SOIL EROSION AND STREAM FLOW ON RANGE AND FOREST LANDS OF THE UPPER RIO GRANDE WATERSHED IN RELATION TO LAND RESOURCES AND HUMAN WELFARE

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FOREWORD

Mr. F. A. SILCOX, Chief, Forest Service, United States Department of Agriculture, Washington, D. C.

DEAR MR. SILCOX: I have read with extreme interest the manuscript entitled "Soil Erosion and Stream Flow on Range and Forest Lands of the Upper Rio Grande Watershed in Relation to Land Resources and Human Welfare" by Messrs. Cooperrider and Hendricks of the Forest Service. A number of members of the Soil Conservation Service staff likewise have reviewed the manuscript.

1 The Southwestern Forest and Range Experiment Station is maintained in cooperation with the University of Arizona at Tucson.

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This organization feels that publication of the paper will provide a valuable and extremely interesting contribution to the literature of soil erosion.

Very sincerely yours,

H. H. BENNETT,
Chief, Soil Conservation Service.

INTRODUCTION

The damaging effects of erosion and recent floods in the upper Rio Grande watershed have brought the inhabitants of one of the oldest regions of continuous irrigation and range agriculture in the United States face to face with the question whether these forces threaten destruction of their land resources and imperil human welfare. Not only is soil erosion in rapid progress throughout this drainage, but also destructive channeling of alluvial valley lands, silting up of water reservoirs and other irrigation works, and excessive filling of the main river channel in the middle Rio Grande Valley. Moreover, productive agricultural lands have become waterlogged, and destructive flash floods are causing an increasing number of wash-outs of public highways and railroads.

The striking evidences of destructive erosion led to a general survey of the range and forest lands within the upper Rio Grande watershed to determine the facts regarding the relation of soil erosion and the vegetation. This survey was made during the summer of 1931 under the direction of C. K. Cooperrider. The survey included an examination of the erosion conditions in Mesilla Valley, particularly the bordering range lands, below Elephant Butte Dam. Information regarding the Colorado part of the watershed was obtained from unpublished Forest Service reports, including one on erosion by J. Higgins of the Rocky Mountain region of the Forest Service. The methods used in the survey were developed by the Southwestern Forest and Range Experiment Station. The conclusions drawn are based not only on the results of this survey, but also on knowledge gained by the senior author from 20 years' experience in this area, on published and unpublished records (including vegetation maps) of the Forest Service, reports of the Middle Rio Grande Conservancy District, and on reports of State engineers of New Mexico.

The results of the investigation have shown that the land resources of this watershed are actually in danger of destruction, and that the real cause of accelerated run-off and erosion may be traced principally to the serious decline of and change in the natural vegetation of the range and forest lands.

On only about 25 percent of the lands of the upper Rio Grande drainage, exclusive of the Colorado area, is there sufficient plant cover to control surface-soil erosion within normal and moderate limits; on about 35 percent of the lands accelerated soil erosion has progressed to an advanced stage; and on 40 percent of the lands rapid land destruction is in progress.

That surface run-off and soil erosion were controlled by plant cover for centuries is shown by the stable condition of the areas that still have protective vegetation. This indicates that if the land resources

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are to be preserved the lands must have a protective plant cover. The denuded, eroded, and practically useless condition of extensive areas necessitates their revegetation. Moreover, it is equally important to effect conservative utilization of the range and forest lands that are still in good or fair condition. The situation found justifies an additional investigation of the vegetation and stream flow, particularly of the physical factors that affect them, in order to ascertain the fundamental facts and principles on which the most effective conservation of the land resources should be based.

GENERAL DESCRIPTION OF THE UPPER RIO GRANDE WATERSHED

The upper Rio Grande watershed includes all the area that contributes waters to the Rio Grande above Elephant Butte Dam. This area extends from the southern Rocky Mountains, which surround the San Luis Valley in southern Colorado, to the southern part of New Mexico. It comprises approximately 18,000,000 acres, or about 28,000 square miles, of which nearly one-fourth is in Colorado (fig. 1).

This drainage is so extensive and has such wide variations in relief, climate, and vegetation that it is important that the reader first gain a general knowledge of these features in order to enable him better to understand the run-off and erosion problems and how these problems affect land resources and human welfare.

PHYSICAL FEATURES

SURFACE RELIEF

The relief varies from low valleys and low plains to very high mountains. Between these extremes of elevation are high valleys, high plains, plainlike tablelands (mesas), foothills, and low mountains.

The low valleys are bordered on each side by low plains. Owing to increasing elevation northward, many of the low valleys with their adjoining low plains become "high" valleys and "high" plains; and like the low valleys and plains, these may be flanked by either mesas, foothills, or low or high mountains. The largest low valley extends along the middle Rio Grande between Elephant Butte Reservoir and White Rock Canyon, a distance of about 175 miles. It is a narrow flood plain from 3 to 5 miles wide, sloping gently from 4,400 to 5,500 feet elevation.

White Rock Canyon, a deep gorge, separates the middle valley from the floor of Española Basin. North of this basin, for a distance of about 70 miles, the Rio Grande has cut a deep gorge into a basaltic formation which fashions a high plain whose elevation varies from 6,800 to 8,000 feet and whose north end constitutes the south brim of the high San Luis Valley. This high northern valley is a great basin about 2,500 feet higher than the middle valley at Albuquerque.

High mountains rise to elevations of 9,500 to 14,000 feet. Those included in the Colorado part of the drainage form a horseshoe-shaped divide which encloses the San Luis Valley and separates the north end of the watershed from the Arkansas River Basin to the east and from the Colorado River Basin to the north and west. The mountains that form the southern extension of the horseshoe-shaped divide—Sangre de Cristo Range—extend far into New Mexico, forming the east boundary of the watershed. Those in the north-
Figure 1.—The upper Rio Grande watershed.
central part of the watershed—Tierra Amarilla and Jemez—constitute extensive mountain masses. Mountains such as the San Mateo and Manzano, in the south half of the drainage, are isolated. Zuni and Taylor are small mountain masses which form a part of the high plateau-and-mesa country that characterizes the western part of New Mexico.

STREAMS

The rivers and other streams of the watershed may be classed as perennial and intermittent or ephemeral. Those of the first group flow the year round and include the Rio Grande and some of its large and small tributaries, in whole or in part, such as Rio Chama, Rio Conejos, Red River, Jemez Creek, and Rio Taos. Many tributaries that have their origin in mountains are perennial, but their waters sink into the ground when they reach the lowlands. Good examples of such streams are those of the east and north parts of the Colorado division of the watershed, where their flow ends in marshy lakes or their waters sink into sand and gravel as they approach the Rio Grande. The large drainages that embrace extensive areas of plains and valley lands, such as the Puerco, Salado, and Galisteo, may have permanent streams only at their extreme headwaters, but the main streams are intermittent—that is, they dry up periodically. The streams of a great number of similar but smaller drainages are also ephemeral, as they are dry most of the time, except after heavy rains.

CLIMATE

The climate of the upper Rio Grande drainage varies widely, from warm and semiarid in the low valleys and on the low plains to cold in the high mountainous districts where there is sufficient precipitation to support forest growth (fig. 2). In the low valleys and on the low plains the summers are long and warm, and the winter temperatures rarely fall below 0° F. Here the rainfall varies from 8 to 10 inches, and snow rarely occurs. In the high mountainous districts the summers are short and cool, and in winter the temperature may fall as low as —25°. Here the mean annual precipitation varies from 18 to 34 inches or more, much of which falls in the form of snow.3

In the intermediate high valleys, on the high plains, tablelands, and in the foothills and low mountains, the annual precipitation varies from about 7 inches in the high valleys to about 18 inches in the foothills and low mountains. In these intermediate districts, minimum temperatures as low as 0° to —15° F. may occur suddenly for only a short duration on 1 or 2 days in any month from November to February, inclusive.

In general, the temperature decreases as the elevation increases, but not so with precipitation. Although, in a given district, the rainfall may vary directly with elevation, this relationship does not hold for all points throughout the watershed. On some areas that are situated at about the same altitude, there may be a difference in annual precipitation of 11.5 inches. To illustrate: Chama, N. Mex., at an elevation of 7,851 feet, receives a mean annual precipitation of 22.61 inches; whereas San Luis, in San Luis Valley, at about the same elevation (7,794 feet), receives only 11.20 inches.

LEGEND

Rainfall—from 7 to 12 inches
(See text)
Temperature—summers long and warm below Rio Chama, and short and cool in the northern part of the watershed

Rainfall—from 9 to 18 inches
Temperature—intermediate to cool [high valleys, high plains and tableland, foothills, and low mountains]

Rainfall—from 18 to 24 inches
Temperature—cool to cold [high mountainous districts]

FIGURE 2.—Climatic regions of the upper Rio Grande watershed.
Further, the mean annual precipitation of the low valleys and plains which represent the areas of low elevation of the watershed is similar to that of the high San Luis Valley and the high plains that join it on the south, both of which are at an elevation of about 2,500 feet above the low areas. But the mean annual temperatures of these low and high areas differ widely, effecting a marked influence on the vegetation.

The climate of the high San Luis Valley and the adjacent high plains to the south, so far as its effect on vegetation is concerned, is similar to that of the western part of the south half of the watershed (excepting the high mountains), even though both the mean annual precipitation and temperature of this southwestern part are different. This southwestern section, which averages in elevation about 1,000 feet lower than the northern districts considered, has a greater mean annual precipitation but a higher mean annual temperature. The effect of the higher rainfall on the growth of vegetation is lessened by the higher temperature and greater evaporation.

**VEGETATION**

As in any given region, the natural vegetation of any part of the upper Rio Grande watershed may be regarded as one of the best physical expressions of the climate of that area. Owing to the wide differences in the climates of various parts of the watershed and to the influence of edaphic, biotic, and physiographic factors, the vegetation also differs widely—from semidesert savannas (grass-and-shrub vegetation) of the lowest semiarid plains, to pine-fir and spruce-fir forests of the high mountainous districts. The vegetation of different areas is herein designated according to the plant cover characterizing them, as follows:

**Grassland:**
1. Semidesert savannas (grasses and shrubs) of the lowest plains.
2. Semidesert grasslands of the low plains and valleys.
3. Semidesert grasslands of the high valleys.
4. Semidesert grasslands of the high tablelands.

**Sagebrush:**
5. Sagebrush lands (shrubs with grasses) of the cooler high valleys and tablelands.

**Woodland:**
6. Savanna woodlands of high plains, low mountains, and tablelands.
7. Woodlands of foothills, mountains, and some high plains.

**Forest:**
9. Spruce-fir forests (including aspen areas and parks).

Each of these types is described later in this bulletin.

**LAND RESOURCES**

The principal resources of the upper Rio Grande watershed are, according to their importance: Usable water, principally for irrigation but also for domestic and industrial purposes; agricultural, especially irrigable, lands; livestock range forage; forest products; wildlife; and recreational uses.

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4 The mean annual precipitation in the San Luis Valley, according to the records of nine U. S. Weather Bureau stations, varies from 6.81 to 11.20 inches, with an average of 8.41 inches, which fall is similar to that of the middle and lower parts of Rio Grande valleys in New Mexico.
The usable water in this area is supplied almost entirely by the Rio Grande and its tributaries, on which most of the people are wholly dependent. Other sources include springs and underground water. The population is distributed principally on narrow, noncontiguous strips of rich alluvial lands which include the San Luis Valley in southern Colorado and those along the Rio Grande through New Mexico and, below the upper watershed, along the borders of Texas and Mexico.

The term "usable water", as applied to conditions on the watershed, implies two distinct properties regarding the water supply, namely, quantity of water which can be made available for all uses, and water (especially the regular or steady flow) free from silt and harmful alkali salts. The quantity of water that can be taken directly from a regular-flow stream for irrigation purposes is greater than that taken from an ephemeral stream of equal total discharge during the irrigation season, unless provision is made for storage of the entire flow. Practically all the run-off of the watershed is used for irrigation either through diversion or storage.

Records of the flow of the Rio Grande at San Marcial show that prolonged maximum delivery of water into Elephant Butte Reservoir, the main storage basin on the watershed, is in the spring and that short-time swell flows may occur during summer. A protective cover of vegetation prolongs the flows by retarding the run-off, and it aids water to enter the ground where it is temporarily stored as ground water which appears again in the form of seepage water, springs, and small perennial streams. There is still much to be known regarding the influence of vegetation on stream flow. However, the work of Duley and Miller (9), Forsling (11), and Lowdermilk (15, 16) has shown that vegetation (including litter) not only protects the ground surface, but it also maintains porosity and acts as a filterlike mantle which keeps the soil pore spaces from becoming clogged with clay, thus allowing maximum absorption of precipitation water.

The water supply is determined by precipitation and its disposal. The principal source is in the high mountainous districts where the mean annual precipitation may be as high as 34 or more inches. Here protective forest vegetation and also water-absorbing soils control erosion and allow most of the precipitation to soak into the ground to become the source of springs and small permanent streams that feed the Rio Grande and establish its perennial flow.

The large total acreage of the valleys, plains, and tablelands contributes very little to the perennial flow, as compared with the high mountainous districts. But because of the destruction of and change in the protective plant cover, these lands outside the high mountains contribute most of the water and silt of flash floods that occur during the summer rainy period. Such floods result in excessive filling of the main channel of the Rio Grande and in silting up of water reservoirs and other irrigation works, as well as in destructive erosion and frightful flood damage to property. Moreover, accelerated run-off means a material reduction of the quantity of precipitation water that would ordinarily soak into the ground and that is necessary for the maintaining of a protective cover of vegetation.

* Italic figures in parentheses refer to Literature Cited, p. 87.
AGRICULTURAL LANDS

Irrigable lands constitute about 5 percent of the watershed. About 95 percent consists of range and forest lands. Lands permanently suited for dry farming are very limited. Although the irrigable lands occur in scattered tracts and the total acreage is small, each tract is a primary land resource and the focal point around which the economic and social structure of the people developed. That this is true may be shown by the fact that settlements have developed wherever there were tracts or strips of irrigable lands.

LIVESTOCK RANGES

The millions of acres of grasslands and most of the forested areas are important grazing grounds for sheep and cattle. The grasslands are used for both year-long and winter grazing, and the forested areas for summer grazing. The importance of range in human affairs is not indicated by the total numbers of animals on the ranges nor by the few outfits which number their sheep and cattle by the thousands, but rather by a great many small farm owners each of whom depends on a few range animals to piece out a livelihood.

FORESTS

The saw-timber forests in the New Mexico part of the watershed constitute a large part of the timber resources of the State. Most of the pine and some fir and spruce have been cut, either clear of all merchantable trees or conservatively. These cut-over lands, however, remain important potential sources of timber. Beginning in the 1880's and during the rapid expansion of railroad building and the development of mining and agriculture in southern Colorado, the headwater areas of the Rio Grande, principally the Chama drainage, supported large lumbering operations. Up to about 1920, extensive areas of virgin ponderosa pine were lumbered. Most of the timber was marketed in or went out to market through Colorado. Operations in other districts, such as in the Santa Barbara drainage near Embudo and those in the Zuni Mountain district, for many years supplied raw material for a large tie-treating plant of the Santa Fe Railroad and a modern sawmill in Albuquerque. Most of the cut of the last few years has been in small tie and sawmill operations scattered here and there, and from extensive cuttings on the Jemez drainage which furnished logs for a mill at Bernalillo. Woodlands have been and continue to be important as sources of fuel wood, fence posts, mine timbers, piñón nuts, and similar products for which there is a steady local demand.

WILDLIFE AND RECREATIONAL RESOURCES

Game and fish have played an important role in human affairs from the beginning of prehistoric settlement. Taos and Santa Fe were the field centers of the fur trade during beaver-trapping days. The mountains, with many miles of trout streams and big-game country, where deer, elk, mountain lion, bear, turkey, grouse, and the like are found, and the low country with its quail, waterfowl, and lake fish, are among the best hunting and fishing grounds in the West, although conditions on many such areas could be greatly improved. The opportunities for recreation and field study afforded by the vast areas of mountain wilderness, the health-building climate of the lowlands, the abundance
and superiority of things of interest to archeologists and artists, the
land of the Pueblo Indians, and the present-day remnants of a six-
teenth-century "New Spain" are bringing recreation to the front so
rapidly that these particular resources may some day be the principal
assets of the area.

**STRIKING EVIDENCES OF ACCELERATED EROSION**

Fundamentally, this study of the relationship between the state of
the plant cover and soil erosion is based on the premise that: A cer-
tain degree of soil erosion (so-called normal) takes place under the
cover of natural vegetation; but ordinarily that vegetation offers
sufficient protection to the ground surface to allow not only the gradual
accumulation of soil-forming materials but also the development of
distinguishing soil features to a greater or lesser degree.

The striking evidences of accelerated run-off and erosion on the
upper Rio Grande watershed include channeled or trenched valleys,
arroyos, gullied slopes, sand washes, sand dunes, altered courses of
mountain streams, accumulations of loose stones and sand on the
ground surface, soil humps, disappearance of luxuriant valley grasses,
disappearance of soils, particularly topsoil, and even extensions of
natural badlands.

**BREAK-DOWN UNDER NORMAL CONDITIONS**

Among these striking evidences of accelerated run-off and erosion
are small areas where rapid break-down takes place recurrently, even
under normal conditions. They may be considered the result of
normal erosion and geologic processes and include (1) areas with
badland features and (2) steep-slope slips in places in the upper Red
River Canyon and the gorge district between the upper and lower
basins of the Rio Chama.

The so-called badland areas aggregate less than 0.1 percent of the
total area of the watershed, consisting principally of a small area
north of Cuba and others in the Santa Fe-Espanola section. That
north of Cuba occurs in exposures of an easily eroded formation along
the southeastern edge of a vast area, described by Gregory (12) and
Miser (17), which has many similar exposures and constitutes a part
of the lower San Juan and Colorado drainages. This formation also
includes the areas known as the Painted Desert in Arizona and the
badlands of Utah.

The badlands in the Santa Fe-Espanola district occur in exposed
areas of "Santa Fe marl." The frequently changed locations of the
Santa Fe-Taos Highway made since about 1910 indicate the rapidity
of land break-down in this district during the last 20 years. In con-
sidering the badland features found here, recognition should be given
the fact that these areas form a part of range and woodlands that have
been intensively used for more than 300 years. One can therefore
only make conjectures as to how much of these lands had badland
features originally. The examples given are indicative of the rapidly
changing relief and rapid land break-down. Originally small, these
areas have developed into more extensive ones following destruction
of protective plant cover. Well-defined V-shaped gullies which form
during a single storm soon become rounded depressions. The great
quantity of earth eroded during a single storm may change the flow
of small drainages to new courses, and subsequent storms restore
the flow to its old course.

Areas within the San Juan basin but in the same extensive geologic
formation indicate the former protective influence exerted by vegeta-
tion on these critical areas in the Rio Grande watershed. Here
spots with badland features are scattered over such an extensive
area that in places lands have escaped depletion. In these places,
valley and mesa plains have a good cover of semidesert vegetation,
although temperature is similar and rainfall less than in either the
Cuba or Santa Fe-Espanola districts. The explanation of the develop-
ment of a dense growth of tall grasses in these valleys lies in the fact
that the low run-off of extensive areas drains onto and spreads over
these comparatively small valley plains, thereby supplying water
somewhat resembling periodic application of irrigation water. Here
the thick growth of grasses functions not only in protecting the land
from the erosive forces of normal flood flows but also in effecting
sedimentation of alluvium and, through centuries of time, in allowing
the development of definite soil characteristics.

On the mesa lands above the valleys, semidesert grasses principally
and some woodland trees and shrubs, although not forming so dense
a growth as occurs in the valleys, provide a protective ground cover.
Where valley grassland forms a footing below and mesa vegetation
a cap above the steep slope areas with exposures of peculiar forma-
tions, areas with badland characteristics are small and well con-
trolled. But when the vegetation on these valley and mesa lands is
depleted, accelerated run-off first floods with raw silt, then channels,
and eventually destroys them. Run-off also spills off the edge of
mesas down the slopes, bares more of the critical formations, erodes
them into fantastic forms, and greatly extends the areas with badland
characteristics.

The other striking manifestations of normal erosion, steep slope
slips, are very limited in area but have distinctive features. They
have no relation to the badland areas and may occur regardless of
the influence of vegetation. The Red River area furnishes good
examples. Here a deep ash and agglomerate formation which rests
on the sill of dense igneous rock is exposed in places in the canyon
slopes. Avalanchelike slips have occurred at intervals in the uncon-
solidated deposits. They probably resulted from accumulated water
that saturated layers of the unconsolidated formation above the
dense base rock near the level of the canyon floor or at higher levels.
Some such disturbance probably explains the cause of local caving-in
of these canyon walls, even though dense forest growth occurs above
the rim of the canyon. Where the loose stones and ash from cave-ins
come to rest in long, steep talus slopes, creep must be slow for forests
have invaded the lesser slopes and large trees grow near the base
of them.

CHANNELED OR TRENCHED VALLEYS

Continuous vertical-walled channels have cut through extensive
alluvial valleys where formerly the run-off spread over meadowlike
areas. Some of these channels are 300 feet wide and 30 or more feet
deep. Many smaller tributary channels cut across the valley floors
and connect the main channels with arroyos, or large gullies, which
discharge into the valleys from the adjoining upland plains and foot-
hills. In the Puerco Valley between Cuba and La Ventana, the
former valley plains have been so badly gouged through channeling that they have also assumed badland features, making it practically impossible to maintain a permanent passable highway through the valley. These conditions even contributed to the abandonment of a railroad in 1931, after less than 10 years of operation (pl. 1, A).

Owing to the erosive force of the flood waters that concentrate in these canyonlike channels and the vast quantities of easily eroded alluvium that make up the valley floors, these valleys constitute the source of enormous quantities of silt which, if removed by flood waters at the present rate, may easily ruin reservoirs and other artificial works that have been designed for the development of water resources. Every large and practically every small valley of the watershed has been channeled from 50 to 100 percent of its length. A good example of deep channeling is that in the Rio Puerco Valley shown in plate 1, B.

ARROYOS, GULLIED SLOPES, AND SAND WASHES

In some places arroyos as large as 50 feet wide and 20 feet deep have formed where there were originally only shallow drainage depressions (fig. 3). These arroyos, likewise their gully "feeders" which are commonly as much as 8 feet wide and 5 feet deep, may work themselves back across the mesas sometimes to connect with canyons of distant mountains. Arroyo Tonque, which joins the middle Rio Grande Valley near the Indian pueblo of San Felipe, is a good example. Near its source in the foothills of Sandia and Ortiz Mountains, this arroyo is practically a vertical-walled trench from 5 to 20 feet deep and from 20 to 50 feet wide, cut into what was at one time only a drainage depression. From it long gully tributaries branch like the veins of a leaf over the mesa plain.

Similar manifestations of destructive erosion may be found in the high mountains, where, in some districts, as in the lower Rio Jemez drainage, some slopes have become badly gullied, and many alluvial mountain valleys—those that were formerly meadows—now have arroyos draining them. Arroyos have already cut through at least 25 percent of the mountain valleys, and in 40 to 50 percent of them active arroyo cutting is in progress.

Along the lower courses of many streams, floods during recent years have carried away alluvium that was formerly deposited there, and sand is now taking its place, thus converting the stream channels
4. Destruction of a trestle of the Bernalillo-Cuba railroad where it crossed Arroyo Salado, a branch of the Rio Jemez.  

B. Destructive channeling in the alluvial Puerco Valley. Here flood waters from overgrazed ranges not only destroy highly productive grazing lands but also choke the Rio Grande with enormous quantities of sediment.
A. A large sand wash which was once a shallow drainageway on Santa Fe-Taos highway near Española, N. Mex. Flood waters have damaged the concrete dip. B. Run-off from overgrazed and eroded lands has completely changed the character of this stream channel. It is strewn with boulders and is dry, except when it carries flood flows.
into wide desertlike sand washes (pl. 2, A). Where sand so accumulates, it may become an almost inexhaustible source of blow sand from which dunes are being formed. The process becomes progressive; during recent years spectacular dune areas have extended rapidly from sand-wash points on the Puerco, Salado, and Jemez.

ALTERED COURSES OF MOUNTAIN STREAMS

Mountain streams, particularly those in the upper Chama Basin that drain destructively lumbered and grazed lands, have lowered and widened beds which at points of least gradient are covered with boulders and sand. Such a boulder-strewn bed is shown in plate 2, B. The lower course of Truchas Creek, a small stream in the mountains east of Española, also illustrates altered conditions. Narrow strips of flood plain that formerly paralleled this stream in some places have washed away; the widened and deepened channel has no drift piles or any obstructions such as trees against which drift piles might form; pools are filled with silt and sand, and boulders in rapids are coated with clay (pl. 3, A). Above the point on Truchas Creek just described and beyond only a fence, there is a shallow and narrow channel fringed by either alders and willows or forest trees. Natural dams of drift (sticks, leaves, and trash against a log jam) check the velocity of flow by building up successive levels in the course of the stream. Deep pools, rapids that have clean rock-and-gravel beds, and high-water marks that show little or no mud are other characteristic features of this part of the stream (pl. 3, B).

ACCUMULATIONS OF LOOSE STONES AND SAND

In some places, particularly on gravelly soils like those of the low plains that border the middle valley, loose stones cover the ground. These stones, together with the damaged condition of vegetation and land, indicate that topsoils, and in some places even the subsoils, have been washed away, exposing clayey subsoils or substrata. These are really desert conditions that have developed as the result of the deterioration of semidesert lands.

Where vegetation is still in good condition, surface stones are firmly embedded in the ground among roots of plants, particularly grasses. Only on small bare areas, as the larger spaces between grass clumps and on rodent mounds, are there any loose stones or sand.

Sand ripples and remnants only of a former grass cover may indicate both washing and blowing away of soils. When bared of a protective cover, the finer particles of sandy loam soils are carried away during rain and dust storms. The coarser soil particles left are shifted about by wind. Spectacular dunes form where sand from these wind-blown areas is carried over the edge of cliffs or steep slopes, as west of the valley at Albuquerque and in the vicinity of Laguna.

