Hydrologic and Biotic Characteristics of Grazed and Ungrazed Watersheds of the Badger Wash Basin in Western Colorado, 1953-58

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1532-B

Prepared in collaboration with the U.S. Department of Agriculture, Forest Service; U.S. Department of Interior, Fish and Wildlife Service, Bureau of Land Management, and Bureau of Reclamation

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By GREGG C. LUSBY, GEORGE T. TURNER, J. R. THOMPSON, *and* VINCENT H. REID

HYDROLOGIC EFFECTS OF LAND USE

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By Gregg C. Lusby, George T. Turner, J. R. Thompson, and Vincent H. Reid

ABSTRACT

A comprehensive study of the hydrologic and biotic characteristics of small drainage basins on the Colorado Plateau and the effect of grazing on these characteristics was begun in 1953. This report presents data obtained during the first 5 years of the proposed 20-year study.

Periodic observations were made at permanent transects in 8 paired fenced and unfenced watersheds to characterize plant and ground cover, determine degree of use by livestock and measure changes in watershed cover. Results after 5 years of study indicate that changes in watershed cover have been relatively small on both grazed and ungrazed areas. Changes that did take place were mainly on shale and mixed type soil. Ground-cover index on mixed type soil was significantly higher, 4 percent, on ungrazed areas than on grazed areas at the end of 5 years.

Plot records were obtained using the Rocky Mountain Infiltrometer at 12 plots in each of the 8 study watersheds to determine the effect of livestock exclusion on infiltration and sheet erosion. Infiltration rates for the last 20 minutes of both the wet and dry runs were significantly higher in 1958 than they were 5 years before, but this difference was not associated with treatment because rates on both grazed and ungrazed plots increased about the same amount. The initial water-absorbing capacity increased significantly on ungrazed plots. No change in erosion rates was observed.

Rainfall was variable and below normal during 4 of the first 5 years of study. Runoff was produced mainly by thunderstorms during the summer months and was characterized by high rates of flow for short periods. Comparison of runoff in grazed and ungrazed watersheds indicates a change in the relation between precipitation and runoff because of exclusion of livestock. More sediment per unit area was produced during the 5 years of study from grazed areas than from ungrazed areas.

No definite trend in small mammal population on grazed and ungrazed watersheds has yet been determined. Results of preliminary studies on rabbit population indicates that rabbits prefer to inhabit ungrazed areas, but populations were judged to be not high in any area.

INTRODUCTION

In many of the more arid regions of the Western States, erosion and runoff from rangelands create problems. Some of these problems are the damage to manmade structures by high peak flows in ephemeral-stream channels; the erosion and loss of great quantities of soil material each year, the reduced productivity of land due to rapid loss of runoff water, and the rapid filling with sediment of downstream storage structures. An example of this type of rangeland is the Colorado Plateau in western Colorado and eastern Utah, which contains thousands of square miles of land underlain by highly erodible rocks and soils and has only a sparse vegetational cover.

Because of the increasing importance of these lands in the general economy of the area, more information is needed to manage the land properly. Attempts to reseed lands in the arid areas have usually failed, and because the land has little value, mechanical treatments such as terracing, pitting, or contour furrowing are usually not justified. The most logical initial approach to the problem, therefore, is to evaluate the effects of livestock grazing or of the exclusion or regulation of livestock on runoff, sediment production, plant growth, and other factors.

Because of its work on the utilization and development of water in the Colorado River basin, the Bureau of Reclamation is concerned with the sediment contribution from the upland areas and the effect of treatment practices to reduce this contribution. The Colorado Plateau contributes a large part of the sediment but only a small part of the runoff to the Colorado River. In order to design adequate facilities for use of water, information is needed on the sediment storage that must be provided and the protection works required for irrigation canals and other operation structures. In addition, treatment of land to reduce erosion and sediment damage is of importance to the maintenance of highways and railroads in the area.

PURPOSE AND SCOPE

A need for quantitative data on the effect of treatment practices on this type of land has long been recognized, and in 1953 the Sedimentation Subcommittee of the Pacific Southwest Interagency Committee made a special effort to locate a site for the study. The Badger Wash basin in western Colorado was chosen by the subcommittee, because it was considered typical of a large part of the Colorado Plateau and because facilities were available for measuring runoff and sediment yield.

The primary purpose of the study is to compare runoff and sediment production from grazed and ungrazed watersheds. Other objectives are to determine (a) the amount and rate of runoff and sediment yield from storms of various magnitude and duration, (b) the relative infiltration and erosion rates on different soils and their response to grazing treatment, (c) the effect of livestock exclusion on vegetation and other watershed cover, and (d) the relative abundance of small rodents and rabbits on grazed and ungrazed areas.

The study area is limited to Badger Wash basin, which contains a number of separate, complete, and well-defined drainage basins. Of those watersheds, 4 were fenced to exclude livestock in the fall of 1953, and 4 adjacent and similar watersheds continued to be grazed by sheep and cattle during winter months. In addition, records of runoff and sediment yield were maintained at 10 other grazed watersheds in the Badger Wash basin to supply additional data at sites where investigations may be made in the future.

This report is the first of a series on the hydrologic and biotic characteristics of small grazed and ungrazed watersheds in western Colorado. The study is conducted jointly by several federal agencies and is coordinated by a committee composed of one member from each agency. During the period covered by this report committee membership was as follows: U.S. Geological Survey, H. V. Peterson (1954) and K. R. Melin (1955–58); U.S. Forest Service, George T. Turner (1954–58); Bureau of Land Management, James S. Andrews (1954–58); Bureau of Reclamation, W. Harold Hirst (1954–58); and U.S. Fish and Wildlife Service, Victor B. Scheffer (1956) and Vincent H. Reid (1957–58).

Forest Service personnel are attached to the Rock Mountain Forest and Range Experiment Station, maintained at Fort Collins, Colo., in cooperation with Colorado State University. Studies of infiltration and erosion on infiltrometer plots were started by H. E. Brown and were continued by J. R. Thompson. Work on watershed morphology was done by S. A. Schumm and R. F. Hadley of the U.S. Geological Survey

Five Federal agencies are presently cooperating in the study. The Bureau of Land Management is responsible for administration of the area, for construction and maintenance of dams, fences, and roads, and for assisting the Forest Service in measuring grazing use. The Bureau of Reclamation has assisted financially in the construction and maintenance of facilities and, in addition, made the original surveys and maps of watersheds and reservoirs. The Geological Survey measures precipitation, runoff, erosion, and sedimentation; and the Forest Service prepared soil maps, maintains periodic records of watershed cover and infiltration and erosion rates on different soils, and measures forage utilization each year. The Fish and Wildlife Service, which entered the study in 1955, is determining trends in the population of small rodents and rabbits on the study areas.

Because of the history of slow recovery of vegetation in arid regions, it was agreed that the study would continue for 20 years. This paper reports findings during the first 5-year period.

The report was prepared by the U.S. Geological Survey, U.S. Forest Service, and U.S. Fish and Wildlife Service and was assembled for publication under the technical supervision of H. V. Peterson and

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K. R. Melin. The complete report was reviewed by the technical staffs of the cooperating agencies.

LOCATION

The Badger Wash basin is in western Colorado a few miles east of the Utah-Colorado boundary and about 25 miles west of Grand Junction, Colo. Badger Wash is tributary to West Salt Wash, which in turn is tributary to the Colorado River (pl. 1). The part of the basin being studied is at an elevation of about 5,000 feet and covers 6.5 square miles. It lies north of the Bureau of Reclamation Highline Canal, which follows generally the boundary between the hilly lands and the plain of Grand Valley. Badger Wash does not extend into the Book Cliffs as do the larger streams in the area. The upper end of the drainage basin is separated from the base of the cliffs by a valley about 1 mile wide.

METHODS OF STUDY

Twenty-two small reservoirs ranging in capacity from 0.9 to 22.4 acre-feet, were constructed in 1952–53 in the Badger Wash basin by the Bureau of Land Management in cooperation with the Bureau of Reclamation. Field representatives of the various agencies involved then selected watersheds above eight reservoirs for intensive study of the effects of grazing exclusion on runoff, sedimentation, vegetation, and infiltration. To save time of calibration, the watersheds were chosen in four adjoining pairs, of which each pair was as nearly similar as possible in slope, soil type, vegetation, and size. One watershed of each pair was fenced to exclude grazing, and the other was to receive the normal grazing use for the area. Watersheds were designated by numbers and letters. The designation for one pair of watersheds contains the same number, and the letters A and B denote grazed and ungrazed, respectively. Additional reservoirs in which runoff and sediment yield were measured were designated by numbers only. Location of study watersheds is shown in plate 1.

Originally, each paired watershed contained one reservoir, except 2–A and 3–A, which contained two reservoirs. After the 1955 season, the upstream dam in watershed 3–A was removed. The second reservoir in watershed 2–A is directly downstream from the spillway of the main reservoir and is used to retain any spill from the main reservoir and runoff from the small area adjacent to the reservoir.

DESCRIPTION OF THE AREA

TOPOGRAPHY AND GEOLOGY

Badger Wash is in an area of intricately dissected terrain along the base of the Book Cliffs. Although the entire Badger Wash basin is underlain by the Mancos Shale of late Cretaceous age, the lithology differs somewhat in various parts of the basin. The shale in the western and upper parts contains a number of thin sandstone layers less than 1 foot thick. Because of their greater resistance to erosion, these layers cause an alternation of steep and gentle slopes. The gently sloping areas are on top of a sandstone layer. Channels are similarly affected; they are moderately incised on the relatively steep slopes underlain by shale and have wide, shallow cross sections on the benches.

On the eastern side of the basin, the sandstone layers are absent, and the topography is more uniform, with very steep hillslopes merging with gentle colluvial slopes at their bases. Channels are everywhere incised into the shale. Figure 1 is a general view of terrain in the Badger Wash basin showing typical plants and erosion characteristics.

FIGURE 1.—General view of Badger Wash. Flashy runoff and severe erosion are typical of the area.

SOILS

Soil in the area is poorly developed and consists mainly of a shallow weathered mantle overlying the Mancos Shale bedrock. Because sandstone occurs in the west and north parts of the basin, the soil is distinctly more sandy there than on the east side. In this study four types of soil are recognized—those derived from shale, those derived from sandstone, a mixture of the two, and alluvium. The mixed type, derived from a mixture of shale and sandstone, is the most extensive. Soils derived from either shale or sandstone are the next most common, and alluvial soils are least extensive. All except alluvium are residual.

Soils derived from sandstone are usually thicker, have less pore space, are chemically more basic, and support more vegetation than shale or mixed-type soils. Shale soils are highly erodible and frequently occur on steep slopes. The mixed type is intermediate between shale and sandstone soils in these characteristics but most nearly resembles the shale soil. The alluvial soils are extremely variable in all characteristics. For this reason and because of their limited extent, they were not described or sampled in this study.

CLIMATE

The climate of Badger Wash is arid to semiarid. The average annual precipitation at Fruita, Colo., about 16 miles southeast of the study area, is 8.3 inches, based on 58 years of Weather Bureau records. Precipitation from April to October occurs generally as thunderstorms and is characterized by rainfall of high intensity. The least average monthly precipitation is 0.47 inch in May and June, and the greatest is 0.96 inch in August; the second greatest is 0.94 inch in September.

Summer temperatures at Fruita are generally high during the day and low at night; average maximum during July is in the midnineties, and the average minimum in the midfifties. Yearly average temperatures is 51.3°, and the average for the period April to October is 64.3°. The frost-free period during the first 5 years of study averaged about 130 days, from about May 15 to September 20.

The average relative humidity at Grand Junction for the months June to September is about 50, 20, 30, and 40 percent. These percentages are for the hours of 5:00 a.m., 11:00 a.m., 5:00 p.m., and 11:00 p.m., respectively, and were obtained by averaging the average monthly values of humidity published in Weather Bureau Climatological Data.

Because of the high daytime temperatures and low relative humidity, potential evaporation rates in the area are very high. The average evaporation measured in a USWB class–A evaporation pan at Grand Junction, Colo., for the months April to October during the years 1954–58 was 92.6 inches. The highest monthly average was 18.2 inches in July, and the lowest was 7.5 inches in October.

During the period 1954–58, annual precipitation at Fruita ranged from 5.39 to 18.08 inches. Precipitation during 1954–56, and 1958 was less than the long-term means, and that during 1957 was more than the mean.

VEGETATION

Vegetation on the Badger Wash drainage basin is of the salt-desert-shrub type. Though not everywhere sharply defined, several subtypes may be distinguished. These subtypes reflect local differences in soil characteristics and available soil moisture.

On the lower part of the main drainage basin, black greasewood (*Sarcobatus vermiculatus*) is dominant. Pure stands of mat saltbush (*Atriplex corrugata*) occur on alkaline flats in upper reaches of the drainage basin. Big sagebrush (*Artemesia tridentata*) and rubber rabbitbrush (*Chrysothamnus nauseosus*) grow along the tributaries, mainly on alluvial soils.

On the uplands, sandy soils support shadscale (*Atriplex confertifolia*) and a relatively dense understory of galleta (*Hilaria jamesii*); Gardner saltbush (*Atriplex nuttallii*) predominates on clay soils (fig. 2). On mixed soils, the vegetation is made up of species found on both clay and sandy soils.

FIGURE 2.—Shadscale (*Atriplex confertifolia*) and galleta (*Hilaria jamesii*) are characteristic of sandstone-derived soils (foreground). A sparse cover of Gardner saltbush (*Atriplex nuttalii*) occupies the shale hillside in the background.

Except in local areas, the plant cover on the drainage basin is sparse; crowns of living perennial plants cover perhaps 10 to 20 percent of the surface. In wet years the density of cover is usually increased somewhat by cheatgrass brome and other annuals. Although flowers of woody aster and milkvetch may be conspicuous during wet periods, those plants contribute relatively little to watershed cover.

HISTORY OF RANGE USE

According to statements made by pioneers who settled in the vicinity of Badger Wash, domestic livestock were first brought into the area during the decade 1880 to 1890, when thousands of cattle were imported from Texas. Many early settlers state that the Badger Wash area and adjacent lands supported a luxuriant growth of desert-type forage.

For many years, beginning about 1915, large flocks of migratory sheep moved across the area from Utah enroute to summer range in the Colorado mountains. In their migration the sheep naturally spread out to graze all available forage. In addition to this use, deterioration of the Badger Wash area occurred because the area was near a railway shipping point and large numbers of both cattle and sheep were held in the area pending shipment.

After the passage of the Taylor Grazing Act in 1934, the Cimarron Trail was established nearby to confine the livestock to a much narrower trail than during free-range days. Nevertheless, a large number of animals continued to use the range. Deterioration continued until, as a result of improved transportation facilities—mainly trucking—the stock driveway was closed in 1957.

Since the beginning of this study, the use on the allotment, of which the Badger Wash drainage basin is a part, has been approximately 3,750 sheep from November 16 to May 15 and 500 cattle from November 16 to April 30. The total area of the allotment is 33,680 acres.

WATERSHED CHARACTERISTICS

SOILS DESCRIPTION AND DISTRIBUTION

The areas and relative extent of soil types on the eight experimental watersheds are listed in table 1 and outlined on figures 3–7.

Descriptions of soil profiles present in the three major soil types were made by Forest Service personnel in 1953. A total of 48 pits were used in determining these profiles: 32 on the mixed soil, 10 on the shale soil, and 6 on the sandstone soil. A soil core was taken from the top 2-inch layer for tests of tension, and a loose sample was taken from the same general layer for tests of texture by the hydrometer method, pH by the Truog reaction method, and phosphorus by the sodium bicarbonate method.

TABLE 1.—*Extent of soil types within watersheds*

Watershed	Shale		Mixed		Sandstone		Alluvium		Total acres
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	
1-A	1	2	29	69	9	22	3	7	42
1-B	20	37	22	41	3	6	9	16	54
2-A	12	11	69	64	22	21	4	4	107
2-B	0	0	70	69	27	27	4	4	101
3-A	12	32	22	58	0	0	4	10	38
3-B	21	68	6	19	0	0	4	13	31
4-A	0	0	14	100	0	0	0	0	14
4-B	0	0	12	100	0	0	0	0	12
Grazed	25	12	134	67	31	15	11	6	201
Ungrazed	41	21	110	55	30	15	17	9	198

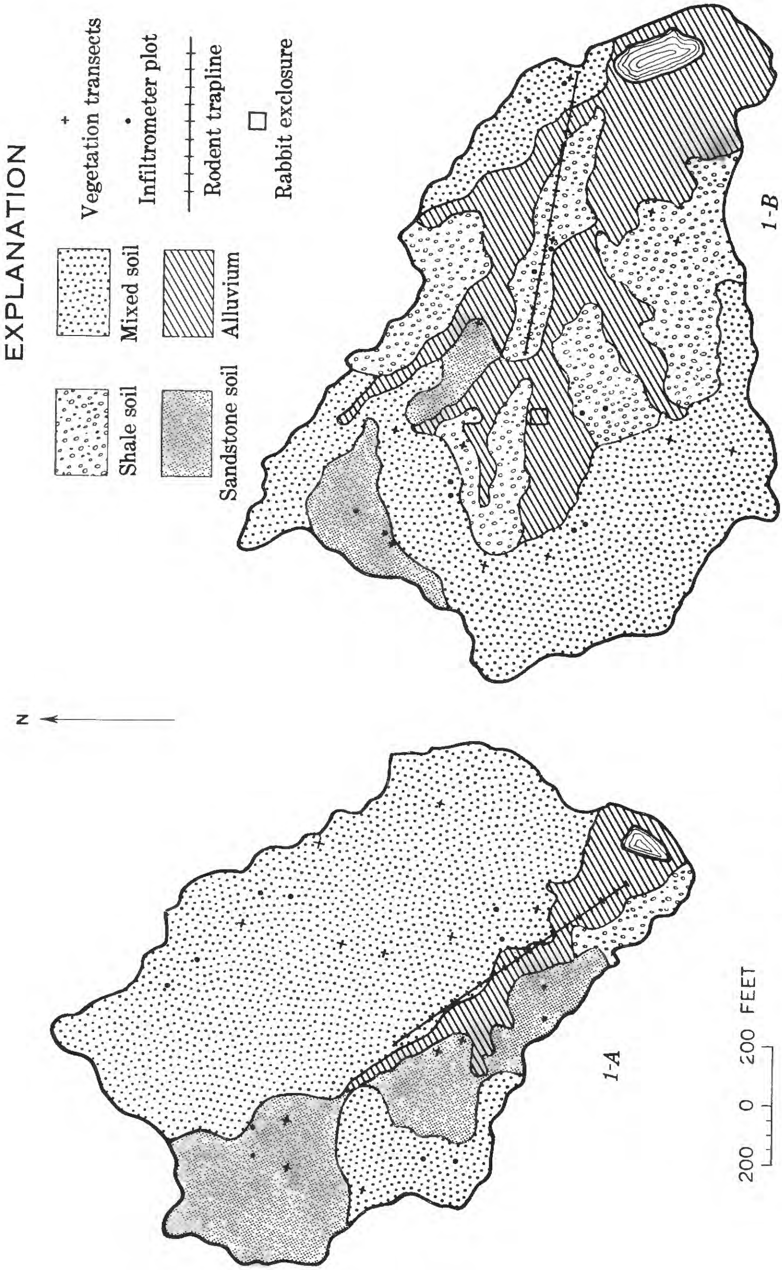

FIGURE 3.—Map showing areas of soil types and observation points, watersheds 1-A and 1-B.

