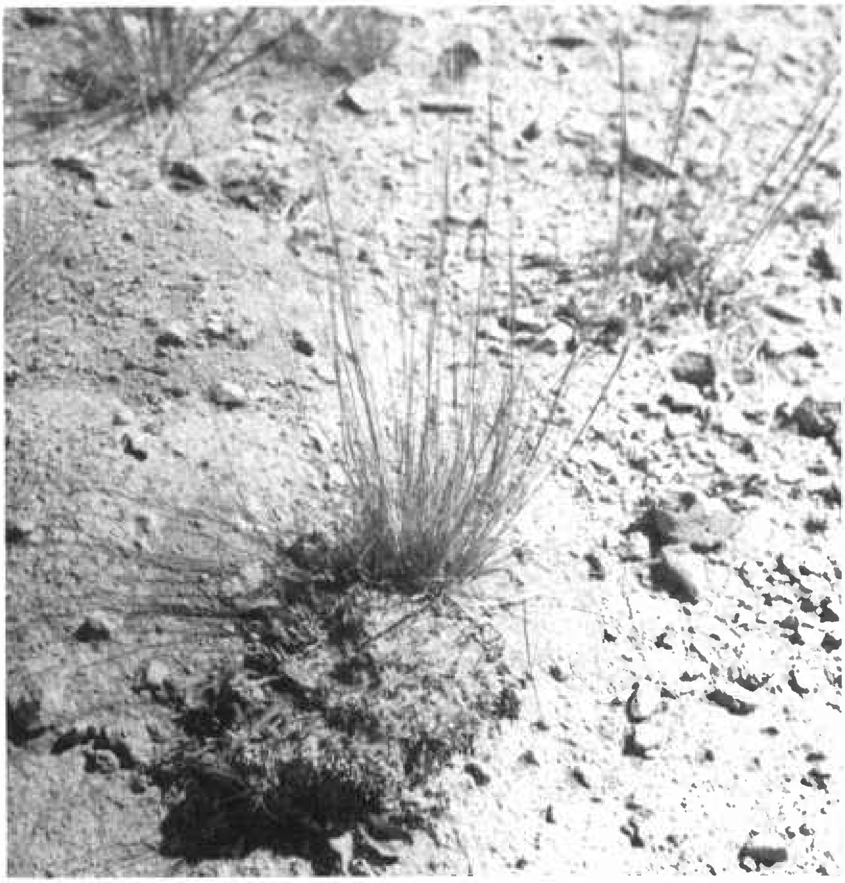

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FIGURE 31.—Stubble of needlegrass that has been grazed excessively by sheep, in front of ungrazed fescue. On range so badly deteriorated such removal of herbage of weakened plants aggravates an already serious condition.

tions should be made as to time and intensity of utilization, opportunity to flower and produce seed, and success or failure in establishment of young plants.

*Condition.*—Current utilization is more an indicator of trend than of condition.

*Trend.*—Current utilization is one of the most sensitive indicators of trend, suggesting changes before they occur as well as while they are


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FIGURE 32.—Marked change in appearance of range brought about by one season's utilization: *A,* Before grazing; *B,* after grazing.

in progress. Continued heavy use may result either in preventing reproduction of desirable species or in outright death of established plants, and is therefore an indicator of downward trend. If a heavily grazed species is low in palatability, or if its most unpalatable parts, (e.g., coarse stems) are grazed, the trend is more steeply downward. Heavy utilization of all or most of the vegetation in the stand is an even more definite indicator of downward trend. If the utilization is so severe as to result in baring and disturbance of the soil, the rate of downward trend is very rapid indeed.

On the other hand, if the most desirable species in a stand are moderately or lightly utilized, and have the opportunity to flower and scatter seed, there is reason to expect maintenance and increase of those species. At least one necessity—a seed source—has been provided, and upward trend will depend in large part upon the success with which new plants become established.

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