SOIL HUMPS

In some places, particularly in alluvial valleys, prominent pedestal-shaped soil humps plainly show accelerated erosion, and give the land a distinctly humpy appearance. These humps, some 2 or more feet high, represent small "spots" where the ground is still protected by dead grass tufts that cap the humps and have a network of deep roots that bind the pedestal base of each hump, the soil between the humps having been eroded away (pl. 4, A).
Similar but lower humps which appear as raised spots of the ground surface—some as large as the crown spread of a tree or shrub and others no larger in area than the spread of a clump of grass—characterize recently eroded lands where trees, shrubs, or remnant herbaceous plants still furnish some protection to the ground. These low mounds are gradually reduced in size and lowered through surface soil erosion until, ultimately, they disappear. (See "Measurements of surface soil erosion", p. 40, for a discussion of these low humps.) Such evidence of destructive soil erosion was found common on at least 50 percent of the eroded lands of the watershed.

DISAPPEARANCE OF LUXURIANT VALLEY GRASSES

Sacaton has disappeared from most of the low alluvial valleys. Badly gullied and arroyo-dissected low valleys, which formerly produced large yields of sacaton hay and pasturage as the result of abundant moisture, are now barren or have only scattered growths of weeds which have little or no forage value and which give but little protection to the ground surface. Here, too, dark-colored topsoil either has been entirely washed away or covered with sand and silt.

The mountain valleys that have become drained through the formation of gullies and arroyos now have mostly iris and other weeds, in contrast to dense growths of grasses and grasslike plants of valleys still in good condition.

DISAPPEARANCE OF SOILS

On many areas accelerated surface soil erosion is commonly not recognized, principally because of the absence of such evidence as trenches or large gullies. Nevertheless, sheet erosion on thousands of acres has resulted in the disappearance of soils, particularly the upper humic part or the topsoil, in many places exposing the subsoils and geologic substrata. This phase of erosion involved a special study and is discussed later.

DESTRUCTIVE EFFECTS OF ACCELERATED RUN-OFF

Recent damaging effects of floods and silt include the destruction of numerous primitive works for diverting water, excessive silting up of the main channel of the Rio Grande and of irrigation works, and destruction of farm lands. Wash-outs of highways and railroads have apparently increased both in number and destructiveness, coincident with a greatly increased area of despoiled lands. Other harmful effects of erosion which should concern the population of this area is the damage done to recreational and wildlife resources.

DESTRUCTION OF PRIMITIVE IRRIGATION WORKS

Two unpublished records of State engineers of New Mexico (reports for 1896 and 1928) and the 1931 survey records show that many primitive works that were effectively used for centuries in diverting waters for irrigation purposes from Galisteo Creek, part of Rio Puerco, and from Rio Salado have been destroyed by floods, silt, and the deepening and widening of channels during recent years. Such destruction has progressed until the inhabitants of the old native
settlements involved have abandoned all efforts to cope with the situation. Moreover, no other or modern works have been attempted in these drainages to restore irrigation. These and the data shown in table 1 are but indications of the extent of areas that have been destroyed for irrigation.

### Table 1.—The destruction of primitive irrigation ditches and diversion works by erosive forces in the Upper Rio Grande watershed

<table>
<thead>
<tr>
<th>Drainage district</th>
<th>Valley</th>
<th>Name of ditch</th>
<th>When ditch was constructed</th>
<th>Acreage irrigated in 1896</th>
<th>Subsequent history of ditches and diversion works</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 8, Galisteo...</td>
<td>Galisteo...</td>
<td>No name (private).</td>
<td>Before 1880 (very early).</td>
<td>300</td>
<td>Destroyed beyond repair by a flood, August 1926; no irrigation practiced since 1929.</td>
</tr>
<tr>
<td></td>
<td>Galisteo...</td>
<td>Colorado Plaza</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Galisteo...</td>
<td>San Cristobal</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Galisteo...</td>
<td>Galisteo Plaza</td>
<td></td>
<td>400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Galisteo...</td>
<td>Ortiz</td>
<td></td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Galisteo...</td>
<td>Los Carrillos</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tijon Arroyo...</td>
<td>Tijon</td>
<td></td>
<td>80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td>1,140</td>
<td></td>
</tr>
<tr>
<td>No. 10, Rio Puerco (below Cuba).</td>
<td>Rio Puerco...</td>
<td>No name (private).</td>
<td>1872</td>
<td>150</td>
<td>Most of these works were destroyed beyond repair by floods before 1928; all were destroyed before 1931.</td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>La Ventana</td>
<td></td>
<td>180</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>La Tijeras</td>
<td></td>
<td>320</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>Cabezon</td>
<td></td>
<td>600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>No name (private).</td>
<td>1872</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>Santa Clara</td>
<td></td>
<td>300</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>Acrequia de la Glorieta</td>
<td>1872</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>Acrequia Guadalupe</td>
<td>1872</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>Commune de Salazar</td>
<td>1872</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>Acrequia del Cochino</td>
<td>1872</td>
<td>3,600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>No name (private).</td>
<td>1872</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rio Puerco...</td>
<td>Total</td>
<td></td>
<td>3,600</td>
<td></td>
</tr>
<tr>
<td>No. 11, Rio Salado.</td>
<td>Alamocito Creek</td>
<td>No name (private).</td>
<td>Before 1880</td>
<td>300</td>
<td>Destroyed before 1928.</td>
</tr>
<tr>
<td></td>
<td>Rio Salado...</td>
<td>Santa Rita</td>
<td>Before 1880 (very early).</td>
<td>300</td>
<td>Destroyed by 1920 and 1931 floods.</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td>600</td>
<td></td>
</tr>
</tbody>
</table>

All these primitive community ditches and diversion works, which irrigated 5,340 acres in 1896, were destroyed during a period of rapid land degeneration. Apparently there were community ditches destroyed before 1896, inasmuch as in the data on the Puerco drainage district in the 1928 record, five ditches listed as "old" and four others as having been constructed in 1872 were not accounted for in 1896. As only ditches in use were considered in 1896, the nine old ones referred to probably had ceased to function or the diversion works were temporarily washed out.

The communal ditches in the Galisteo and Rio Puerco drainages are excellent examples of the fate of these old irrigation works. The developments in the Galisteo Valley must have been very old, inasmuch as the Spanish settlements of Galisteo and San Cristobal were among the first in New Mexico, whereas those in Puerco District were not so old; yet in both these drainages rapid destruction of these community ditches occurred during the same period, between 1896 and 1913.
According to Yeo, irrigation in the Galisteo Valley was abandoned in 1926, following destructive floods (in August) which eroded the channel of Galisteo Creek so deeply as to destroy all the ditch headings. Many irrigation ruins and settlements that have been abandoned during comparatively recent years indicate that a much larger acreage had been under irrigation in the Galisteo Valley than that indicated in table 1.

On his way to California in 1849, Pancoast (18) described the Galisteo Valley as "a large plain of grass" where there were "many acres planted with corn and other vegetables, and irrigated." He arrived at Galisteo Plaza late in July. From his description, it must have been about the beginning of a belated summer rainy season. He had been traveling for months by wagon train in company with a large party, and a rest camp was made at Galisteo, because of the grass, water, and agriculture found there.

In describing an excursion, on foot, from their camp to the village and return, Pancoast wrote: "Just outside of town, I had to walk a plank across a creek." A great change has taken place in this watercourse since 1849, because in 1931 the stream channel both above and below Galisteo Plaza was a vertical-walled earth canyon from 15 to 25 feet deep and from 50 to 200 feet wide.

Pancoast pointed out the fact that the flocks and herds of the Mexicans in the Galisteo Valley were held beyond the irrigated farms in order to prevent their destroying the crops, because there were "no fences around their fields, except in some instances Cactus hedges."

Pancoast mentioned the purchase of 500 sheep and the acquisition of horses, mules, cattle, oxen, and goats by various members of the party while at Galisteo. It is interesting to note that the sheep were eventually sold in the California gold camps. Particularly when the conditions afforded for grazing around the night camps of a wagon caravan are considered, this number of animals, together with the several hundred oxen of the wagon train, would indicate that there must have been considerable forage available at that time even in the driest sections of the country through which the party traveled, in contrast to the desertlike aspect of much of the same country today.

On leaving Galisteo, Pancoast described the first day's journey down the valley in these words: "We passed through a flat country this day, where farming was done as in the days of Abraham." One following the same route today will find not only a barren waste dissected by a great many deep straight-walled channels but also numerous barriers in the form of deep arroyos.

RIO PUERCO VALLEY

In the Rio Puerco Valley below Cuba there were 3,600 acres irrigated in 1896. Yeo's unpublished records show that there were not more than 500 acres left in 1928. In 1931 only three brush-and-dirt diversion works remained; two were badly damaged, the dam and head gate of the third were almost buried in silt, and the diversion ditches below the buried head gate were destroyed by deep channeling of the main watercourse (pl. 4, B).

Destruction of farm lands in this valley progressed so rapidly since 1910 as to force the abandonment of practically all the irrigated lands.

6 Unpublished records of the State engineer of New Mexico, 1928.
A. The upper Rio Santa Cruz where it flows through an overgrazed and deteriorated area and where flood waters have widened and deepened its channel.  
B. The same stream, a short distance above the point shown in A, where conditions are good because of protective forest vegetation.
A. Pedestal-shaped "humps" of soil held together by roots of dead sacaton (grass). The tops (root crowns) of these humps indicate the former level of the ground surface. B. A brush-earth dam which was used to divert irrigation water from Rio Puerco at the old settlement of Cabezón. Silt overwhelmed the dam and the canal head gate.
A. With the destruction of farm lands through overgrazing and accelerated run-off, goats become an increasingly important factor in aiding native settlers to obtain subsistence.  

B. Ruins of Tijon, an old native village recently abandoned after soil erosion deprived its inhabitants of irrigation water and farm lands.
A. The Rio Grande near Albuquerque. There are places in the middle valley where the oozy silty bed of this stream is higher than the valley lands opposite. This condition makes the use of levees and jetties necessary.  
B. Destruction of crops and farms by flash floods that originate on deteriorated range lands.
This is true even in the more recently developed districts above Cuba regarding which neither of the two of the State engineer reports (1896 and 1928) contains any information. The lands that are still under ditch above Cuba, only a small acreage, are irrigated from small mountain streams whose waters are diverted before they reach deeply eroded channels.

While the main channel of the Rio Puerco at Cuba, now a continuous channel, was being made deeper and wider through erosion, the surface runs and even the trails, roadways, and irrigation ditches of the adjoining lands were converted into arroyos by run-off from surrounding slopes no longer adequately protected by their plant cover.

The lower valley of the Rio Puerco between San Luis and Cabezon and in the vicinity of Salazar and Guadalupe has been described as a “paradise” by residents of the early 1880’s. Remnants of cottonwood groves and substantial houses in this valley indicate former periods of fruitful agriculture and profitable livestock ranching. Now most of the valley part of the Rio Puerco drainage presents a deplorable appearance. Enormous straight-walled channels, some 1,000 feet wide and from 20 to 40 feet deep, continue to increase in number and size, the last stages of the destruction of formerly productive lands.

**PRIMITIVE COMMUNITY WORKS IN RELATION TO THE WHOLE WATERSHED**

From the beginning of irrigation in these valleys, waters for irrigation purposes must have been easily diverted, at first from noncontinuous channels and later, since destructive erosion set in, from small continuous channels through the use of brush-and-earth dams. During recent years, deep and wide channeling has made it impossible to cope with the destructive force of the greatly accelerated flood flows, hence the abandonment of so many old agricultural communities.

Remnants of dams that show many repairs and extensions indicate community effort to save farm lands and homes from destructive erosive forces. The dams were extended as the stream channels widened, the work being done in progressive stages. To illustrate: The brush used in the first 20- or 30-foot extension of a dam may consist of the limbs and trunks of juniper trees; the second extension, longer than the first, may contain both piñon and juniper logs; whereas the third or last section may be strengthened by pine logs that were brought from the mountains. The uniformity of the old and original sections of these structures, as shown in the preserved poles and limbs, indicates that these old dams had remained intact for many years; and the pieced nature of the last extensions shows that, for a comparatively few years before abandonment, repairs were made frequently.

With the destruction of their farm lands, native farmers have been forced to find other ways of gaining a livelihood. Many have already abandoned their homes. Small flocks of goats and sheep, which were formerly included in the system of primitive farming, have become an important source of subsistence (pl. 5, A) supplemented by small patches of land (remnants of formerly irrigated tracts) which are now dry-farmed. The adjoining range lands, already seriously damaged, are becoming more and more denuded of vegetation, owing to the fact that the numbers of goats and sheep are in excess of the grazing capacity.
The conditions regarding the primitive irrigation works described and these cases of the decline and destruction of farm lands of comparatively small segregated communities are typical of many parts of the watershed. The history of the small agricultural communities closest to the origin of the accelerated run-off show that destructive soil erosion is more than a menace to the land resources and human welfare; it is, rather, land destruction itself (pl. 5, A and B). Moreover, if such destruction continues it will probably manifest itself ultimately in a similar manner not only on the small scattered areas left but also on larger areas of agricultural lands along the Rio Grande and its principal tributaries.

SILTING UP OF RIVER CHANNELS AND WATER RESERVOIRS

Silt chokes the channel of the Rio Grande throughout the middle valley (pl. 6, A). It is discharged into the river below Embudo from streams and arroyos that drain damaged range and forest lands in such enormous quantities that the regular and even the flood flows cannot remove it by channel scouring, despite the fact that channel scouring has been aided incidentally in many places by recently constructed bridges, flood-protection dikes, and jetties. Moreover, the reduction in regular flow, which has resulted mainly from the taking of water directly out of the river for irrigation, diminishes channel scouring.

Since 1880, when definite measurements were begun, to 1929 (prior to the August and September floods), a rise of the channel bed of the Rio Grande extending from the upper to the lower end of the middle valley had taken place. This channel filling is in progress for 167 miles down the valley—gradually increasing downstream—until at San Marcial, at the lower end, it amounted to a 12-foot rise in 1929. According to the surveys made by the Middle Rio Grande Conservancy District, in many places the bed of this river is now from 2 to 4 feet higher than corresponding low points in the valley.

WATERLOGGING OF AGRICULTURAL LANDS

The excessive silting up of the main channel throughout the middle valley has resulted in the waterlogging of many thousands of acres of formerly productive farm lands, and has led to a $10,000,000 program for flood control and drainage, undertaken by the Middle Rio Grande Conservancy District (?).

Between 1880 and 1925, the acreage of farmed lands in the middle valley had shrunk from about 125,000 to about 40,000 acres, a decrease of 68 percent. Of the 85,000 acres that had been rendered unfit for farming, about 80,000 were given up on account of waterlogging which resulted from the silting up of the main river channel and a corresponding rise of old canals and ditches to levels far above those of bordering lands.

SILTING UP OF RESERVOIRS

The enormous discharge of silt into the Rio Grande and the movement of this fine earthy material downstream mean that the Elephant Butte Reservoir will ultimately be the recipient of most of it. According to the records in the United States Reclamation Service office at El Paso, Tex., this reservoir, during the 17-year period 1915–31 had already received a quantity of silt sufficient to cover 337,939 acres
SOIL EROSION AND STREAM FLOW ON RIO GRANDE

1 foot deep, of which 231,500 acre-feet were deposited during the period from 1915 to September 1925.

The average annual displacement of the water capacity of this reservoir by silt for the 17-year period is about 19,900 acre-feet. Inasmuch as the original storage capacity of the reservoir was 2,638,860 acre-feet, there remains (Jan. 1, 1932) an estimated total capacity of 2,300,921 acre-feet. If silting up continues at the same rate, by 1982 the reservoir capacity would be reduced to only 1,305,921 acre-feet, and entirely displaced by silt by the year 2048.

The above figures indicate that, at the present rate of silting, the original effectiveness of the Elephant Butte Reservoir for flood control and storage will be reduced about 50 percent within the next 50 years. The disastrous effect that such an untimely reduction in the storage capacity would have on land resources and human welfare in this area constitutes a serious problem.

Other storage reservoirs thus affected are the smaller ones on the tributaries of the Rio Grande, such as that located on the Santa Cruz a few miles east of Española. Here the quantity of silt already deposited at the head of the reservoir is enormous. Even though the upper Rio Santa Cruz is a stream that has its source in a forested section from which there seems to be but little silt, the stream, for some distance above the reservoir, flows through a badly depleted area where grazing is uncontrolled.

FLOOD DESTRUCTION BELOW ELEPHANT BUTTE DAM

Although floods in the Rio Grande above Elephant Butte Dam no longer reach the valley below the dam, flash flows from the watershed below the dam produce river floods that are very destructive to valley lands and property. Restriction of the river channel has made these floods particularly destructive.

A description of these channel changes has been given by Fiock, of the United States Reclamation Service, as follows:

There has been a general narrowing of the river channel to accommodate itself to the normal regulated flow of the irrigation supply. Above El Paso the narrowing of the river bed or channel has been most noticeable where it was formerly wide and shallow and then had the appearance of a sand flat. This narrowing has occurred by the sodding over of the area not now normally occupied by the waterflow, first by grass then by brush, as illustrated by the Anthony river cross section. Also by the formation of islands in the wide shallow sections and gradual enlargement of the islands until they join with the bank on one side, leaving the narrowed river channel to the other side. Every tree trunk or other drift lodging over these wide shallow sections of river bed is potentially the start of an island. Grass, weeds, and brush soon begin to grow in the silt and sand deposited below the lodged drift and an island of increasing size is formed. Increased flows are now not of sufficient amounts, frequency or duration to dislodge the anchored drift and scour out the deposited silt which becomes more permanently fixed by the rapid growth of vegetation on it. The remaining wide sections of river bed in the upper valleys are dotted with these islands, the sizes of which are continually increasing. The effect of this establishment of a narrower normal water course through the former wide bed is to reduce the effective floodway, for even though some of the side area may still be overflowed during flood stages the vegetation retards the flow. Some of the former river bed is even now being farmed, but with risk of being overflowed.

This condition has caused the city of El Paso and the irrigation districts in the lower valley to plan a $5,000,000 flood-protection program. If such a program is deemed necessary under present

1 Unpublished report on the effect of the operation of Elephant Butte Reservoir on the river through the Rio Grande project.
conditions, when the reservoir impounds all the main-river waters, one would wonder what might be required for protection when the reservoir capacity is reduced to the point where it will no longer take care of flood flows.

**DESTRUCTION OF LANDS AND PROPERTY ABOVE ELEPHANT BUTTE DAM**

The important valleys of the watershed, particularly the middle valley, have suffered severely during recent years from floods. In this valley, farm lands (pl. 6, B) and buildings have been destroyed and highways and railroads have been seriously impaired by wash-outs.

The most damaging floods occurred in August and September 1929, the last one being the most destructive (pl. 7, A and B). According to Yeo (21), the damage done to farm and town properties by these floods (principally the September flood) between the Elephant Butte Reservoir and the mouth of the Rio Puerco was estimated at $1,181,500, exclusive of flood relief and railroad losses. The Atchison, Topeka & Santa Fe Railway had to construct 4,000 feet of temporary trestle and raise the roadbed several feet for a number of miles through the valley. The damage to highways was placed at $230,000. According to the New Mexico Highway Department, three large bridges, valued at $21,000, were washed out on the Rio Puerco alone. Besides the cost of construction, an additional expenditure of $13,500 was required for installation of works to provide footing protection for these and other bridges.

In August 1931, near Española, a flash flood, which originated on the lower part of the course of a small drainage—a drainage that is now a large sand wash—undermined and tore out parts of a newly constructed concrete highway “dip” between Santa Fe and Taos (pl. 2, A). Many such wash-outs have occurred throughout the Rio Grande drainage, particularly during years of heavy summer rainfall.

A September storm in 1931 caused so much caving in of the banks of deep arroyos as to endanger the highway through the Rio Puerco Valley between Bernalillo and Cuba. Figure 4 shows how the caving in of an arroyo has twice forced the abandonment of the road across it. The present road is in danger of destruction if the caving in continues.

Accelerated floods during recent years have greatly increased the cost of highway and railroad construction, reconstruction, and maintenance. The increasing number of flash floods calls for more and longer bridges, more expensive grade approaches, larger culverts, and many more protective embankments. Such works, together with frequent cleaning of channels of silt and continual repairing of flood damages, require an enormous outlay of capital.

A vital point in the construction and maintenance of highways is proper protection of the rights-of-way from destructive erosion. Inasmuch as these strips of land are usually bared of vegetation and left without adequate protective ground cover, road building has in some places greatly aided the destructive forces of erosion. These strips are usually made even more susceptible to erosion by deep cuts, high earth embankments, and long and unobstructed gradients. Such damage along roads calls for revegetation of these strip areas, in order to provide ground protection and to aid in the control of accelerated run-off and soil erosion. The advantage of a vegetation ground
Destruction of properties in the town of San Marcial by the September flood of 1929: 

A. Destruction in the business section; B. sediment filled this house halfway to the ceiling of the first floor.
Soil Erosion on Upper Rio Grande Watershed

A. Semidesert grassland on the mesa northeast of Albuquerque, in the driest part of the upper Rio Grande watershed. On left, severely overgrazed. On right, lightly grazed 10 or more years. B and C, Typical quadrats on the overgrazed and lightly grazed ranges, respectively.
cover, in relation to erosion control, may be seen in fenced railroad rights-of-way. Here, although practices such as burning are common, natural revegetation has developed a protective cover, principally because new vegetation is not destroyed at intervals by regrading, but rather earth is hauled in and applied from above in maintaining the roadbed.

**DAMAGE TO RECREATIONAL AND WILDLIFE RESOURCES**

The Rio Grande area offers superior opportunities for recreation, conservation of wildlife, and study of prehistoric peoples, and is of increasing importance to the people of not only the Southwest but also of the whole United States.

![Diagram showing areas affected by soil erosion in the Rio Grande area.](image-url)

**Figure 4.—Caving in of the banks of main and secondary drainage ways is endangering the road that crosses this channeled valley.**

Injury to the vegetation and land greatly depreciates aesthetic values and may destroy the beauties of nature as well as the land itself. It also renders unusable the natural water supplies and impairs those lands that are most suitable for camps, homes, and recreation centers. Many of the beauty spots of this area, which have already attracted the attention of people far and wide, are actually menaced with destruction.

Changes in ground cover that result in alternate flash floods and low flows unfavorably affect both the home and food of fish. Lack of shade and irregular flow make water temperature less constant, silt destroys resting and hiding places by filling pools, and flood flows destroy natural dams and feeding grounds. Many formerly beautiful trout streams have been converted into mere channels for flood waters (pl. 3) or, according to Ligon (14), have become retreats for only bonytail suckers.

An abundance of wildlife in places where the vegetation has been preserved is not merely a coincidence. Both animals and birds
thrive best where there is plenty of food and protection from enemies. Nor is it a coincidence that few informed travelers and recreation seekers follow routes that have been rendered desert-like through the depletion of vegetation and made unsafe because of frequent floods and destructive erosion.

CAUSES OF DETERIORATION OF RANGE AND FOREST LANDS

Three hypotheses have been advanced to explain why accelerated run-off and erosion are in progress in the upper Rio Grande area. According to one theory, these destructive processes are coincident with a marked change in climate; according to another, with tilting of the earth’s crust; and according to a third, with deterioration of the vegetation, particularly through overgrazing and destructive lumbering.

THE CLIMATIC-CHANGE THEORY

The theory that change in climate to much drier conditions has caused a marked decline of the natural protective vegetation may seem plausible when one observes the desert-like conditions that have resulted from the destruction of vegetation, particularly in the low valleys and on plains and tablelands. One of the weak points in this theory is the fact that there is no indication, as shown by vegetation protected from overuse, of any general change in the climate of this area within recent years.

If a change to a drier condition has already set in sufficient to exert a marked and sustained adverse influence on the vegetation of the ranges, the change must be general over the whole watershed, and the change should affect the growth of all vegetation, including the forests. No indications have been found of any extraordinary decrease or increase in the area of forest vegetation that is not explained by the control of timber cutting and fire. Large forest areas have been changed to brush lands by cutting and fire, and where fire and other damaging factors have been controlled young pines have extended their limit slightly below pine trees that are hundreds of years old. Likewise, junipers have come farther down onto the lower adjoining grasslands, in some places a considerable distance below large junipers that must be about 1,000 years old.

Furthermore, natural protective vegetation exists today on nonirrigated areas in the district around Albuquerque, in the very heart of the driest part of the watershed where the present desert-like appearance of so much of the area gives the impression that the climate of the districts concerned is and has been too arid to support a protective cover of vegetation. The areas referred to include enclosures like old cemeteries and conservatively grazed range lands. The amount of the vegetation, by classes, on one of these enclosures (an old cemetery), which is located on the mesa 2 miles southwest of Albuquerque, follows:

<table>
<thead>
<tr>
<th>Vegetation:</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasses</td>
<td>85</td>
</tr>
<tr>
<td>Weeds</td>
<td>2</td>
</tr>
<tr>
<td>Shrubs</td>
<td>13</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Thirty percent of the ground surface is covered, based on the crown spread of the plants. When all conditions are considered, this may be
regarded as a good density, as compared with an average density of about 45 percent for the properly used semidesert grasslands of the low semiarid valleys and plains.

In this old cemetery the vegetation has attained the high density indicated, in spite of the fact that both the vegetation and soil have been subjected to disturbing influences, principally grave-digging and rodents. The large number of burrows and trails shows that rodents play an important role, for in districts of depleted grasslands they usually concentrate in small enclosures of better vegetation and greatly interfere with its development.

The high percentage of grasses indicates that the vegetation of this enclosure is a good expression of semidesert grassland. On extensive surrounding areas, the grasses have become practically extinct through overgrazing, and the total density of the present vegetation (weeds and half-shrubs) is less than one-third of that within the enclosure.

One of these districts, adjoining Albuquerque to the east, had suffered extreme depletion from overgrazing, the grasses having been nearly destroyed. Owing to the fact that the extension of the city has cut off the drift of livestock to and from the river, this district has been only moderately grazed during recent years, allowing revegetation and noticeably lessening the severity of dust storms originating here. It should be pointed out also that revegetation has been favored by the gentle slope of the mesa, soils that allow easy penetration of rain water into the ground, and other factors that have minimized soil erosion during the period of deteriorated vegetation. For this reason in most places the topsoils have remained in place and have made possible rather rapid revegetation by providing media favorable for plant growth. The vegetation of the open range adjoining this district on the north, east, and south is in a badly damaged state.