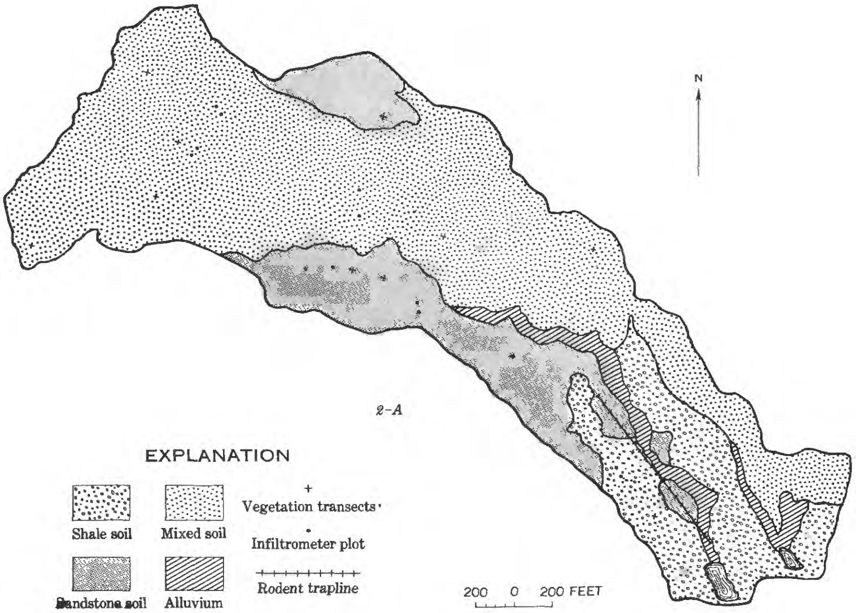

FIGURE 4.—Map showing areas of soil types and observation points, watershed 2–A.

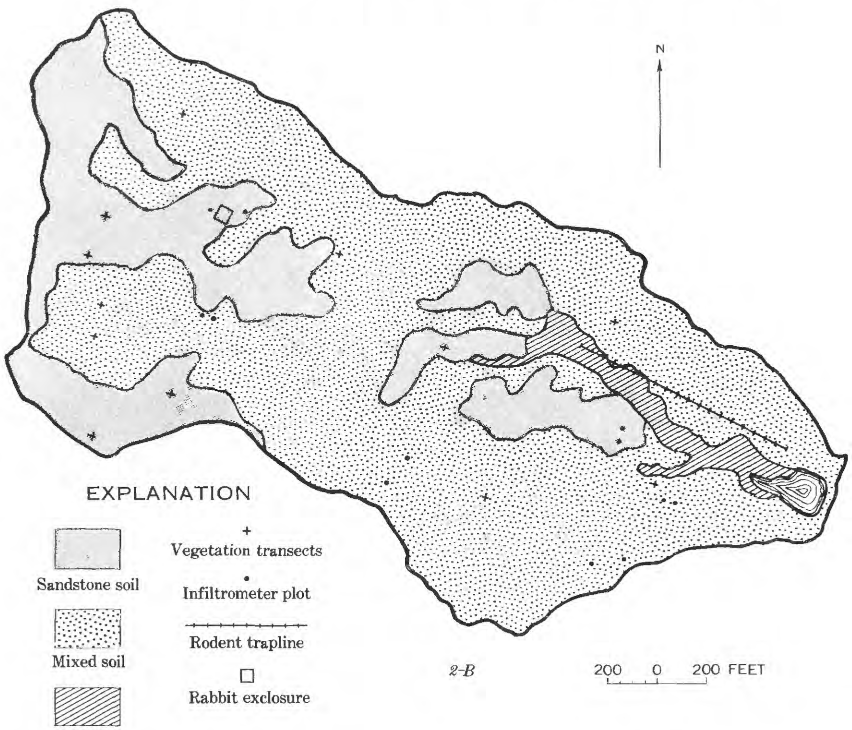

FIGURE 5.—Map showing areas of soil types and observtion points, watershed 2–B.

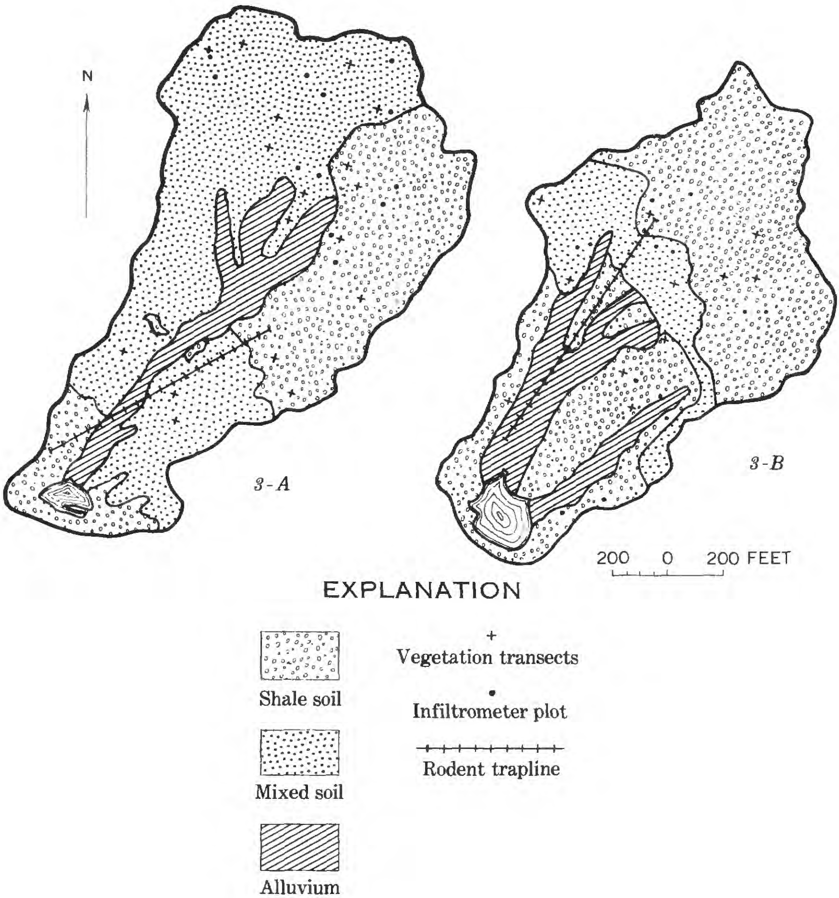

FIGURE 6.—Map showing areas of soil types and observation points, watersheds 3-A and 3-B.

A short description of soil horizons is contained in the following table. A more complete description may be obtained from Agriculture Handbook No. 18 (1951).

Horizon	*Description*
A_{00}	Loose leaves and organic debris, largely undecomposed.
A_0	Organic debris partially decomposed or matted.
A_1	A dark-colored horizon with a high content of organic matter mixed with mineral matter.
A_2	A light-colored horizon of maximum eluviation. Prominent in podzolic soils; faintly developed or absent in chernozemic soils.
A_3	Transitional to B, but more like A than B. Sometimes absent.
B_1	Transitional to B, but more like B than A. Sometimes absent.
B_2	Maximum accumulation of silicate clay minerals or of iron and organic matter; maximum development of blocky or prismatic structure; or both.
B_3	Transitional to C.
C	The weathered parent material. Subscripts are used for parts of the C horizon of slightly altered chemistry.

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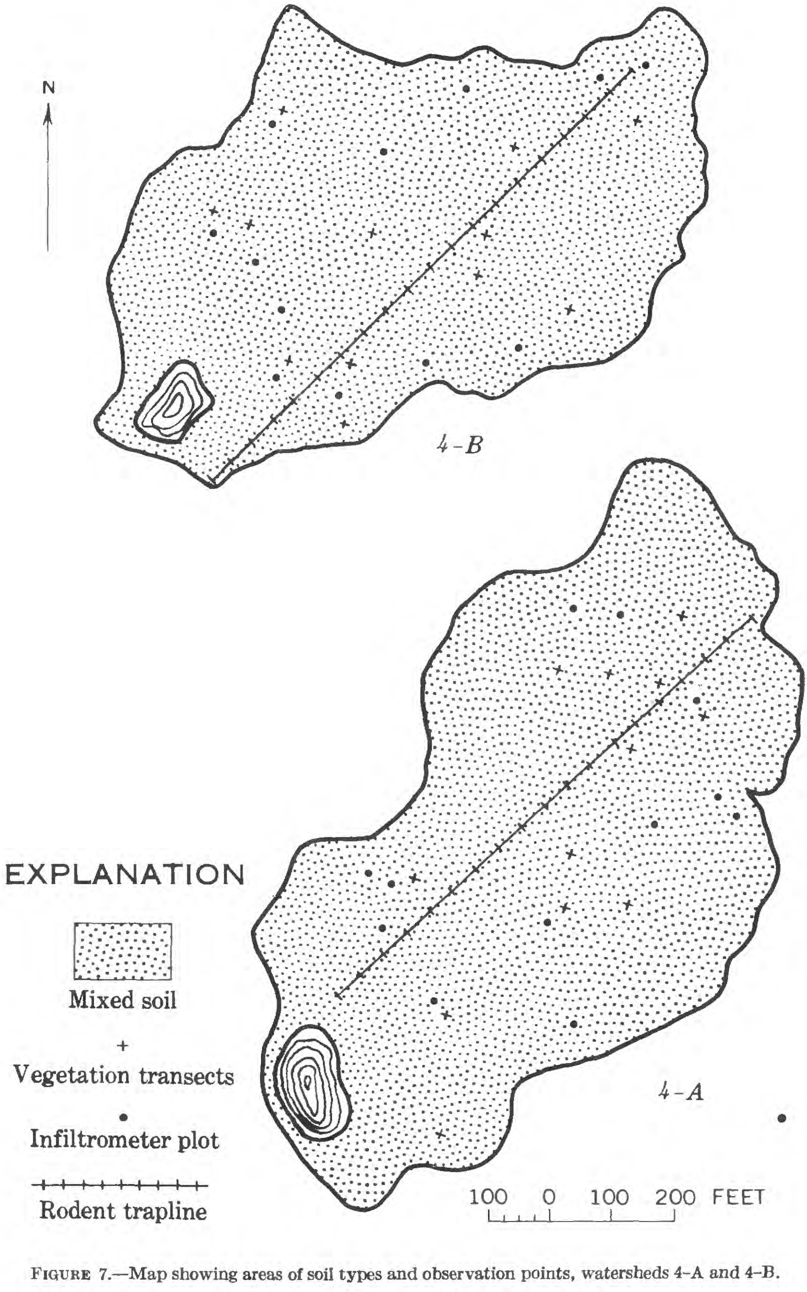

FIGURE 7.—Map showing areas of soil types and observation points, watersheds 4-A and 4-B.

Only the sandstone soils had a true litter (A_{00}) horizon. A small amount of litter was found under some shrubs on the mixed and shale soils but not enough to be called an A_{00} horizon. A humus (A_0) horizon was not present on any of the soil types. No true B horizons were identified; however, on the sandstone and mixed soils, some of the characteristics of a B horizon were present in the A_3 horizon in a few of the pits. This evidence may indicate that B horizons do exist in some of these types of soils.

The main profile differences among the three soil types occur in the A_1 horizons. The A_3, C_1, and C_2 horizons were very similar. Sandstone soils had a predominantly deeper A_1 horizon, a higher pH, and less pore space than shale or mixed soils. The shallow shale soil was highest in pore space and lowest in pH and phosphorus. The mixed soil was intermediate between the shale and the sandstone soils (table 2).

TABLE 2.—*Description of A_1 horizon by soil type*

[Figures in parentheses are number of samples]

A_1 horizon	Depth (inches)	Color (wet)	Textural analysis (percent)			Textural classification	Structure
			Sand	Silt	Clay		
Shale	2	Brown	16	53	31	Silty clay loam	Granular
Mixed	2	do	37	42	21	Loam	do
Sandstone	8	Reddish brown	49	38	13	do	do

A_1 horizon	Consistency	pH[1]	Phosphorous as P_2O_5 (pounds per acre)	Water loss at 50 cm tension[2] (percent)	Saturated pore space[2] (percent)	Bulk density[2]
Shale	Loose	8.1(10)	26.7(2)	17(27)	53(27)	1.31(35)
Mixed	do	8.5(31)	28.5(8)	16(94)	48(95)	1.35(127)
Sandstone	do	9.3(6)	61.4(2)	12(18)	47(20)	1.31(28)

[1] Difference between soil types significant at 5 percent level.
[2] Differences between soil types not significant at 5 percent level.

WATERSHED MORPHOLOGY

As one part of the cooperative study, the Bureau of Reclamation mapped the eight paired watersheds on a scale of 1:1,200 with a contour interval of 5 feet. The excellent detail on these maps prompted the Geological Survey to make an investigation of the drainage-network characteristics for each watershed. A field check showed that many of the smaller stream channels were not shown on the maps. These channels were added to the maps by additional mapping in the field before the Survey started to measure features of the watersheds such as stream-channel lengths and watershed areas.

The streams on each map were classified by order number. First-order drainage channels are defined as those with a recognizable drainage area and with well-defined valley sideslopes. This definition eliminates all rill channels that may not be permanent features. The junction of two first-order streams forms a second order stream, etc. (Strahler, 1957). Each stream of each order was numbered on the maps so that measurements could be checked and additional information could be obtained without confusion from the same watershed. Drainage divides were then outlined; their position was judged by the form of the contours between adjacent channels. The stream lengths and watershed areas were then measured.

The channel lengths measured are total channel lengths; that is, the lengths of all channels of all orders within any one watershed were measured.

Additional measurements were made within each watershed and are defined as follows:

1. Relief ratio (h/1) is the ratio of the difference in elevation between the spillway of dam and a mean divide elevation, which eliminates lowest and highest points on the divide, to the maximum length of the watershed measured parallel to the main channel (Schumm, 1955).
2. Mean slope of a drainage basin is obtained by weighting the mean slope of contour belts. The area between two adjacent contours is divided by the average length of the contours to obtain a mean width. Mean width is then divided into the difference in elevation to obtain a mean slope for that contour belt (Strahler, 1957). Each contour belt slope is then weighted according to the width of the belt.
3. Texture, expressed as drainage density (Horton, 1945), is the total channel length in miles divided by the watershed area in square miles.
4. Angles of tributary junction are angles measured between major tributaries and main channel.

The values of the preceding items for seven watersheds are shown in table 3. Watershed 1–A was omitted from this phase of the study, because it contains an upstream reservoir which might complicate the relation between hydrologic and geomorphic characteristics. This table indicates that the measured characteristics for paired watersheds are sufficiently similar that any large differences in runoff or sediment yield between pairs would be due to some factor other than watershed morphology.

TABLE 3.—*Morphometric measurements*

Watershed	Relief ratio	Mean slope (percent)	Drainage density	Angle of junction (degrees)
1–A	[1]	[1]	[1]	[1]
1–B	0.043	14.3	86	57
2–A	.044	15.6	85	58
2–B	.039	15.7	80	59
3–A	.051	18.3	96	63
3–B	.056	20.3	92	63
4–A	.070	25.8	108	72
4–B	.067	27.8	121	69

[1] Not determined.

WATERSHED COVER AND FORAGE UTILIZATION

By George T. Turner[1]

To characterize plant and ground cover, to facilitate measurement of livestock grazing, and to provide a means of measuring changes in watershed cover, permanent transects were established in the fall of 1953 for periodic observation of vegetation in the eight experimental watersheds.

Each watershed was sampled with 12 clusters of two transects each (figs. 3–7).[2] As shown in the following table, clusters were allotted to soil types (except alluvium) in proportion to the relative extent of each soil in each watershed. Location of clusters within areas occupied by a given soil was determined by a random selection.

Number of transect clusters on each soil

Parent material	Watershed								Total		Grand total
	1–A	1–B	2–A	2–B	3–A	3–B	4–A	4–B	Grazed	Ungrazed	
Shale	------	4	2	------	4	9	------	------	6	13	19
Mixed	8	6	6	8	8	3	12	12	34	29	63
Sandstone	4	2	4	4	------	------	------	------	8	6	14
Total	12	12	12	12	12	12	12	12	48	48	96

Within each cluster area, which is 50 feet square, the ends of two 50-foot transects were located at random along a base line. Transects were laid out from those points as nearly on the contour as possible, except locations were rejected where the tape was more than 3 feet above the ground or where the transects were less than 10 feet apart.

Records of watershed cover were obtained along the transects by a loop method similar to that described by Parker (1951). Each transect also served as one side of a 2-foot-wide belt transect on which forage utilization estimates were made.

Although original plans were to record watershed cover in the fall of the year at 5-year intervals, it was found necessary after the first observations to change the time of observation from fall to spring to obtain a better measure of ephemeral vegetation. Therefore, transects measurements were again recorded in May 1955 and May 1958. Beginning in 1955, forage-utilization records were obtained at the close of the grazing season each spring. The Bureau of Land Management assisted the Forest Service in establishing transects and in collecting these fields records.

[1] U.S. Forest Service.

[2] Although five additional transect clusters were located in the lower portion of watershed 3–A after it was enlarged, records of watershed cover in this report are from transects in the original watershed. Records of forage utilization for the period 1956–58 are based on 12 of the 17 clusters used to sample the enlarged watershed.

WATERSHED COVER

METHOD OF MEASUREMENT

Watershed cover was measured by the loop-transect method. Observations were made through a ¾-inch loop at 6-inch intervals along a 50-foot tape, making 100 observations on each transect. Records of understory included bare soil, rock, litter, moss, and perennial plants recorded by species. (Botanical and common names of plants in the study area are given in table 4.) Annuals were tallied where present but were not included in the basic record of watershed cover. Shrub crowns were recorded separately as overstory. Any portion of crown observed through the loop was considered a "hit" and was recorded by species.

In addition to those observations, locations and intercepts of shrub crowns along each transect were plotted to scale. Records of intercept are intended to provide information on the establishment, growth, and mortality of shrubs and thus a better understanding of the ecology of the vegetation types in the area.

Changes in watershed cover were determined by comparing records from the same transects from one period to another. These changes or differences were analyzed by statistical t-tests to determine their significance. When significant changes were noted, and when they were in the same direction, fiducial limits of mean differences were used to determine whether one change was greater than another Analyses of variance were used only in evaluating the effect of treatment on ground-cover indices.

TABLE 4.—*Botanical and common names of plants found in Badger Wash basin*

[Botanical names follow Harrington (1954). Common names follow Kelsey and Dayton (1942). An asterisk indicates a specific common name is not available for the plant listed]

Botanical name	*Common name*
Grasses	
Bromus tectorum L.	Cheatgrass brome
Elymus salinus Jones	Salina wildrye
Festuca octoflora hirtella Piper	Hairy sixweeks fescue
Hilaria jamesii (Torr.) Benth.	Galleta
Oryzopsis hymenoides (R. & S.) Ricker	Indian ricegrass
Poa secunda Presl.	Sandberg bluegrass
Sitanion hystrix (Nutt.) J. G. Smith	Bottlebrush squirreltail
Forbs	
Abronia fragrans elliptica Heimerl	Snowball sandverbena
Allium sp.	Onion
Arabis pulchra pallens Jones	Rockcress*
Aster hirtifolius Blake [1]	Aster
Aster venustus M. E. Jones	Woody aster*
Astragalus asclepiadoides Jones	Milkvetch*
Astragalus chamaeleuce Gray	Milkvetch*
Astragalus confertiflorus Gray	Milkvetch*
Astragalus missouriensis Nutt.	Milkvetch*
Bahia nudicaulis Gray	Bahia*
Calochortus sp.	Mariposa
Castilleja chromosa A. Nels.	Paintedcup*
Cirsium sp.	Thistle

[1] Not listed by Harrington (1954).

TABLE 4.—*Botanical and common names of plants found in Badger Wash basin*—Con.

Botanical name	*Common name*
Cryptantha elata (Eastw.) Payson	Cryptantha*
Cymopterus spp	Chimaya*
Erigeron pumilus concinnoides Cronquist	Low fleabane*
Eriogonum bicolor Jones	Eriogonum*
Eriogonum fusiforme Small	Eriogonum*
Eriogonum ovalifolium Nutt	Cushion eriogonum
Lappula redowskii (Hornem.) Greene	Stickseed*
Lepidium densiflorum bourgeauanum (Thell.) C. Hitch	Prairie pepperweed*
Lepidium montanum Nutt	Pepperweed*
Malcolmia africana (L.) R. Br	----------
Mentzelia sp	Mentzelia
Oenothera caespitosa montana (Nutt.) Durand	Tufted eveningprimrose
Oenothera scapoidea Nutt. ex T. & G	----------
Penstemon moffatii Eastw	Penstemon*
Phacelia corrugata A. Nels	Phacelia*
Phlox longifolia Nutt	Longleaf phlox
Physaria australis (Payson) Rollins	Twinpod*
Plantago purshii Roem. & Schult	Wooly Indianwheat
Salsola kali tenuiflora Tausch	Tumbling Russianthistle
Sphaeralcea coccinea (Pursh) Rydb	Scarlet globemallow
Stanleya pinnata (Pursh) Britton	Desert princesplume
Townsendia sp	Townsendia
Shrubs	
Artemisia spinescens D. C. Eaton	Bud sagebrush
Artemisia tridentata Nutt	Big sagebrush
Atriplex confertifolia (Torr. & Frem.) Wats	Shadscale saltbush
Atriplex corrugata Wats	Saltbush*
Atriplex nuttallii S. Wats	Gardner saltbush
Chrysothamnus greenei filifolius (Rydb.) H & C	Greenes rabbitbrush
Chrysothamnus nauseosus (Pallas) Britt	Rubber rabbitbrush
Ephedra sp	Ephedra
Eurotia lanata (Pursh) Moq	Common winterfat
Gutierrezia sarothrae (Pursh) Britt. & Rusby	Broom snakeweed
Mammillaria sp	Mammillaria
Opuntia sp	Pricklypear
Tetradymia spinosa Hook. & Arn	Cottonthorn horsebrush

DEFINITION OF TERMS

Terms used in describing data from loop transects are defined as follows:

Bare soil. Soil that occupies more than half the loop and is not covered with rock or organic matter.

Rock. Rock particles at least one-eighth inch in diameter that singly or together occupy more than half the loop.

Litter. Dead organic matter that occupies more than half the loop, except leaves still attached to live plants.

Plant density index. The number of hits on root crowns of perennial plants in 100 observations.

Shrub overstory. Any portion of a shrub crown, except openings within the crown, that occupies any portion of the loop.

Ground-cover index. An expression of watershed cover computed as 100 minus the number of hits on bare soil and rock not under a shrub overstory.

CHARACTERISTICS OF COVER AT BEGINNING OF THE STUDY

When measurements were first made in October 1953, the cover was generally similar on all watersheds except for distinct differences due to soil. Because soils strongly influence plant and ground cover, the relative extent of each soil is reflected in cover characteristics of individual watersheds. Composition of ground cover on the three principal soils at the beginning of the study was shown as follows:

Ground cover	Parent material		
	Shale (percent)	Mixed (percent)	Sandstone (percent)
Bare soil	79	54	53
Rock (erosion pavement)	2	25	7
Total, bare soil and rock	81	79	60
Litter and moss	15	17	34
Plants (plant-density index)	4	4	6
Shrub overstory	13	11	12
Ground-cover index	24	26	43

The principal difference in cover on shale and mixed soils (disregarding plant composition) was in the amount of erosion pavement. Mixed soils had many more rock particles on the surface than either shale or sandstone soils. Bare soil and rock combined, although similar for shale and mixed soils, were considerably less extensive on standstone. Sandstone soils, on the other hand, had more litter and moss and a higher ground-cover index than shale or mixed soils.

The composition of perennial plant cover on the various soils also was distinctly different. As shown in the following table shale soils supported mostly shrubs, whereas on sandstone soils grasses were predominant. Mixed soils, as might be expected, supported nearly equal density of grasses and shrubs. Forbs were relatively scarce on all soils.

Relative density and composition of plant cover on different soils, 1953

[Based on plant-density index]

Kinds of plants	Shale		Mixed		Sandstone	
	Hits per transect	Percent	Hits per transect	Percent	Hits per transect	Percent
Grasses	0.37	10	1.78	45	4.99	78
Forbs	.76	22	.60	15	.50	7
Shrubs	2.45	68	1.60	40	.96	15
Total, all perennials	3.58	100	3.98	100	6.45	100

Characteristics of cover on individual watersheds at the beginning of the study are summarized in table 5. Most striking, perhaps, is the large amount of bare soil and rock. When combined, those items totaled 70 to 87 percent of the ground surface. Plant-density index ranged from 3 to 5 percent, litter and moss from 9 to 25 percent, and ground-cover index from 18 to 34 percent. Shrub overstory ranged from 8 to 15 percent. Very few annual plants were recorded, probably because most of them were dead when observations were made.

Watersheds 4–A and 4–B, which contain only mixed soil, had substantially more rock (erosion pavement), less litter and moss, and a lower ground-cover index than other watersheds.

TABLE 5.—*Composition of ground cover on individual watersheds, 1953–58*
[In number of hits per 100 observations. Tr=trace (less than 1 percent)]

	Year	Watershed								Average	
		1–A	1–B	2–A	2–B	3–A	3–B	4–A	4–B	Grazed	Ungrazed
Bare soil	1953	53	64	59	52	61	74	52	56	56	61
	1955	60	67	70	57	77	80	64	61	68	65
	1958	58	61	70	52	76	72	74	57	70	59
Rock	1953	18	14	11	20	12	5	34	31	19	18
	1955	17	15	6	21	8	5	27	28	15	18
	1958	10	14	4	20	3	5	17	26	8	17
Bare soil and rock	1953	71	78	70	72	73	79	86	87	75	79
	1955	77	82	76	78	85	85	91	89	82	83
	1958	68	75	74	72	79	77	91	83	78	76
Litter and moss	1953	24	19	25	23	23	17	10	9	21	17
	1955	20	16	20	18	13	12	7	8	15	14
	1958	28	22	21	24	18	20	6	12	18	20
Plants (plant-density index)	1953	5	3	5	5	4	4	4	4	4	4
	1955	3	2	4	4	2	3	2	3	3	3
	1958	4	3	5	4	3	3	3	5	4	4
Shrub overstory	1953	14	14	10	12	12	15	9	8	11	12
	1955	13	16	7	12	11	16	7	11	9	14
	1958	14	18	9	14	10	16	8	12	10	15
Ground-cover index	1953	34	28	33	33	31	27	18	18	29	26
	1955	29	28	27	29	22	26	14	18	23	25
	1958	36	32	30	34	24	29	15	22	26	29
Annual plants	1953	1	1	2	Tr	1	Tr	Tr	Tr	1	Tr
	1955	11	7	13	9	3	2	Tr	1	7	5
	1958	14	5	10	7	10	3	1	2	9	4

Although cover on individual pairs of watersheds was similar, the influence of different soils is apparent, mainly in the amount of bare soil and rock and in composition of vegetation. For example, bare soil constituted only 61 percent of the surface of watershed 3–A, in which shale occupies one-third of the area, compared with 74 percent on watershed 3–B, where shale occupies three-quarters of the area. The measurements, however, showed no significant difference in ground-cover index between watersheds of any pair at the beginning of the study.

Averages for individual components of ground cover were even more similar for grazed and ungrazed watersheds. None differed more than 5 percent. For a given soil type, initial differences in ground cover between grazed and ungrazed watersheds were also small, the largest being 6 percent (table 6).

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TABLE 6.—*Composition of ground cover by soil origin and treatment, 1953–58*

[In number of hits per 100 observations. Tr=trace (less than 1 percent)]

	Year	Soil origin and treatment					
		Shale		Mixed		Sandstone	
		Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed
Bare soil	1953	76	80	53	55	55	50
	1955	87	86	65	59	63	54
	1958	87	79	70	55	56	46
Rock	1953	5	1	25	26	4	10
	1955	3	2	20	26	3	12
	1958	1	1	12	24	1	12
Bare soil and rock	1953	81	81	78	81	59	60
	1955	90	88	85	85	66	66
	1958	88	80	82	79	57	58
Litter and moss	1953	15	15	18	15	34	34
	1955	8	9	12	12	29	30
	1958	10	17	15	17	37	39
Plants (Plant-density index)	1953	4	4	4	4	7	6
	1955	2	3	3	3	5	4
	1958	2	3	3	4	6	3
Shrub overstory	1953	10	15	11	11	12	12
	1955	8	17	10	13	7	11
	1958	11	18	11	14	9	12
Ground-cover index	1953	22	25	27	24	43	43
	1955	14	24	21	23	36	37
	1958	17	27	23	27	45	45
Annuals	1953	0	Tr	1	Tr	2	2
	1955	Tr	Tr	4	3	24	23
	1958	Tr	1	7	3	25	17
Number of transects		12	26	68	58	16	12

CHANGES IN WATERSHED COVER

Plant and ground cover changed relatively little during the first 5 years of the Badger Wash study. In fact, fence-line differences were difficult to detect at the end of the period. The most noticeable difference was in the vigor of plants on grazed and ungrazed areas. Records from permanent transects, however, did reveal changes that were not apparent to the eye. For example, ground-cover index on mixed soils was found to be significantly higher on ungrazed watersheds at the end of the period than on grazed watersheds. At the beginning of the study there was no significant difference.

Strictly speaking, valid comparisons of changes in watershed cover under the two treatments can be made only from records for 1955 and 1958. Otherwise, seasonal differences are involved that cannot be separated from treatment effects. Nevertheless, data from the three periods of observation are probably helpful in interpreting transect records and in evaluating changes in watershed cover.

In reviewing tables 5 through 7, one should keep in mind that initial observations in the eight experimental watersheds were made about 5 months after livestock had been removed for the summer, that plant growth for the year was almost complete, and that rain from summer storms had largely obscured surface evidence of trampling and trailing. In other words, watershed cover on the eight watersheds was as nearly comparable as could be expected.

When observations were made in May 1955 and 1958, plant growth was only partly complete. On grazed watersheds, evidence of grazing and trailing was conspicuous, and browsing had removed some twig growth from shrubs. On ungrazed watersheds, plant growth had continued to accumulate, and evidence of trailing was notably absent. In fact, in many areas the ground surface had a network of cracks caused by intermittent expansion and contraction of the soil (fig. 8). On grazed watersheds, this structure was usually destroyed by livestock by the end of the grazing season.

Ground cover is discussed in later sections first on the basis of watersheds, then by soils. Information on mixed soil is generally more reliable than that for shale or sandstone soil because of the larger sample on which it is based.

GROUND-COVER CHANGES, 1955–58

Highlights of changes in ground cover from 1955 to 1958 are summarized in table 7. Most noticeable, perhaps, is the large number of NC's, indicating that changes, if any, were not significant at a 5 percent level of probability. However, the area of bare soil and rock declined and the area of litter and moss increased on all ungrazed watersheds. Similar results were observed on grazed watersheds 1–A and 3–A, but 2–A and 4–A showed no change. Increases in plant-density index were significant on watersheds 4–A and 4–B; in other watersheds, the index did not change significantly.

TABLE 7.—*Significance of changes in ground cover by treatment, watershed, and soil, 1955–58*

[Based on *t*-tests of changes on individual transects. Legend: ++, Increase, significant at 1 percent level; +, Increase, significant at 5 percent level; NC, No change (difference not significant at 5 percent level); −, Decrease, significant at 5 percent level; −−, Decrease, significant at 1 percent level]

	Watershed				Soil		
					Shale	Mixed	Sand
Grazed watersheds							
	1–A	2–A	3–A	4–A			
Bare soil and rock	−−	NC	−−	NC	NC	−−	−−
Litter and moss	++	NC	++	NC	NC	++	+
Plant-density index	NC	NC	NC	+	NC	+	NC
Shrub overstory	+	+	NC	NC	+	NC	+
Ground-cover index	++	NC	+	NC	+	+	+
Annual plants	++	NC	++	++	(1)	++	NC
Number of transects					12	68	16
Ungrazed watersheds							
	1–B	2–B	3–B	4–B			
Bare soil and rock	−−	−−	−−	−−	−−	−−	−−
Litter and moss	++	++	++	++	++	++	++
Plant-density index	NC	NC	NC	++	NC	++	NC
Shrub overstory	NC	++	NC	NC	NC	+	NC
Ground-cover index	++	++	++	++	++	++	+
Annual plants	−	−	NC	++	(1)	NC	−−
Number of transects					26	58	12

[1] Data not analyzed because of scarcity of annuals on shale soil.