Another area of several square miles located a few miles northeast of Albuquerque was fenced more than 10 years ago, after which it was lightly grazed. In 1931 the range surrounding this area was still overgrazed, although not so severely as it is known to have been in the past (pl. 8). The percent of vegetation by classes and the charted density per square meter within and without the fenced area are given below:

<table>
<thead>
<tr>
<th></th>
<th>Overgrazed open range</th>
<th>Conservatively grazed fenced range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasses</td>
<td>70%</td>
<td>96%</td>
</tr>
<tr>
<td>Small shrubs</td>
<td>29%</td>
<td>4%</td>
</tr>
<tr>
<td>Weeds</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Density per square meter</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1,000</td>
<td>2,000</td>
</tr>
</tbody>
</table>

These comparative measurements show that the fenced area had twice as much cover as the surrounding range. From this one can easily conclude that the fenced lands would also have twice as much protection from erosive forces. But the protection that vegetation gives the ground surface is not necessarily directly proportional to density. The kinds of plants involved are an important factor. The vegetation on the fenced range undoubtedly affords more than twice the protection, owing to the fact that the grasses of the fenced area form close-to-the-surface matlike tufts, as compared with the overstory growth of small shrubs on the surrounding lands.

In considering the vegetation of the protected and conservatively grazed areas previously described, it is known that the density of such vegetation declines during a period of several years of diminished rainfall and that it increases during a period with normal or above-normal fall.
Nevertheless the good condition of the vegetation on the protected areas around Albuquerque shows that the climate of even that section can still sustain a protective cover of vegetation; and that when the land is given protection from overgrazing, or when the ranges are conservatively grazed, the vegetation comes back, particularly where topsoil still remains.

Great swings in climate, such as that from the last ice age to the present time, are generally recognized. Furthermore, the climatic changes that caused the receding of the water of Lake Bonneville, Utah, 20,000 or more years ago (2) probably also affected the Southwest. According to Douglas (8), climate goes in great cycles which embrace many smaller cycles, and a most severe drought occurred in the Southwest during the last half of the thirteenth century. We experience the alternate, comparatively short wet and dry periods and know the temporary effect that they produce in increase or decline of short-lived vegetation. Because of such experience and because of the short period covered by available precipitation records, it is easy to speculate regarding the effects of the great climatic swings. Thus the question regarding a change of climate to drier conditions is commonly raised in connection with the recent extensive deterioration of the vegetation of the range and forest lands of the upper Rio Grande watershed. The fact that distinguishing features (such as dark-colored topsoils) have developed in many of the soils of this area indicates that protective vegetation must have been in existence for many centuries.

VALLEY TRENCHING IN RELATION TO THE CLIMATIC THEORY

The climatic-change theory has been linked with valley trenching. Bryan has established the fact that only small channels existed in the upper Rio Puerco Valley, for example, prior to 1885 (6). Early historical accounts and the experience of old native Spanish-Americans who knew this section during the 1880’s have confirmed Bryan’s conclusions. There are now deep channels in places where, in 1890 or 1910, there were no indications whatever of any active channeling.

NONCONTINUOUS CHANNELS

Previous to the present period of active cutting, short noncontinuous channels must have formed at different times and at certain places in valleys such as the Rio Puerco, Rio Salado, and Galisteo. Evidence of these short channels is found principally at the narrows of valleys, where surface and ground water flows concentrated and where the successive levels in a valley floor slope rather abruptly to lower levels. Such evidence consists of irregular deposition in sediments and may be seen in the banks of deep recently formed channels. It indicates that the noncontinuous channels must have formed and filled recurrently through the centuries. At some of the narrows the relics of different channels may be seen where recently formed channels have cut across old channel “fills”, thus exposing “buried” channels. A buried channel has been exposed at La Vega de La China in the upper Puerco Valley between Cuba and La Ventana. “Vega” in Spanish has the significant meaning of meadow or fertile plain. But now the lands in this district, barren of grass, support only scattered shrubs and annual weeds.

The total acreage of valley lands affected by channeling in time past, as might be shown by irregular deposition of sediments, is probably
A. Dark-colored topsoil developed in soil of the alluvial Rio Puerco Valley above Cuba, where grasses once predominated.  
B. Banding of alluvial deposits commonly found at the narrows of valley floors; Arroyo San José above Cuba.  
C. Faint banding and distinct development of topsoil commonly found in broad valleys.
Vegetation in an old cemetery which proves that the surrounding country was once semidesert grassland. This cemetery is near the old town of Bernalillo, shown in the background.
very small in comparison with the extensive areas now dissected by erosion channels.

It is worthy of note that the principal narrows of a valley were commonly places of permanent waters, the ground water from an extensive plain above the narrows coming to the surface here and forming a cienaga, or marshy area. Cienagas, which are common in mountain valleys, were formerly just as common in the low valleys and on the plains, as evidenced by many place and settlement names that include the term itself, such as La Cienega, an old town on the Cienaga land grants on the Arroyo Hondo, and Cieneguilla, another old town on the Santa Fe Creek. The vegetation on such wet areas grew luxuriantly; and this dense vegetation, together with the sediments deposited in it and held in place by it, functioned as a dam. Such a dam had the same physical limitations as a dirt dam covered with vegetation, and was subjected to the destructive influence of occasional flood flows that gathered on the valley plain above and concentrated at the narrows. Existing cienagas, such as those in the mountain valleys, may have small lagoonlike bodies of water surrounded by dense vegetation, including trees, and from them streams usually flow for short distances.

That water flowed in short channels, in time past, from the narrows of the low valleys where irregular deposition of sediments and other evidence of past channeling may be found, is indicated by the location of dwellings of prehistoric people and of Indians, Spaniards, and Mexicans, who diverted water from these stream channels for irrigation. This was done, for example, at the old settlements of Galisteo, San Cristobal, and Cerrillos in the Galisteo drainage and at Los Cerros, Casa Salazar, and Cabezon in the Puerco Valley. Moreover, these were the channels that were recurrently deepened and cut back into the high valley floors through the centuries, forming short noncontinuous valley channels. Most of these cienaga-formed dams and diversion stream channels have been destroyed during recent years inasmuch as they were critical points and hence were the first to be injuriously affected by excessive flooding and deep valley channeling. Fortunately, some of the cienagas and streams from them have been preserved in part by brush-and-earth works which were constructed for the purpose of diverting water for irrigation.

Examination of valley floors and associated drainages showed that vegetation must have prevailed generally over the valley in time past. In some places where the valley floor has been drained by a deep channel and there is now no grass on the main valley floor, old dead roots of large bunchgrasses, which were found exposed to depths of 10 and more feet, extend through deposits of homogeneous loamy alluvium to clay, indicating that a heavy growth of grass must have existed there at one time. Floodwaters, as evidenced by the uniform texture of the fill and the old plant roots, must have spread over these thickly grass-covered valley floors and distributed whatever alluvium they carried. That the gradual development of valley lands must have progressed through hundreds of years of such deposition is evidenced by the existence of deep dark-colored topsoils (underlain by similar-textured and progressively lighter-colored silty materials) which, we can well assume, required centuries for development under semiarid conditions (pl. 9, A). Striking examples of such alluvial plains occur in the upper Galisteo Valley, where the old grass roots extended down to red clay.
In the upper Galisteo Valley channels have recently cut through gray alluvial deposits and into the underlying red clay that occurs at depths ranging from 6 to 10 feet. The fact that these exposed banks show well-developed dark-colored topsoil but no evidence of any disturbance of the valley fill or of greatly changed rate of deposition, indicates a very long period of protective ground cover.

**Valley-Filling**

Deep recent channels in the valley alluvium of the Rio Puerco expose in cross section alternating bands of light-colored silts and sands with horizons darkly stained with humus (pl. 9, B). These no doubt reflect the activity of the eroding processes during many ages past. The humic layers mean that the valley floor remained stationary for a long period. The light-colored layers mean that the depositional processes were speeded up and that valley-filling was accelerated for some time. This was followed by another period of plant growth and stabilization of the valley floor. These changes must have occurred several times during the period of valley-filling. Rapid deposition of the sediments that constitute the light-colored zones may possibly be associated with old forest burns in the mountainous districts of the drainages concerned and with recurrent breakdown of peculiar geologic formations in certain foothill districts, such as the old burns on the Sierra Nacimiento which parallels the upper Puerco Valley, and the badlands located in the same drainage, north of Cuba.

Apparently, whatever the recurrent destructive factors might have been, their damaging effects were only local, and in time declined, thus allowing rebuilding of the equilibrium between the vegetation and soil-erosive forces, making possible through centuries of time the development of dark-colored topsoils (pl. 9, C).

**Recent Deposition of Sediments and Channeling**

The deposition of alluvium, which is associated with past development of valley floors, should not be confused with the recent rapid deposition of light-colored and varied-textured sediments over diminishing parts of alluvial valleys that are not yet channeled. These parts are being rapidly covered with silt and detritus washed in by accelerated run-off from slopes on which the vegetation has deteriorated. This deposition of sediment is in progress particularly in the lower parts of tributary drainages where it precedes destructive channeling. However, the spreading of flood waters and the deposition of sediment over the valley floors cease as channeling progresses up the valleys. In the advancing valley channels may be seen the banding that results from recent deposition of sediments. Ordinarily at a given point the exposed, recently formed bands are underlain by a dark-colored zone which represents a formerly well-developed, humus-containing topsoil.

**The Theory of Tilting of Earth's Crust**

According to those who hold to the theory that the recently accelerated erosion is the result of diastrophism, or tilting of the earth's crust, certain land areas, as a result of uplift and tilting, have been given steeper slopes, and this change in slope is responsible for the accelerated run-off and erosion. The weakness of this theory lies in
the fact that accelerated erosion is general throughout all parts of the watershed and that it has taken place during the same time on opposite slopes. Any tilting of extensive areas through uplift, and probably sinking also, would increase one slope and decrease the opposite slope. Accordingly, there should be slopes with evidence of greatly accelerated run-off and opposite slopes with corresponding evidence of retarded run-off, such as revegetation and healing of trenches and gullies. No evidence of such difference in run-off or erosion was found.

It is of interest here to note that Bailey (1) in studies of recent accelerated erosion in the upper Colorado River drainage found geological evidence which pointed to the destruction of vegetation as being the principal cause of the accelerated erosion. Gradational processes of erosion on areas that may never have been protected by vegetation had not been accelerated, while accelerated erosion was in progress on the surrounding areas that were once stabilized by plant cover.

PAST USE OF LAND RESOURCES

Historical evidence shows that general accelerated run-off and destructive erosion now in progress in the upper Rio Grande watershed followed recent modern developments. Pueblos and old Spanish settlements, such as Santa Fe, Taos, Espanola, Abiquiu, and those in the middle valley, existed for centuries as agricultural communities. And although grazing began with the Spaniards and large flocks of sheep and goats were grazed during the Mexican era, any deterioration of land from overgrazing undoubtedly must have been local, and principally close to the old settlements. The history of these old settlements shows clearly that widespread decline of agricultural and range lands began following recent misuse and abuse of the land resources.

AGRICULTURAL HISTORY

The upper Rio Grande watershed is the area of the oldest continuous irrigation and range agriculture in the United States. Ruins of ancient villages and canals indicate that irrigation has been practiced along the Rio Grande from time immemorial—probably since about the Christian Era—first by prehistoric peoples, then by Pueblo Indians and later by white settlers. Neither the prehistoric peoples nor the Pueblo Indians had any horses, mules, burros, cattle, sheep, or goats. Livestock was introduced by the Spaniards. For convenience, the use of the land resources in relation to land deterioration will be discussed according to three historical periods—Spanish, Mexican, and recent.

THE SPANISH PERIOD

The first Spaniards to visit New Mexico were Coronado and his followers in 1539. These visitors were treasure seekers who left, disappointed, in 1542. Don Juan de Onate, who organized a colonization expedition in Mexico in 1598, established settlements in the Rio Grande area as far north as the mouth of the Rio Chama, where San Juan, the first capital of the new Spanish empire, was located. Colonization was extended to Santa Fe and environs in 1609. Nearly three-quarters of a century of peaceful habitation followed, until 1680, when the Spaniards were driven from what is now northern New Mexico by the Pueblo Indians. Twelve years later, however, the
Indians were reconquered, and soon after Spanish settlements were permanently established. The livestock, principally sheep and goats, which the Spaniards introduced into this section, were grazed only within comparatively short distances from the settlements, for fear of the Plains Indians.

About 70 pueblo settlements were found in the Rio Grande Basin at the time of the Spanish exploration and conquest. In the records left by Castenada, the number of pueblos given is 80, probably including the Hopi and Zuni villages, Pecos, and the Salinos pueblos outside the drainage. Burkholder (7) has concluded that the Pueblo Indians who once lived in the middle valley irrigated about 25,000 acres. Many old Indian villages still exist, whereas others, like Bernalillo, have lost most of their Indian characteristics. During the days of Spanish occupation, some of the Spaniards, in settlements, joined with the Pueblo Indians for the purpose of protection from a common enemy, the marauding Indians of the Plains.

THE MEXICAN PERIOD

Hundreds of old placitas (hamlets) and ranchos, typical of Mexican life—some deserted and others still inhabited—are evidences of Mexican occupation between the Colorado line and Socorro, N. Mex., during the period from 1821 to 1846, inclusive. These old placitas and ranchos (commonly on sites used by prehistoric people) were found far back in the tributary drainages wherever there were available water and small areas of irrigable land. This would indicate not only how completely these tributary drainages were settled, but also how favorable the conditions must have been to make possible the dependable supplies and sources of water.

According to Bloom (5), 5,000 cattle and 240,000 sheep and goats had use of the ranges in the Santa Fe and Albuquerque districts near the beginning of the Mexican period in 1827 (table 2).

<table>
<thead>
<tr>
<th>District</th>
<th>Mares</th>
<th>Horses</th>
<th>Mules</th>
<th>Cattle</th>
<th>Sheep and goats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santa Fe, its alcaldías, and 6 pueblos</td>
<td>93</td>
<td>184</td>
<td>592</td>
<td>1,450</td>
<td>62,000</td>
</tr>
<tr>
<td>Province of the villa of Albuquerque, etc</td>
<td>105</td>
<td>192</td>
<td>566</td>
<td>2,550</td>
<td>155,000</td>
</tr>
<tr>
<td>Province of the villa of Canada, etc</td>
<td>102</td>
<td>174</td>
<td>690</td>
<td>1,000</td>
<td>23,000</td>
</tr>
</tbody>
</table>

1 Mules probably includes burros.

Such large numbers of animals, if the ranges adequately supported them, indicate a higher grazing capacity and a vastly better condition of the ranges close to these settlements during the early years of the nineteenth century than now exists. That far-from-settlement grazing was not practiced commonly even as late as the first decade of United States occupancy (1847–56) is shown by historical records.

1 The first settlement in San Luis Valley, aside from native villages, as Ortiz and Conejos, was made on San Luis Creek in 1852. These first settlers, however, were driven out by the Ute Indians. Permanent settlement dates from 1854. Below Socorro settlement was prevented, until the United States occupation, by the Apache Indians (7).

2 By "grazing capacity" is implied the number of stock of given class or classes which a range unit will support each season, year after year, without injury to the range or other land resources.
Frequent raids of marauding Plains Indians restricted the areas on which the flocks could graze with safety. Damage close to old settlements must have been severe even at an early date. Present conditions may be typically illustrated by those around Bernalillo in 1931, in the middle valley above Albuquerque, to wit:

At a point 1 mile west of the irrigated valley at Bernalillo the vegetation was scanty and the topsoil was entirely gone, leaving a sandy subsoil exposed to wind erosion and covered with drifting sand. At a point 3 miles farther west the conditions were somewhat better. At a point 6 miles out the conditions were still better—there were some turf-forming grasses, shrubs, and half-shrubs, and not so many weeds, which together formed a cover that afforded some protection to the ground surface. Although erosion was active, some topsoil was still in place. Even here the vegetation was not more than 30 percent of the original cover, when compared with similar situations where the vegetation had not declined.

Near this old town of Bernalillo the higher nonirrigated lands have a desertlike appearance, and one might easily conclude that the country round about was originally a low-valley desert. Small enclosed areas nearby, such as an old cemetery, however, show that the vicinity must have had quite a different aspect at one time. Within these fenced areas the ground was covered with living native grasses, despite the fact that they were not protected from damaging rodents. This plainly indicates that this area was not originally a desert waste, but semidesert grassland (pl. 10).

RECENT OR MODERN USE OF LAND RESOURCES

Prior to the Civil War, the area was practically isolated from the rest of the world. Although it had been the center of the beaver-skin trade of the far West and commerce was carried on with distant places in Mexico, communication with the East and with Mexico City, or even Chihuahua, necessitated long and arduous journeys over dangerous trails.

During this early period the use of the ranges was very limited, because there was only a local demand for animal products, and the grazing was confined to the range lands in the vicinity of settlements and where there were good supplies of water, particularly in the valleys and on adjacent uplands. At first sheep were the principal animals grazed. However, with the advent of army posts, the control of the Plains Indians, and the approach of railroads to the Southwest a greater demand for beef stimulated cattle raising. An account of early range development in the Southwest has been given by Barnes (3).

A period of rapid development followed the Civil War. Irrigation agriculture in the middle valley reached its greatest acreage development in the 1880's, and the grazing of range lands was extended considerably beyond the environs of the old settlements. The irrigation farming, although rather extensive, was primitive.

The building of railroads made markets available for livestock and animal products and timber resources accessible for mining and agricultural developments, principally in Colorado, and for railroad construction. During and following this railroad-building period, beginning during the early 1880's, many forests on private land grants were practically clean-cut, and the burning of slash and, on some lands, of
timber completed the destruction of forests over extensive areas. At the same time the ranges far beyond the environs of the settlements then became important and valuable grazing lands, and both sheep and cattle ranching flourished.

During this period of modern development, plant cover declined and run-off and erosion were accentuated. However, unlike the well-known temporary decline in herbaceous plant cover during series of droughty years, this decline has continued in many places and has been extended to new areas.

Development of the San Luis Valley may be considered modern. As regards recent development in irrigation agriculture in the New Mexico part of the watershed, modern procedures, including the construction of huge storage reservoirs and works for flood control and drainage, have gradually displaced primitive methods. Elephant Butte Dam was completed in 1915. The latter works not only make possible the extension of irrigated lands below the dam in New Mexico and Texas which now aggregate about 155,000 acres, but also guarantee certain irrigation water to Mexico (in accord with international agreement). Several smaller dams have been built on tributaries of the Rio Grande. More recent developments, now in progress, include the Middle Rio Grande Conservancy District in which construction work was begun in 1928.

Dry farming was begun about 1900 and was confined mainly to the valleys and plains that are located above an elevation of 6,000 feet. The principal developments took place with colonization schemes immediately following the World War. These ventures resulted in a large acreage passing into private ownership, but most of these dry-farming lands have since been abandoned.

In livestock ranching, the more recent developments include the establishment of fence control of certain private and public range lands and the construction of facilities for watering livestock in districts heretofore without water, such as on dry mesas, thereby extending the use of the ranges to include areas where in time past the forage was not fully utilized.

SOURCE OF DESTRUCTIVE FLOOD WATERS AND SILT

The silt-laden waters of flood flows clearly indicate destructive soil erosion resulting from accelerated surface run-off.

TWO KINDS OF FLOOD FLOWS

The flood flows in the middle valley are of two kinds, normal or protracted and sudden or flash flows. The former are ordinarily caused by the spring precipitation, that is, the spring rains and melting of mountain snows. These protracted flood flows gradually rise and exceed the capacity of the main channel (12,000 second-feet) and then gradually recede. The flash floods, on the other hand, so-called because their flows commonly reach the peak in a very short time and then recede as quickly, result from summer-rain run-off. Some of these floods have been the largest and most destructive along the Rio Grande. The relation between Rio Grande flood flows and the seasonal precipitation is shown by the data in table 3.
### Table 3.—The relation between seasonal precipitation on the upper Rio Grande watershed and flood flows of the Rio Grande

<table>
<thead>
<tr>
<th>Winter-spring precipitation which caused normal or protracted flood flows</th>
<th>Month and year</th>
<th>Upper end of valley at Buckman</th>
<th>Lower end of valley at San Marcial</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 1897</td>
<td>15,300</td>
<td>21,750</td>
<td></td>
</tr>
<tr>
<td>June 1903</td>
<td>19,300</td>
<td>18,880</td>
<td></td>
</tr>
<tr>
<td>May 1905</td>
<td>19,500</td>
<td>29,070</td>
<td></td>
</tr>
<tr>
<td>May 1912</td>
<td>23,800</td>
<td>15,270</td>
<td></td>
</tr>
<tr>
<td>May 1916</td>
<td>15,900</td>
<td>15,145</td>
<td></td>
</tr>
<tr>
<td>May 1920</td>
<td>28,800</td>
<td>22,500</td>
<td></td>
</tr>
<tr>
<td>June 1921</td>
<td>17,400</td>
<td>19,360</td>
<td></td>
</tr>
<tr>
<td>May 1924</td>
<td>16,910</td>
<td>12,400</td>
<td></td>
</tr>
<tr>
<td>October 1897</td>
<td>3,465</td>
<td>15,500</td>
<td></td>
</tr>
<tr>
<td>July 1898</td>
<td>6,580</td>
<td>10,775</td>
<td></td>
</tr>
<tr>
<td>October 1904</td>
<td>17,700</td>
<td>33,000</td>
<td></td>
</tr>
<tr>
<td>October 1911</td>
<td>15,600</td>
<td>11,780</td>
<td></td>
</tr>
<tr>
<td>August 1929</td>
<td>7,090</td>
<td>24,000</td>
<td></td>
</tr>
<tr>
<td>September 1929</td>
<td>11,000</td>
<td>47,000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Summer rains which caused damaging flash-flood flows</th>
<th>Second-feet</th>
<th>Second-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>(May 1897</td>
<td>15,300</td>
<td>21,750</td>
</tr>
<tr>
<td>June 1903</td>
<td>19,300</td>
<td>18,880</td>
</tr>
<tr>
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</tr>
<tr>
<td>September 1929</td>
<td>11,000</td>
<td>47,000</td>
</tr>
</tbody>
</table>

1 Data compiled from various sources, principally from a report of the chief engineer of the Middle Rio Grande Conservancy District (7).

2 Flows that exceeded 12,000 second-feet, the capacity of the main channel through the middle valley, are regarded as floods.

3 Buckman is located in the White Rock Canyon about 20 miles above the extreme upper end of the middle valley.

Of the 10 flood flows that entered the middle valley—those caused by run-off from the watershed above Buckman—eight were normal or protracted flood flows and two were sudden or flash floods. One of these flash floods diminished, but the other was greatly augmented by summer rain run-off from tributary drainages below Buckman. The other four flows, notably the one in September 1929, were not flood flows when they entered the middle valley, but increased to flash floods below Buckman.

### ORIGIN OF THE DAMAGING FLOOD WATERS

The results of the study of the origin and concentration of the waters that caused the damaging flood in the middle valley in September 1929, made by Hosea, designing engineer of the Middle Rio Grande Conservancy District, showed that the drainages below Buckman contributed most to this flood flow. When these drainage areas were compared with the records of vegetation-erosion conditions of the watershed, it is evident that the destructive flash-flood waters originated largely on impoverished range lands. (See figs. 1 and 2.)

The rain that caused this September flood was general over the watershed above the Elephant Butte Reservoir, and the total average fall for the 3-day period of the storm varied from 0.61 to 3.38 inches in different drainage areas. The distribution of this fall is shown in table 4.

Areas 1 and 2, which discharge their flows into the Rio Grande above Buckman, received the least rainfall during that 3-day September storm. Most of area 1, particularly the part in Colorado (7,700 square miles), probably had less rainfall than is indicated by the three New Mexico stations (Red River, Taos, Eagle Rock), which stations represent about 2,369 square miles.
TABLE 4.—Rainfall that caused the flood in middle Rio Grande Valley, September 1929

<table>
<thead>
<tr>
<th>Drainage areas of the watershed above Elephant Butte Reservoir</th>
<th>Weather station</th>
<th>Rainfall by days</th>
<th>Total rainfall for station and average for area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sept. 21</td>
<td>Sept. 22</td>
</tr>
<tr>
<td>1. Rio Grande Basin above the mouth of Rio Chama</td>
<td>Red River</td>
<td>0.42</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>Taos</td>
<td>0.33</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>Eagle Rock</td>
<td>0.46</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aspen Grove</td>
<td>0.50</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td>Bateman’s Ranch</td>
<td>0.45</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>Chama</td>
<td>0.50</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Tier Amarilla</td>
<td>0.38</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Rio Chama</td>
<td>Alamos Ranch</td>
<td>1.05</td>
<td>2.21</td>
</tr>
<tr>
<td></td>
<td>Truchas</td>
<td>1.22</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Albuquerque</td>
<td>1.34</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>Jemez Springs</td>
<td>1.44</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>Los Lunas</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>Santa Fe</td>
<td>1.35</td>
<td>2.73</td>
</tr>
<tr>
<td></td>
<td>Tijeras</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bluewater</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>Laguna</td>
<td>0.38</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>Lee Ranch</td>
<td>Trace</td>
<td>1.62</td>
</tr>
<tr>
<td></td>
<td>Regina</td>
<td>1.30</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>San Fidel</td>
<td>0.62</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Area between the mouth of Rio Chama and Buckman</td>
<td>No stations</td>
<td>Trace</td>
<td>1.62</td>
</tr>
<tr>
<td>4. Middle Rio Grande Valley between Buckman and the mouth of Rio Puerco</td>
<td>Socorro</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>5. Rio Puerco</td>
<td></td>
<td>Trace</td>
<td>1.62</td>
</tr>
<tr>
<td>6. Rio Salado</td>
<td></td>
<td>Trace</td>
<td>1.62</td>
</tr>
<tr>
<td>7. Valley of Rio Grande between the mouth of Rio Puerco and San Marcial</td>
<td></td>
<td>Trace</td>
<td>1.62</td>
</tr>
</tbody>
</table>

1 Data from U. S. Weather Bureau reports.

The rainfall of that storm was greatest in areas 3 and 4; the former is comparatively small, and the latter, immediately below Buckman, is nearly seven times as large.

The rainfall for the Rio Puerco drainage area averaged 1.8 inches, which is 1.58 and 1.10 inches less, respectively, than that received by areas 3 and 4 (table 5).