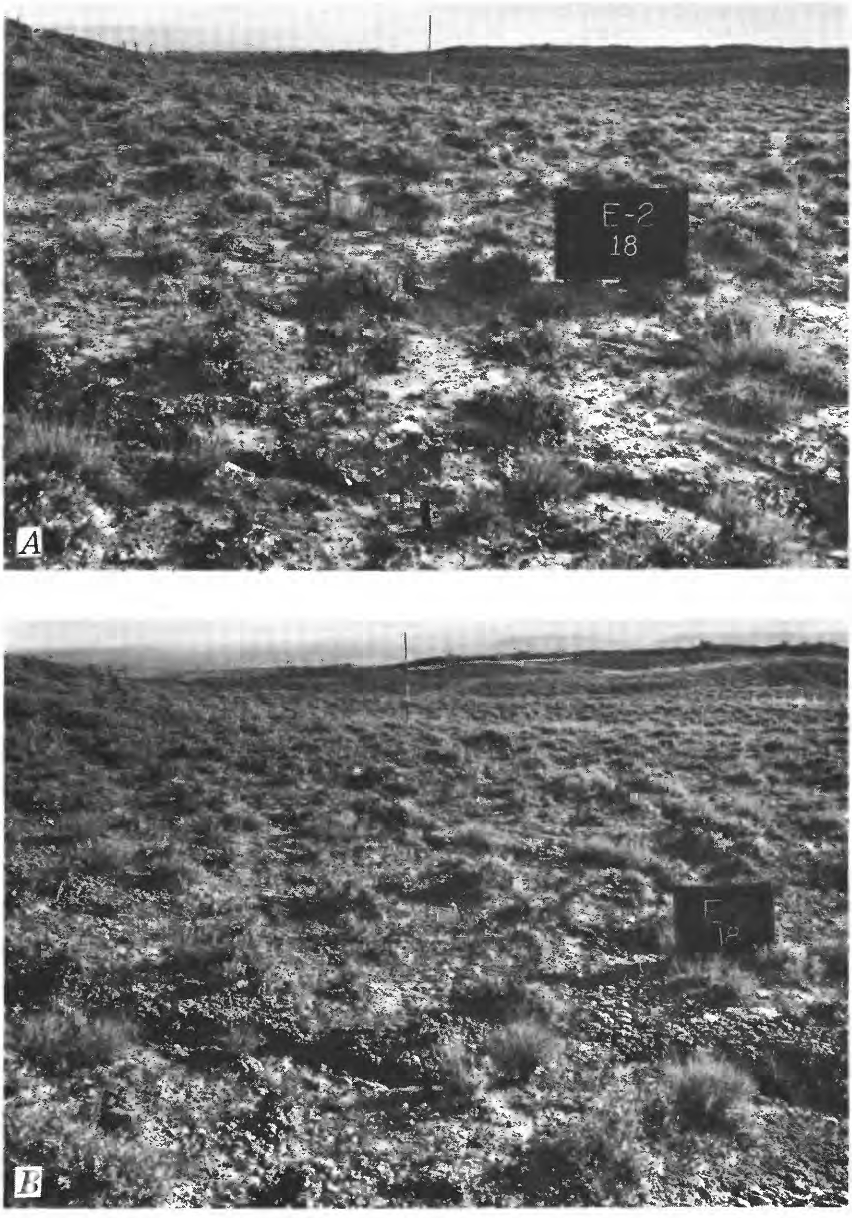

FIGURE 8.—A network of cracks commonly formed and persisted in the surface soil of ungrazed watersheds. *A*, View of the smooth surface of watershed 3–B in 1953 shortly after livestock were removed. *B*, View of the same area 5 years later.

Shrub overstory changed very little during the period, as changes on 5 of 8 watersheds were not significant.

Although the ground-cover index became larger on all ungrazed watersheds, it also became significantly larger on grazed watersheds 1–A and 3–A.

A comparison of number of hits on annual plants in 1955 and 1958 indicates a highly significant increase on three of the grazed areas. On ungrazed areas changes were erratic.

Table 5 indicates that rock cover (erosion pavement) declined considerably on grazed areas but remained nearly constant on areas protected from livestock. The reduction in rock cover on grazed areas might be due to trampling and trailing by livestock. Field observations indicate that the small rock particles that compose erosion pavement are commonly covered with soil when trampled and that they reappear when the soil is washed away. Consequently, the amount of exposed rock on grazed watersheds probably varies from time to time and from place to place, depending on intensity of trampling, rainfall, and amount of mixed soil present. Disturbance due to trampling apparently had been largely obscured by summer rains when observations were first made in the fall of 1953. Further study is needed to prove or disprove this hypothesis.

Analyses of changes in cover on individual soils (table 7) show that the area of bare soil and rock decreased significantly under both treatments and on all soils except shale in grazed areas; however, the areas of bare soil and rock on shale and mixed soil declined more in ungrazed than in grazed areas (table 6). Reductions in those items were compensated for mainly by a general increase in litter. Although the ground-cover index increased significantly on all soils, there was little evidence of differential change due to watershed treatment.

PLANT-COVER CHANGES, 1953–58

It has been pointed out that plant-density index did not change appreciably from 1955 to 1958. Table 8 further indicates that relatively little change in the abundance or composition of individual plant species occurred during the entire period 1953 to 1958.

A comparison of changes by plant groups shows a slight reduction in total grasses and total shrubs and a slight increase in total forbs on both grazed and ungrazed areas. The change, however, was never greater than an average of one hit per transect. Changes is composition, though small, were similar for grazed and ungrazed areas.

TABLE 8.—*Relative abundance and composition of perennial plants on grazed and ungrazed areas, 1953–58*

[Based on plant-density index. Tr=trace (less than 1 percent)]

Species	Abundance (hits per transect)						Composition (percent)					
	Grazed			Ungrazed			Grazed			Ungrazed		
	1953	1955	1958	1953	1955	1958	1953	1955	1958	1953	1955	1958
Grasses												
Elymus salinus	0.34	0.21	0.17	0.12	0.17	0.16	8	8	5	3	5	4
Hilaria jamesii	2.17	1.33	1.67	1.22	.84	.83	48	47	47	30	28	22
Oryzopsis hymenoides	------	------	.04	.05	------	.02	------	------	1	1	------	1
Sitanion hystrix	.02	.01	.01	.02	.01	.04	Tr	Tr	Tr	1	Tr	1
Total	2.53	1.55	1.89	1.41	1.02	1.05	56	55	53	35	33	28
Forbs												
Aster venustus	0.14	0.11	0.09	0.21	0.21	0.18	3	4	3	5	7	5
Astragalus spp	.03	------	.14	.04	------	.15	1	------	4	1	Tr	4
Erigeron pumilus	.19	.07	.59	.26	.23	.68	4	3	16	6	8	18
Eriogonum spp	.04	.01	.02	.08	.05	.11	1	Tr	1	2	2	3
Phlox longifolia	------	.01	.02	------	.03	.14	------	Tr	1	------	1	3
Sphaeralcea coccinea	.09	.04	.04	.02	.01	.02	2	2	1	1	Tr	1
Other forbs [1]	.07	.05	.06	.06	.04	.09	1	1	1	2	1	2
Total	.56	.29	.96	.67	.57	1.37	12	10	27	17	19	36
Shrubs												
Atriplex confertifolia	0.33	0.35	0.18	0.34	0.28	0.20	7	13	5	9	9	5
Atriplex corrugata	------	------	------	.05	.04	.04	------	------	------	1	1	1
Atriplex nuttallii	.51	.24	.08	.71	.53	.48	11	8	2	17	17	12
Chrysothamnus spp	.24	.18	.16	.50	.37	.29	5	6	4	12	12	8
Gutierrezia sarothrae	.22	.11	.23	.23	.15	.25	5	4	6	6	5	7
Opuntia sp	.08	.02	.02	.02	.01	------	2	1	1	1	Tr	------
Other shrubs [2]	.06	.06	.03	.07	.08	.05	1	2	1	2	3	2
Total	1.44	.96	.70	1.92	1.46	1.31	31	34	19	48	47	35
Grand total	4.53	2.80	3.55	4.00	3.05	3.73	99	99	99	100	99	99

[1] Includes *Abronia fragrans*, *Allium* sp., *Arabis pulchra*, *Aster hirtifolius*, *Bahia nudicaulis*, *Cryptantha elata*, *Cymopterus* spp., *Oenothera caespitosa*, and *Physaria australis*.
[2] Includes *Artemisia spinescens*, *Artemisia tridentata*, *Ephedra* sp., *Eurotia lanata*, and *Tetradymia spinosa*.

Records indicate somewhat greater changes in plant cover relative to soil type (table 9). For example, grasses on sandstone soil in ungrazed areas declined by nearly 2 hits per transect, and shrubs declined 1.16 hits. On grazed watersheds, shrubs on shale soil declined 1.58 hits per transect. Those records, however, are subject to considerable sampling error as they are based on only 12 transects each. Records for mixed soils indicate smaller reductions in grasses and shrubs.

On the basis of composition (table 10), forbs increased on all soils and under both treatments, and shrubs decreased. Grasses showed little or no change.

TABLE 9.—*Relative abundance of perennial plants on different soils in grazed and ungrazed areas, 1953–58*

[In number of hits on basal crown per 100 observations]

Species	Shale				Mixed				Sandstone			
	Grazed		Ungrazed		Grazed		Ungrazed		Grazed		Ungrazed	
	1953	1958	1953	1958	1953	1958	1953	1958	1953	1958	1953	1958
Grasses												
Elymus salinus	0.75	0.42	0.08	0.15	0.35	0.16	0.17	0.19	------	------	------	------
Hilaria jamesii	------	------	.04	------	1.73	1.21	1.16	.91	5.62	4.88	4.08	2.25
Oryzopsis hymenoides	------	------	------	.04	------	.06	.07	.02	------	------	.08	------
Sitanion hystrix	------	------	.08	.08	.03	------	------	.03	------	.06	------	------
Total	.75	.42	.20	.27	2.11	1.43	1.40	1.15	5.62	4.94	4.16	2.25
Forbs												
Aster venustus	0.83	0.25	0.42	0.35	0.04	0.09	0.16	0.14	------	------	------	------
Astragalus spp	------	.17	.04	.12	.04	.16	.05	.16	------	------	------	0.17
Erigeron pumilus	------	------	.04	------	.24	.74	.33	1.00	0.12	0.44	0.42	.58
Eriogonum spp	------	------	.19	.27	.06	.03	.05	.07	------	------	------	------
Phlox longifolia	------	------	------	.19	------	.03	------	.14	------	------	------	------
Sphaeralcea coccinea	------	------	------	------	.04	.03	.03	.03	.38	.12	------	------
Other forbs	------	.08	.04	.04	.09	.06	.08	.14	.06	------	------	------
Total	.83	.50	.73	.97	.51	1.14	.70	1.68	.56	.56	.42	.75
Shrubs												
Atriplex confertifolia	------	------	------	------	0.38	0.13	0.41	0.29	0.38	0.50	0.75	0.17
Atriplex corrugata	------	------	0.19	0.12	------	------	------	.02	------	------	------	------
Atriplex nuttallii	2.08	0.33	1.31	.69	.35	.06	.59	.48	------	------	------	------
Chrysothamnus spp	------	.08	.89	.54	.32	.19	.41	.24	.06	.06	.08	------
Gutierrezia sarothrae	.08	.17	.12	.31	.28	.29	.22	.28	.06	------	.50	------
Opuntia sp	------	------	------	------	.09	.03	.03	------	.12	------	------	------
Other shrubs	------	------	.08	.08	.06	.01	.08	.06	.06	.12	------	------
Total	2.16	.58	2.59	1.74	1.48	.71	1.74	1.37	.68	.68	1.33	.17
Grand total	3.74	1.50	3.52	2.98	4.10	3.28	3.84	4.20	6.86	6.18	5.91	3.17

TABLE 10.—*Composition of perennial-plant cover by soils and treatment, 1953–58*

[Based on plant-density index, in percent. Tr=trace (less than 1 percent)]

Species	Shale				Mixed				Sandstone			
	Grazed		Ungrazed		Grazed		Ungrazed		Grazed		Ungrazed	
	1953	1958	1953	1958	1953	1958	1953	1958	1953	1958	1953	1958
Grasses												
Elymus salinus	20	28	2	5	9	5	4	5	------	------	------	------
Hilaria jamesii	------	------	1	------	42	37	31	22	82	79	70	72
Oryzopsis hymenoides	------	------	------	1	------	2	2	Tr	------	------	1	------
Sitanion hystrix	------	------	2	3	1	------	------	1	------	1	------	------
Total	20	28	5	9	52	44	37	28	82	80	71	72

TABLE 10.—*Composition of perennial-plant cover by soils and treatment, 53–1958*—Con.

[Based on plant-density index, in percent. Tr—trace (less than 1 percent)]

Species	Shale				Mixed				Sandstone			
	Grazed		Ungrazed		Grazed		Ungrazed		Grazed		Ungrazed	
	1953	1958	1953	1958	1953	1958	1953	1958	1953	1958	1953	1958
Forbs												
Aster venustus	22	16	13	12	1	3	4	3	------	------	------	------
Astragalus spp	------	11	1	4	1	5	1	4	------	------	------	5
Erigeron pumilus	------	------	1	------	6	22	8	24	2	7	7	18
Eriogonum spp	------	------	5	9	1	1	1	2	------	------	------	------
Phlox longifolia	------	------	------	6	------	1	------	3	------	------	------	------
Sphaeralcea coccinea	------	------	------	------	1	1	1	1	5	2	------	------
Other forbs	------	6	1	1	2	1	2	2	1	------	------	------
Total	22	33	21	32	12	34	17	39	8	9	7	23
Shrubs												
Atriplex confertifolia	------	------	------	------	9	4	11	7	5	8	13	5
Atriplex corrugata	------	------	5	4	------	------	------	Tr	------	------	------	------
Atriplex nuttallii	56	22	38	24	9	2	15	12	------	------	------	------
Chrysothamnus spp	------	6	26	19	8	6	11	6	1	1	1	------
Gutierrezia sarothrae	2	11	3	10	7	9	6	7	1	------	8	------
Opuntia sp	------	------	------	------	2	1	1	------	2	------	------	------
Other shrubs	------	------	2	2	1	Tr	2	Tr	1	2	------	------
Total	58	39	74	59	36	22	46	32	10	11	22	5

Although records of intercept of shrub crowns provide information similar to that for shrub overstory, changes in intercept are more pronounced (table 11). Intercept of crowns declined 20 percent on grazed watersheds and increased 5 percent on ungrazed areas. Part of the change in intercept, however, is probably due to browsing and may be temporary. As explained on page B20, records in 1953 were taken when plants were fully grown and ungrazed, while in 1958 many shrubs on grazed watersheds had been browsed, and growth may not have been complete.

TABLE 11.—*Intercept of shrub crowns by species and watersheds, 1953–58*

[In linear feet per 1,200 feet of transect]

Species	Year	Watershed								Total	
		1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B	Grazed	Ungrazed
Artemisia tridentata	1953	18	12	5	8	2	------	------	4	25	24
	1955	14	13	3	7	1	------	------	4	18	24
	1958	16	18	3	8	1	------	------	5	20	31
Atriplex confertifolia	1953	133	97	84	104	98	31	1	8	316	240
	1955	102	75	55	89	74	22	1	7	232	193
	1958	106	83	55	94	81	26	3	8	245	211
Atriplex nuttallii	1953	------	45	28	------	31	73	79	60	138	178
	1955	------	36	16	------	20	68	39	60	75	164
	1958	------	47	27	------	30	84	57	70	114	201
Chrysothamnus spp	1953	32	35	16	51	26	67	36	44	110	197
	1955	17	37	8	41	18	70	27	42	70	190
	1958	20	48	12	58	24	86	26	45	82	237
Gutierrezia sarothrae	1953	20	21	10	19	26	38	23	14	79	92
	1955	37	28	8	24	25	32	13	19	83	103
	1958	29	16	14	34	15	18	19	20	77	88
Tetradymia spinosa	1953	6	7	4	1	6	7	3	4	19	19
	1955	4	8	3	2	3	6	2	4	12	20
	1958	4	7	4	1	5	4	5	5	18	17
Other shrubs [1]	1953	1	3	2	0	6	7	7	3	16	13
	1955	1	2	1	0	3	6	5	5	10	13
	1958	2	4	1	1	3	9	4	7	10	21
Totals	1953	210	220	149	183	195	223	149	137	703	763
	1955	175	199	94	163	144	204	87	141	500	707
	1958	177	223	116	196	159	227	114	160	566	806

[1] Includes *Artemisia spinescens*, *Atriplex corrugata*, *Ephedra* sp., *Eurotia lanata*, and *Opuntia* sp.

Intercept of shadscale saltbush (*Atriplex confertifolia*) declined 22 percent under grazing and 12 percent under protection from livestock between 1953 and 1958. Mortality of this species may have been caused by drought or insects. Crowns of Gardner saltbush (*Atriplex nutallii*) and rabbitbrush (*Chrysothamnus greenei filifolius*) tended to expand under protection and to decline under grazing. Meanwhile, the crowns of other shrubs changed very little.

FORAGE UTILIZATION

Estimates of forage utilization provide the only quantitative measure of grazing intensity on Badger Wash watersheds. Although the object is to graze the unfenced watersheds about as closely as the remainder of the allotment, grazing within individual study basins actually is subject to little control. Degree of use is influenced through efforts of the sheepherder, abundance of forage, and availability of stock water. Fenced watersheds in the area also tend to encourage livestock concentration in local areas.

Data on the utilization of forage, in addition to providing a measure of watershed treatment, should be helpful in explaining changes in the condition of the watershed. The data will also provide information on the relative palatability of individual species and their response to the grazing treatment.

METHOD OF MEASUREMENT

Ocular estimates of forage utilization on the four grazed watersheds were made on belt transects 2 feet wide and 50 feet long (fig. 9). The lower side of each belt transect was formed by a line transect used in measuring ground cover. To facilitate estimating, each belt was divided into segments 10 feet long. Utilization of individual species within each segment was estimated independently by two observers, and the average was recorded. An average for each transect was obtained by combining data from its five segments. Averages for watersheds were computed for 24 transects each.

Utilization of old and new growth was estimated separately, and recorded as a percentage of weight removed. Old growth is defined as herbage produced the preceding year and new growth as herbage produced during the current year of observation. Estimates were made at or near the end of the grazing season during the first 2 weeks in May.

Utilization of individual species may have little meaning unless the relative abundance and distribution of the various species are known. To provide that information, frequency of occurrence of each species was computed on the basis of 24 transects in each watershed.

Although utilization estimates were made in 1955, they were based on old and new growth combined. They are not therefore, comparable to data for ensuing years and are not included in this report.

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FIGURE 9.—Forage utilization is estimated each year at the close of the grazing season. Belt transects 2 feet wide and 50 feet long are used for this purpose.

FINDINGS FROM 1956 TO 1958

All unfenced watersheds were grazed at about the same intensity from 1956 to 1958. Although degree of use varied somewhat from year to year, the relative use of individual species was about the same. Some were grazed very closely, and others were practically ungrazed.

Utilization data for grasses and shrubs are summarized in table 12. Forbs are not listed because they are relatively scarce, provide little forage, and are believed to be poor indicators of grazing intensity on winter range.

Of the grasses, Salina wildrye (*Elymus salinus*) was grazed most closely; in fact, practically all available old growth of many plants was grazed. Average use ranged from 64 to 81 percent. Indian ricegrass (*Oryzopsis hymenoides*) was second highest in degree of use, which ranged from 41 to 55 percent. Evidently neither of those species, however, furnished as much forage as galleta (*Hilaria jamesii*), which was grazed 30 to 35 percent. Cheatgrass brome (*Bromus tectorum*) was practically ungrazed, possibly because new growth occurred too late in the spring to be readily available. Bottlebrush squirreltail (*Sitanion hystrix*) was little used because most plants were protected by shrubs. Although Sandberg bluegrass (*Poa secunda*) was readily grazed, it occurred infrequently on all watersheds.

TABLE 12.—*Average utilization and frequency of occurrence, in percent, of grasses and shrubs on belt transects, 1956–58*

Species	Utilization								Frequency of occurrence			
	Old growth				New growth							
	1–A	2–A	3–A	4–A	1–A	2–A	3–A	4–A	1–A	2–A	3–A	4–A
Grasses												
Bromus tectorum	------	------	------	------	Tr	Tr	0	0	99	86	68	44
Elymus salinus	76	64	77	81	13	4	9	13	50	5	18	57
Festuca octoflora	------	------	------	------	0	0	0	------	22	28	11	------
Hilaria jamesii	32	35	30	33	1	5	Tr	Tr	71	83	53	50
Oryzopsis hymenoides	44	46	41	55	8	12	6	7	26	38	28	72
Poa secunda	12	42	35	55	0	18	20	18	3	5	5	5
Sitanion hystrix	5	7	11	4	Tr	2	1	2	72	37	58	7
Shrubs												
Artemisia spinescens	65	40	28	39	14	0	0	Tr	4	4	5	27
Artemisia tridentata	37	51	20	------	Tr	1	Tr	------	36	12	15	------
Atriplex confertifolia	2	5	3	7	Tr	Tr	Tr	0	100	91	57	21
Atriplex corrugata	------	Tr	1	------	------	0	Tr	------	------	5	12	------
Atriplex ruttallii	Tr	13	16	16	0	0	Tr	Tr	3	24	71	95
Chrysothamnus greenei	35	40	35	43	8	4	6	12	72	45	71	70
Chrysothamnus nauseosus	------	------	30	33	------	------	8	3	------	------	11	4
Ephedra sp	23	------	61	81	5	------	7	4	4	------	7	8
Eurotia lanata	17	49	54	85	0	Tr	4	0	5	25	7	1
Gutierrezia sarothrae	5	8	3	5	1	Tr	Tr	Tr	74	47	63	85
Opuntia sp	0	0	0	------	0	0	0	------	45	11	5	------
Tetradymia spinosa	4	3	5	6	0	0	Tr	Tr	14	15	33	17

Of the more common shrubs, Greenes rabbitbrush (*Chrysothamnus greenei filifolius*) was grazed most heavily. Average use of old growth ranged from 35 to 43 percent. Shadscale saltbush (*Atriplex confertifolia*), Gardner saltbush (*Atriplex nuttallii*), and broom snakeweed (*Gutierrezia sarothrae*) were lightly browsed, and the use of any of those species in any watershed did not exceed 16 percent. Among the less common shrubs, bud sagebrush (*Artemisia spinescens*), big sagebrush (*Artemisia tridentata*), rubber rabbitbrush (*Chrysothamnus nauseosus*), *Ephedra*, and common winterfat (*Eurotia lanata*) were grazed readily and sometimes heavily. Mat saltbush (*Atriplex corrugata*), cottonhorn horsebrush (*Tetradymia spinosa*), and pricklypear (*Opuntia*) were seldom grazed.

Utilization of new growth of all species was comparatively light. On individual watersheds averages were as high as 20 percent for Sandberg bluegrass (*Poa secunda*), 13 percent for Salina wildrye (*Elymus salinus*), and 12 percent for Indian ricegrass (*Oryzopsis hymenoides*) and Greenes rabbitbrush (*Chrysothamnus greenii*). Other plants were grazed even less.

CONCLUSIONS

Records during the first 5 years show that changes in watershed cover have been relatively small, both on grazed and ungrazed areas. A reduction in cover is indicated on grazed watersheds, compared to an increase on ungrazed areas. Part of the change on grazed watersheds, however, may be caused by current grazing and, if so, would be a seasonal difference. Because of the relatively small changes recorded, only tentative conclusions regarding the response of watershed cover to grazing treatment should be drawn at this time.

The fact that precipitation was below average in 4 of the 5 years of study may explain, in part, the failure of plant cover to improve appreciably under protection from grazing.

Evidence to date indicates that changes in watershed cover were mainly on shale and mixed soils. Ground-cover index on mixed soil was significantly higher on ungrazed areas than on grazed areas at the end of the 5-year period, even though the difference was only 4 percent. Cover on sandstone soils apparently is less sensitive to grazing than that on shale and mixed soils, as it showed little if any differential response to the two treatments.

Forage utilization on the unfenced experimental watersheds was similar during 3 years of record. Although drastic differences in utilization of individual species were observed, there is little evidence that grazing has affected abundance or composition of plant cover since the beginning of the study.

INFILTROMETER PLOT RECORDS

By J. R. Thompson [3]

The purpose of this phase of the Badger Wash study is to test the effects of livestock exclusion on infiltration and on sheet erosion within the major soil types of the area. Data were collected under controlled conditions on infiltrometer plots selected by a random method. Determination of infiltration and erosion responses by soil type should facilitate the extrapolation of these data so that findings may be applied to other similar areas. The information should also be helpful in interpreting runoff and erosion data obtained at the reservoirs.

A secondary objective of this study is to determine whether infiltrometer plot records provide a reliable means of predicting runoff and sediment discharge from small watersheds.

SAMPLING PROCEDURE

Infiltrometer measurements were made on 12 plots on each of the 8 watersheds. On a given watershed the number of plots on each soil type—shale, sandstone, and mixed shale and sandstone—is in proportion to the relative extent of that soil type (table 13). The general location of the randomly selected plots is shown in figures 3–7. In 1958, plots were located 10 feet upslope from the original random plots. Subsequent 10-, 15, and 20-year plots will be located 10 feet left (facing upslope), 10 feet right, and 10 feet upslope from the 1958 plots, respectively.

[3] U.S. Forest Service.

On watershed 3–A all infiltrometer plots are on the upper part of the present watershed, above the original retention dam. After the study was begun, the watershed was enlarged to include the drainage area, as shown in figure 6.

TABLE 13.—*Distribution of infiltrometer plots by soils and watershed*

Watershed	Soil			Total
	Shale	Mixed	Sandstone	
1–A	--------	8	4	12
2–A	2	6	4	12
3–A	4	8	--------	12
4–A	--------	12	--------	12
Subtotal	6	34	8	48
1–B	4	6	2	12
2–B	--------	8	4	12
3–B	8	4	--------	12
4–B	--------	12	--------	12
Subtotal	12	30	6	48
Total	18	64	14	96

METHODS

Fieldwork took place during the fall in 1953, 1954, and 1958. Although it was originally planned to complete infiltrometer runs during the fall season every fifth year beginning in 1953, one-half the initial runs were postponed until the fall of 1954 because of cold weather. The first 5-year post-treatment measurements were made on all plots during the 1958 field season. Remeasurements will continue at 5-year intervals through 1973.

In addition to infiltration, runoff, and erosion rates obtained by the use of the infiltrometer, measurements of ground cover and soil-bulk density were made on each plot in 1953, 1954, and 1958. Penetrometer readings were made in conjunction with the infiltrometer data for the first time in 1958. This supplementary information was obtained to account for changes that might occur in infiltration and erosion rates.

INFILTRATION AND EROSION

Using the Rocky Mountain infiltrometer (fig. 10) as described by Dortignac (1951), artificial rainfall was applied to 2½-square-foot plots at the rate of about 5 inches per hour. This rate was maintained as nearly constant as possible throughout all runs.

Accurate measurements were made of the amount of runoff coming from the plots and the amount and intensity of "rainfall" received by the plots. The difference between these two amounts for a given time interval was calculated to be the infiltration rate for that interval.

FIGURE 10.—Rocky Mountain infiltrometer in operation at Badger Wash.

Measurements at the end of ten 5-minute intervals were made on each infiltrometer run.

Two infiltrometer runs were made on each plot. The soil moisture at the start of the "dry" run, was almost always near the wilting point. At the completion of the dry run, the plot was immediately covered to prevent moisture loss and to allow natural drainage. Twenty-four hours later a second 50-minute run was made on the plot. This was designated as the "wet" run. The soil moisture at the beginning of the wet run was approximately at field capacity.

The amount of water applied to the plot prior to the start of runoff was used as a measure of initial water-absorbing capacity. This capacity was computed by using the time elapsed to the start of runoff and the average rainfall application rate for that time interval. It includes initial absorption, depression storage, and detention storage.

Upon completion of the infiltrometer runs, all runoff water and the sediment deposited in the runoff collector trough, were placed in sediment cans. This turbid solution was allowed to settle for several days before the water was siphoned off. The remaining sediment was then ovendried and weighed.

Average infiltration and erosion rates for a given soil and treatment were used to synthesize these same data on a watershed basis; that is, by using the overall average for each of the three soil types and weighting these by the relative extent of the types within a given watershed, the average infiltration and erosion rates for the watershed were computed.

GROUND COVER

Prior to the infiltrometer runs, a gridcount measurement of ground cover was made on each plot. A wire grid having 154 intersections was placed on the plot, and a record of hits by ground-cover categories was tabulated. Any part of a plant that fell under the vertical projection of the grid intersection points was recorded as a hit on that plant. These figures were then converted to percentages based on 154 total possible hits.

Upon completion of the runs the vegetation was clipped to ground level, and the litter was collected from the plots. The litter was then air dried, weighed, and converted to pounds per acre.

The purpose of these ground-cover measurements is to show the conditions that existed on the plots used for infiltrometer runs. They do not necessarily apply to the entire watershed.

SOIL-BULK DENSITY

Bulk density of the upper 2 inches of soil was determined for each infiltrometer plot. An undisturbed soil core was obtained from an area free from rock and vegetation by using a cylinder 5 cm high and 6.4 cm in diameter. The cores were taken 2 or 3 days after the wet runs were completed, at which time moisture conditions were similar for all samples.

The ovendry weight of the soil core in grams and its volume in cubic centimeters were used to express the bulk density as a ratio of weight per unit of volume.

PENETROMETER READINGS

Penetrometer readings were made on infiltrometer plots for the first time in 1958. These measurements were made using a Proctor penetrometer with a 13/16-inch blunt-end proble. After the wet run, three penetrometer probings were made on each plot. Readings in pounds of pressure required to force the probe into the soil were taken at 1-inch increments of depth. The sampling points on the plots were selected to be free from surface rock and vegetation. At the time the readings were made, the soil moisture was at field capacity well below the maximum depth of penetrometer readings.

FINDINGS

Table 14 summarizes infiltrometer data by watershed and grazing treatment. The number of infiltrometer plots on soils derived from shale and sandstone was found to be statistically inadequate for reliable sampling of most items. For this reason, analyses of differences between years or between treatments have been limited to mixed soils. These soils make up 67 percent of the grazed and 55 percent of the ungrazed area.

INFILTRATION AND EROSION

In 1953–54 the average infiltration rates on mixed soils for the last 20 minutes of the wet and dry runs were significantly higher on the grazed plots than on the plots destined for protection. This difference was 0.15 inch per hour for the dry runs and 0.21 inch per hour for the wet runs.

TABLE 14.—*Average infiltration measurements and erosion rates by watershed and grazing treatment*

[Synthesized from average rates for soil types within treatments. Erosion rates based on dry runs. Dry f_c: average infiltration rate for last 20 minutes of dry run. Wet f_c: average infiltration rate for last 20 minutes of wet run. Water absorbed: amount of water applied prior to start of runoff on dry runs]

Watershed	Dry f_c (inches per hour)			Wet f_c (inches per hour)			Water absorbed (inches)			Erosion rates (tons per acre per inch of rain)		
	1953–54	1958	Difference	1953–54	1958	Difference	1953–54	1958	Difference	1953–54	1958	Difference
1–A	1.18	1.31	+0.13	0.90	1.01	+0.11	0.26	0.27	+0.01	1.98	2.02	+0.04
1–B	.82	1.04	+.22	.64	.86	+.22	.18	.34	+.16	2.31	2.19	−.12
2–A	1.14	1.28	+.14	.88	1.00	+.12	.25	.27	+.02	2.21	2.19	−.02
2–B	1.28	1.63	+.35	.89	1.17	+.28	.25	.48	+.23	1.57	1.50	−.07
3–A	.80	1.04	+.24	.70	.90	+.20	.17	.22	+.05	3.33	3.27	−.06
3–B	.66	.84	+.18	.56	.76	+.20	.16	.30	+.14	2.67	2.50	−.17
4–A	.93	1.16	+.23	.79	.95	+.16	.18	.21	+.03	2.41	2.43	+.02
4–B	.79	.98	+.19	.60	.78	+.18	.17	.28	+.11	2.08	2.04	−.02
Grazed	1.01	1.20	+.19	.82	.96	+.14	.22	.24	+.02	2.48	2.48	0
Ungrazed	.89	1.12	+.23	.67	.89	+.22	.19	.35	+.16	2.16	2.06	−.10

The differences persisted into 1958 with very little change. On the dry runs the infiltration rates on grazed plots averaged 0.18 inch per hour greater than on the ungrazed plots, and on the wet runs the difference was 0.16 inch per hour.

On both the wet and the dry runs in 1953–54 and 1958, the infiltration rates on the sandstone-soil plots for the last 20 minutes of a run were significantly higher than the rates on mixed- or shale-soil plots for a given treatment. The rates on shale soil were not significantly different from those on the mixed soil on either the grazed or ungrazed plots (table 15).

As shown by the infiltration curves in figures 11–14, the greatest change in infiltration from 1953–54 to 1958 seems to have been in the initial rates on dry soil. For this reason, an analysis was made of the dry runs using the initial water-absorbing capacity as a measure of initial infiltration. The results of this analysis should reflect actual field conditions, since precipitation from the usual high-intensity storm in this area falls on dry soil and is of short duration.

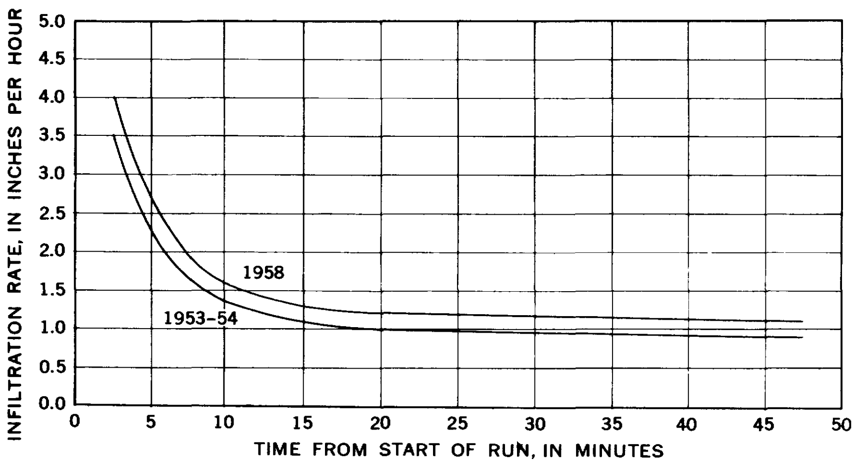


FIGURE 11.—Average dry-run infiltration curves for grazed plots on the mixed soil type.

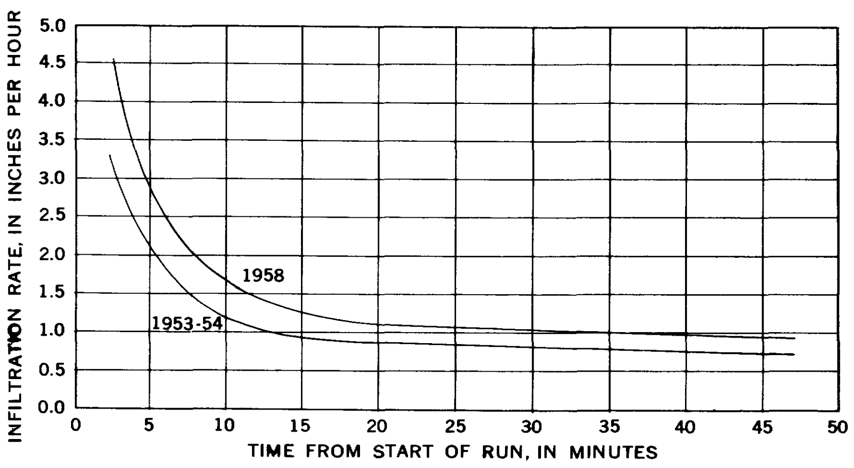


FIGURE 12.—Average dry-run infiltration curves for ungrazed plots on the mixed soil type.

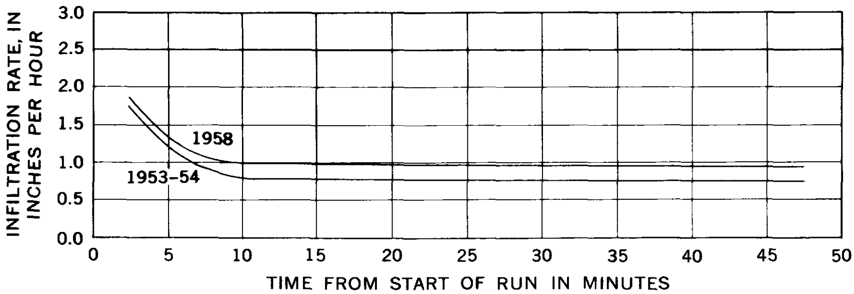


FIGURE 13.—Average wet-run infiltration curves for grazed plots on the mixed soil type.