Although no weather records are available for the Rio Salado area, it is evident, from the enormous flow that came from this area, that this drainage received considerable rainfall. At Magdalena, the nearest outside station with comparable elevation, which is beyond the borders of this drainage to the south, there was a total fall of 1.20 inches.

The lower end of the middle valley received only 0.61 inch of rainfall.

The development of the destructive flood considered is shown in table 5, which gives the drainage areas on which floodwaters originated and the contributions that tributary drainages made to the Rio Grande.

The peak flow of 2,240 second-feet of the Rio Grande at Embudo indicates that the flood originated from drainages that empty into the main stream below this point.

The first flood contributions were made by the Rio Chama, one 42 hours before and the other 18½ hours after the peak flow of the Rio Grande at Buckman. The first discharge, a sudden run-off, resulted from a light rainfall on deteriorated lands in the lower part of the Rio Chama drainage (Tierra Amarilla, table 4), and the other flow resulted from run-off from the distant parts of the drainage.
These two contributions did not synchronize with the peak flow of 2,240 second-feet of the Rio Grande at Embudo.

Table 5.—Contributions to the flood flow of the Rio Grande above Elephant Butte Reservoir during the flood of September 1929

<table>
<thead>
<tr>
<th>Drainage areas of the watershed above Elephant Butte Reservoir</th>
<th>Size of area</th>
<th>Average total rainfall during Sept. 21, 22, 23</th>
<th>Peak flows of streams</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Rio Grande Basin above the mouth of the Rio Chama.</td>
<td>10,069</td>
<td>1.65</td>
<td>1,320</td>
<td>Discharge at Embudo 25 miles above the mouth of the Rio Chama.</td>
</tr>
<tr>
<td></td>
<td>3,150</td>
<td>1.48</td>
<td>4,200</td>
<td>Contribution from the Rio Chama discharged at Chamita 42 hours before the peak flow of Rio Grande at Buckman.</td>
</tr>
<tr>
<td>3. Area between the mouth of Rio Chama and Buckman (529 square miles east, and 165 square miles west of Rio Grande).</td>
<td>694</td>
<td>3.38</td>
<td>8,000</td>
<td>Contribution from the Rio Chama discharged at Chamita 18½ hours after the peak flow of Rio Grande at Buckman.</td>
</tr>
<tr>
<td></td>
<td>4,811</td>
<td>2.90</td>
<td>11,000</td>
<td>Estimated contribution from area on the east side of the Rio Grande (529 square miles). No evidence of flood flows from the area on the west side of the Rio Grande, although this area had received a heavy rainfall. (See record for Alamos Ranch, table 4.)</td>
</tr>
<tr>
<td>5. Rio Puerco</td>
<td>5,170</td>
<td>1.80</td>
<td>37,700</td>
<td>Peak flow of Rio Grande at Escondida bridge about 13 miles below the mouth of the Rio Salado.</td>
</tr>
<tr>
<td>6. Rio Salado</td>
<td>1,148</td>
<td>(t)</td>
<td>20,300</td>
<td>Estimated peak flow of the Rio Grande at San Marcial.</td>
</tr>
<tr>
<td>7. Valley of Rio Grande between the mouth of Rio Puerco and San Marcial.</td>
<td>1,653</td>
<td>.61</td>
<td>47,000</td>
<td>Estimated peak flow of the Rio Grande at Escondida bridge about 13 miles below the mouth of the Rio Salado.</td>
</tr>
</tbody>
</table>

1 No station.

The first large flood contribution was from area 3—principally from the tablelands and foothills southeast of Espanola. This was a flash flow, as indicated by the fact that the resulting peak flow at Buckman was for only a very short period. Although this discharge from area 3, which had a peak of 8,000 second-feet, did not increase the flow of the Rio Grande sufficiently to exceed its capacity of 12,000 second-feet in the middle valley, it was an enormous run-off from so small an area. This comparatively small district is drained by Rio Santa Cruz and Pojoaque Creek whose headquarters are trout streams, but whose lower courses are great sand washes which extend through lands now wastes because of loss of plant cover and erosion.
On the area west of the Rio Grande, which is largely plateau, no evidence of any flood was found. Neither were there any floods in the several large canyons and small streams that drain the mountainous section that adjoins this plateau area to the west and southwest and which discharge their flows directly into the Rio Grande at intervals of 20 miles below Buckman. No floods occurred in this mountainous area; its plant cover was in good condition.

The next contribution of flood waters was made by drainage area 4, which embraces 4,811 square miles of the middle valley above the mouth of the Rio Puerco. A peak flow of 14,850 second-feet, contributed by the Santa Fe and Galisteo Creeks, Arroyo Tonque, and other arroyos, increased the peak flow at San Felipe, about 7 miles above the mouth of Jemez Creek, to 20,500 second-feet. An additional peak-flow contribution of 5,000 second-feet, principally from the Jemez Creek drainage, raised the peak flow at Bernalillo bridge to 25,500 second-feet. But by the time this flow reached Jarales, 45 miles below Albuquerque, it had diminished to 9,500 second-feet, that is, it had lowered to the capacity of the main channel.

Santa Fe Creek illustrates how the once regulated flow of this mountain stream rose to unprecedented flood heights as a result of depletion of the plant cover. There was no destructive flood in Santa Fe Creek at Santa Fe, where this stream is perennial. The average daily flow for the flood period, as shown by surface water-supply records of New Mexico for 1929 (21), was less than 300 second-feet. On the deteriorated mesa lands between Santa Fe and the Rio Grande, however, the peak flow suddenly increased to as much as 6,500 second-feet, which was an enormous flood for this stream. The drainage area above Santa Fe, a well-managed mountainous country of the Santa Fe National Forest, is in good condition. A large part of the Galisteo drainage is badly eroded and damaged, and practically all the lands drained by Arroyo Tonque are in the same condition. Much of the upper part of the Jemez Creek drainage is in excellent condition, but the forest lands and grasslands of the lower part of this drainage are eroded and deteriorated.

Farther down the valley the enormous flows of the Rio Puerco and Rio Salado raised the estimated peak flow of the Rio Grande from 9,500 at Jarales to 62,354 second-feet at Escondida Bridge; and at San Marcial the peak flow was estimated at 47,000 second-feet, or nearly four times the capacity of the main channel at this point. Large areas of the Puerco and Salado drainages are deteriorated and badly eroded.

This analysis of the September 1929 flood shows that the waters that proved to be so destructive in the middle valley came principally from drainage areas 3, 4, 5, 6, and 7, whose streams empty into the Rio Grande below Buckman. When these areas were studied in relation to the condition of the vegetation in various districts of the watershed, it was found that practically all the flood waters came from lands that have a depleted plant cover.

Here a word should be said regarding the run-off from the badly damaged table lands above Embudo (in New Mexico) and from the lower Chama district. With the exception of river gorges, these plain-like areas above Embudo have meandering and very shallow drainage ways. Physical conditions, such as level surface and stony soils, minimize both concentration of drainage waters and soil erosion. Furthermore, the annual rainfall here is low (fig. 2).
In the lower Chama district, however, flood waters do originate, and some have been most destructive and contributed enormous quantities of silt to the Rio Grande.

**ORIGIN OF THE DAMAGING SILT**

Inasmuch as the destructive flash-flood waters originate principally on overused range and forest lands, the heavy load of damaging silt carried comes from the same lands. This fact may be indicated by the quantity of silt that the Rio Grande carried (in suspension only) past San Marcial for 1905 (a year with no summer flood), as compared with 1904 (a year with a normal spring flood and a destructive flood caused by summer rain), as shown in table 6. The data given in this table have been taken from the United States Geological Survey Water-Supply Paper 358 (10, p. 714).

**Table 6.—Quantity of silt carried in suspension by the Rio Grande past San Marcial during 1904 and 1905**

<table>
<thead>
<tr>
<th>Period</th>
<th>Month</th>
<th>1904 (flood in October)</th>
<th>1905</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average quantity of water discharged by the Rio Grande</td>
<td>Weighted average percentage for period of winter-spring precipitation</td>
</tr>
<tr>
<td>Winter-spring precipitation.</td>
<td>November</td>
<td>55,769</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>December</td>
<td>31,752</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>January</td>
<td>16,840</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>February</td>
<td>18,902</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>March</td>
<td>8,000</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>April</td>
<td>(?)</td>
<td>(?)</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>(?)</td>
<td>(?)</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>(?)</td>
<td>(?)</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>10,532</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>55,974</td>
<td>4.14</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>44,727</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>466,249</td>
<td>2.69</td>
</tr>
</tbody>
</table>

1 See also table 3.
2 None.

The quantity of suspended silt during the months of winter-spring precipitation for these years averaged less than 1 percent—0.62 percent for 1904 to 0.74 percent for 1905; whereas during the periods of summer rains the percentages of silt carried were, respectively, nearly four and one-half and three times as much. During 1904, with only one high flow (in October) the quantity of silt carried averaged 2.78 percent, whereas during the period of summer rains in 1905, when there were no high flows, the quantity averaged 2.25 percent.

Large quantities of silt are discharged into the river during the summer period of accelerated run-off and the cleaning out of such temporary deposits is by the protracted high flows of winter. That is, the silt carried in suspension during the winter-spring season is largely that which has already been carried into the main channel, whereas that carried during the summer period is usually washed...
directly from eroded lands of the watershed, because accelerated
run-off from torrential summer rains on denuded lands soon gathers
its maximum load of silt, some of which is deposited in the river
channel and some is moved downstream in suspension and as bed load.

**DAMAGING EFFECTS OF SILT**

Mention has already been made of the damaging effects of excessive
silting of the main channel of the Rio Grande, water reservoirs, and
other irrigation works. In addition to these damages, excessive
silting is an important factor in the destruction of farm lands (pl.
6, B).

Ordinarily, the deposition of silt by irrigation waters, when the silt
originates from watershed lands that have a protective cover of
vegetation, is a beneficial process. It is well known that, within
limits, good silt actually improves the alluvial soils on which it may
be deposited, as through irrigation, and that it may increase or main-
tain the fertility of continually cropped lands. The enduring agri-
culture in the Valley of the Nile, Egypt, where soils have been kept
fertile for many centuries through irrigation and deposition of good
silt from wilderness areas in the headwaters, is a good example.

Excessive deposition of silt, on the other hand, may prove to be
very destructive not only in filling river channels and irrigation works
but also to lands and other farm property, as occurred during the
September 1929 flood in the middle valley. But when accelerated
erosion continues over extensive areas, the eroded topsoil materials
become mixed with large quantities of sand and gravel that originate
from subsoils and geologic deposits of soil-forming materials. Ben-
nett (4, p. 414) has described the deposition of destructive sediments
as follows:

In the fall of 1929 a very destructive flood swept down the Rio Grande. The
Bureau of Chemistry and Soils had completed a detailed soil survey of the alluvial
plain from about the head of water in Elephant Butte Reservoir to about 11 miles
above the confluence of the Rio Grande with the Rio Puerco. This flood covered
so much of the surveyed area with clay and sand that most of it had to be resur-
veyed in 1930. Areas that had been mapped as clay were changed to loose sand,
and sandy lands were deeply buried with clay. In some places the depth of
freshly deposited sand was as much as seven feet, while clay was laid down in
strata exceeding two feet.

Among other damaging effects of fine alluvium may be mentioned
the continual deposition of "raw" clay on irrigated lands, which,
tending to seal the soil pores, interferes with absorption of water and
crop production as well.

Irrigated lands below the Elephant Butte Dam have also been
damaged by excessive deposition of sediments brought down by recent
flood waters. In fact, the danger of such damage has become a matter
of grave concern to landowners in the fertile valley below the dam.
Each year the silt, sand, and gravel discharged from hundreds of
arroyos that drain large areas of deteriorated range lands add to the
huge alluvial fans that have already been built up in this valley, and
each year a considerable acreage of arable land is withdrawn from the
irrigation project. Soils are rendered worthless by being covered with
gravel and boulders, and lands are built up above the level of the
canals and ditches. A large investment in protection works is neces-
sary on many of the farms that border the valley. An idea of the
nature of these protective works may be obtained from figure 5
The same type of flooding and excessive silting is particularly destructive to canals and other engineering works that are used in the distribution of irrigation waters. Expenditures for ditch repair and cleaning reach large sums annually in all the principal irrigation districts. An example of such destructive silting from an arroyo may be described as follows:

On July 3, 1931, flood waters from Picacho Arroyo near Las Cruces, N. Mex., destroyed a house, buried 3 acres of corn 3 feet deep with sand, and obliterated several hundred feet of protection border around the adjoining fields. The flood flow left the channel of the arroyo and, pouring over the highway embankment onto another farm, washed out 100 feet of the road, made a deep trench in the irrigation canal that parallels the road at this point, and destroyed 200 feet of the irrigation-ditch bank (fig. 6). Local residents say that three floods a year from this arroyo, on the average, do more or less damage to the irrigation canal, farm lands, and the highway.

**MUCH SILT EN ROUTE DOWNSTREAM**

Each heavy storm dislodges quantities of earthy material from the surface of wasting lands, some of which is carried away in flood waters while some is moved only a step downward in its journey to the lower main river. Much of the finer earthy materials, fine clay and silt in particular, is carried in suspension, but huge deposits of sediments constitute the bed load of the stream. This bed load may be compared to the constant load on a conveyor belt in that the amount of each delivery into Elephant Butte Reservoir is replaced by new deposits upstream. Each successive flood flow speeds up bed-load movement and its delivery into the reservoir where enormous quantities of it ultimately come to rest.
In their unpublished report to the Middle Rio Grande Conservancy District on erosion and silt control, Bryan and Post have estimated that for 42 years the Rio Puerco alone has discharged annually into the Rio Grande, on the average, a quantity of silt that would cover 9,400 acres 1 foot deep. This immense quantity of silt, which is temporarily deposited at the mouth of this tributary in the form of a vast fan miles in width, is continuously moved downstream by the Rio Grande. Much of the sediment comes from the channeling of the large alluvial valleys, from drainageways that now have arroyos, and from their banks caving in. Rodent burrows along arroyos may also aid in setting into motion damaging silt by providing passageways for run-off waters which ultimately cause the undermining and break-down of the arroyo banks.

VEGETATION-EROSION RELATIONSHIPS

A definite relationship was found between the condition of the vegetation ground cover and soil erosion. In order to evaluate these relationships, studies including measurements were made of vegetation and ground-surface conditions and degree of soil erosion in the various districts of the watershed. These facts were obtained by the quadrat or plot method on representative areas in each of the principal climatic regions of the watershed and for the nine different vegetation types.

INVESTIGATIONAL PROCEDURE AND DEFINITION OF TERMS

THE QUADRAT METHOD

By the quadrat method is meant the use of carefully selected rectangular land areas for making the vegetation-erosion studies. The various districts of the watershed are so large that it was physically impossible to cover every square mile. In order to meet this problem, representative drainage units, or drainages, were selected for intensive study. These selections were based on previous knowledge, unpublished range-appraisal reports, and range and timber maps of the
national forests involved, followed by field examination. These drainages were mapped in the field and on the maps were indicated the types of vegetation, the state of the vegetation (expressed as estimates of composition and density of the ground cover), and the general conditions as regards soil erosion.

Within each typical drainage, areas were designated according to the condition of vegetation represented by different degrees of deterioration—as low, medium, and high—on the basis of comparable are as of relief, soils, and the like, where vegetation was still in good condition. Quadrat areas—ranging in size from 10,000 to 25,000 square feet—were then located to cover each condition and on these the detailed records were made. These records were also supplemented by data obtained on small chart quadrats which varied in size from 1 to 6 m$^2$. The chart-quadrat data included actual measurements of the ground surface covered by different plants that composed the herbaceous vegetation and of the depth to which the soils were eroded.

It was found impracticable to locate the large representative areas and the small chart quadrats within them equidistant from each other or according to any mathematical concept, owing to the diversity of the land conditions as regards erosion channels, arroyos, or large gullies. Obviously, an arroyo or erosion channel, for example, may be regarded as only a point or line where surface water concentrates, and it does not represent at all the land areas on which the accelerated surface run-off originates.

In each case, the facts found on the large quadrats that represented a given type and state of vegetation, supplemented by the measurement data obtained on the chart quadrats—facts that were required to establish any relationship between the state of the plant cover and surface soil erosion—were assumed to hold true for all similar areas having the same type of vegetation and showing a similar degree of deterioration.

**MEASUREMENTS OF DENSITY OF VEGETATION**

The state of the vegetation was determined by making ocular and quadrat measurements of ground-cover density, which may be defined as the degree to which living plants cover the ground, as based on the spread of the plants involved. This spread included the ground cover of the herbs and the crown spread of any shrubs and trees. On overgrazed areas, where the herbaceous vegetation was eaten close to the ground, the density measurements of the grass clumps and herbs consisted of the estimated crown spread of the tufts before utilization, in order to make all density measurements comparable. Further, these measurements of density were made under comparable conditions, as nearly as could be found, with respect to climate, soil, and relief.

The density of the herbaceous vegetation was measured on the small quadrats by means of the chartograph, an instrument built on the pantograph principle. Measurements were made of the density of the deteriorated vegetation and of the vegetation still in good condition. In order to determine as accurately as possible the degree to which the vegetation on a given area had declined, it was necessary to determine the average density of the same type of vegetation still in good condition. Such vegetation was usually found on areas that had been favored with a degree of protection and use that did not appreciably alter the original conditions.
Relative density is an expression of the relation of the changed vegetation to that in good condition. For convenience, three degrees of relative density of deteriorated vegetation are employed in the presentation of results—high, medium, and low.

**Figure 7.—**A, Grass clumps on a typical quadrat of deteriorated semidesert grassland; B, cross section of the quadrat at xy, showing the degree to which the soil was eroded between the grass clumps which occurred on low humps. (See pl. 11, A.)

**Measurements of Surface Soil Erosion**

Facts regarding surface soil erosion were also obtained from representative quadrats on the land area from which surface run-off comes. Obviously, channels, arroyos, and parts that embraced deep gullies were excluded.

In this sampling, it was found that the average conditions regarding surface soil erosion on a selected quadrat area or a comparable series of them, which represented a given type and condition of vegetation,
were indicative of the erosion conditions of the large areas of the watershed that represented the same type and similar state of vegetation. In each case, the average depth (in inches) to which the soils were eroded was determined by measuring how much was washed away, as based on a plane that was defined by the tops of low humps that con-

\[ \text{LEGEND} \]

- Blue grama
- Sand dropseed
- Live ring muhly or ringgrass
- Live galleta
- Dead galleta
- Dead ringgrass

\[ \text{FiUKE 8.—A, Vegetation on a typical quadrat of protected semidesert grassland within a railroad right-of-way; B, cross section of the quadrat at } xy, \text{ showing the effects of a protective ground cover. (See pl. 11, B.)} \]

sisted of soil held in place by live or dead plants, usually grasses (figs. 7 and 8, pl. 11, A and B). The procedure used was a modification of a method developed and adequately tested at the Southwestern Forest and Range Experiment Station for measuring the progress of erosion.
It should be stated that the measurements of surface-soil erosion that were made on many areas having badly damaged vegetation are not as great as the actual conditions of the ground surface inasmuch as the topsoil was partly or entirely washed away and therefore could not be measured.

Lands were grouped, for convenience, according to measured degree of soil erosion—normal erosion and moderate, advanced, and excessive accelerated erosion.

NORMAL SOIL EROSION

So-called normal soil erosion means erosion that takes place on lands where the balance between protective and destructive agencies has not been upset to a degree that prevents soil development. Ordinarily, normal erosion of soil-forming materials may be rapid when the vegetation is sparse, even too rapid for development of soil features, or erosion of well-developed soils may be slow where the ground is protected by a dense plant cover.11

MODERATE SOIL EROSION

The term "moderate soil erosion" may be defined as active erosion that has progressed sufficiently beyond so-called normal to be definitely observed. This degree of erosion was found on lands which had comparatively small quantities of accumulated organic matter on the surface. Some areas moderately eroded had arroyos or gullies in drainage ways that were formerly only shallow surface runs.

ADVANCED SOIL EROSION

Advanced soil erosion may be described as that degree which approaches rapid land destruction. This degree of erosion was found where accelerated surface run-off had left little or no litter and where, except on small areas, none can now accumulate. Destructive channels, arroyos, and deep gullies were usually present.

EXCESSIVE SOIL EROSION

The term "excessive soil erosion" may be defined as that degree which has manifested itself in rapid land destruction. This degree of erosion was found on lands where the litter was gone and none could accumulate.

COMPARISON OF THE VEGETATION-EROSION CONDITIONS

The principal vegetation areas or types and the general relationships between deteriorated vegetation and degree of soil erosion are shown in figures 9 and 10. The complete data on vegetation-erosion relationships are given in tables 7 to 12 which present data by broad vegetation types. In obtaining these data the areas of different types, which were combined in the broad classification of vegetation, shown in figure 9, were considered individually.

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11 Normal soil erosion includes (1) localized destructive effects of run-off that sometimes occur as the result of exceptional action of natural forces, as extraordinary rainstorms; (2) rather rapid erosion caused by run-off from soil-type areas normally supporting a thin plant growth and lacking in rocks or stones which would, if present, afford some protection to the surface as they become exposed; (3) break-down and restoration of equilibrium between vegetation and soil-erosion forces at critical points; and (4) erosion of naturally barren deposits.
Figure 9.—Vegetation areas of the upper Rio Grande watershed, in New Mexico.

LEGEND

- Semidesert Savanna (Grass and Shrubs) of Lowest Valleys and Plains
- Grasslands
- Sagebrush Savannas
- Woodlands and Savanna Woodlands
- Pine-Fir Forests
- Spruce-Fir Forests (Including Vegetation above Timber Line)

MILES

0 25 50
Figure 10.—Degree of soil erosion in relation to the state of the vegetation cover on the upper Rio Grande watershed, in New Mexico.
Data on slope and exposure, although obtained to measure the comparability of areas, are given for comparison of physical conditions influencing run-off, those on soils show the influence of run-off as it is affected by the textural characteristics of soils, and those on origin of soil indicate the relation between soil erosion and soil texture. As regards soils, topsoils may be rather similar insofar as physical make-up affects their susceptibility to erosion, but some surface layers and particularly subsoils of this semiarid region distinctly show the influence of the character of geologic materials from which they originated.

Under condition of the ground surface the effects of run-off on supplemental protective cover, such as litter, and on surface conditions, such as stony or clayey, are described and together with vegetation condition may be considered indicators of land condition.

Erosion measurements include descriptive data for deteriorated areas on which vegetation soil humps were too few to indicate a former ground level and basis for measurements.

In the comparative descriptions of vegetation accompanying tables 7 to 12, and found on areas under good and poor land management, only species most indicative of the type are given.

**SEMIDESERT SAVANNAS**

Semidesert savannas are confined to the lowest and warmest areas (fig. 9), where the average annual rainfall is less than 10 inches. They cover the smallest acreage of any of the semidesert grasslands, representing only about 3 percent of the drainage area. Both vegetation and land deterioration are so far advanced that it was necessary to go beyond the borders of the Rio Grande drainage above Elephant Butte Dam to obtain records for similar vegetation still in good condition. Although not extensive, these badly deteriorated savanna areas, which border Elephant Butte Reservoir and valuable irrigated lands, are the source of destructive flood waters and debris.