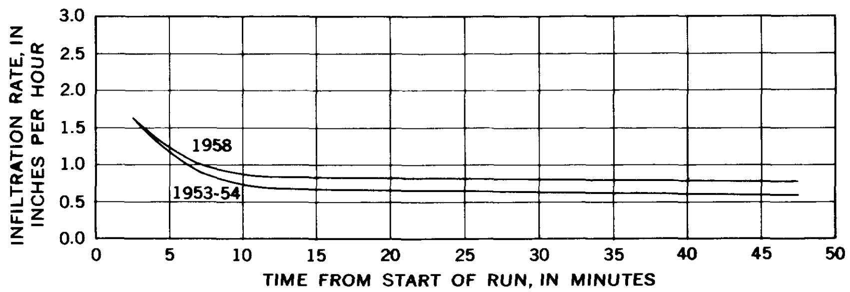


FIGURE 14.—Average wet-run infiltration curves for ungrazed plots on the mixed soil type.

In 1953–54, the grazed and ungrazed plots on the mixed soil were not significantly different in their initial water-absorbing capacity. In 1958, the water-absorbing capacity of ungrazed sites averaged 0.07 inch greater than that of the grazed sites. This difference, when tested statistically, was found to be significant.

TABLE 15.—*Average infiltration measurements by soils and grazing treatment*

[Dry f_c: average infiltration rate for last 20 minutes of dry run. Wet f_c: average infiltration rate for last 20 minutes of wet run. Water absorbed: amount of water applied prior to start of runoff on dry runs]

Treatment	Number of plots	Dry f_c (inches per hour)			Wet f_c (inches per hour)			Water absorbed (inches)		
		1953-54	1958	Difference	1953-54	1958	Difference	1953-54	1958	Difference
Shale										
Grazed	6	0.61	0.86	+0.25	0.57	0.83	+0.26	0.15	0.23	+0.08
Ungrazed	12	.62	.80	+.18	.55	.76	+.21	.16	.30	+.14
Mixed										
Grazed	34	0.93	1.16	+0.23	0.79	0.95	+0.16	0.18	0.21	+0.03
Ungrazed	30	.79	.98	+.19	.60	.78	+.18	.17	.28	+.11
Sandstone										
Grazed	8	2.04	1.85	−0.19	1.30	1.21	−0.09	0.50	0.45	−0.05
Ungrazed	6	2.54	3.29	+.75	1.64	2.15	+.51	.47	.99	+.52

The analysis of initial water absorption among soil types for a given treatment showed no significant difference between shale and mixed types, but absorption by the sandstone soil was significantly higher than that by either of these soils. The same results were found in both 1953–54 and 1958 (table 15).

No significant difference in erosion rates between the grazed and ungrazed sites was detected in either 1953–54 or 1958 for the mixed soil type (table 16).

TABLE 16.—*Average erosion rates, in tons per acre per inch of rain, by soils and grazing treatment*

Treatment	Number of plots	Dry run			Wet run		
		1953–54	1958	Difference	1953–54	1958	Difference
Shale							
Grazed	6	4.73	4.54	−0.19	4.00	4.12	+0.12
Ungrazed	12	2.83	2.62	−.21	2.19	2.23	+.04
Mixed							
Grazed	34	2.41	2.43	+0.02	2.01	2.16	+0.15
Ungrazed	30	2.08	2.04	−.04	1.73	1.83	+.10
Sandstone							
Grazed	8	0.40	0.37	−0.03	0.42	0.43	+0.01
Ungrazed	6	.26	.12	−.14	.52	.23	−.29

SUPPLEMENTARY PLOT DATA

Ground-cover characteristics are listed in terms of pounds per acre in table 17 and as density, in percent in table 18. The large differences in ground-cover weights were due primarily to the presence or absence of woody shrubs. For this reason, the density method seemed to be a more realistic characterization of plant cover and was, therefore, used in the analyses.

In 1953–54, no significant difference existed on the mixed soil between the amount of total ground cover on the grazed plots and the amount on the plots to be fenced. This condition remained the same in 1958. In both periods, total ground cover on the sandstone plots was significantly greater than on the shale or mixed plots. Most of this difference was accounted for by a larger amount of grass on the sandstone plots. Total ground cover on the mixed plots was nearly the same as that on the shale plots; however, a small amount of grass was recorded on the mixed soil plots and no grass was recorded on the shale soil.

The soil-bulk densities on the mixed soils in 1953–54 were approximately the same on the grazed plots as on the plots to be withdrawn from grazing. In 1958 these conditions were unchanged (table 19).

TABLE 17.—*Average ground cover, in pounds per acre, air dried, on infiltrometer plots by soils and grazing treatment*

Ground cover	Soil					
	Shale		Mixed		Sandstone	
	1953–54	1958	1953–54	1958	1953–54	1958
Grazed [Number of plots: 6 on shale; 34 on mixed; 8 on sandstone]						
Grass	0	0	149	120	689	677
Forbs	62	0	76	44	89	6
Shrubs	1,960	181	371	747	3,108	544
Litter	1,563	374	1,600	839	5,048	1,775
Total cover	3,585	555	2,196	1,750	8,934	3,002
Ungrazed [Number of plots: 12 on shale; 30 on mixed; 6 on sandstone]						
Grass	12	3	224	149	1,129	878
Forbs	207	5	97	32	10	0
Shrubs	1,726	983	957	339	3,238	831
Litter	1,048	849	1,362	779	3,306	3,650
Total cover	2,993	1,840	2,640	1,299	7,683	5,359

TABLE 18.—*Average ground-cover density, in percent, on infiltrometer plots by soils and grazing treatment*

Ground cover	Soil					
	Shale		Mixed		Sandstone	
	1953–54	1958	1953–54	1958	1953–54	1958
Grazed [Number of plots: 6 on shale; 34 on mixed; 8 on sandstone]						
Grass	0	0	3	6	25	30
Forbs	2	0	4	3	4	1
Shrubs	13	3	4	7	24	7
Litter	3	13	8	15	19	36
Total cover	18	16	19	31	72	74
Rock	7	2	21	21	1	1
Bare	75	82	60	48	27	25
Ungrazed [Number of plots: 12 on shale; 30 on mixed; 6 on sandstone]						
Grass	0	0	6	8	31	46
Forbs	2	0	2	3	3	5
Shrubs	14	12	9	4	19	8
Litter	8	17	8	13	18	22
Total cover	24	29	25	28	71	81
Rock	2	6	24	41	1	6
Bare	74	65	51	31	28	13

Analysis made using penetrometer data from the mixed soils showed a significantly higher average reading at a 1-inch depth on the grazed plots than on the ungrazed plots in 1958. No significant differences between treatments occurred below the 1-inch probe depth, however.

TABLE 19.—*Average bulk densities, in grams per cubic centimeter, by soils and grazing treatment*

[Numbers in parentheses are the number of samples which the average represents]

Treatment	Bulk density	
	1953–54	1958
Shale		
Grazed	1. 34 (6)	1. 39 (5)
Ungrazed	1. 29 (12)	1. 29 (12)
Mixed		
Grazed	1. 36 (34)	1. 38 (34)
Ungrazed	1. 35 (30)	1. 30 (29)
Sandstone		
Grazed	1. 27 (8)	1. 40 (8)
Ungrazed	1. 24 (6)	1. 31 (6)

On the grazed plots, penetrometer readings on the sandstone soil were significantly higher than on the shale or mixed soils. The plots on the shale soil had about the same average readings as on the mixed soil. On the ungrazed plots no significant difference in penetrometer readings existed among the three soil types. Table 20 summarizes the penetrometer readings.

DISCUSSION AND CONCLUSIONS

On mixed soils, infiltration rates for the last 20 minutes of both the wet and dry runs were higher in 1958 than in 1953–54. Although this difference is statistically significant, it is not associated with treatment because rates are higher on both grazed and ungrazed plots.

In 1953 the infiltrometer runs were made during October and November. The Fruita weather station recorded an average air temperature of 45.9°F for the period. In 1954 the runs were made during September and October when temperatures averaged 58.8°F. The 1958 runs were completed during August and September, when the average air temperature was 69.5°F. The average temperature associated with the combined 1953–54 data was approximately 52°F, which is about 17°F less than the 1958 temperature. Because the temperature of the soil, as well as the temperature of the water applied to the plots, is believed by some to be directly related to infiltration rates, this may explain the consistent increase in rates between 1953–54 and 1958.

The initial water-absorbing capacity of the ungrazed plots on the mixed soil increased significantly from 1953–54 to 1958, but it remained about the same for the grazed plots during this period.

TABLE 20.—*Penetrometer readings, in pounds, by soils and grazing treatment, 1958*

Treatment	Dial readings at depths shown				
	1 inch	2 inches	3 inches	4 inches	5 inches
Shale					
Grazed	42	69	81	103	(1)
Ungrazed	35	68	91	117	--------
Mixed					
Grazed	44	81	103	--------	--------
Ungrazed	36	75	102	--------	--------
Sandstone					
Grazed	65	89	97	105	--------
Ungrazed	30	61	87	102	105

[1] One-third or more of penetrometer readings were beyond dial capacity.

Water absorption, as used here, includes depression and detention storage, and the absence of grazing may have increased the hydraulic roughness of the soil surface as well as its ability to absorb water. In either case, the effect was undoubtedly restricted to a thin surface layer of soil. This is pointed out by the fact that bulk densities at a depth of 2 inches did not change between 1953–54 and 1958, and the 1958 penetrometer readings at a depth of 1 inch were the only ones that showed a difference between grazed and ungrazed plots.

No correlation was obtained between the penetrometer readings at 1 inch and any of the infiltration measurements; however, the readings at 1 inch were significantly correlated with the mixed-soil bulk densities. The grazed and ungrazed plots were similar in ground-cover density for both periods of record on the mixed soils. No treatment effect was detected in erosion rates on the mixed soils.

PRECIPITATION, RUNOFF, EROSION, AND SEDIMENT YIELDS

By GREGG C. LUSBY[4]

OBSERVATION NETWORK

The specific objectives of the Badger Wash cooperative study to which the work of the Geological Survey is related include the determination of rates of runoff and erosion under storms of varying intensity and magnitude and determination of the effect on runoff and erosion of total exclusion of livestock grazing. Also included are the determination of the extent and character of erosion, runoff, and sedi-

[4] U.S. Geological Survey.

ment yield under different conditions of vegetative cover and soil types on grazed and ungrazed watersheds and under varying amounts and intensities of precipitation.

Because of the great range in rainfall from place to place in summer thunderstorms, a relatively dense network of recording rain gages was installed in the basin. A total of 10 gages was installed at the beginning of the study, and 1 gage was added in 1957. Of the 11 gages, 9 are situated in the paired watersheds so that at least 2 gages are included in each pair of special study areas. Location of these gages is shown in plate 1.

Runoff and sediment were measured in reservoirs located at the lower end of each watershed. The reservoirs in watersheds 2–A, 2–B, 4–A, and 4–B are equipped with continuous water-stage recorders. Sediment yield from each watershed was measured by successive topographic surveys of the reservoirs. In addition to measurements made in the paired watersheds, runoff and sediment were measured in 10 reservoirs located in adjacent grazed areas. A dam was constructed on the main stem of Badger Wash during the spring of 1957, and runoff and sediment have been measured there since that time.

Cross sections marked by monuments were established in 1954 on channels at 49 locations in the 8 paired watersheds. In addition, transects for measuring sheet erosion were established on hillside slopes in each of the paired watersheds.

PRECIPITATION

Polygons were drawn using the Thiessen method around the nine recording precipitation gages located in the paired watersheds. Of the 9 gages, 7 are of the weighing type, and 2 are tipping-bucket gages that operate recording pens attached to continuous water-stage recorders at reservoirs. Storm precipitation at each rain gage and for each of the paired watersheds as computed by the Thiessen method is shown in table 21. Gages were operated as recorders during the summer, generally from April through October, and as storage gages during the winter.

The greatest storm of the 5-year period occurred on July 25, 1955, when the most rainfall on a watershed was computed as 1.40 inches and the least was 1.29 inches. Most of this rainfall occurred during a 20-minute period, and the maximum rate was 3.6 inches per hour during a 10-minute interval. In 1956, the minimum average rainfall on the watersheds during a summer season was 2.19 inches, when 21 separate storms occurred, whereas in 1957, the maximum was 7.64 inches, when 41 storms occurred. Rainfall observed at different parts of the Badger Wash basin varied considerably from the average at times, but rainfall on paired watersheds appeared to be nearly uniform from place to place.

TABLE 21.—*Precipitation, Badger Wash*

[When numbers are shown in parentheses, no daily record was obtained and amount was estimated on basis of total catch or other records]

Date	Amount (inches)																		
	Gage number											Watershed							
	1	2	3	4	5	6	7	8	9	10	11	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
1954																			
Apr. 25	0.12	0.10	0.15	(0.15)	0.20	0.20	0.10	(0.10)	0.15	(0.15)	------	0.12	0.11	0.15	0.15	0.20	0.20	0.11	0.10
Apr. 30	.50	.50	.48	(.48)	.57	.57	.42	(.42)	.47	(.45)	------	.50	.50	.48	.48	.57	.57	.43	.42
May 22	.20	.28	.30	(.30)	.25	.25	.18	(.18)	.27	.20	------	.20	.24	.30	.30	.25	.25	.21	.18
June 26	.14	.12	.17	.28	.15	.15	.05	(.05)	.08	.10	------	.14	.13	.20	.17	.15	.15	.06	.05
June 27	.03	.05	.03	(.03)	.08	.03	.04	(.04)	.05	.08	------	.03	.04	.03	.03	.08	.07	.04	.04
Aug. 12-13	.33	(.33)	.58	.83	.35	.44	.32	.60	.45	.23	------	.33	.33	.66	.58	.35	.37	.41	.43
Sept. 8	.58	.40	.47	.51	.48	.45	.43	.50	.47	.30	------	.58	.49	.48	.47	.48	.47	.45	.46
Sept. 12	.95	.72	.85	1.11	.93	.90	.88	1.10	.93	.52	------	.95	.84	.93	.85	.93	.92	.94	.97
Sept. 23-24	1.29	.93	.88	.70	.80	.80	.64	.70	.70	.50	------	1.29	1.12	.82	.88	.80	.80	.67	.67
Sept. 25	.21	.31	.21	.31	.30	.32	.25	.40	.27	.20	------	.21	.26	.24	.21	.30	.31	.29	.31
Oct. 4	.12	.12	.16	.20	.20	.15	.17	.30	.14	.17	------	.12	.12	.17	.16	.20	.19	.19	.22
Oct. 7	.10	.10	.15	.30	.12	.18	.30	.30	(.30)	.10	------	.10	.10	.20	.15	.12	.14	.30	.30
Oct. 9	.40	.40	.37	.40	.33	.40	.53	.34	.67	.05	------	.40	.40	.38	.37	.33	.35	.51	.45
Total, Apr. 1 to Oct. 31	4.97	4.36	4.80	5.60	4.76	4.84	4.31	5.03	4.95	3.05	------	4.97	4.68	5.04	4.80	4.76	4.79	4.61	4.60
1955																			
May 22	0.10	0.08	0.08	(0.08)	0.18	0	0.05	0	0	0.20	------	0.10	0.09	0.08	0.08	0.18	0.13	0.03	.03
May 26	0	0	.06	.10	0	0	.12	.15	.05	.09	------	0	0	.07	.06	0	0	.11	.13
June 4	0	0	0	(0)	0	0	.01	(0)	0	.16	------	0	0	0	0	0	0	.01	.01
June 14-15	.28	.27	.25	.40	.30	.31	.30	.40	.57	.37	------	.28	.28	.30	.25	.30	.30	.37	.34
July 25	1.32	1.25	1.31	1.34	1.40	1.24	1.25	1.41	1.30	.48	------	1.32	1.29	1.32	1.31	1.40	1.35	1.29	1.31
July 31	.10	.03	.30	(.23)	.07	0	.09	(.14)	.12	.12	------	.10	.07	.28	.30	.07	.05	.11	.11
Aug. 2	.15	.10	.20	(.20)	.21	.05	.10	(.16)	.10	0	------	.15	.13	.20	.20	.21	.17	.11	.13
Aug. 4	0	0	0	(0)	0	0	0	(0)	0	.10	------	0	0	0	0	0	0	0	0
Aug. 5	.05	.04	.05	(.09)	.09	0	.05	(.01)	.10	.10	------	.05	.05	.06	.05	.09	.07	.07	.03
Aug. 6	0	0	0	(0)	0	0	0	(0)	.07	.08	------	0	0	0	0	0	0	.01	0
Aug. 7	.42	.28	.50	(.62)	.40	.42	.37	(.48)	.41	.20	------	.42	.35	.54	.50	.40	.40	.40	.41
Aug. 8	0	0	0	(0)	0	0	.10	(.04)	0	.08	------	0	0	0	0	0	0	.07	.08
Aug. 9	0	0	0	(0)	0	0	0	(0)	.04	0	------	0	0	0	0	0	0	.01	0
Aug. 13	.30	.30	.20	(.45)	.37	.25	.26	(.35)	.32	.38	------	.30	.30	.28	.20	.37	.34	.29	.29
Aug. 16	.08	.05	.10	(.09)	.08	.11	.05	.10	0	.06	------	.08	.07	.10	.10	.08	.09	.05	.07
Aug. 24-25	.24	.30	.32	.36	.32	.30	.37	.40	.30	.14	------	.24	.27	.33	.32	.32	.31	.36	.38
Sept. 18	.20	.20	.27	.23	.29	.20	.16	.20	.31	.05	------	.20	.20	.26	.27	.29	.27	.20	.18
Oct. 4	0	0	0	0	0	0	0	0	0	.25	------	0	0	0	0	0	0	0	0
Total:																			
May 16 to Oct. 31	3.24	2.90	3.64	4.11	3.71	2.88	3.28	3.84	3.69	2.86	------	3.24	3.10	3.82	3.64	3.71	3.48	3.49	3.50
Nov. 1, 1954, to May 15, 1955	4.85	5.07	4.78	5.33	4.79	5.19	4.16	5 59	5.01	4.71	------	------	------	------	------	------	------	------	------

1956																			
Apr. 11	(0)	(0)	(0.17)	0.10	(0.05)	(0.05)	(0)	0	(0)	------	------	0	0	0.15	0.17	0.05	0.05	0	0
Apr. 27	(.08)	(.08)	(0)	0	(.08)	(.08)	(.10)	.10	(.06)	------	------	.08	.08	0	0	.08	.08	.09	.10
Apr. 28	(.07)	(.07)	(0)	0	(.07)	(.07)	(.10)	.10	(.06)	------	------	.07	.07	0	0	.07	.07	.09	.10
May 26	(.10)	(.10)	(.20)	.20	(.10)	(.10)	(.08)	0	(.05)	------	------	.10	.10	.20	.20	.10	.10	.06	.05
June 30	0	0	.05	0	0	.04	.07	0	.10	0	------	0	0	.03	.05	0	.01	.06	.04
July 1	0	.01	0	0	0	0	0	0	0	0	------	0	0	0	0	0	0	0	0
July 2	.12	.10	.14	.10	.15	.08	.13	.20	0	.10	------	.12	.11	.13	.14	.15	.13	.12	.16
July 12	.08	.09	.12	0	.03	.09	.02	0	.10	.02	------	.08	.08	.08	.12	.09	.05	.03	.01
July 22	0	0	0	.10	0	0	.03	0	0	0	------	0	0	.03	0	0	0	.02	.02
July 28	0	0	0	0	.08	.08	.04	0	0	.12	------	0	0	0	0	.08	.08	.02	.02
July 30	.60	.40	.55	.50	.47	.49	.54	.70	.60	1.30	------	.60	.50	.53	.55	.47	.47	.59	.60
July 31	.20	.17	.12	.10	.13	.10	.08	.10	.15	0	------	.20	.19	.11	.12	.13	.12	.10	.09
Aug. 1	.10	0	0	0	0	0	0	0	0	0	------	.10	.05	0	0	0	0	0	0
Aug. 14	(.04)	.06	0	0	0	.08	.04	0	0	0	------	(.04)	.05	0	0	0	.02	.02	.02
Aug. 15	(.26)	.33	.16	.20	.34	.50	.44	.50	.48	.28	------	.30	.31	.17	.16	.34	.38	.46	.46
Aug. 17	(0)	0	0	0	0	0	.02	0	0	0	------	0	0	0	0	0	0	.01	.01
Aug. 19	(.12)	0	0	0	.18	0	.06	0	0	.05	------	.12	0	0	0	.18	.13	.04	.04
Oct. 1	0	0	0	0	0	0	.12	0	0	0	------	0	0	0	0	0	0	.07	.07
Oct. 23	(.20)	(.18)	(.18)	.10	(.15)	(.18)	(.15)	.10	(.20)	(.14)	------	.20	.19	.15	.18	.15	.16	.15	.13
Oct. 24	(.20)	(.20)	(.20)	.10	(.15)	(.20)	(.20)	0	(.10)	(.14)	------	.20	.20	.17	.20	.15	.16	.14	.12
Oct. 29	(.20)	(.20)	(.20)	0	(.22)	(.20)	(.20)	.20	(.20)	(.16)	------	.20	.20	.14	.20	.22	.21	.20	.20
Total:																			
Apr. 1 to Oct. 31	2.37	1.99	2.09	1.50	2.20	2.34	2.42	2.00	2.10	2.34	------	2.41	2.13	1.89	2.09	2.26	2.22	2.27	2.24
Nov. 1, 1955 to Mar. 31, 1956	3.28	------	3.15	3.60	------	3.51	2.85	1.64	3.24	2.51	------	------	------	------	------	------	------	------	------
1957																			
May 8	0	0	0.08	(0.07)	0	0	0	(0)	(0)	0.08	------	0	0	0.07	0.08	0	0	0	0
May 10	.40	0	.30	(.28)	.05	.13	.07	(.11)	.05	(.10)	------	.40	.21	.29	.30	.05	.07	.07	.08
May 11	0	0	.20	(.19)	.23	.12	.18	(.28)	(.13)	(.20)	------	0	0	.20	.20	.23	.20	.19	.22
May 15	(.19)	.12	(.21)	(.20)	.18	.36	.22	(.34)	(.17)	(.20)	------	.19	.16	.21	.21	.18	.20	.24	.27
May 16	(.48)	(.30)	(.52)	(.49)	.25	.30	.34	(.53)	(.42)	.27	------	.48	.39	.51	.52	.25	.26	.40	.41
May 19	(.48)	.30	.30	(.28)	.19	.19	.28	(.43)	(.35)	.10	------	.48	.39	.29	.30	.19	.19	.33	.34
May 23	(.24)	.15	(.21)	(.20)	.05	.04	.08	(.13)	(.10)	.12	------	.24	.20	.21	.21	.05	.05	.10	.10
May 23–24	(.66)	.41	(.57)	(.54)	.39	.35	.30	(.46)	(.38)	.34	------	.66	.54	.56	.57	.39	.38	.35	.37
May 31	0	0	0	0	0	0	0	0	0	.10	------	0	0	0	0	0	0	0	0
June 10	0	0	(.05)	(.05)	.08	0	.05	(.05)	0	0	------	0	0	.05	.05	.08	.06	.04	.05
June 15	.46	(.41)	(.76)	(.70)	.43	.46	.70	(.74)	.52	.36	------	.46	.43	.74	.76	.43	.44	.68	.72
June 16	.10	(.09)	(.11)	(.10)	.06	.07	.10	(.11)	.04	.20	------	.10	.09	.11	.11	.06	.06	.09	.10
July 7	.10	.06	0	0	.06	.02	0	0	0	0	0	.10	.08	0	0	.06	.05	0	0
July 11	.07	.12	0	.10	.15	.15	.11	.10	.12	.09	.20	.07	.10	.03	0	.15	.15	.11	.11
July 12	0	.01	0	.10	0	.02	.03	.10	0	0	0	0	0	.03	0	0	0	.04	.06
July 18	.19	.18	.20	.10	.21	.15	.13	.20	.13	.08	0	.19	.19	.17	.20	.21	.19	.14	.16
July 27	(.13)	.13	.19	.20	.17	.11	.16	.20	.17	.20	.20	.13	.13	.19	.19	.17	.16	.16	.18
Aug. 4	(.22)	.22	.23	.10	.14	.29	.15	.40	.14	(.10)	.20	.22	.22	.19	.23	.14	.18	.21	.25
Aug. 5	(.42)	.42	.44	.80	.39	.44	.60	.40	.49	(.20)	.50	.42	.42	.56	.44	.39	.41	.54	.52
Aug. 6	(.02)	.02	0	0	0	.02	.02	0	0	(0)	0	.02	.02	0	0	0	0	.01	0
Aug. 7–8	(.50)	.50	.34	.60	1.18	1.17	.48	.60	.62	(.32)	.40	.50	.50	.42	.34	1.18	1.18	.60	.53
Aug. 8	(0)	0	0	0	0	.02	0	0	0	.33	0	0	0	0	0	0	0	0	0
Aug. 11	0	.03	.05	0	.03	0	0	0	0	0	0	0	.01	.03	.05	.03	.02	0	0
Aug. 19	.10	.01	.07	0	0	0	0	0	0	0	0	.10	.05	.05	.07	0	0	0	0
Aug. 20	.60	.54	.77	.60	.53	.68	.70	.60	.57	.50	.80	.60	.57	.71	.77	.53	.57	.64	.66
Aug. 21	.20	.16	0	0	.13	.04	.04	.20	.16	.13	.10	.20	.18	0	0	.13	.11	.10	.10
Aug. 21–22	.14	.14	0	.30	.09	.10	.07	.10	0	0	0	.14	.14	.10	0	.09	.09	.06	.08
Aug. 25	.04	.04	.02	0	.03	(.04)	.03	0	0	.20	.10	.04	.04	.01	.02	.03	.03	.02	.02
Aug. 26	.32	.35	.17	.30	.24	(.30)	(.14)	.30	.12	.14	.10	.32	.34	.22	.17	.24	.26	.17	.20

TABLE 21.—*Precipitation, Badger Wash*—Continued

[When numbers are shown in parentheses, no daily record was obtained and amount was estimated on basis of total catch or other records]

Date	Amount (inches)																		
	Gage number											Watershed							
	1	2	3	4	5	6	7	8	9	10	11	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
Aug. 29	.30	.33	.25	.40	.20	(.24)	.32	.40	.20	.19	.50	.30	.32	.30	.25	.20	.21	.32	.35
Aug. 30	.32	.37	.40	.30	.28	(.35)	.36	.40	.36	0	.30	.32	.35	.37	.40	.28	.30	.37	.37
Aug. 31	.08	.07	.07	.10	.05	(.06)	.05	.10	0	0	.10	.08	.07	.08	.07	.05	.05	.05	.07
Sept. 19-20	.08	.12	.13	.10	.08	.09	.08	.10	.10	.11	.10	.08	.10	.12	.13	.08	.08	.07	.09
Oct. 6	0	.06	0	0	0	0	.04	0	0	.06	.10	0	.03	0	0	0	0	.02	.02
Oct. 11	.05	(.06)	.09	.10	.08	.05	.05	.10	.07	0	.10	.05	.06	.10	.09	.08	.07	.06	.07
Oct. 12-13	.48	(.58)	.41	.60	.50	.60	.53	.70	.51	(.34)	.40	.48	.53	.47	.41	.50	.53	.56	.61
Oct. 14	0	(0)	(0)	0	0	.03	.04	0	0	0	.10	0	0	0	0	0	.01	.02	.02
Oct. 15	0	(0)	(0)	0	0	.02	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct. 18	.16	(.19)	(.20)	.30	.12	.20	.21	.30	.21	(.30)	.30	.16	.17	.23	.20	.12	.14	.23	.25
Oct. 20	.29	(.35)	(.27)	.40	.26	.38	.29	.30	.25	(.10)	.40	.29	.32	.31	.27	.26	.29	.29	.29
Oct. 21	.21	(.26)	(.20)	.30	.19	.20	.15	.30	.11	(.20)	.10	.21	.23	.24	.20	.19	.19	.18	.21
Total:																			
May 1, to Oct. 31	8.03	7.10	7.81	8.90	7.02	7.79	7.10	9.08	6.49	5.66	5.10	8.03	7.58	8.17	7.81	7.02	7.18	7.48	7.88
Nov. 1, 1956 to Apr. 30, 1957	5.87	------	5.32	5.90	------	6.10	5.25	------	5.87	------	------	------	------	------	------	------	------	------	------
1958																			
Apr. 4	0.10	0.09	(.10)	0.10	0.02	0.03	0	0.20	0.06	0	0.10	0.10	0.10	0.10	0.10	0.02	0.02	0.06	0.08
Apr. 23	0	.02	(.02)	(.02)	(.02)	(.02)	.02	(.02)	(.02)	(.02)	(.02)	0	.01	.02	.02	.02	.02	.02	.02
May 1	0	0	0	(0)	0	.02	.03	(0)	0	0	(0)	0	0	0	0	0	.01	.02	.03
May 11	.20	.17	.17	.10	.16	.15	.09	.20	.12	.14	.10	.20	.19	.15	.17	.16	.16	.12	.14
May 12	.10	0	0	(0)	0	0	0	(0)	0	0	(0)	.10	.05	0	0	0	0	0	0
June 6	.12	.14	.14	.20	.12	.18	.20	.30	.24	.32	.40	.12	.13	.12	.14	.12	.14	.23	.24
July 5	.01	.04	0	(0)	0	.03	.04	.10	0	0	(0)	.01	.02	0	0	0	.01	.05	.06
July 18	.12	.10	.10	(.10)	.10	.04	.03	(.04)	.06	.10	.10	.12	.11	.10	.10	.10	.08	.04	.03
July 26	.10	.12	.10	(.09)	.15	.12	.09	.20	.06	.06	.10	.10	.11	.10	.10	.15	.14	.11	.14
July 30	.04	.05	.06	(.06)	.06	.04	0	(.02)	.03	0	(0)	.04	.04	.06	.06	.06	.05	.01	.01
Aug. 17	.14	.15	.26	.20	.20	.18	.15	.20	.20	.52	.40	.14	.14	.24	.26	.20	.19	.17	.17
Aug. 21	.40	.40	.30	.30	.48	.38	.25	.40	.50	.35	.30	.40	.40	.30	.30	.48	.45	.33	.31
Sept. 12	.28	.28	.32	.20	.20	.25	.18	.30	.20	.18	.30	.28	.28	.28	.32	.20	.21	.21	.23
Sept. 13	0	0	0	.10	0	0	0	0	.02	0	(0)	0	0	.03	0	0	0	0	0
Sept. 23	.10	.09	.14	(.10)	.14	.17	.15	.10	.02	.03	.10	.10	.10	.14	.14	.14	.15	.11	.13
Sept. 24	.44	.44	.28	.40	.20	.33	.21	40	.30	.20	.30	.44	.44	.32	.28	.20	.23	.27	.29
Oct. 25	.18	.20	.14	.10	.20	(.20)	.13	.10	.10	.20	(.20)	.18	.19	.13	.14	.20	.20	.12	.12
Nov. 12	(.46)	.55	(.50)	.50	(.50)	(.50)	.52	.50	(.44)	(.50)	(.55)	.46	.50	.50	.50	.50	.50	.50	.51
Nov. 15	(.02)	.01	(.10)	.10	(.08)	(.06)	0	0	(0)	(.10)	(.05)	.02	.02	.10	.10	.08	.07	0	0
Nov. 16	(.02)	.02	(.02)	(.02)	(.02)	(.01)	0	0	(0)	(0)	(0)	.02	.02	.02	.02	.02	.02	0	0
Total:																			
Apr. 1 to Nov. 19	2.83	2.87	2.75	2.69	2.65	2.71	2.09	3.08	2.37	2.72	3.02	2.83	2.85	2.71	2.76	2.65	2.65	2.37	2.51
Nov. 1, 1957, to Mar. 31, 1958	------	6.40	5.73	6.14	------	6.63	------	6.40	------	5.60	5.97	------	------	------	------	------	------	------	------

Measured rainfall at Fruita and Grand Junction, Colo., the nearest Weather Bureau stations, should be similar to that at Badger Wash. Frequency curves (fig. 15) drawn on the basis of seasonal

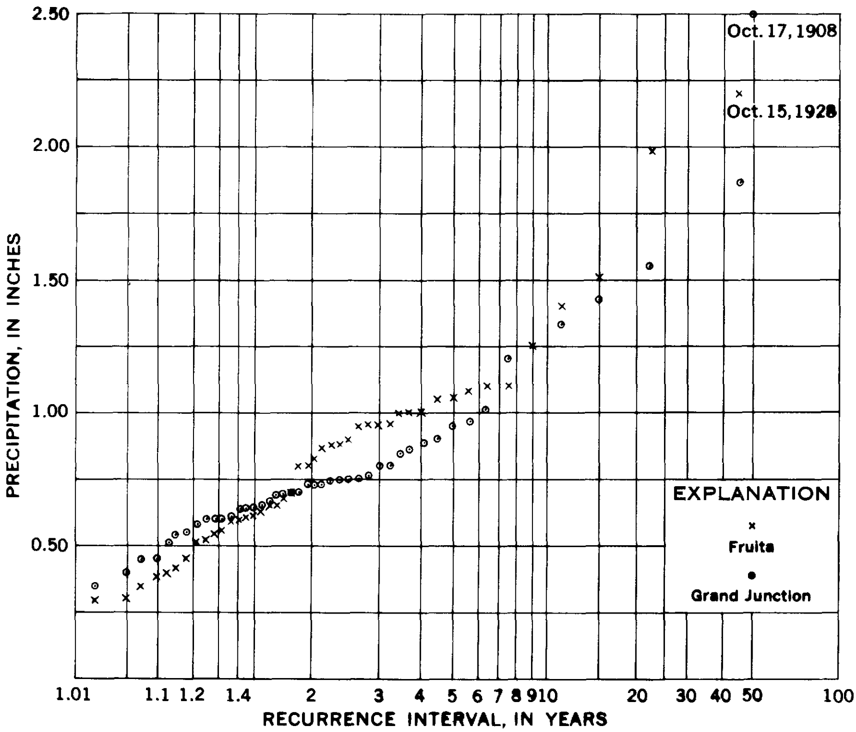


FIGURE 15.—Seasonal maximum daily rainfall (Apr.-Oct.) at Fruita and Grand Junction, Colo., period 1914–57.

maximum daily rainfall were plotted for both Weather Bureau stations using 44 years of record. The data were plotted on a graph designed so that data conforming to the theory of extreme-values would plot as a straight line. According to the theory, the mean of a large number of annual storms should equal the storm having a recurrence interval of 2.33 years. From this curve, the mean annual storm—one with a recurrence interval of 2.33 years—would appear to be about 0.80 inch. The storm of July 25, 1955, had a recurrence interval of about 10 years. Table 22 shows the frequency of occurrence of storms by size class at Fruita, Grand Junction, and Badger Wash. The amounts of precipitation at Badger Wash, which were computed as the average of the amounts received in the recording rain gages, seem to be similar to those at Fruita for the 5-year period 1954–58; both stations recorded a slightly smaller number of storms of the given size classes than indicated by the long-term mean.

TABLE 22.—*Occurrence of storms by size class*

Period	Average number of storms per season (April-October).				
	0.25–0.50	0.51–1.00	1.01–1.50	1.51–2.00	2.01–3.00
Fruita					
1914–57	5. 3	1. 7	0. 19	0. 05	0. 02
1954–58	4. 4	2. 0	. 20	0	0
Grand Junction					
1914–57	5. 0	1. 7	0. 14	0. 02	0
1954–58	5. 6	2. 2	0	0	0
Badger Wash					
1954–58	4. 6	1. 4	0. 20	0	0

RUNOFF

Runoff at Badger Wash occurs almost wholly in response to summer rainstorms. Winter precipitation, usually in the form of snow, does not produce appreciable runoff.