In good condition, these savannas are composed of highly drought-resistant grasses and scattered shrubs some of which are treelike. They have the lowest average density (35 percent) of any of the vegetation types concerned. Yet this growth is a protective cover under these semiarid conditions. But its protective influence may be easily destroyed. Where the density has declined only by about one-third, or to 25 percent, erosion has progressed to advanced stages. The state and condition of this type is summarized in table 7. The present composition of the vegetation and the associated condition of the ground surface under good and poor management are as follows:

<table>
<thead>
<tr>
<th>Good land management</th>
<th>Poor land management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GRASSES</strong></td>
<td><strong>GRASSES</strong></td>
</tr>
<tr>
<td>Gramas (<em>Bouteloua</em> spp.), principally black grama (<em>B. eriopoda</em>).</td>
<td></td>
</tr>
<tr>
<td>Dropseeds (<em>Sporobolus</em> spp.), largely sand dropseed (<em>S. cryptandrus</em>).</td>
<td></td>
</tr>
<tr>
<td>Bush muhly or hoegrass (<em>Muhlenbergia porteri</em>).</td>
<td></td>
</tr>
<tr>
<td>Tobosa (<em>Hilaria mutica</em>) principally in depressions (in which run-off collects), where it forms good stands.</td>
<td></td>
</tr>
<tr>
<td>Sacaton (<em>Sporobolus wrightii</em>) and alkali sacaton (<em>S. airoides</em>) attain high density in small alluvial drainageways which are occasionally flooded.</td>
<td></td>
</tr>
<tr>
<td>There are only remnants of the most valuable forage grasses (gramas and dropseeds). These survive largely because of protection afforded by the shrubs.</td>
<td></td>
</tr>
<tr>
<td>Fluffgrass (<em>Triodia pulchella</em>), of little protective value and of still less forage value, and burro grass (<em>Scleropogon brevifolius</em>) occur as scattered tufts.</td>
<td></td>
</tr>
<tr>
<td>Perennial weeds (mostly of no forage value) and annual herbs grow in thin stands. Most tobosa areas have remnant clumps of grass but some are bare.</td>
<td></td>
</tr>
<tr>
<td>Sacaton areas are destroyed.</td>
<td></td>
</tr>
</tbody>
</table>
**Table 7.—Soil erosion in relation to the state of vegetation of the low semiarid plains**

**Semidesert savannas (grasses and shrubs) of the lowest plains**

<table>
<thead>
<tr>
<th>Condition of the ground surface</th>
<th>Area no.</th>
<th>Slope of area</th>
<th>Direction of exposure</th>
<th>Origin of soil-forming materials</th>
<th>Textural class</th>
<th>Average depth eroded</th>
<th>Cover density as found</th>
<th>Total deteriorated cover density</th>
<th>Total good cover density of area</th>
<th>Relative density</th>
<th>Degree of deterioration</th>
<th>Forage density</th>
<th>Degree of soil erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine gravel.</td>
<td>151</td>
<td>3</td>
<td>NE.</td>
<td>Alluvium</td>
<td>Shallow sandy loam</td>
<td>0.50</td>
<td>23%</td>
<td>1%</td>
<td>2%</td>
<td>37%</td>
<td>51%</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>Do.</td>
<td>163</td>
<td>2</td>
<td>NE.</td>
<td>do</td>
<td>Clay loam.</td>
<td>1.00</td>
<td>18%</td>
<td>5%</td>
<td>2%</td>
<td>71%</td>
<td>71%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Average.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20%</td>
<td>3%</td>
<td>2%</td>
<td>25%</td>
<td>71%</td>
<td>29%</td>
<td>29%</td>
</tr>
<tr>
<td>Gravel and sand.</td>
<td>151a</td>
<td>3</td>
<td>NE.</td>
<td>do</td>
<td>Shallow sandy loam</td>
<td>1.50</td>
<td>3%</td>
<td>1%</td>
<td>1%</td>
<td>14%</td>
<td>14%</td>
<td>37%</td>
<td>37%</td>
</tr>
<tr>
<td>Small stones and cobbles.</td>
<td>175</td>
<td>6</td>
<td>SW.</td>
<td>Conglomerate.</td>
<td>Gravelly loam.</td>
<td>3.00</td>
<td>4%</td>
<td>2%</td>
<td>9%</td>
<td>43%</td>
<td>43%</td>
<td>63%</td>
<td>63%</td>
</tr>
<tr>
<td>Do.</td>
<td>167</td>
<td>20</td>
<td>S.</td>
<td>do</td>
<td></td>
<td>3.00</td>
<td>1%</td>
<td>3%</td>
<td>14%</td>
<td>51%</td>
<td>51%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Average.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3%</td>
<td>2%</td>
<td>8%</td>
<td>13%</td>
<td>37%</td>
<td>63%</td>
<td>3%</td>
</tr>
</tbody>
</table>

**Origin of soil-forming materials:**
- Alluvium
- Shallow sandy loam
- Clay loam

**Textural class:**
- Shallow sandy loam
- Clay loam
- Gravelly loam

**Degree of soil erosion:**
- Normal
- Advanced
- Excessive
- Do.

**Average values:**
- Soil erosion
- Cover density as found
- Total deteriorated cover density
- Total good cover density of area
- Relative density
- Degree of deterioration
- Forage density
<table>
<thead>
<tr>
<th>Average</th>
<th>40</th>
<th>2</th>
<th>3</th>
<th>45</th>
<th>100</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some grass mulch, no stones.</td>
<td>140</td>
<td>(*)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some grass mulch, some stones.</td>
<td>138</td>
<td>1</td>
<td>S.</td>
<td>do</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some stones.</td>
<td>157</td>
<td>4</td>
<td>SW</td>
<td>do</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do.</td>
<td>159</td>
<td>2</td>
<td>E.</td>
<td>do</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some grass mulch, no stones.</td>
<td>179</td>
<td>(*)</td>
<td>SE</td>
<td>Alluvium.</td>
<td>do</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel and coarse sand</td>
<td>129a</td>
<td>(*)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stones and sand</td>
<td>131</td>
<td>5</td>
<td>W.</td>
<td>do</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine gravel</td>
<td>135</td>
<td>1</td>
<td>W.</td>
<td>do</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small, angular stones</td>
<td>159a</td>
<td>(*)</td>
<td>E.</td>
<td>Rhyolite.</td>
<td>do</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy</td>
<td>122</td>
<td>(*)</td>
<td>Alluvium.</td>
<td>Fine sandy loam.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse sand and gravel</td>
<td>129</td>
<td>(*)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse sand</td>
<td>130</td>
<td>2</td>
<td>W.</td>
<td>do</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine gravel</td>
<td>136</td>
<td>(*)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy</td>
<td>139</td>
<td>5</td>
<td>E.</td>
<td>do</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 The average relative density of 35 percent was estimated, based on areas of like vegetation in the Rio Grande drainage, but not of the watershed above Elephant Butte Dam. No areas of undeteriorated vegetation of this type were found in the parts of the watershed considered.

2 The average relative density of 45 percent is based on the best comparable conditions found in the Rio Grande drainage within and without the watershed above Elephant Butte Dam.

3 Less than 1°.

4 Sand ripples.

5 Badly eroded.
SHRUBS

Yuccas (Yucca spp.) occur as scattered individuals, and, being principally of the tree species, contribute most to the savanna aspect of the type.

Tarbush or blackbrush (Flourensia cernua) in gravelly areas.

Mesquite (Prosopis chilensis) in sandy areas, and creosotebush (Covillea tridentata) in the driest thin-soil locations.

VEGETATION INFLUENCES

The grasses, although in rather thin stands, form a well-distributed protective cover on the uplands. Small areas or spots between the grass tufts are afforded some protection by litter, sand, gravel, and stones which are held in place by the surrounding grasses (pl. 12, A).

SHRUBS

Shrubs, instead of grasses, are dominant. Mesquites (dwarfed upland individuals of sand-hill type), creosotebushes, and blackbrushes, together with the sandy and stony character of wind-swept surfaces, give deteriorated savannas a desert aspect.

VEGETATION INFLUENCES

With the grasses scanty and poorly distributed, areas of increased size between the tufts, litter and the originally thin topsoils (except under shrubs in a few places) gone, practically all protective influences have disappeared. Loose stones and gravel cover the ground (pl. 12, B) or sand (in sandy areas) forms shifting ripples and even some dunes.

Annual herbs—one growth in the spring and another in late summer—furnish some protection both while growing and when dead.

The shrubs, although scattered, seem to exert a protective influence over the herb growth by lessening the drying effect of the winds.

The tobosa flats have considerable litter on the small open spots between the grass tufts.

Although the areas influenced by sacaton are small, they are the control points where run-off in small drainageways is checked and spread.

In the tobosa areas run-off from adjoining lands has so increased that these areas have become covered with raw clay, and so flooded at times and so desiccated and cracked at other times that practically no vegetation can grow.

Drainageways, formerly with alluvial soils and sacaton, are now washes, in places with accumulations of blow sand from which bordering dunes have formed.

SEMIDESERT GRASSLANDS OF LOW PLAINS

The grasslands of the low plains and low valleys border the savannas and occur at somewhat higher elevations and under more favorable conditions for growth (lower temperature and greater rainfall). About one-eighth of the drainage consists of these grasslands. They directly affect many miles of the main channel of the Rio Grande and bordering irrigable lands.

Well-managed lands are in good condition and have an average plant density of 45 percent. Where the density has declined to 24 percent, erosion is advanced, and where the density is only 12 percent, erosion is excessive (table 7). The conditions found on well and poorly managed lands may be compared as follows:
A. Representative quadrat of deteriorated semidesert grassland, showing the state of the vegetation and condition of the ground surface. This is the same vegetation shown in figure 7. B. Representative quadrat of protective semidesert-grassland vegetation. This is the same kind of vegetation as shown in figure 8.
A. Semidesert savanna of one of the lowest plains (mesas). On left, overgrazed range; on right, a somewhat typical grass-shrub vegetation on a fenced area.  

B. Badly deteriorated semidesert savanna on a mesa slope. Only shrubs remain, which do not form an effective ground cover.  

C. A conservatively grazed area of high semiarid valley. Vegetation in good condition.
SOIL EROSION AND STREAM FLOW ON RIO GRANDE

Low Plains

Good land management

Grasses
Gramas, particularly black grama, some hairy grama (Bouteloua hirsuta), and even blue grama (B. gracilis) in places.

Tobosa on flats.
Three-awns (Aristida spp.).
Sand dropseed.
Indian ricegrass (Oryzopsis hymenoides).

Shrubs
Soapweed, or amole (Yucca glauca).
Cacti (Opuntia spp.), principally the round-stemmed kinds.
Jointfirs, or Mormon-teas (Ephedra spp.), principally E. antisyphilitica, and four-winged saltbush (Atriplex canescens) along drainage ways.

Low Valleys

The vegetation of the low valleys is similar to that of the alluvial drainage-ways in semidesert-savanna areas (including alkali sacaton, principally, with some shrubs and trees, as mesquites), but is more extensive.

Vegetation Influences
The close-to-the-surface rather evenly distributed grass growth forms a good cover, as is evidenced by the protected condition of these low plains areas. Where run-off from one area is checked on another and sinks, growth is denser and soils are better developed. Thus the growth and influence of the vegetation may vary.

Run-off from exceptionally severe storms, particularly those following drought periods, may become destructive even where plant cover is in good condition. But these eroded places tend to heal during long intervals between such storms.

Large valleys may be channeled and small valleys have arroyos in places, but changes in channel and arroyo banks are slow. The dense growths of tall grasses do not check the flow in arroyos, but they do control run-off into them from valley floors. The older trenches have new growth in places, and as healing progresses these recently formed channels cease cutting and tend to fill.

Poor land management

Grasses
Burro grass.
Fluffgrass.
Three-awns and a thin stand or remnants of the formerly abundant forage grasses with such weeds as Russian-thistles (Salsola) and half-shrubs, such as snakeweeds (Gutierrezia spp.).

Shrubs
Most of the unpalatable shrubs have increased in number. Even some highly drought-resistant shrubs common to the semidesert savannas are becoming established and aid in giving a desert appearance to these plains. The palatable four-winged saltbush is either browsed down or destroyed.

Low Valleys

Low valleys are grazed out. They have only thin stands of weeds, some shrubs, and annuals. Remnant clumps of sacaton and the spots they have protected are mute evidence of the former dense grass stand and the conditions under which it developed.

Vegetation Influences
Thin stands of closely cropped grasses are a poor cover, as is evidenced by the washed, gravelly and sandy, or barren aspect of slopes and the network of gullies where dense grass formerly checked run-off and soils were comparatively deep. Vegetation growth varies greatly. Good growth occurs only on small areas which are so located as to be fed rather than destroyed by run-off. Destructive soil losses occur with almost every heavy summer rain and run-off from even low falls, but of high intensity, may choke gullies and arroyos with flood flows.

Vegetation may greatly increase during favorable years, but most of the increase, being annuals, is temporary. Even perennials that spread during favorable periods to eroded areas where subsoils are exposed are usually short-lived. Thus any healing of eroded areas is temporary because of the temporary nature of new growth.

Channeled and arroyo-cut valleys are being rapidly destroyed.
TABLE 8.—Soil erosion in relation to the state of vegetation of the high semiarid valleys

SEMIDESERT GRASSLANDS OF HIGH VALLEYS

<table>
<thead>
<tr>
<th>Condition of the ground surface</th>
<th>Origin of soil-forming materials</th>
<th>Soil factors</th>
<th>Vegetation conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Textural class</td>
<td>Density found</td>
<td>Vegetation conditions</td>
</tr>
<tr>
<td></td>
<td>Average depth eroded (Inches)</td>
<td>Grasses (%)</td>
<td>Forbs (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shrubs (%)</td>
<td>Altered or deteriorated density of area (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relative density (%)</td>
<td>Degree of soil erosion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Forage density (%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area no.</th>
<th>Slope of area</th>
<th>Degree of soil erosion</th>
<th>Origin of soil-forming materials</th>
<th>Density found</th>
<th>Vegetation conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shale and sandstone.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sandy clay loam.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sandy loam.</td>
<td>.50</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay loam.</td>
<td>(7)</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Deep clay loam.</td>
<td>(6)</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fine sandy loam.</td>
<td>(5)</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sandy clay.</td>
<td>(2)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay loam.</td>
<td>(2)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay loam.</td>
<td>(3)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay loam.</td>
<td>(4)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay loam.</td>
<td>(5)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay loam.</td>
<td>(6)</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay loam.</td>
<td>(7)</td>
<td>7</td>
</tr>
</tbody>
</table>

**Degree of soil erosion**
- Normal.
- Near-advanced.
- Near-excessive.
- Excessive.
<table>
<thead>
<tr>
<th>No litter, no stones</th>
<th>80a</th>
<th>W.</th>
<th>Cretaceous shale.</th>
<th>Sandy clay loam</th>
<th>Sandy clay</th>
<th>Fine sandy loam</th>
<th>Sandy</th>
<th>Sandy clay</th>
<th>Sandy clay</th>
<th>Basalt and sandstone</th>
<th>Shales and sandstone</th>
<th>Shales and sandstone</th>
<th>Shales and sandstone</th>
<th>Sandy clay loam</th>
<th>Clay loam</th>
<th>Deep clay loam</th>
<th>Fine sandy loam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>82</td>
<td>1</td>
<td>(1)</td>
<td></td>
<td></td>
<td>(1)</td>
<td>4.00</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>2.00</td>
<td>5</td>
</tr>
<tr>
<td>Clayey</td>
<td>90</td>
<td>2</td>
<td>(1)</td>
<td></td>
<td>2</td>
<td>4</td>
<td>2</td>
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<tr>
<td>Coarse sand</td>
<td>93</td>
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<tr>
<td>Sandy</td>
<td>123</td>
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<td>SW.</td>
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<td>142</td>
<td>2</td>
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<td>142a</td>
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<tr>
<td>Do</td>
<td>92</td>
<td>1</td>
<td>N.</td>
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<td>Combined average of near-excessive and excessive</td>
<td></td>
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</tr>
</tbody>
</table>

1 Less than 1°.
2 Normal.
3 Slight.
4 Sand ripples.
5 Badly eroded.
The semidesert grasslands of the high valleys probably include, in the aggregate, 10 percent of the drainage. This peculiar semidesert vegetation has resulted from periodic flooding by run-off from vast upland areas. The valleys where it grows have tremendous deposits of alluvium and form a network of drainageways through which run-off from more than one-half of the watershed flows long distances before being discharged into the Rio Grande.

On lands still in fair condition (pl. 12, C) the plant density averages 60 percent. On overgrazed eroded areas this good density has declined 47, 63, and in places as much as 72 percent. The detailed data for this type is summarized in table 8. The striking differences in the plant cover and accompanying condition of the ground surface of well and poorly managed areas are as follows:

**Good land management**

**GRASSES**
- Alkali sacaton (in damper areas).
- Bluestem (*Agropyron smithii*).
- Vine-mesquite (*Panicum obtusum*).
- Gypgrass (*Sporobolus nealleyi*).
- Gramas and other high plains grasses (in drier locations).

**SHRUBS**
- Greasewood (*Sarcobatus vermiculatus*) and saltbushes occur as individuals and also in rather dense stands but intermixed with grasses.

**VEGETATION INFLUENCES**
The dense stand of grasses, together with much litter, affords a high degree of ground protection. Furthermore, the stems and leaves of the tall grasses protect the spots between the grass clumps from the beating action of rains and the drying effects of the sun and winds. This thick cover prevents run-off from gaining a high velocity. It also spreads flood waters, thus causing deposition of silt.

**Poor land management**

**GRASSES AND FORBS**
- Grasses occur in thin stands. Alkali sacaton persists as scattered patches, mostly in low spots. Bluestem and vine-mesquite make straggling growth on flooded areas and on remnants of good soils. Where not continually destroyed, gramas and other high plains grasses have extended into drained valleys.
- Weeds, largely of little or no forage value, and Russian-thistle are common.

**SHRUBS**
- Shadscales (*Atriplex confertifolia*), snakeweeds, and similar shrubs occur as scattered plants, and where moisture conditions are favorable, in dense stands.

**VEGETATION INFLUENCES**
The vegetation, altered in composition and density, no longer adequately protects the ground nor prevents high velocity of flood flows. Much of the ground surface is bare of living plants and litter. Such areas periodically become wet and very dry.

Flood waters have channeled and gullied these valley lands so that they have become sources of tremendous quantities of river silt.

**SEMIDESERT GRASSLANDS OF HIGH TABLELANDS**

Semidesert grasslands of high tablelands total about one-eighth of the watershed. Because of the prominence of turf-forming grasses, these grasslands resemble somewhat those of the Great Plains. Where kept in good condition through conservative grazing, the average density is 56 percent; whereas on overgrazed, deteriorated areas the vegetation has declined as much as 52 and 70 percent, resulting in destructive erosion. Other data on the conditions for this type are summarized in table 9. The state and influence of the vegetation under the two conditions are compared as follows:
SOIL EROSION AND STREAM FLOW ON RIO GRANDE

Good land management

GRASSES

Blue grama (principally).
Galleta (Hilaria jamesii), although best adapted to clay soils, is widespread and not confined to depressions as is the closely similar and related tobosa grass.
Hairy grama (in places).
Dropseeds (Sporobolus spp.).
Three-awns.
Bluestem.
Ring muhly (Muhlenbergia porteri).
Sand muhly (M. arenicola).

These grasses in good condition are one of the most valuable sources of forage in the watershed.

SHRUBS

Apache-plumes (Fallugia paradoxa) and both large and small rabbitbrushes (Chrysothamnus spp.) extend in noncontinuous lines along drainageways, and are also numerous on stony outcrops.

VEGETATION INFLUENCES

The grasses constitute a well-distributed, turf-forming cover. On stony areas, particularly volcanic formations, vegetation and stones almost completely cover the ground. Where surface stones are few, small open spaces between grass clumps are partly covered with litter and dead grass tufts.

Drainage depressions are well grassed. In only a few places are bare areas large enough to allow accelerated run-off for more than short distances or for short periods before it is checked. The slow rate of erosion in old trails and roads indicates the protection afforded them by the bordering well-grassed areas.

Of all the semidesert grasslands of the drainage (5\textfrac{1}{2} million acres), only 5 percent is in good condition. About 35 percent represent advanced stages of erosion, and 60 percent are excessively eroded. The desertlike appearance of deteriorated areas forcefully indicates what extreme changes may result from loss of precipitation through accelerated run-off and increased evaporation from the ground surface, and from the washing away of soils. The nearer grasslands approach desert conditions, the more striking are the effects of such induced changes, and the more rapidly they take place. The forces that tend to develop vegetation and soil and those that tend to cause deterioration come nearest balancing each other in the drier, more critical areas such as those with semidesert or desert vegetation. This explains why these areas, where destructive forces gain the upper hand through comparatively slight changes, are so badly depleted. A similar degree of deterioration of the other, more humid grasslands is possible, although it requires a longer period of misuse to bring it about.

Poor land management

GRASSES AND FORBS

Thin, ragged stand of grasses and weeds. Most grasses are of the same species as on lands in good condition. They persist according to their ability to withstand close grazing and the droughty conditions that result from abnormal run-off and high evaporation from exposed subsoils.

Galleta tends to grow only in patches in depressions. Ring muhly may become prominent; it can survive on growth too short to graze.

So many of the plants are unpalatable that the total forage yield is less than total density would indicate.

SHRUBS

Palatable shrubs have been browsed to extinction. Large rabbitbrushes have spread. Snakeweeds and small rabbitbrushes are common; on nearly level areas (not subject to severe washing) they may form rather dense stands.

VEGETATION INFLUENCES

Both the forage yield and the ground protection qualities of this vegetation are low. The overstory growth of weeds and half-shrubs, even in fairly dense stands, affords much less protection than the close-to-the-ground growth of grasses. Open spaces between grass tufts and clumps of vegetation are large—on badly damaged lands many times larger than the areas covered by vegetation. Over large areas the soils are bleached and lifeless. Bare areas are washed and wind-blown, leaving the ground sandy or covered with loose stones. Small gullies seam the ground surface. They join in formerly shallow drainageways forming large gullies which in turn feed arroyos and washes. Through this network of erosion channels, run-off races down to and floods the valleys below.
Table 9.—Soil erosion in relation to the vegetation of high semiarid plainlike tablelands  

**SEMIDESERT GRASSLANDS OF HIGH TABLELANDS**

<table>
<thead>
<tr>
<th>Condition of the ground surface</th>
<th>Area no.</th>
<th>Slope of area</th>
<th>Direction of exposure</th>
<th>Origin of soil-forming materials</th>
<th>Textural class</th>
<th>Average depth eroded</th>
<th>Density found</th>
<th>Vegetation conditions</th>
<th>Degree of soil erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Grasses</td>
<td>Figs</td>
<td>Shrubs</td>
</tr>
<tr>
<td>Grass mulch</td>
<td>72d</td>
<td>(1)</td>
<td>SW.</td>
<td>Sandstone</td>
<td>Sandy loam</td>
<td>(9)</td>
<td>51</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Thick grass mulch</td>
<td>116a</td>
<td>(1)</td>
<td>SW.</td>
<td>Basalt</td>
<td>Sandy clay loam</td>
<td>(9)</td>
<td>54</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Grass mulch and embedded stones.</td>
<td>111</td>
<td>(1)</td>
<td>SW.</td>
<td>Sandstone</td>
<td>Clay loam</td>
<td>(9)</td>
<td>52</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Grass mulch</td>
<td>132</td>
<td>4</td>
<td>E.</td>
<td>Sandstone</td>
<td>Fine sandy loam</td>
<td>(9)</td>
<td>34</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Grass mulch and some stones.</td>
<td>152</td>
<td>7</td>
<td>N.</td>
<td>Rhyolite</td>
<td>Gravelly loam</td>
<td>(9)</td>
<td>54</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>49</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Some grass mulch</td>
<td>39</td>
<td>(1)</td>
<td>W.</td>
<td>Granite and basalt</td>
<td>Gravelly clay loam</td>
<td>0.25</td>
<td>28</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Grass mulch and some small stones</td>
<td>5</td>
<td>(1)</td>
<td>W.</td>
<td>Shales</td>
<td>Gravelly loam</td>
<td>0.50</td>
<td>24</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Grass mulch and cobblestones.</td>
<td>20</td>
<td>5</td>
<td>N.</td>
<td>Alluvium</td>
<td>Gravelly loam</td>
<td></td>
<td>26</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Fragments of shale</td>
<td>18</td>
<td>5</td>
<td>W.</td>
<td>Shales</td>
<td>Gravelly loam</td>
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<td>39</td>
<td>1</td>
<td>0</td>
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<tr>
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<td>43</td>
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<td>W.</td>
<td>do</td>
<td>Fine sandy loam</td>
<td>0.50</td>
<td>27</td>
<td>2</td>
<td>1</td>
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<tr>
<td>Small stones</td>
<td>59</td>
<td>2</td>
<td>W.</td>
<td>do</td>
<td>Gravelly clay loam</td>
<td>1.50</td>
<td>34</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Some grass litter</td>
<td>72b</td>
<td>3</td>
<td>W.</td>
<td>Sandstone</td>
<td>Sandy loam</td>
<td>0.25</td>
<td>28</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Do.</td>
<td>101</td>
<td>4</td>
<td>NW.</td>
<td>do</td>
<td>Fine sandy loam</td>
<td>0.50</td>
<td>37</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Stony</td>
<td>121</td>
<td>(1)</td>
<td>W.</td>
<td>do</td>
<td>Sandy loam</td>
<td>0.25</td>
<td>40</td>
<td>0</td>
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<tr>
<td>Some grass litter. No stones.</td>
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<td>S.E.</td>
<td>Alluvium</td>
<td>Gravelly loam</td>
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<td>11</td>
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<tr>
<td>Grass mulch and some stones.</td>
<td>152a</td>
<td>9</td>
<td>S.</td>
<td>Rhyolite</td>
<td>Stony loam</td>
<td>0.50</td>
<td>32</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Stones and grass litter</td>
<td>156</td>
<td>3</td>
<td>W.</td>
<td>do</td>
<td>...</td>
<td>0.50</td>
<td>42</td>
<td>3</td>
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<tr>
<td>Average</td>
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<td>31</td>
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<td>Percentage</td>
<td>Description</td>
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<tr>
<td>Bare—pebbles</td>
<td>19</td>
<td>5%</td>
<td>Clay loam...</td>
<td></td>
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<td></td>
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<tr>
<td>Some cobblestones</td>
<td>22</td>
<td>6%</td>
<td>Clay loam...</td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Small stones</td>
<td>34</td>
<td>11%</td>
<td>Clay loam...</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Clayey</td>
<td>38</td>
<td>12%</td>
<td>Clay loam...</td>
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</tr>
<tr>
<td>Small stones</td>
<td>39a</td>
<td>12%</td>
<td>Clay loam...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy</td>
<td>55</td>
<td>17%</td>
<td>Clay loam...</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Very stony</td>
<td>81a</td>
<td>27%</td>
<td>Clay loam...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Some stones</td>
<td>95a</td>
<td>31%</td>
<td>Clay loam...</td>
<td></td>
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<tr>
<td>Flat stones</td>
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<td>26%</td>
<td>Clay loam...</td>
<td></td>
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</tr>
<tr>
<td>Sandy</td>
<td>102</td>
<td>33%</td>
<td>Clay loam...</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Clayey</td>
<td>169</td>
<td>53%</td>
<td>Clay loam...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Many stones</td>
<td>121a</td>
<td>40%</td>
<td>Clay loam...</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Average: 23 2 2 27 46 52 22

1 Less than 1°.
2 Very slight.
3 Normal.
4 Sand ripples.
5 Badly eroded.
TABLE 10.—Soil erosion in relation to the vegetation of the cooler high semiarid valleys and high plainlike tablelands
SAGEBRUSH LANDS OF COOLER HIGH VALLEYS AND HIGH TABLELANDS

<table>
<thead>
<tr>
<th>Condition of the ground surface</th>
<th>Area no.</th>
<th>Slope of area</th>
<th>Direction of exposure</th>
<th>Origin of soil-forming materials</th>
<th>Textural class</th>
<th>Density found</th>
<th>Vegetation conditions</th>
<th>Degree of soil erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Density found</td>
<td>Alteration of soil</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Grasses</td>
<td>Forbs</td>
<td>Shrubs</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Grass and sagebrush litter</td>
<td>2a</td>
<td>7</td>
<td>SW.</td>
<td>Boscon</td>
<td>Gravelly loam</td>
<td>(1)</td>
<td>35</td>
<td>18</td>
</tr>
<tr>
<td>Do</td>
<td>164</td>
<td>5</td>
<td>SE.</td>
<td>Sandstone  and shale.</td>
<td>Deep sandy loam</td>
<td>(1)</td>
<td>36</td>
<td>22</td>
</tr>
<tr>
<td>Do</td>
<td>173</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>48</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Some litter and small stones.</td>
<td>2</td>
<td>2</td>
<td>SE.</td>
<td>Alluvium</td>
<td>Loam</td>
<td>(1)</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Thin litter</td>
<td>27</td>
<td>1</td>
<td>W.</td>
<td>Boscon</td>
<td>Stony clay loam</td>
<td>.50</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Average</td>
<td>166</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Small stones</td>
<td>3</td>
<td>6</td>
<td>W.</td>
<td>Basalt</td>
<td>Sandy clay loam</td>
<td>1.50</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Stones</td>
<td>3a</td>
<td>2</td>
<td>W.</td>
<td>do</td>
<td>Sandy loam</td>
<td>1.25</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Small stones and sand</td>
<td>7</td>
<td>2</td>
<td>W.</td>
<td>do</td>
<td>Sandstone</td>
<td>1.25</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Gravelly</td>
<td>10</td>
<td>1</td>
<td>S.E.</td>
<td>do</td>
<td>Silty loam</td>
<td>2.00</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Small stones</td>
<td>25</td>
<td></td>
<td></td>
<td>Boscon</td>
<td>Clay loam</td>
<td>1.50</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Scattered stones</td>
<td>1</td>
<td>10</td>
<td>N.</td>
<td>Basalt</td>
<td>Deep clay loam</td>
<td>4.00</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Stony</td>
<td>4</td>
<td>3</td>
<td>E.</td>
<td>do</td>
<td>Clay loam</td>
<td>2.00</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Clayey</td>
<td>12a</td>
<td>5</td>
<td>W.</td>
<td>do</td>
<td>Shale</td>
<td>3.50</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Flat stones</td>
<td>12c</td>
<td>14</td>
<td>W.</td>
<td>do</td>
<td></td>
<td>4.00</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>4</td>
<td>19</td>
</tr>
</tbody>
</table>

1 Less than 1°.  2 Normal.  3 Slight.  4 Badly eroded.
A. Sagebrush savanna of the cooler high semiarid plain west of Taos Mountains. Grama grass, which occurs as a thick stand between the sagebrush shrubs and which has been closely winter grazed, has not yet made its annual growth.  
B. Deteriorated sagebrush-savanna land, caused by accelerated soil erosion which followed the killing of the grasses through overgrazing.
A. Conservative use of forage and wood of this savanna woodland has maintained these resources and has therefore conserved the soils that produced them. B. Deteriorated savanna woodland. Overgrazing has destroyed the protective cover of grasses, which deterioration, in turn, has resulted in the loss of topsoil necessary for the production of good forage.
SAGEBRUSH LANDS

Sagebrush lands, as shown in figure 9, compose only about one-sixteenth of the drainage area. However, large sage bushes are rather common high-plains plants throughout the northern part of the drainage where they occur in woodland, particularly in valleys near the lower limits of pine forest and in grassland on the thin, rocky soils of knolls and ridges.

The typical vegetation is of savanna structure; grasses compose nearly 65 percent of the total density (table 10). This combination of grasses and shrubs makes good winter range for sheep but one on which the grasses are particularly apt to be overgrazed. Grasses are more palatable and are taken first, and yet after they are closely grazed there is always an abundance of shrub forage which makes it possible to continue the destruction of the grasses. Furthermore, the intense demand for winter range has contributed to overgrazing of these shrub ranges. Some years ago, hundreds of thousands of sheep from other States were winter grazed on the sagebrush ranges of New Mexico.

Between 1919 and 1925 large areas within the sagebrush type were taken up during a short-lived wave of homesteading. Many homesteads were never plowed and usually only small parts of them were cleared for cultivation. Nearly all of these lands were abandoned, but some were held for grazing, either as key locations or consolidated range units.

On well-managed lands which still support a good cover of vegetation (pl. 13, A), soil erosion is negligible. Advanced or excessive erosion is common where the plant density has declined to about half that found on well-managed lands, particularly where the decrease represents a decline of the grasses (pl. 13, B). The composition and influence of the vegetation under good and poor management are described as follows:

<table>
<thead>
<tr>
<th>Good land management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GRASSES</strong></td>
</tr>
<tr>
<td>The grasses are the same as those of the adjacent grasslands of high tablelands.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Poor land management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GRASSES AND FORBS</strong></td>
</tr>
<tr>
<td>Thin stands and scattered tufts, particularly of blue grama; also many weeds such as pingue (Actinea spp.).</td>
</tr>
</tbody>
</table>

|                                                                                       |
| **SHRUBS**                                                                            |
| Large sagebrushes (Artemisia tridentata) and some small shrubs, including estafiata (A. frigida). |

<table>
<thead>
<tr>
<th>VEGETATION INFLUENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>The combination of close-to-the-surface grasses, which form at least two-thirds of the average density, and overstory shrubs provide a good ground cover. The grasses, well-distributed, are good ground protection in themselves. The overstory of shrubs provides some litter and protects the ground from the beating action of rain, and undoubtedly reduces the drying effects of wind and sun. The run-off in shallow draws is controlled and spread by the dense clumps of shrubs and the thick grass growth of intervening glades.</td>
</tr>
</tbody>
</table>

|                                                                                       |
| **VEGETATION INFLUENCES**                                                            |
| Sagebrush never grows so dense as to develop a closed canopy. Where the grasses are grazed out or otherwise become inadequately protective, the remaining cover of shrubs, being overstory and concentrated in clumps, neither adequately protects the ground or prevents acceleration of run-off. However, the degree of acceleration of run-off is least beneath shrub crowns, thus washing rapidly lowers the ground surface of the open areas between the shrubs. The mounds of root-bound soil beneath shrubs shunt run-off first one way and then the other, forming a network of run-off erosion paths that converge in deep gullies of formerly shallow well-vegetated draws. The weeds on areas formerly cleared and cultivated afford poor protection. |
| **SHRUBS**                                                                            |
| Large sagebrushes. Rabbitbrushes. Snakeweeds with remnants of the most palatable shrubs, such as estafiata. |

|                                                                                       |
| **Weeds**                                                                            |
| Only a few species of weeds are definite. However, these can be particularly troublesome on ranges where the shrubs and grasses are inadequately protected. They consist of various species of air plants (Oxalis spp.), which grow among the roots of the shrubs and grasses and which are especially abundant in the spring. |

|                                                                                       |
| **SOIL LOSS**                                                                        |
| Soil loss on well-managed lands is negligible. On land subject to excessive erosion, the amount of soil loss is much greater. |
### Table 11.—Soil erosion in relation to the vegetation of some high tablelands, foothills, and low mountains

**SAVANNA WOODLANDS OF HIGH PLAINS, LOW MOUNTAINS, AND TABLELANDS**

<table>
<thead>
<tr>
<th>Condition of the ground surface</th>
<th>Area no.</th>
<th>Slope of area</th>
<th>Direction of exposure</th>
<th>Origin of soil-forming materials</th>
<th>Textural class</th>
<th>Soil factors</th>
<th>Vegetation conditions</th>
<th>Density found</th>
<th>Degree of soil erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average depth eroded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass and tree litter</td>
<td>47</td>
<td>2</td>
<td>N.</td>
<td>Limestone</td>
<td>Clay loam</td>
<td>(°)</td>
<td>45</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Embedded stones</td>
<td>149</td>
<td>12</td>
<td>NE.</td>
<td>Rhyolite</td>
<td>Deep sandy loam</td>
<td>(°)</td>
<td>49</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Grass and tree litter, some stones.</td>
<td>160</td>
<td>2</td>
<td>NE.</td>
<td>Porphyry</td>
<td>Sandy loam</td>
<td>(°)</td>
<td>44</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Do</td>
<td>171</td>
<td>5</td>
<td>SE.</td>
<td>Rhyolite</td>
<td>gravelly loam</td>
<td>(°)</td>
<td>27</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41</td>
<td>2</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Grass and tree litter, some stones.</td>
<td>48a</td>
<td>3</td>
<td>NE.</td>
<td>Sandstone and limestone.</td>
<td>Fine sandy loam</td>
<td>(°)</td>
<td>37</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Stones and some litter</td>
<td>61</td>
<td>1</td>
<td>S.</td>
<td>Volcanic</td>
<td>Sandy loam</td>
<td>1.00</td>
<td>20</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sandy</td>
<td>120</td>
<td>3</td>
<td>E.</td>
<td>Sandstone</td>
<td>do</td>
<td>1.50</td>
<td>29</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Very stony</td>
<td>150</td>
<td>12</td>
<td>E.</td>
<td>Rhyolite</td>
<td>do</td>
<td>1.00</td>
<td>20</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Clayey</td>
<td>48</td>
<td>1</td>
<td>W.</td>
<td>Shales and sandstones.</td>
<td>Deep clay loam</td>
<td>2.00</td>
<td>16</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Sandy</td>
<td>115</td>
<td>3</td>
<td>SE.</td>
<td>Sandstone and shale.</td>
<td>Sandy loam</td>
<td>2.00</td>
<td>16</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>8</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Soil Type</td>
<td>Percentage</td>
<td>Soil Type</td>
<td>Percentage</td>
<td>Soil Type</td>
<td>Percentage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>------------</td>
<td>------------------------------------</td>
<td>------------</td>
<td>------------------------------------</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small flat stones</td>
<td>78</td>
<td>NW. Shales</td>
<td>7</td>
<td>Sandy</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobblestones</td>
<td>21</td>
<td>SE. Alluvium</td>
<td>20</td>
<td>Some tree litter</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy</td>
<td>58</td>
<td>SW. do</td>
<td>4</td>
<td>Some tree litter</td>
<td>81</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobblestones</td>
<td>81</td>
<td>W. do</td>
<td>20</td>
<td>Some tree litter</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some tree litter</td>
<td>113</td>
<td>NE. Sandstone</td>
<td>(*)</td>
<td>Some tree litter</td>
<td>81</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Average**

- Small flat stones: 76%
- Cobblestones: 21%
- Sandy: 58%
- Some tree litter: 113%

**Woodlands of Foothills, Mountains, and High Plains**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Percentage</th>
<th>Soil Type</th>
<th>Percentage</th>
<th>Soil Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass and tree litter</td>
<td>165</td>
<td>NE. Rhyolite</td>
<td>4</td>
<td>Grass and tree litter</td>
<td>178</td>
</tr>
<tr>
<td>Grass and tree litter and embedded stones</td>
<td>176</td>
<td>NW. Limestone</td>
<td>5</td>
<td>Grass and tree litter</td>
<td>178</td>
</tr>
<tr>
<td>Grass and tree litter</td>
<td>178</td>
<td>W. Sandstone</td>
<td>(*)</td>
<td>Grass and tree litter</td>
<td>178</td>
</tr>
</tbody>
</table>

**Average**

- Grass and tree litter: 165%
- Grass and tree litter and embedded stones: 176%
- Grass and tree litter: 178%

**Soil Erosion and Stream Flow on Rio Grande**

1 Normal.  2 Slight.  3 Badly eroded.  4 Less than 1°.  5 Sand ripples.  6 Very slight.
Most sagebrush lands are badly deteriorated through destruction of the grasses. Only 5 percent of these lands are still in good condition. On 40 percent, erosion has reached advanced stages; and on 55 percent, extreme stages. The more easily recognized evidences of erosion may be lacking on the almost level tablelands; but some of the most spectacular land break-down on the drainage is in mountain valleys and foothills where grasses are wiped out in the spaces between the sage bushes.

WOODLANDS

The woodlands, next to the grasslands in extent, cover approximately one-third of the watershed. They usually border the grasslands, but they may occur next to the sagebrush lands. On the high mesas and foothills in the northern part there are coniferous woodlands, while in the extreme southern part broad-leaved trees are common on the slopes of the mountains. In most places these woodlands are savannas. They consist of grasses and orchardlike open stands of trees; the grasses constitute about three-fourths of the average plant density of 56 percent. In other places (even on some extensive areas), the trees grow in rather dense stands and make up from one-half to three-fourths of the average plant density of 65 percent. Other data are summarized in table 11.

Woodlands have been important grazing grounds and the principal source of firewood and small timbers since the beginning of settlement. The protective ground cover, particularly of the savanna woodlands, has been changed by overgrazing more than by timber cutting. The great variation in the relation of total density of depleted vegetation to ground-surface condition is accounted for in part by the effect of different destructive influences and in part by the difference in degree of protection afforded by the close-to-the-ground cover of grasses and by the overstory of trees. The destruction of a unit of grass cover resulted in more serious erosion than a similar unit of tree cover.

Some small tracts, usually of the better soils, have been farmed for years; others were homesteaded only recently. The older of these tracts indicate that farming practices, such as contour plowing, bordering, and terracing will be necessary to retain the soil and effectively preserve the moisture. Such of these lands as have proved to be submarginal or uneconomic farm units, and hence have been abandoned, seldom support more than a scant stand of weeds and are badly eroded. On the other hand, grasses on the unfarmed parts of some fenced areas are better than on the outside. The plant cover of overgrazed cut-over savanna woodlands has declined as much as 70 percent, and dense woodlands, 72 percent. Comparative effects of good and poor land management on plant cover in relation to land conditions are summarized as follows:
SOIL EROSION AND STREAM FLOW ON RIO GRANDE 61

JUNIPER-PiñON Woodlands

Good land management

TREES

One-seeded juniper (Juniperus monosperma).

Piñons (Pinus cembroides vars.) and some Rocky Mountain red cedars (Juniperus scopulorum).

Uncut and cut-over areas have trees of different age classes; the uncut include old, overmature, and dead trees that are removed on cut-over areas.

SHRUBS

Sagebrush and rabbitbrush in the northern part of the watershed; small sage plants (Artemisia spp.) and Apache-plume in the southern part.

GRASSES

The grasses are the same kinds as those of the adjacent semidesert grasslands of high tablelands and plains; gramas, principally blue grama, with bluestem and others in almost pure stands in glades and parks.

Poor land management

TREES

Young junipers are common in openings, formerly well-grassed areas. They have become so numerous in places as to be a serious detriment to the range. The stunted bush growth and the density of the present, as compared with the original, stand would indicate that most of these trees will make timber of little value.

SHRUBS

Valuable browse plants are few and badly deformed by browsing animals; unpalatable shrubs, such as snake-weeds, are numerous.

GRASSES

Grasses consist largely of low-growing tufts of blue grama on spots where run-off is the least destructive. Thin stands of weeds grow in the parks and glades.

OAK-JUNIPER Woodlands

TREES

Live oaks, usually Emory oak (Quercus emoryi) and Q. grisea, and alligator junipers (Juniperus pachyphloea) in open stands and in places in dense groves. The best oak growth is in depressions and basins. Alligator junipers commonly occur in open but almost pure stands on mountain benches and flats. Cutting of oaks and junipers has been confined almost entirely to dead and overmature trees.

SHRUBS

Shrub live oaks (Quercus spp.). Mountain-mahoganies (Cercocarpus spp.), browsed but in good condition. Buckthorns (Rhamnus spp.). Silktassels (Garrya spp.).

GRASSES

Side-oats grama (Bouteloua curtipendula). Hairy grama. Blue grama. Ricegrasses (Oryzopsis spp.).

Stunted broad-leaved trees and shrubs, which evidently became established when the grasses declined but before the topsoil was washed away, give a brush-field character to the plant cover. Only a few oak seedlings are coming in on badly eroded areas. Alligator-juniper seedlings are numerous at the upper limits of juniper growth, particularly in shade and where soils are still intact, but they are scarce at the lower elevations and on badly eroded areas.

SHRUBS

Valuable browse plants, such as mountain-mahoganies, have dead and mutilated branches; many have died from too close browsing.

GRASSES

Grasses have almost entirely disappeared from steep, eroded slopes and form only thin weedy stands on the juniper benches and flats.
VEGETATION INFLUENCES

On the small areas of cedar brakes where slopes are steep and soils poor and thin, stunted junipers form the principal growth. Excepting these small critical areas, the savanna woodlands have a good ground cover of grass which is similar to the semidesert grasslands of the high tablelands, and which provides the real protection afforded by this woodland vegetation. The scattered trees undoubtedly offer some protection by controlling wind movement and thus evaporation, and by breaking the force of rain.

In the dense woodland stands, the protective cover is also a combination of grasses and trees, but here trees and tree litter play a more important role. Even in these dense woodlands, grasses grow well up under the tree crowns, sometimes forming a broken turf of very short growth beneath the trees.

Where timber cutting and grazing have been so managed that the wheel ruts are not kept open indefinitely or cut anew at intervals and conservative grazing permits the naturally rapid increase of herbs in stump patches, any decrease in ground protection caused by cutting is soon offset by new growth.

The woodlands are in somewhat better condition than either the grasslands or sagebrush lands. About 20 percent of the total woodland area is in good condition (pl. 14, A). About 45 percent of these lands have reached advanced stages of erosion (pl. 14, B); on 35 percent erosion is extreme. Preservation of the woodland areas has been favored by relief, stony surfaces, and lack of available stock waters. More than half the woodlands are comparatively level mesas, and at least half the mesas are studded with malpais rocks. These rocky areas are rather resistant to overgrazing and erosion, whereas the steep marly and shale slopes are eroded into badlands.

PINE-FIR FORESTS

The pine-fir forests occur at high elevations above the woodlands and below the spruce-fir forests of the still higher parts of the mountains. They cover about one-eighth of the watershed and constitute the principal source of saw timber. Well-managed lands still support a good plant cover of about 76 percent average density and soil erosion is negligible. On destructively lumbered and overgrazed areas where the plant density of well-managed lands has declined 52 and 61 percent, destructive erosion is in progress (the data are summarized in table 12).
A comparison of the vegetation and accompanying condition of the ground under good and poor land management is made as follows:

**Good land management**

**TREES AND SHRUBS**

- Ponderosa pine (*Pinus ponderosa*).
- Douglas fir (*Pseudotsuga taxifolia*).
- White firs (*Abies concolor*), commonly as scattered individuals.
- Gambel oaks (*Quercus gambelii*) as scattered, dwarfed trees, almost all of which may be regarded as shrubs.
- Different kinds of shrubs, principally small deerbrush (*Ceanothus fendleri*), occur as scattered individuals, although in places they are rather prominent.
- Owing to fire or some other cause, Gambel oaks commonly constitute local brush fields, principally on steep slopes.
- Lumbered and grazed areas have a protective ground cover which consists of herbs, shrubs, litter, timber reproduction, and trees left in good forestry practices.

**GRASSES AND FORBS**

- Bunchgrasses, including mountain muhly (*Muhlenbergia montana*) needlegrasses (*Stipa spp.*), bluegrasses (*Poa spp.*), junegrass (*Koeleria cristata*), bromegrasses (*Bromus spp.*), and Arizona fescue (*Festuca arizonica*), are common, and blue grama sometimes occurs near the lower margin of the forest.
- Associated with the bunchgrasses are many forbs, principally legumes of high forage value, and composites.

**VEGETATION INFLUENCES**

- The most important factors in ground protection in the pine stands are the bunchgrasses and the accumulated litter (pine straw and grass); and in the fir stands, tree and herb litter. Herb density varies widely, averaging about 25 percent as compared with an average total density of 76 percent, including trees.
- The overstory of trees protects the ground from winds and the beating action of rains. But the real protection from surface run-off and erosion is afforded by herbs and litter, the herbs aiding materially in the accumulation of tree litter by serving as pins in holding the litter in place (pl. 15).

**Poor land management**

**TREES AND SHRUBS**

- Trees are the same kinds as those on lands still in good condition. Deterioration of uncut areas is largely lack of timber reproduction, and alteration of herbaceous vegetation through overgrazing and fire. In some places, particularly where all merchantable timber is removed, Gambel oaks occur as brush fields or with New Mexican locusts (*Robinia neomexicana*) and sagebrush shrubs as clumps and scattered individuals; timber reproduction is practically absent. Although timber cutting temporarily alters vegetation and disturbs the ground cover, it is not necessarily destructive.

**GRASSES AND FORBS**

- In some places the grasses have declined, and the most palatable forage plants, such as vetches (*Vicia spp.*), pea vines (*Lathyrus*), and deervetches (*Lotus spp.*), are few in number. Senecios (*Senecio spp.*), pingues, snakeweeds, and other unpalatable or noxious plants are the dominant herbs.

**VEGETATION INFLUENCES**

- Where the herbaceous cover has materially declined, accelerated run-off prevents the accumulation of litter. On slopes where plant stems have been closely grazed, the old accumulations of litter may be washed away in a single season. In the absence of the litter cover, run-off becomes still more highly accelerated, particularly between the trees, and destructive erosion progresses rapidly (pl. 16). Where damage has resulted from destructive lumbering, as on large areas at the headwaters of the Rio Chama, a nonforest type of vegetation has developed which is characterized by Gambel oak and herbs. In some places the charred stumps of logs indicate that slash fires played a role in the destruction of uncut pine poles and in the development of oak-grass vegetation.
<table>
<thead>
<tr>
<th>Condition of the ground surface</th>
<th>Area no.</th>
<th>Slope of area</th>
<th>Direction of exposure</th>
<th>Origin of soil-forming materials</th>
<th>Textural class</th>
<th>Soil factors</th>
<th>Vegetation conditions</th>
<th>Degree of soil erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Degrees</td>
<td></td>
<td></td>
<td></td>
<td>Average depth eroded</td>
<td>Density found</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inches (1)</td>
<td>Grasses</td>
<td>Forbs</td>
</tr>
<tr>
<td>Much litter</td>
<td>15b</td>
<td>7</td>
<td>NE.</td>
<td>Sandstone and shale.</td>
<td>Loam</td>
<td>22</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Do</td>
<td>24</td>
<td>30</td>
<td>N.</td>
<td>Conglomerate</td>
<td>Sandy loam</td>
<td>(1)</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>Do</td>
<td>42</td>
<td>7</td>
<td>N.</td>
<td>Granite</td>
<td>Gravelly loam</td>
<td>(1)</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Do</td>
<td>63</td>
<td>7</td>
<td>E.</td>
<td>Rhyolite.</td>
<td>Loam</td>
<td>(1)</td>
<td>19</td>
<td>11</td>
</tr>
<tr>
<td>Deep litter</td>
<td>74</td>
<td>5</td>
<td>W.</td>
<td>Sandstone and shale.</td>
<td>do.</td>
<td>(1)</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Average of areas 24, 42, 63, and 74</td>
<td>32</td>
<td>20</td>
<td>N.</td>
<td>Sandstone and shale.</td>
<td>do.</td>
<td>.50</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Some tree litter, some stones</td>
<td>32</td>
<td>20</td>
<td>N.</td>
<td>Sandstone and shale.</td>
<td>Sandy loam</td>
<td>.50</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>Some litter, some stones</td>
<td>36</td>
<td>8</td>
<td>SE.</td>
<td>Sandstone and granite.</td>
<td>Gravelly loam</td>
<td>.25</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>Some litter</td>
<td>51b</td>
<td>7</td>
<td>N.</td>
<td>Sandstone and shale.</td>
<td>Fine sandy loam</td>
<td>(1)</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Some litter and stones</td>
<td>65</td>
<td>28</td>
<td>N.</td>
<td>Sandstone and shale.</td>
<td>do.</td>
<td>.25</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Do</td>
<td>155</td>
<td>3</td>
<td>N.</td>
<td>Rhyolite.</td>
<td>Loam</td>
<td>.50</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>7</td>
</tr>
</tbody>
</table>

1 Weighted average.
A pine-fir forest (natural state) which has important resources, such as timber and water, and also range and recreational values.
A deteriorated pine-fir forest, the result of unregulated lumbering and grazing. Here no provisions were made for conserving any of the forest-land resources.
<table>
<thead>
<tr>
<th>Some shale fragments</th>
<th>13</th>
<th>3</th>
<th>N.</th>
<th>Shale</th>
<th>Loam</th>
<th>$0.75$</th>
<th>12</th>
<th>12</th>
<th>6</th>
<th>0</th>
<th>30</th>
<th>67</th>
<th>Advanced. Do.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>15a</td>
<td>7</td>
<td>N.</td>
<td>do</td>
<td></td>
<td>$0.75$</td>
<td>10</td>
<td>11</td>
<td>4</td>
<td>5</td>
<td>30</td>
<td>67</td>
<td>Do.</td>
</tr>
<tr>
<td>Many small stones</td>
<td>24a</td>
<td>45</td>
<td>S.</td>
<td>Sandstone and shale.</td>
<td>Loam</td>
<td>$0.50$</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>34</td>
<td>49</td>
<td>55</td>
<td>Do.</td>
</tr>
<tr>
<td>Loose stones</td>
<td>72a</td>
<td>5</td>
<td>SW.</td>
<td>Sandstone</td>
<td>do</td>
<td>$1.50$</td>
<td>11</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>25</td>
<td>38</td>
<td>Do.</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$0.75$</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>20</td>
<td>32</td>
<td>42</td>
<td>Do.</td>
</tr>
<tr>
<td>Weighted average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$0.75$</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>16</td>
<td>32</td>
<td>48</td>
<td>52</td>
</tr>
<tr>
<td>Many stones</td>
<td>36a</td>
<td>11</td>
<td>SE.</td>
<td>Granites</td>
<td>Gravelly loam</td>
<td>$0.50$</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>0</td>
<td>7</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>Small stones</td>
<td>51a</td>
<td>7</td>
<td>N.</td>
<td>Sandstone</td>
<td>Loam</td>
<td>$1.00$</td>
<td>7</td>
<td>11</td>
<td>0</td>
<td>7</td>
<td>25</td>
<td>33</td>
<td>Do.</td>
</tr>
<tr>
<td>Clayey</td>
<td>105</td>
<td>6</td>
<td>N.</td>
<td>Sandstone and shale.</td>
<td>Clay loam</td>
<td>$1.00$</td>
<td>2</td>
<td>18</td>
<td>2</td>
<td>6</td>
<td>28</td>
<td>37</td>
<td>Do.</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1.00$</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>16</td>
<td>32</td>
<td>48</td>
<td>52</td>
</tr>
<tr>
<td>Weighted average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1.00$</td>
<td>2</td>
<td>18</td>
<td>2</td>
<td>6</td>
<td>28</td>
<td>37</td>
<td>Do.</td>
</tr>
<tr>
<td>Scattered stones</td>
<td>174</td>
<td>12</td>
<td>NW.</td>
<td>Shale</td>
<td>Loam</td>
<td>$2.00$</td>
<td>8</td>
<td>4</td>
<td>28</td>
<td>0</td>
<td>40</td>
<td>53</td>
<td>Do.</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$2.00$</td>
<td>7</td>
<td>11</td>
<td>8</td>
<td>4</td>
<td>30</td>
<td>39</td>
<td>53</td>
</tr>
</tbody>
</table>

**SPRUCE-FIR FORESTS**

<table>
<thead>
<tr>
<th>Much herb litter</th>
<th>17a</th>
<th>15</th>
<th>SW.</th>
<th>Volcanic</th>
<th>Deep loam</th>
<th>(1)</th>
<th>52</th>
<th>10</th>
<th>3</th>
<th>0</th>
<th>65</th>
<th>90</th>
<th>Normal. Do.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herb mulch</td>
<td>30</td>
<td>14</td>
<td>NW.</td>
<td>Limestone and sandstone.</td>
<td>do</td>
<td>(1)</td>
<td>40</td>
<td>14</td>
<td>36</td>
<td>0</td>
<td>40</td>
<td>63</td>
<td>Do.</td>
</tr>
<tr>
<td>Weighted average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>51</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>$66$</td>
<td></td>
<td>Do.</td>
</tr>
<tr>
<td>Deep litter</td>
<td>35</td>
<td>(19)</td>
<td>NW.</td>
<td>Sandstone</td>
<td>Deep loam</td>
<td>(1)</td>
<td>17</td>
<td>8</td>
<td>0</td>
<td>60</td>
<td>85</td>
<td>Do.</td>
<td></td>
</tr>
<tr>
<td>Forest litter</td>
<td>41</td>
<td>15</td>
<td>E.</td>
<td>Granite</td>
<td>Deep loam</td>
<td>(1)</td>
<td>38</td>
<td>9</td>
<td>4</td>
<td>34</td>
<td>85</td>
<td>Do.</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22</td>
<td>8</td>
<td>4</td>
<td>51</td>
<td>85</td>
<td></td>
<td>Do.</td>
<td></td>
</tr>
</tbody>
</table>

1 Normal.
2 Cut-over timberlands on which a protective cover of shrubs, timber reproduction, and herbs has developed.
3 In comparing deteriorated with good vegetation, the densities on areas 14, 23, 13, and 15a are compared with the density of 45, based on area 15b (characterized by altered vegetation which developed after timber destruction), and areas 32, 36, 51b, 65, 155, 24a, 72a, 36a, 51a, 105, and 174 are compared with the average density of 76, based on areas numbered 24, 42, 63, and 74.
4 Slight.
5 Weighted averages are obtained by evaluating the 2 averages found under the degree of erosion concerned, moderate and advanced, according to the part of the total area each represents, namely, the average of areas 14 and 23—and 13 and 15a at 25 percent, and areas 32, 36, 51b, 65, and 155—areas 24a and 72a at 75 percent.
6 The measurements represent general surface erosion exclusive of badly eroded places, as in glades, small valleys, canyon bottoms, logging roads, and the like.
7 Badly eroded.
8 Not weighted, because excessive deterioration of both tree and ground-surface vegetation occurred where extensive areas are excessively eroded.
9 In comparing deteriorated with good vegetation, areas 12, 12b, 162, 16, and 17 are compared with density of 66, based on a weighted average of areas 17a and 30, rated at 95 and 5 percent, respectively (17a representing drained uplands, characterized by grasses and grasslike plants in old burns and the like, and 30 representing low wet areas or meadows), areas 31, 35a, 161, and 8 are compared with an average density of 85, based on areas 35, 40a, and 41 (characterized by aspen and open stands of spruce and fir), and areas 40c and 180 are compared with the density of 95, based on area 40b (characterized by dense stands of spruce and fir).
10 Less than 1°.
<table>
<thead>
<tr>
<th>Condition of the ground surface</th>
<th>Area no.</th>
<th>Slope of area</th>
<th>Direction of exposure</th>
<th>Origin of soil-forming materials</th>
<th>Textural class</th>
<th>Soil factors</th>
<th>Vegetation conditions</th>
<th>Density found</th>
<th>Degree of soil erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep litter</td>
<td>40b</td>
<td>Degrees 5</td>
<td>NE.</td>
<td>Limestone and sandstone.</td>
<td>Deep loam</td>
<td>Inches 1</td>
<td>23 8 4 49 84 100 30</td>
<td>Weighted average</td>
<td></td>
</tr>
<tr>
<td>Weighted average11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Percent 1</td>
<td>Normal</td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Herb litter</td>
<td>12</td>
<td>4 W.</td>
<td></td>
<td>Volcanic</td>
<td>Deep loam</td>
<td>Percent 5</td>
<td></td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Do.12b</td>
<td>12</td>
<td>12 W.</td>
<td></td>
<td>do</td>
<td>Deep loam</td>
<td>Percent 3</td>
<td></td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>31</td>
<td>2 SW.</td>
<td></td>
<td>Limestone</td>
<td>Deep loam</td>
<td>Percent 86</td>
<td></td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Weighted average12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Percent 95</td>
<td>Normal</td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Some forest litter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Some loose stones</td>
<td>162</td>
<td>5 NE.</td>
<td></td>
<td>Rhyolite</td>
<td>Deep loam</td>
<td>1.00</td>
<td>20 23 2 45 68 68 71</td>
<td>Advanced</td>
<td></td>
</tr>
<tr>
<td>Thin litter</td>
<td>35a</td>
<td>(10)</td>
<td></td>
<td>Sandstone</td>
<td>do</td>
<td>.50</td>
<td>12 12 36 60 71 100</td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Do.161</td>
<td></td>
<td></td>
<td></td>
<td>Granite</td>
<td>Loam</td>
<td>.75</td>
<td>6 1 32 49 100 81 47</td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Average of areas 35a and 161</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Thin litter</td>
<td>40c</td>
<td>8 NW.</td>
<td></td>
<td>Granite</td>
<td>Coarse sandy loam</td>
<td>.25</td>
<td>15 3 2 30 50 59 59</td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Weighted average13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Few large stones</td>
<td>16</td>
<td>15 E.</td>
<td></td>
<td>Volcanic</td>
<td>Gravelly loam</td>
<td>2.50</td>
<td>15 4 1 20 30 41 16</td>
<td>Excessive</td>
<td></td>
</tr>
<tr>
<td>Dead crowns of bunch</td>
<td>17</td>
<td>20 W.</td>
<td></td>
<td>do</td>
<td>Deep loam</td>
<td>3.00</td>
<td>24 14 2 40 61 61 12</td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>grasses in places</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Do</td>
<td></td>
</tr>
<tr>
<td>Loose gravel</td>
<td>8</td>
<td>20</td>
<td>NW.</td>
<td>Sedimentary</td>
<td>Deep loam</td>
<td>3.00</td>
<td>4</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>-------------</td>
<td>---</td>
<td>----</td>
<td>-----</td>
<td>------------</td>
<td>----------</td>
<td>------</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Thin litter in places</td>
<td>180</td>
<td>10</td>
<td>SW.</td>
<td>do.</td>
<td>do.</td>
<td>2.00</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Weighted average</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

1 Normal.
2 Slight.
3 In comparing deteriorated with good vegetation, areas 12, 12b, 162, 16, and 17 are compared with density of 66, based on a weighted average of areas 17a and 30, rated at 95 and 5 percent, respectively (17a representing drained uplands, characterized by grasses and grasslike plants in old burns and the like, and 30 representing low wet areas or meadows), areas 31, 35a, 161, and 8 are compared with an average density of 85, based on areas 35, 40a, and 41 (characterized by aspen and open stands of spruce and fir), and areas 40c and 180 are compared with the density of 95, based on area 40b (characterized by dense stands of spruce and fir).

4 Weighted averages are obtained by evaluating the weighted average density of areas 17a and 30, the average density of areas 35, 40a, and 41, and the density of area 40b at 25, 45, and 30 percent, respectively, according to the part of the total area each plot area represents, as nontimbered, aspen and open stands of spruce and fir, and dense stands of spruce and fir.

5 Weighted averages are obtained by evaluating the average density of areas 35a and 161, the density of area 40c, and the density of area 40b at 25, 45, and 30 percent, respectively, according to the part of the total area each plot area represents.

6 Weighted averages are obtained by evaluating the average density of areas 16 and 17, area 8, and area 180 at 25, 45, and 30 percent, respectively, according to the part of the total each plot area represents.
SPRUCE-FIR FORESTS

The spruce-fir forests include large aspen and park areas and the vegetation above timber line. They aggregate only about one-fourteenth of the watershed (table 12). Both timbered and meadow areas are more densely vegetated than lands elsewhere in the drainage. Here where the main streams have their sources and precipitation is high, deterioration of so good a protective ground cover results in far reaching changes in the character of stream flow. Overgrazing of even a few small meadow areas where little waters rise has resulted in silt pollution of large tributaries of the Rio Grande.

Lands that had not suffered seriously and are now well managed have an average plant cover density of 84 percent. Where this good cover has declined as much as 41 percent, erosion is advanced, and where such decline has reached 63 percent, erosion is excessive. Good and poor conditions of vegetation in relation to condition of land and water resources are compared as follows:

Good land management

TREES AND SHRUBS
Engelmann spruce (Picea engelmannii).
Douglas fir.
Alpine fir (Abies lasiocarpa).
Blue spruce (P. pungens).
Aspen (Populus tremuloides aurea).
Bearberry, or kinnikinnick, (Arctostaphylos uva-ursi) and ground juniper (Juniperus sibirica) shrubs commonly occur in spruce forests.

Shrubby cinquefoil (Potentilla fruticosa) and willows (Salix spp.) are among the common shrubs of open areas.

GRASSES AND FORBS
Herbs, particularly forage plants, are almost absent in dense conifer forest. In aspen stands, fleshy herbs, many being valuable for forage, grow luxuriantly and constitute an excellent ground cover.

Grasses and grasslike plants are characteristic of all open areas. Large bunchgrasses, such as spike trisetum (Trisetum spicatum), fescues (Festuca spp.) and stipas (Stipa spp.) grow in the parks (open islandlike areas, plate 17, A, and narrow strips along streams), which constitute the most valuable grazing grounds of these high mountain districts. A short, dense growth of herbaceous vegetation (in places almost tundralike) occurs above timber line. In wet meadows sedges (Carex spp.) and rushes (Juncus spp.) occur with grasses.

Poor land management

TREES AND SHRUBS
Trees are the same on destructively lumbered as on well-managed areas, but differ in number and condition. In places the opening up of the spruce stand has resulted in uprooting by wind of trees left during cutting. On some cut-over or burned areas secondary protective cover of shrubs and herbs had formed before the litter and topsoils were washed away, in others this growth was held in check by overgrazing and accelerated run-off.

Palatable shrubs like willows together with herbs (the formerly protective stream-bank vegetation) have been deformed or killed by overbrowsing.

GRASSES AND FORBS
The scant herbaceous growth of dense conifer-timber areas is little grazed. Aspen areas, which have an abundance of valuable forage plants, are commonly overgrazed. Here, aspen sprouts as well as palatable herbs are thinned out and closely cropped.

Overgrazed park lands no longer have dense stands of bunchgrasses (which are easily killed by close grazing), but have, instead, a thin cover of weeds and turf grasses (mostly bluegrasses). (Pl. 17, B) Beds of unpalatable iris plants (Iris spp.) now grow in gullied and hence drained meadows. Small open areas, especially those above timber line, have suffered from destructive grazing, not so much from overstocking or because of scant forage supply, but because these open sunny spots are sought by sheep herders during the rainy season, in preference to the cold, wet, timbered areas.
The tree stands, particularly of conifers, form a dense canopy; litter, lichens, and some low shrubs cover the ground beneath. The overstory of spruce and fir trees affords fairly good protection, much better than that of pines or woodland trees, and the ground cover so aids absorption that even torrential summer rains sink readily. Here run-off from the ground surface is almost nil, but the absorbed water constitutes the source of most of the permanent streams. On aspen areas both the thicket growth of young stands and the luxuriant herb and shrub growth of open mature stands afford good protection.

In all the herb-covered areas except some burns, dense growth and herb litter afford excellent protection, and soils, rich in organic matter, are highly absorptive. In wet meadows the dense growth has formed a peatlike layer.

The forests are in the best condition of any of the vegetation areas on the watershed. On only about 15 percent of the lands has erosion reached advanced stages, and on only 5 percent has erosion become excessive. The soils throughout the saw-timber forests are naturally thin and rocky. The best development occurs in the aspen and meadow areas and on the more gentle slopes of the rugged mountains. Topsoil is particularly shallow in spruce-fir areas, but moisture conditions are so favorable that lichens cover sticks, logs, and stones as well as exposed ground surfaces beneath the forest canopy. Such surface conditions greatly favor absorption and percolation of precipitation waters.

Although temperature conditions are more favorable for growth in the pine-fir forests than at higher elevations, soil development undoubtedly has been retarded by recurring fires which consumed much of the forest litter without destroying the larger trees. The thinnest soils in the spruce-fir forest districts are on old burns or insect-infested areas which are now covered with upland sedges. Here many surface stones and old healed gullies indicate a period of accelerated erosion following destruction of the former forest cover. Nevertheless, surface run-off and erosion have been controlled by the vegetation to an extent to allow soil formation and development of distinct soil features to a greater or lesser degree throughout the forested districts. Conservative use has not destroyed such control, as is evidenced by the uneroded condition of well-managed lands which have vegetation that is still in good condition.

Streams usually reach maximum size in pine-fir forest areas, but spruce-fir forests deliver the most water per unit of area.

Aside from the stream-bank control afforded by living vegetation, stream flow is controlled by natural dams (many in small streams of
spruce-fir districts) formed by fallen trees, driftwood, and debris, which have caused abrupt changes in the gradient of streams, forming a succession of pools and rapids. Undoubtedly beavers aided in stream control in the past. The abundant evidence of beaver dams is proof of the regulated flow of mountain streams. Where vegetation has deteriorated and stream flow is accelerated, beavers are unable to maintain dams. Their dams are frequently washed out and lakes fill with silt, sometime during a summer or even a single flood period.

Except in gorges and at steepest grades, small alluvial flood plains normally parallel stream courses. Well-developed soils of such small flood plain areas indicate that although the normal flood flows may commonly exceed the capacity of the stream channel, soil destruction which usually accompanies highly accelerated stream flow did not occur but there resulted instead a slow and uniform accumulation of silt and development of soil and vegetation. Further evidence of controlled stream flow is the clear character of the water during normal flood flows.

**SUMMARY OF VEGETATION-EROSION RELATIONSHIPS**

The ranges in percentages of deterioration of vegetation on lands eroded to the several degrees overlap somewhat. This is to be expected. It indicates the influence of differences in annual precipitation and relief, and principally in composition of vegetation. For example: The effectiveness of any savanna vegetation is influenced more by the loss of a unit of grass density than by the loss of a corresponding unit of tree or shrub cover. The significant fact is, however, that within a given type the degree of soil erosion increases with a decrease in the vegetation; and as regards the watershed as a whole, this holds true generally, as is shown in figure 11.

The curve in figure 11, which represents the relation of soil erosion to decline in vegetation, was determined by the average densities of each of the nine types of vegetation that were found on quadrat areas that represent low, medium, and high degrees of deterioration and the average depths to which soils were eroded on the same quadrats.

The curve in figure 11 shows three important general relationships:

1. Under the low degree of deterioration of vegetation (0 to 25 percent in fig. 11) and even most of the medium stage (25 to 50 percent), the rate of soil deterioration is relatively not so great as that of
the vegetation. This may be explained largely by the fact that much topsoil material, still remaining, functions in absorbing the precipitation water, thereby checking accelerated surface run-off to a greater or lesser degree. Moreover, so long as topsoil remains, annual herbs increase in number as the perennial plants (especially the grasses) decrease. The annuals temporarily afford some protection to the ground.

(2) As the vegetation further declines, a point is reached where soil erosion rapidly becomes destructive. This may be regarded as the critical period in the deterioration of vegetation. This critical stage is shown to begin in about the middle of the second or medium stage of deterioration (approximately 35 percent in fig. 11).

(3) After the critical stage is reached, the rate of accelerated soil erosion becomes relatively greater than that of the deterioration of vegetation. Disappearance of vegetation and surface-soil erosion are interactive factors, which means that the one adversely affects the other. To illustrate: As the vegetation of the watershed deteriorates to medium and high degrees, the topsoil gradually washes away and in some places even the subsoils disappear. On the loss of the topsoil, the range plants (especially the grasses) are deprived of their main sources of subsistence, including both available water from summer rains, on which the grasses largely depend, and nutrient elements, particularly nitrogen. With the absorbent topsoil gone, the rain water, instead of soaking into the ground as it formerly did, quickly collects as damaging accelerated run-off. And finally, the grasses die as the result of the baring of their roots or the deprivation of subsistence, or they are actually washed out and carried away with the soil materials themselves (figs. 7 and 12).
On certain cut-over areas in the high pine-fir districts a cover of shrubs and herbs has developed, which, in some places, affords a comparatively high degree of protection to the ground surface.

SOIL EROSION IN RELATION TO RANGE VALUES

There are approximately 13,000,000 acres of range and other forage-producing lands in the upper Rio Grande watershed, exclusive of the Colorado part. Practically 90 percent of these lands have been used for grazing, and land injury was found in progress in varying degrees on overgrazed ranges throughout the area. On all these overgrazed range and forest lands, the decline of the vegetation and accelerated erosion have resulted in a loss of fully 50 percent of the forage, as compared with normal vegetation.

In some places the lands have been grazed by livestock for many years with no appreciable damage. On extensive areas, however, the forage has greatly depreciated, and on many areas there is practically nothing left. Reduction in the stand of forage plants, as the result of continual overuse, is accompanied by rapid depletion of the other range plants, owing to the loss of productive topsoil and loss of available water through accelerated surface run-off (figs. 7 and 12, pl. 14, B).

Based on the forage densities for each vegetation type (tables 7 to 12), the average decline in forage density in relation to the degree of erosion for the whole watershed is shown in table 13.

Table 13.—Soil erosion in relation to deterioration of vegetation and decline in forage densities

<table>
<thead>
<tr>
<th>Degree of erosion</th>
<th>Vegetation density</th>
<th>Forage density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average total</td>
<td>Deterioration</td>
</tr>
<tr>
<td>Normal</td>
<td>59</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>44</td>
<td>23</td>
</tr>
<tr>
<td>Advanced</td>
<td>30</td>
<td>47</td>
</tr>
<tr>
<td>Excessive</td>
<td>20</td>
<td>66</td>
</tr>
</tbody>
</table>

On the lands of normal and moderate erosion (only one-fourth of the total area) on which the density of the forage vegetation averages 33 percent, 2.6 acres are required, on the average, to provide one cow with forage for 1 month. On 35 percent of the lands, where the density of the forage vegetation on badly eroded lands averages 19 percent, 4.5 acres are required to maintain one cow for 1 month. On 40 percent of the lands, excessively eroded, where the density of the forage vegetation averages only 8 percent, 10.6 acres, on the average, are required for one cow per month. Where, on excessively eroded lands, the density of the forage vegetation averages as low as 3 percent, the acreage required for one cow per month is as high as 28 acres.

These values do not indicate the maximum number of animals that may be grazed for only a short time. The figures show, rather, the estimated sustained grazing capacity which is based on forage density and on the conservative estimate that about 0.85 acre fully covered with forage vegetation could carry one cow for 1 month. Maximum
"Parks" in spruce-fir forests. A, Here the protective vegetable ground cover has been preserved. B, An overgrazed park (unregulated land) near the head of Taos Canyon. This is typical of park slopes on which the topsoil and in some places even the subsoil have been washed away, leaving stony surfaces.
A. Rapid land destruction goes on as overgrazing continues; Galisteo Valley.  B. Natural revegetation in progress on a range that is moderately grazed.  The development of the vegetation is bringing accelerated soil erosion under control.  A few years ago the conditions here were similar to those shown in A.  Both areas are in the same district in the Galisteo Valley.
stocking at any time and sustained average grazing capacity for a period of years are two quite different things. The kind of maximum stocking in which no consideration is given to the range, beyond the quantity of forage that could be wrung from it, has been responsible, in a large measure, for the present erosion conditions within the watershed. "Sustained grazing capacity", on the other hand, implies grazing on a sustained basis year after year without impairment or injury to the forage and other resources of the land. Cognizance should be taken of the fact that the grazing capacity of some ranges may be altered through influences other than grazing. For example, a forest range may be affected for a period of years by lumbering and by increases and decreases in numbers of tree reproduction and small trees.

**PRODUCTION OF FORAGE**

On the range and forest lands still in fair to good condition and highly productive of forage the average relative forage production was estimated at 85 percent, as compared with the forage produced by vegetation in its normal state, represented by 100 percent. On lands badly eroded the relative forage production was estimated at only 49 percent; and on those excessively eroded, 21 percent (fig. 13). In other words, 45 percent of the total forage produced on the range and forest lands of the watershed (exclusive of the part in Colorado) is obtained from only one-fourth of the total area. In contrast, the excessively eroded lands, or two-fifths of the watershed area, produce only about 18 percent of the total forage.

Furthermore, ranges that now have a low grazing capacity have high operating costs, because they require high investments per head of livestock in fences, watering places, and ranch equipment. As in agriculture, range lands whose forage-production values have declined to the point where profits can no longer be assured may be regarded as submarginal in character. On extensive areas of submarginal lands, where the decline has progressed to medium or advanced degrees and where the conditions are in a state of delicate balance, continued overgrazing can result ultimately in nothing less than complete land destruction.
THE COLORADO PART OF THE WATERSHED

The foregoing discussion regarding the relation of soil erosion to the state of vegetation concerns the New Mexico part of the watershed primarily. This does not mean, however, that the Colorado part of this drainage has no erosion problem, for it may be said that the conditions regarding vegetation and soil erosion in the high mountainous districts and on the high plains that surround the irrigated San Luis Valley are similar to those of the high mountainous districts and high plains of the northern part of New Mexico, particularly on the range lands that border this valley.

Owing to the fact that some streams of the Colorado part of the watershed sink as they approach the Rio Grande and the waters of others are diverted for irrigation this part of the drainage may be regarded as practically independent of the New Mexico part. For this reason the data regarding vegetation and erosion in the Colorado part were not collected in sufficient detail to allow their inclusion in those gathered from the New Mexico part.

SOLUTION OF THE WATERSHED PROBLEM

The facts that have been given with respect to soil erosion and vegetation in the upper Rio Grande watershed bring out clearly that (1) if erosion is permitted to continue it will ultimately destroy the land resources which are the basis of human existence in this area and (2) that the land resources may best be preserved and human welfare secured by aiding the development of a protective cover of vegetation.

RESTORING THE PROTECTIVE GROUND COVER

On areas where more or less vegetation and topsoil are left, rapid revegetation may be effected through the control of the influences that have caused land impairment. On more seriously damaged lands natural revegetation is very slow, particularly in the driest situations; and artificial means of restoring vegetation may be necessary. Generally, plants naturally adapted to the climatic and edaphic conditions of a given region or district are the best. General artificial restoration of vegetation, even if successful, would be prohibitive because of the cost. However, the sowing of seed and spot transplanting to establish nuclei are quite essential.

In the field work studies were made of the influence of a protective plant cover in controlling run-off by comparison of conditions on overgrazed areas and those on which vegetation has come back sufficiently to control erosion (pl. 18, A and B). A number of typical examples are here cited.

NOGAL CREEK DRAINAGE

In August 1931 a flood, originating on overgrazed lands in the Nogal Creek drainage, broke through the protection embankment at the mouth of the stream and seriously damaged the town of San Antonio on the Rio Grande a short distance below Socorro (fig. 14). An examination of the part of this drainage where the flood originated showed that the grass of these low-plain semidesert grasslands had deteriorated more than 50 percent, and at the time of the flood was very closely grazed. A small part of this drainage was fenced private land on which was an excellent growth of vegetation.
On the overgrazed lands the drainage lines were definitely channeled (pl. 19, A). The channel banks were undercut, shrubs and weeds were torn away, and drift deposits of grass, duff, and litter were everywhere. In contrast, the lands with protective plant cover showed no evidence whatever of any destructive flood flow, soil erosion, nor of washing away of the grass litter.

A careful examination of the vegetation of these two areas showed the following differences in composition and density:

### HEAVILY GRAZED LANDS

<table>
<thead>
<tr>
<th>Grasses</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black grama</td>
<td>25</td>
</tr>
<tr>
<td>Blue grama</td>
<td>15</td>
</tr>
<tr>
<td>Side-oats grama</td>
<td>10</td>
</tr>
<tr>
<td>Ring muhly</td>
<td>5</td>
</tr>
<tr>
<td>Dropseed</td>
<td>3</td>
</tr>
<tr>
<td>Three-awn</td>
<td>2</td>
</tr>
</tbody>
</table>

Grass composition 60

<table>
<thead>
<tr>
<th>Forbs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Snakeweed</td>
<td>35</td>
</tr>
<tr>
<td>Other species</td>
<td>4</td>
</tr>
<tr>
<td>Shrubs</td>
<td>1</td>
</tr>
</tbody>
</table>

Density, or percentage of the ground surface covered:

| South slope                 | 20     |
| North slope                 | 35     |

### CONSERVATIVELY GRAZED LANDS

<table>
<thead>
<tr>
<th>Grasses</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>Blue grama</td>
<td>30</td>
</tr>
<tr>
<td>Side-oats grama</td>
<td>15</td>
</tr>
<tr>
<td>Three-awn</td>
<td>5</td>
</tr>
<tr>
<td>Other species</td>
<td>1</td>
</tr>
</tbody>
</table>

Grass composition 91

<table>
<thead>
<tr>
<th>Forbs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Snakeweed</td>
<td>3</td>
</tr>
<tr>
<td>Other species</td>
<td>3</td>
</tr>
<tr>
<td>Shrubs</td>
<td>3</td>
</tr>
</tbody>
</table>

Density, or percentage of the ground surface covered:

| South slope                 | 35     |
| North slope                 | 60     |

Attention is called to the fact that the ground cover of the conservatively grazed lands has about 52 percent more grass than that of the deteriorated lands. Furthermore, the forb-shrub composition of the eroded land is 40 percent, whereas that of the uneroded land is only 9 percent. On the basis of density, the vegetation of the eroded lands represents a deterioration of about 43 to 50 percent. The conservatively used area demonstrated that these low-plains grasses afforded excellent protection against soil-erosion forces.
Although the Puerco drainage, particularly its alluvial valleys, has been drawn upon for striking examples of land deterioration, this drainage also has outstanding examples of areas where reestablished vegetation is restoring control of run-off.

In a winter pasture on Lee Evans' ranch which embraces an area of high-plain semidesert grassland in the district near Mount Taylor, grasses were rapidly reclaiming gullies and even arroyos that had developed during a previous period of overuse. The natural revegetation in progress here resulted from lighter stocking of the range and from the protection that winter grazing has afforded the grasses during the growing season. One of the reasons for rapid improvement of this pasture is that overgrazing was stopped before advanced stages of damage, both to the vegetation and soil, were reached.

An example showing effective revegetation of high-valley semidesert grassland is the part of the San Miguel Valley, north of Mount Taylor, now reserved by the Fernandez Cattle Co. for winter use only. On this high-valley range, on which accelerated erosion had resulted principally from the severe injury to the plant cover through overgrazing, sacaton and other grasses, under conservative grazing, have already developed to a degree sufficient not only to reestablish ground protection in the valley, but to actually reclaim eroded lands as well (pl. 19, B). It is definitely known that the improvement in these lands has taken place within a period of about 10 years. Undoubtedly, topsoil has played an important role in effecting such rapid natural revegetation.

Instances of revegetation of savanna woodlands were found in the upper Rio Puerco Valley, particularly on areas southwest of Cuba, where, since about 1915, many 640-acre tracts have been homesteaded. On one of these tracts, for example, where deep, wide arroyos commonly found in this district indicate destructive erosion in time past, bluestem and galleta under conservative grazing had already made rapid progress in forming a protective ground cover. There were no signs of any active soil erosion on the sloping lands, and even the bottoms of the old arroyos supported grasses which in some places had a density as high as 45 percent. Here again topsoil aided materially in the revegetation.

Another typical example of natural erosion control through new forest growth is the Senorito Canyon area on the Santa Fe National Forest. This area, which is separated from the east side of Cuba Valley by a fence, consists of a lower strip of foothill woodlands and a mountainous district of pine forest. Years ago the livestock from nearby overgrazed range lands around the settlements drifted at will in and out of this area and thus overgrazed it.

Since the fencing of the national-forest boundary, herbs, shrubs, and small trees have formed a dense cover between the old trees. The accelerated flow of the creek has been checked. The controlled flow was indicated by the good condition of the stream bed and banks on the national forest. Outside the fenced area, where the vegetation was badly depleted, the stream course was a deeply trenched valley channel which has greatly enlarged during recent years.

General heavy rains in September 1931, which resulted in flood flows that damaged roads and bridges in Cuba Valley, did not cause
A. Overstocked eroded range lands in the Nogal Creek drainage photographed at A on figure 14. The flash flood of August 1931 that seriously damaged San Antonio originated on such lands. B. Revegetation of formerly excessively eroded lands on the now conservatively grazed winter range of the Fernandez Cattle Co., in the Mount Taylor district. Sacaton, vine-mesquite, and other grasses are reclaiming arroyos.
Check dams in a gully on an area of deteriorated savanna woodland, for use in controlling accelerated soil erosion and in aiding revegetation.
any destructive flood flow in the upper Senorito Canyon. Old gullies on this drainage area have healed, and the canyon bottom is a jungle of growth. In contrast, the vegetation on the unprotected foothill and valley lands beyond the boundary fence has declined to the point where not only the grass but even the sagebrush is disappearing, and erosion is developing badland features.

**RIO CHAMA DRAINAGE**

Certain parts of the Rio Chama drainage may also be cited to illustrate how control of surface run-off may be brought about through revegetation of cut-over timberlands. Large-scale lumbering operations, which began in the upper Chama basin in the 1890's, continued until the 1920's. That there was a period of excessive flooding of some of the headwater streams that flow through areas of cut-over lands, resulting from unregulated lumbering, is indicated by many stones and much gravel and sand that are deposited at the mouths of these streams and are similar to those shown in plate 2, B. The conditions found along some of these headwater streams in 1931, such as the narrowing of their wide flood-flow channels, deposits of sediments between rocks in the outer margins of the stream channels, and, in some places, new growth of willows and herbs on these sediments indicate that the destructive force of floods is decreasing. And where new vegetation was reestablishing a protective cover on cut-over lands, recent floods have not piled up deposits of rock and debris at the mouths of the streams as they did in the past. Furthermore, no evidence of destructive floods was found in parts of the Rio Chama section where there are virgin-forest lands that have not been overgrazed.

**SANTA FE CREEK DRAINAGE**

In the pine-fir forest part of Santa Fe Creek, representative of many large and small drainages in the region of the Sangre de Christo Range, revegetation is well under way, following fencing in 1926 against drifting livestock. The rapid growth on the canyon bottom is arresting the movement of debris, which originates from denuded and eroded canyon slopes, and causing its deposition, thus preventing much of it from reaching the reservoir that is a part of the municipal waterworks of Santa Fe. New growths of alders, willows, and herbaceous plants are effective in reestablishing the normal channel of this creek, as may be seen by comparing this improved channel with normal ones of similar streams that drain areas on which the vegetation has not suffered deterioration.

These examples, which are only a few among the many that might be given for types that vary from semidesert grasslands to spruce-fir forests, are convincing evidence that the gradual renewal of vegetation on lands that are not too badly eroded will tend to reestablish control if given protection from deteriorative factors. With the exception of small areas and badly eroded drainageways, about 60 percent of the lands of the watershed fall into this category. Moreover, the state of these example areas as regards soil erosion indicates that the rate of vegetation recovery will be determined largely by the quantity of topsoil that is left.

Revegetation of extremely deteriorated lands, on the other hand, calls for seeding or transplanting, or supplementary artificial works.
SUPPLEMENTARY ARTIFICIAL WORKS

Owing to the badly eroded condition of about 40 percent of the watershed, particularly the lands on which very scant vegetation remains and where the topsoil and even some of the subsoil have been washed away, it would appear impractical to attempt to revegetate the whole area artificially in any reasonable period. Sufficient natural restoration to materially check the rate of soil erosion would undoubtedly require many years. In order to effect some control as soon as possible, nature should be given some assistance in reestablishing vegetation through the use of works like water-spreading devices, contour furrows and terraces, and check dams where the values involved justify the cost. Check dams and gully plugs provide immediate control at critical points (pls. 13, B and 18, A) where otherwise plant growth would be greatly hindered and destructive gullying would continue unabated until vegetation on the slopes had reestablished equilibrium between run-off and ground cover.

Small detention works (pl. 20) may serve, among other ways, to check the velocity of accelerated run-off and thereby effect deposition of silt in which plants may establish themselves.

There are two classes of artificial works—storage and protective. Those of the first class, including large storage dams, are used, among other purposes, to control and regulate stream flow and water supply. Such works are necessary even on watersheds that have protective vegetation.

The second group includes large dams for silt retention and for flood-water detention, small works for erosion control and for aiding revegetation, levees for flood protection, and jetties for stream-bank protection and channel control. These supplementary works are necessary for counteracting the damaging effects of accelerated run-off and excessive soil erosion, but they can never take the place of the vegetation that had heretofore effected control of these destructive forces. The protection that is afforded storage reservoirs and public and private properties by artificial works, particularly those for flood control and large-scale silt retention, may be regarded as only temporary and cannot in themselves correct the causes of rapid surface washing. The period of usefulness of protective works will depend on the condition of the vegetation on a watershed and the development and maintenance of a protective ground cover will extend the term of their usefulness. Small works to aid revegetation near the seat of origin of the run-off and silt are more important than building a single large dam in the lower course of the stream, a structure that may seem more economical but which cannot be of equal effectiveness in establishing permanent control. Large works such as detention dams also have their place if constructed in series or well up on the tributaries of the main stream, particularly in the erosion channels of large alluvial valleys.

OTHER FACTORS AFFECTING CONSERVATION AND REVEGETATION OF RANGE AND FOREST LANDS

Besides the state of the vegetation, soil erosion, available water for plant growth, and the use of artificial works, there are other important factors that should be considered in the conservation and revegetation of the forest and range lands of the upper Rio Grande watershed.
These include (1) land utilization, (2) range management, (3) lack of understanding and appreciation of the consequences of overgrazing, destructive lumbering, and fire, and of the fact that the deteriorated lands of this area once supported a cover of protective vegetation, and (4) management of wildlife, including game animals and rodents.

**LAND UTILIZATION**

Land utilization is one of the most important factors in the conservation of the lands of this drainage, because it affects not only the revegetation of the denuded and eroded areas but also the use of lands that are still in good or fair condition. Land utilization involves both land ownership and land control.

Land ownership in the watershed is complex, owing to the fact that Federal, State, and private titles are involved. Federal ownership and control embraces national forests, Indian lands, unreserved public domain, and national monuments. State titles include principally forest and range lands that the Federal Government allotted to the States from unreserved public domain. Private titles involve land grants, patented lands, and purchased State lands. Most of the Indian lands considered are old Spanish land grants over which the Government exercises authority. Figure 15 shows that Federal (national forests and Indian lands) and private lands (land grants) comprise large areas of the watershed, whereas other large districts involve mixed ownership, including Federal, State, and private.

There is a close relationship between land ownership or control, on the one hand, and deterioration and conservation of forest and range lands, on the other. This relationship may be understood better when the circumstances that led to land impairment are considered, among which are the following.

**RANGE LANDS POORLY WATERED**

With the exception of some areas, particularly in the high mountainous districts, the ranges were poorly provided with water for live-stock. The distance (usually 15 to 40 or more miles) was so great from stream to stream or from a valley watering place to water in the foothills or mountains that there was only occasional grazing at the points far from these watering places, or only when temporary stock waters became available in the form of rain or snow. Consequently, a range that was poorly watered was usually stocked on the basis of the quantity of forage found on most of the range and not on the basis of the forage readily obtainable from permanent watering places. This led to overstocking of those parts of the ranges that were easily reached from stock waters and consequently to early deterioration of not only the easily accessible vegetation but also of the forage plants along the trails that radiated from these waters to more distant points, like spokes from a hub. Owing to the fact that permanent waters were usually available in the large valleys, the vegetation there suffered extreme damage and the lands became badly eroded.

When those parts of the ranges that were accessible from natural waters declined to a low grazing capacity, stock waters, such as seep developments and wells, were made available where there was still good forage, that is, between the natural watering places. Usually, however, the developed waters did not relieve the grazing situation, but, instead, increased the area of overgrazed lands, because the basis
FIGURE 15.—Land ownership in the upper Rio Grande drainage (based on title), exclusive of the part in Colorado. (Compare fig. 10.)
of range stocking remained the same, namely, total forage rather than forage readily accessible from stock waters.

The cost of developed water on many naturally dry ranges, plus the ordinary range operating expenses, including those for land control, was commonly so great that overstocking was resorted to in the attempt to realize profits and, sometimes, in the effort to support heavy investments. Talbot (19) has shown that development of range-watering places in certain sections of the Southwest is very costly.

LACK OF LAND CONTROL

During the period of rapid development of the livestock industry, particularly up to the 1890's, most of the lands of this watershed constituted unreserved public domain on which there was no regulation of grazing whatsoever. Furthermore, community and family rights to many of the old Spanish and Mexican land grants were so involved that it delayed for years the perfecting of land titles, during which period authority for control of these grants was very indefinite.

This lack of direct authority, particularly over public lands, created a situation that benefitted neither the ranges nor the users. The grazing industry in this watershed developed rapidly, because the forage on productive range lands, then in the virgin state, could be had for the taking, and it was possible to build up a stock outfit in a comparatively short time. The better lands soon became stocked beyond the limits of their sustained grazing capacity and sharp competition between livestock outfits brought about further overstocking which resulted in rapid injury to both the vegetation and the lands. The forage plants, continually closely cropped, gradually weakened and died; and unpalatable weeds and shrubs, which cannot form so good a protective ground cover as do the grasses, took the place of the forage plants that disappeared.

An important effect of this loose land control was the range abuse that resulted from out-of-season grazing. Because of the mild climate, large areas of the drainage were peculiarly suited for year-long use, but many more lands were grazed year-long than were adapted for such use. In other districts the mountain and low-country climates made possible summer and winter ranges, respectively, which afforded the opportunity to develop a grazing balance between these two types of ranges. But such balance was usually upset, and overstocking of either the summer or winter range in a given district resulted because of the lack of unified control for any constructive land-utilization policy. For example, in some districts year-long grazing of winter ranges, and in other districts the homesteading and cultivation of much of the best winter-range lands—lands that proved to be submarginal for farming—seriously reduced the acreage of the winter ranges, thereby upsetting the winter-summer grazing balance.

It is true that a certain degree of land control developed, but it was only temporary because it was continually upset. This lack of unified control of large areas of public lands, particularly the unreserved public domain, also led to severe depreciation and even ruination of much of them.

The loose control that was first based on right of occupancy and use of land was in time strengthened by control that was exercised through the homesteading of already occupied key areas or ranches,
notably those that controlled permanent waters. But such key-
ranch control was soon weakened by new settlers who also home-
steaded at vantage points on the same ranges, and built up livestock
outfits of their own.

The increase in the number of stock outfits not only reduced the
size of many of the old livestock operations, but it also increased the
competition for range lands, until in time it resulted in the consolida-
tion, through purchase, of the competing outfits in a given district.
The control that was thus effected, however, was incomplete and only
temporary, owing to successive homestead acts; each act weakened
any control that had previously developed.

Lack of coordinated land control was an important factor in in-
creasing the valuation of ranches, and, in turn, in hastening the
impairment of grazing lands. To illustrate: A owned a 160-acre
key homestead ranch, in itself worth no more than $2,500, but it
controlled grazing privilege on surrounding or adjoining public lands.
B purchased this ranch for $9,000, which meant that he paid $6,500
for the grazing privilege. B soon found that, in order to protect his
interests, he was forced to buy the homestead of a new settler who
was building up an outfit on the same range, for which he paid $3,500.
B’s fixed capital invested in key ranches was then as high as $12,500,
and he felt that he had to graze all the livestock he possibly could,
which meant overgrazing.

Users of public lands never found it advantageous to protect or
even conservatively graze any range they did not fully control.
They found, for example, that any forage left at the end of summer
served as a temptation not only to tramp outfits who were always
seeking feed and to neighbors who, on seeing any available or reserve
forage, would increase the size of their own herds, but also to any
outsider who, if he saw good or favorable range conditions, would
come in to homestead.

Homesteaders who settled as groups or colonies on the most favor-
able of the remaining tracts of unreserved public domain also con-
tributed to the impairment of range lands. They found that the small
areas of alluvial soils that they dry-farmed and their pastures from
which they expected to gain a livelihood were, after all, only meager
resources. For a time many of them believed that whatever was
responsible for the untoward state of things was abnormal and that
if they could produce enough to live on for another year, conditions
would be better. They therefore grazed in common the surrounding
public lands to the utmost, in the attempt to eke out subsistence.
Their attempts to dry-farm and to produce animal products led to
rapid decline and even ruination of both farm and public lands as the
result of the erosion of their cultivated fields and severe overgrazing.
When the homesteaders realized that the conditions they found were
normal and that they could not make even a living from both their
own and public lands, they were forced to abandon their homesteads
sooner or later.

Here mention should be made of lands that are naturally sub-
marginal or that have been rendered thus through injurious forest
and range practices. These should be withdrawn from the uses that
make them submarginal as soon as possible, either permanently or
until revegetation shall have developed sufficiently to make some use
advisable or profitable. A practical classification of all lands of this
watershed should be made on the basis of their suitability for use. In such a classification special emphasis should be placed upon revegetation and the feasibility of conducting a profitable operation.

HIGH RENTS AND TAXES AIDS TO LAND DECLINE

High rents and taxes, which were based on the same arbitrary land value for a given county and which were determined by the number of animals commonly grazed on good ranges, may also be regarded as important factors in overgrazing. The ranges that suffered most were those that had a low grazing capacity, because they were naturally poor or by reason of depleted vegetation, inasmuch as the land users, in their endeavor to compensate for these high charges, stocked the ranges as heavily as possible. Moreover, on many large land grants that were acquired as investments or for future development of mineral or other resources, the charges made for the grazing privilege were always as much as could be obtained. No limit, so far as any reasonable grazing capacity is concerned, was set on the number of animals that should be grazed per unit area of land.

DESTRUCTIVE LUMBERING

Timber operators on private forest lands, endeavoring to profit through the use of all available land resources, seldom made any provision for protecting cut-over lands from fire or for any future forest growth. In some instances, even the slash was burned in the attempt to increase the production of forage plants on lands that were clean cut. As the result, private cut-over lands were usually left in a deplorable condition.

RANGE AND FOREST MANAGEMENT

Although unified land control may be regarded as the first step in the working out of an effective land-utilization program in the upper Rio Grande area, the objects desired in such a program, so far as the conservation of vegetation and lands is concerned, can be realized on usable lands only through range-management plans that include, among other things, the following four provisions:

1. The grazing of a range with a class of livestock, such as cattle or sheep, that is best suited to the range conditions.
2. The use of ranges or parts of them only during seasons or periods for which they are best adapted, such as during summer or winter, for a short period, or year long.
3. Range stocking on the basis of the number of animals that available forage can carry through the grazing season or period without causing damage to the ranges.
4. Distribution and handling of the livestock on a range in a manner to effect not only a conservative degree of forage utilization, in order to protect the most important forage plants, but also the most uniform grazing possible, in order to minimize any grazing damage that might take place on any part of the range.

These four range-management principles are based on the fundamental proposition that plant cover is required on these range and forest lands to protect them from induced drought and soil erosion and thereby maintain their production of forage. If the land resources of the watershed are to be conserved or improved, the stocking of a range or its grazing capacity should not be based on the
greatest quantity of forage that can be taken off the range, but rather on how much should be left to improve and maintain the density of the principal forage plants. Principles of land management for western range lands have been fully discussed by Jardine and Anderson (13), and Wooton (20) has described the influence of factors that affect the management of semidesert range lands in New Mexico.

Most of the timbered districts of the upper Rio Grande drainage are now included in national forests, where sustained yield determines the forest-management policies. Some parts of the national forests were once old land grants, which included large bodies of timber, that were acquired as Federal lands through exchanges of national-forest timber for private lands. Although usually cut over before acquisition, such lands have good watershed and potential forest values. The exchange provisions that have been made for obtaining forest lands may be regarded as constructive measures that fit well into any general land-utilization program, in that through such measures Federal management of forest lands is provided. This is true particularly of forest lands on which the virgin timber has been cut, inasmuch as profitable management of such lands in private hands seems to be impracticable. In fact, the exchanging of timber on national forests for private cut-over lands has been the only feasible means of bringing these lands under a control that would give them the protection necessary for their restoration.

Large areas of privately owned forest lands are still unregulated. It may be impossible or impracticable to obtain public control of all these lands through exchange. Nevertheless, it seems highly desirable to unify control of all forest lands, in order that protective management may be provided for those important watershed and timber lands.

**APPRECIATION OF PROTECTIVE VEGETATION**

There seems to be a general failure to appreciate the fact that the deteriorated range and forest lands of the upper Rio Grande drainage once supported a protective cover of vegetation. Coordinated land control and land management for the conservation of these range and forest resources can be effected only slowly, at best, so long as owners and users of lands and all other people concerned fail to fully appreciate the ultimate consequences of destructive practices.

It is not surprising that many persons apparently accept the deteriorated state of some range and forest lands as normal, for they may never have seen these lands in any other condition. For example, a resident of Albuquerque, who enjoys fishing on the upper Rio Cebolla in the Jemez Mountains, where there is virgin forest, and who also knows the district not far south of the town of Chama, where cut-over lands are now covered with brush, is inclined to accept the conditions of these two areas as regards vegetation and soil erosion as being their natural features. That both districts referred to were once similar is appreciated only by those who know what these lands were in their natural state and who still associate them with forests, mountain meadows, and trout streams.

To aid in bringing about an appreciation of vegetation, it seems advisable to collect and disseminate facts regarding forest and range resources and the effect that excessive use has on these resources, in order that both administrators and users of the watershed lands may have the necessary information on which to base proper forest and range practices.
WILDLIFE MANAGEMENT

The relation of wildlife to deterioration and revegetation of the lands of this watershed requires thorough study, in order that wildlife management might find its proper place in any range-management program that may be worked out. It also seems advisable to coordinate game preservation and livestock production, and to exercise control of wild animals through scientific wildlife management.

THE IMMEDIATE NEED

The immediate need in the preservation of land resources and in the securing of human welfare in the upper Rio Grande watershed is such restoration and meanwhile and thereafter such use of the vegetation as will hold all destructive factors in proper check. Immediate restricted use is to be regarded as the first step in any endeavor that may be made to solve the land-impairment problem, for three principal reasons:

(1) It will result in checking the present progress of deterioration of the vegetation and therefore of the land.
(2) Whatever response depleted vegetation on badly eroded lands makes to adequate protection will reveal the value of the present vegetation on a given area, what can be expected of it in establishing new vegetation, and the critical points where artificial measures to obtain plant cover and to control run-off should be considered.
(3) Adequate restriction of all land uses appears to be the only practicable method of prolonging the term of usefulness of any artificial or temporary protective works and of making a start towards establishing natural and permanent control of surface run-off and soil erosion.

Prompt initiation of an investigational program to meet these broad objectives is urgent. It should comprehend intensive studies to determine the minimum essential requirements for forest and range-land restoration, revegetation, and maximum utilization upon which to base principles of proper management and conservation of the lands of the watershed. The conduct and prompt completion of experimental work of this character will make it possible for the lands of the upper Rio Grande watershed to be improved to approximately their original valuable condition to be passed down to future generations as an accredited heritage.

SUMMARY

The upper Rio Grande watershed, which embraces at least 18,000,000 acres, or about 28,000 square miles, has supported irrigation agriculture continuously since about the beginning of the Christian era and livestock ranching since about the Spanish conquest in 1598.

The lands of this watershed were originally covered with vegetation varying from semidesert savannas of the lowest plains to coniferous forests of the high mountainous districts. For centuries the natural vegetation protected the ground surface from accelerated erosion and also functioned in regulating the flow of the streams on which prehistoric peoples, Pueblo Indians, and early white settlers long depended for their supply of usable waters for irrigation and other purposes.
But with recent intensive use of the land resources of this water-shed accelerated run-off and soil erosion, destructive floods, and land deterioration have set in and are causing the inhabitants grave concern.

The striking evidences of these effects include deeply and continuously channeled alluvial valleys; deep arroyos and wide sand washes where formerly there were only shallow surface runs; gullied slopes; increasing areas of badlands; and altered courses of mountain streams. Other definite manifestations are accumulations of loose stones and sand on the ground surface, soil humps capped by vegetation and remnants of topsoil, shifting sand and sand dunes, and disappearance of luxuriant valley grasses and soils, particularly of the topsoil.

Accelerated run-off and erosion have destroyed numerous primitive irrigation works, are causing the silting up of river channels and water reservoirs, and are resulting in the waterlogging and destruction of productive farm lands. Damaging floods have apparently increased during recent years, and recreational and wildlife resources are menaced by destruction through soil erosion.

The theories that climatic and geological changes have caused accelerated run-off and erosion do not seem tenable. Historical evidence clearly shows that the recent general decline of the watershed lands and resources began during the 1880's following the impairment of the natural vegetation cover principally through overgrazing and also from wanton timber cutting, man-caused fires, promiscuous wagon trailing, and injudicious dry farming.

The destructive flood waters, laden with damaging silt, originate on overgrazed and damaged range and forest lands. The more the vegetation is injured the greater the degree of accelerated soil erosion.

The lands of the watershed were grouped for convenience according to degree of soil erosion—normal erosion and moderate, advanced, and excessive accelerated erosion. So-called normal erosion takes place under the cover of natural vegetation, and it ordinarily does not prevent soil development. Moderate erosion is in progress on lands whose protective plant cover has declined as little as 7 and as much as 39 percent, depending upon the protection afforded by the different kinds of plants in the different types of vegetation. Advanced erosion, which approaches rapid land destruction, is active on lands where the vegetation has deteriorated 29 to 57 percent. Excessive soil erosion is manifested in rapid land destruction on areas where the vegetation has deteriorated 52 to 74 percent.

On only about 25 percent of the lands of the drainage is there sufficient plant cover to control surface-soil erosion within normal and moderate limits; on about 35 percent of the lands accelerated soil erosion is in an advanced stage; and on 40 percent of the lands rapid land destruction is in progress.

The production of forage has been reduced fully 50 percent, principally as a result of overgrazing and accelerated soil erosion. Such a decline in range resources has not taken place without adversely affecting the range industry and all other businesses of this area.

The preservation of the land resources in this watershed depends on a protective cover of vegetation. Accordingly, restoration of vegetation is needed not only on the lands that are badly denuded, eroded, and practically useless but also on all other deteriorated lands of this area.
Representative areas on which the vegetation has come back sufficiently to check accelerated soil erosion show that, through protective management, as from overgrazing, impaired vegetation cover on lands not too badly eroded will tend to renew its former protective state. The results also show that the rate of recovery will be determined largely by the quantity of topsoil left and by the precipitation water that soaks into the ground and becomes available for plants during critical periods.

Principally because of greater annual precipitation and lower mean annual temperature, protective vegetation regenerates more rapidly on lands of the high, mountainous districts than on low, semiarid lands.

Badly eroded spots within an area where vegetation responds quickly to protective management are soon affected by the influence of the recovering vegetation, and for this reason they heal within a comparatively short time.

Revegetation of seriously damaged lands may be aided through the use of supplementary artificial works, which serve, among other ways, in checking run-off, in preventing land break-down in drainage-ways, and in effecting deposition of silt in which plants may establish themselves.

Supplementary works, such as levees and silt-detention dams for protecting farm lands and other properties in the main valleys, are necessary to counteract the damaging effects of accelerated run-off and erosion which result when the protective vegetation of a watershed declines; but they should never be considered an adequate substitute for the vegetation that had heretofore prevented accelerated erosion. The development and maintenance of a protective ground cover will extend the term of usefulness of such works.

Past lack of land control and of unified effort for any constructive land-utilization policy have been largely responsible for the damage to the vegetation and lands of this watershed.

It seems highly desirable to unify the control of all the forest lands for the purposes of protective and sustained-yield management as is now provided on the national forests.

The conservation of resources for human welfare can be realized only through land planning which takes into account the interrelationships of the protective value and permissible uses of the forest and range land resources. To accomplish these objectives more intensive investigations are needed.

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