Runoff records (table 23) were obtained by measuring runoff stored in reservoirs. Topographic surveys of reservoirs in the 8 paired watersheds were made by Bureau of Reclamation personnel at the start of the study; a contour interval of 1 foot and a scale of 1 inch to 50 feet were used. Stage-capacity curves were constructed from the data of these surveys. Water-stage recorders were installed in four of the reservoirs, and records of water stage in the remaining reservoirs were obtained at time intervals frequent enough that a hydrograph could be drawn. The stage was obtained by measuring the slope distance to the water surface along a range from which the elevation of the water surface could be determined. Distance to high water marks was measured to obtain maximum contents. Stage-capacity curves were adjusted on the basis of periodic resurveys of the reservoirs. Location of reservoirs and type of instrumentation used is shown in plate 1.

TABLE 23.—*Storm runoff measured in observation reservoirs in Badger Wash, April 1954 to October 1958*

[Runoff for summer months only, April–October]

Observation reservoir 1-A

Location.—Lat 39°20′, long 108°56′, in sec. 24, T. 8 S., R. 104 W., near Mack, Mesa County, Colo.
Drainage area.—0.066 sq mi (42 acres).
Records available.—April 1954 to October 1958, summer months only.
Gage.—Reference mark. Crest stages noted; gage read once weekly or oftener. Elevation of reference mark is 5,055.8 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow computed from a stage-capacity curve of the reservoir.
Capacities.—Original capacity 8.30 acre-ft at spillway (gage height of 54.7 ft), survey of December 1953; capacity 7.52 acre-ft, surveys of July 1955 and November 1956; capacity 7.27 acre-ft, surveys of October 1957 and November 1958.
Maxima.—Maximum storm inflow 3.27 acre-ft, or 49.5 acre-ft per sq mi, July 25, 1955.
Remarks.—Records good.

Date [1]	Precipitation (inches)	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow	
					Acre-ft per sq mi	Inches
1954						
Sept. 8	0.58	0.02	0	0.02	0.30	0.01
Sept. 12	.95	1.01	0	1.01	15.3	.29
Sept. 23	1.29	2.24	0	2.24	33.9	.64
Oct. 7	.10	.19	0	.19	2.88	.05
Oct. 9	.40	.35	0	.35	5.30	.10
1955						
July 25	1.32	3.27	0	3.27	49.5	.94
Aug. 24	.24	.48	0	.48	7.27	.14
1957						
June 15	.46	.48	0	.48	7.27	.14
Aug. 5	.42	.58	0	.58	8.79	.17
Aug. 8	.50	.24	0	.24	3.64	.07
Aug. 20	.60	.69	0	.69	10.4	.20
Aug. 26	.32	.30	0	.30	4.55	.09
Aug. 29	.30	.21	0	.21	3.18	.06
Aug. 30	.32	.27	0	.27	4.09	.08
Oct. 12	.48	.44	0	.44	6.67	.13
Oct. 13	------------	.08	0	.08	1.21	.02
Oct. 18	.16	.12	0	.12	1.82	.03
Oct. 20	.29	.61	0	.61	9.24	.17
Oct. 22	.21	.03	0	.03	.45	.01

[1] No runoff in 1956 and 1958.

TABLE 23.—*Storm runoff measured in observation reservoirs in Badger Wash, April 1954 to October 1958*—Continued

Observation reservoir 1-B

Location.—Lat 39°20′, long 108°56′, in sec. 25, T. 8 S., R. 104 W., near Mack, Mesa County, Colo.
Drainage area.—0.084 sq mi (54 acres).
Records available.—April 1954 to October 1958, summer months only.
Gage.—Reference mark. Crest stages noted; gage read once weekly or oftener. Elevation of reference mark is 5,023.7 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow computed from a stage-capacity curve of the reservoir.
Capacitites.—Original capacity 19.8 acre-ft at spillway (gage height of 19.5 ft), survey of December 1953; capacity 19.2 acre-ft, surveys of July 1955, November 1956, October 1957, and November 1958.
Maxima.—Maximum storm inflow volume 3.30 acre-ft, or 39.3 acre-ft per sq mi, July 25, 1955.
Remarks.—Records good.

Date [1]	Precipitation (inches)	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow	
					Acre-ft per sq mi	Inches
1954						
Sept. 8	0.49	0.01	0	0.01	0.12	Tr
Sept. 12	.84	1.50	0	1.50	18.3	0.33
Sept. 23	1.12	2.15	0	2.15	25.6	.48
Oct. 7	.10	.25	0	.25	2.98	.06
Oct. 9	.40	.34	0	.34	4.05	.08
1955						
July 25	1.29	3.30	0	3.30	39.3	.73
Aug. 24	.27	.40	0	.40	4.76	.09
1957						
May 18	.39	.29	0	.29	3.45	.06
June 15	.43	.06	0	.06	.71	.01
Aug. 5	.22	.09	0	.09	1.07	.02
Aug. 8	.50	.94	0	.94	11.2	.21
Aug. 20	.57	1.22	0	1.22	14.5	.27
Aug. 26	.34	.83	0	.83	9.88	.18
Aug. 30	.35	.99	0	.99	11.8	.22
Oct. 12	.53	.37	0	.37	4.40	.08
Oct. 20	.32	1.00	0	1.00	11.9	.22

[1] No runoff in 1956 and 1958.

TABLE 23.—*Storm runoff measured in observation reservoirs in Badger Wash, April 1954 to October 1958*—Continued

Observation reservoir 2–A

Location.—Lat 39°19′, Long 108°57′, in sec. 36, T. 8 S., R. 104 W., near Mack, Mesa County, Colo.
Drainage area.—0.167 sq mi (107 acres).
Records available.—April 1954 to October 1958, summer months only.
Gage.—Water-stage recorder. Elevation of gage is 4,946.43 ft above mean sea level. Reservoir on side drainage in same watershed equipped with reference mark; crest stages noted. Gage read once weekly or oftener. Elevation of reference mark is 4,940 ft (from topographic map).
Runoff and discharge determinations.—Contents of reservoirs and volume of inflow computed from a stage-capacity curve of the reservoir.
Capacities.—Original capacity of main reservoir 6.30 acre-ft at spillway (gage height of 45.3 ft), survey of December 1953; capacity 4.47 acre-ft, surveys of July 1955 and November 1956; capacity 3.98 acre-ft, surveys of October 1957 and November 1958. Capacity of auxiliary reservoir 6.14 acre-ft at spillway (gage height of 44.7 ft), survey of December 1953. Capacity 5.71 acre-ft, surveys of July 1955, November 1956, October 1957, and November 1958.
Maxima.—Maximum storm inflow volume 7.71 acre-ft, or 46.2 acre-ft per sq mi, July 25, 1955. Inflow lasted 50 minutes.
Remarks.—Records good.

Date	Precipitation (inches)	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow	
					Acre-ft per sq mi	Inches
1954						
Aug. 13	.66	0.55	0	0.55	3.29	0.06
Sept. 8	.48	.20	0	.20	1.20	.02
Sept. 12	.93	3.19	0	3.19	19.1	.36
Sept. 23	.82	3.58	0	3.58	21.4	.40
Oct. 7	.20	.80	0	.80	4.79	.09
Oct. 9	.38	1.58	0	1.58	9.46	.18
1955						
July 25	1.33	7.71	0	7.71	46.2	.86
July 31	.28	1.12	0	1.12	6.71	.13
Aug. 2	.20	.06	0	.06	.36	.01
Aug. 7	.54	.92	0	.92	5.51	.10
Aug. 24	.33	.94	0	94	5.63	.11
Sept. 18	.26	.03	0	.03	.18	Tr
1956						
July 30	.53	.06	0	.06	.36	.01
Aug. 15	.17	.06	0	.06	.36	.01
Oct. 24	----------	.03	0	.03	.18	Tr
1957						
Apr. 16	----------	.10	0	.10	.60	.01
May 11	.20	.08	0	.08	.48	.01
May 15	.21	.08	0	.08	.48	.01
May 16	.51	.25	0	.25	1.50	.03
May 19	.29	.23	0	.23	1.38	.03
May 23	.21	.08	0	.08	.48	.01
May 24	.56	.74	0	.74	4.43	08
June 15	.74	1.18	0	1.18	7.07	.13
July 18	.17	.12	0	.12	.72	.01
Aug. 5	.56	1.04	0	1.04	6.23	.12
Aug. 8	.42	2.34	0	2.34	14.0	.26
Aug. 20	.71	.98	0	.98	5.87	.11
Aug. 26	.22	.65	0	.65	3.89	.07
Aug. 29	.30	.24	0	.24	1.44	.03
Aug. 30	.37	1.57	0	1.57	9.40	.18
Oct. 12	.47	.66	0	.66	3.95	.07
Oct. 18	.23	.04	0	.04	.24	Tr
Oct. 20	.31	1.50	0	1.50	8.98	.17
Oct. 21	.24	.01	0	.01	.06	Tr
Oct. 22	----------	.16	0	.16	.96	.02
1958						
Nov. 12	----------	.13	0	.13	.78	.01

TABLE 23.—*Storm runoff measured in observation reservoirs in Badger Wash, April 1954 to October 1958*—Continued

Observation reservoir 2-B

Location.—Lat 39°20′, long 108°57′, in sec. 25, T. 8 S., R. 104 W., near Mack, Mesa County, Colo.
Drainage area.—0.158 sq mi (101 acres).
Records available.—April 1954 to October 1958, summer months only.
Gage.—Water-stage recorder. Elevation of gage is 4,970 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow computed from a stage-capacity curve of the reservoir.
Capacities.—Original capacity 8.45 acre-ft at spillway (gage height of 68.8 ft), survey of December 1953; capacity 6.09 acre-ft, surveys of July 1955, November 1956, October 1957, and November 1958.
Maxima.—Maximum storm inflow volume 6.29 acre-ft, or 39.8 acre-ft per sq mi, July 25, 1955. Inflow lasted 90 minutes.
Remarks.—Records good.

Date [1]	Precipitation (inches)	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow	
					Acre-ft per sq mi	Inches
1954						
Aug. 13	0.58	0.71	0	0.71	4.49	0.08
Sept. 8	.47	.27	0	.27	1.71	.03
Sept. 12	.85	2.65	0	2.65	16.8	.32
Sept. 23	.88	3.47	0	3.47	22.0	.41
Oct. 7	.15	.65	0	.65	4.11	.08
Oct. 9	.37	1.28	0	1.28	8.10	.15
1955						
July 25	1.31	6.29	0	6.29	39.8	.75
July 31	.30	.30	0	.30	1.90	.04
Aug. 2	.20	.10	0	.10	.63	.01
Aug. 7	.50	.78	0	.78	4.94	.09
Aug. 24	.32	.61	0	.61	3.86	.07
Sept. 18	.27	.04	0	.04	.25	Tr
1957						
May 24	.57	.18	0	.18	1.14	.02
June 15	.76	.41	0	.41	2.59	.05
Do	------------	.10	0	10	.63	.01
July 18	.20	.02	0	.02	.13	Tr
Aug. 5	.44	.07	0	.07	.44	.01
Do	------------	.23	0	.23	1.46	.03
Aug. 8	.34	1.20	0	1.20	7.59	.14
Aug. 20	.77	.42	0	.42	2.66	.05
Aug. 22	------------	.01	0	.01	.63	Tr
Aug. 26	.17	.42	0	.42	2.66	.05
Aug. 29	.25	.06	0	.06	.38	.01
Aug. 30	.40	.05	0	.05	.32	.01
Do	------------	.86	0	.86	5.44	.10
Aug. 31	.07	.01	0	.01	.06	Tr
Oct. 12	.41	.49	0	.49	3.10	.06
Oct. 13	------------	.01	0	.01	.06	Tr
Oct. 18	.20	.01	0	.01	.06	Tr
Do	------------	.04	0	.04	.25	Tr
Oct. 20	.27	.35	0	.35	2.22	.04
Do	------------	.67	0	.67	4.24	.08
Oct. 21	.20	.01	0	.01	.06	Tr
Oct. 22	------------	.10	0	.10	.63	.01

[1] No runoff in 1956 and 1958.

TABLE 23.—*Storm runoff measured in observation reservoirs in Badger Wash, April 1954 to October 1958*—Continued

Observation reservoir 3-A

Location.—Lat 39°20′, long 108°56′, in sec. 25, T. 8 S., R. 104 W., near Mack, Mesa County, Colo.
Drainage area.—0.059 sq mi (38 acres).
Records available.—April 1954 to October 1958, summer months only.
Gage.—Reference mark. Crest stages noted; gage read once weekly or oftener. Elevation of reference mark is 5,031.5 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow computed from stage-capacity curve of the reservoir.
Capacities.—Original capacity 12.9 acre-ft at spillway (gage height of 29.5 ft), survey of December 1953; capacity 12.65 acre-ft, surveys of July 1955 and November 1956; capacity 12.55 acre-ft, surveys of October 1957 and November 1958.
Maxima.—Maximum storm inflow volume 2.98 acre-ft, or 50.5 acre-ft per sq mi, July 25, 1955.
Remarks.—Records good.

Date [1]	Precipitation (inches)	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow	
					Acre-ft per sq mi	Inches
1954						
Sept. 12	0.93	0.70	0	0.70	11.9	0.22
Sept. 23	.80	1.47	0	1.47	24.9	.46
Oct. 7	.12	.21	0	.21	3.56	.07
Oct. 9	.33	.45	0	.45	7.63	.14
1955						
July 25	1.40	2.98	0	2.98	50.5	.94
Aug. 24	.32	.30	0	.30	5.08	.09
Sept. 18	.29	.04	0	.04	.68	.01
1956						
Aug. 15	.34	.05	0	.05	.85	.02
1957						
May 24	.39	.02	0	.02	.34	.01
June 15	.43	.15	0	.15	2.54	.05
Aug. 5	.39	.15	0	.15	2.54	.05
Aug. 8	1.18	2.47	0	2.47	41.9	.78
Aug. 20	.53	.96	0	.96	16.3	.30
Aug. 26	.24	.48	0	.48	8.14	.15
Aug. 29	.20	.23	0	.23	3.90	.07
Aug. 30	.28	.90	0	.90	15.3	.28
Oct. 12	.50	1.18	0	1.18	20.0	.37
Oct. 20	.26	.66	0	.66	11.2	.21
Oct. 21	.19	.20	0	.20	3.39	.06

[1] No runoff in 1958.

TABLE 23.—*Storm runoff measured in observation reservoirs in Badger Wash, April 1954 to October 1958*—Continued

Observation reservoir 3-B

Location.—Lat 39°20′, long 108°56′, in sec. 25, T. 8 S., R. 104 W., near Mack, Mesa County, Colo.
Drainage area.—0.048 sq mi (31 acres).
Records available.—April 1954 to October 1958, summer months only.
Gage.—Reference mark. Crest stages noted; gage read once weekly or oftener. Elevation of reference mark is 5,013.67 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow computed from a stage-capacity curve of the reservoir.
Capacities.—Original capacity 8.10 acre-ft at spillway (gage height of 9.5 ft), survey of December 1953: capacity 7.70 acre-ft, surveys of July 1955 and November 1956; capacity 7.66 acre-ft, surveys of October 1957 and November 1958.
Maxima.—Maximum storm runoff volume 2.38 acre-ft, or 49.6 acre-ft per sq mi, July 25, 1955.
Remarks.—Records good.

Date [1]	Precipitation (inches)	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow	
					Acre-ft per sq mi	Inches
1954						
Sept. 12	0.92	0.70	0	0.70	14.6	0.27
Sept. 23	.80	.83	0	.83	17.3	.32
Oct. 7	.14	.18	0	.18	3.75	.07
Oct. 9	.35	.43	0	.43	8.96	.17
1955						
July 25	1.35	2.38	0	2.38	49.6	.92
Aug. 24	.31	.26	0	.26	5.42	.10
Sept. 18	.27	.07	0	.07	1.46	.03
1956						
Aug. 15	.38	.05	0	.05	1.04	.02
1957						
May 24	.38	.14	0	.14	2.92	.05
June 15	.44	.24	0	.24	5.00	.09
Aug. 5	.41	.24	0	.24	5.00	.09
Aug. 8	1.18	1.74	0	1.74	36.2	.67
Aug. 20	.57	.33	0	.33	6.88	.13
Aug. 26	.26	.30	0	.30	6.25	.12
Aug. 30	.30	.43	0	.43	8.96	.17
Oct. 12	.53	.86	0	.86	17.9	.33
Oct. 20	.29	.33	0	.33	6.88	.13
Oct. 21	.19	.03	0	.03	.62	.01

[1] No runoff in 1958.

TABLE 23.—*Storm runoff measured in observation reservoirs in Badger Wash, April 1954 to October 1958*—Continued

Observation reservoir 4–A

Location.—Lat 39°19′, long 108°56′, in sec. 36, T. 8 S., R. 104 W., near Mack, Mesa County, Colo.
Drainage area.—0.022 sq mi (14 acres).
Records available.—April 1954 to October 1958, summer months only.
Gage.—Water-stage recorder. Elevation of reference mark is 4,944.83 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow computed from a stage-capacity curve of the reservoir.
Capacities.—Original capacity 3.05 acre-ft at spillway (gage height of 44.5 ft), survey of December 1953; capacity 2.55 acre-ft, surveys of July 1955 and November 1956; capacity 2.35 acre-ft, surveys of October 1957 and November 1958.
Maxima.—Maximum storm inflow volume 1.20 acre-ft, or 54.5 acre-ft per sq mi, July 25, 1955. Inflow time 45 minutes.
Remarks.—Records good.

Date	Precipitation (inches)	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow	
					Acre-ft per sq mi	Inches
1954						
Sept. 12	0.94	0.30	0	0.30	13.6	0.26
Sept. 23	.67	.43	0	.43	19.5	.37
Sept. 25	.29	.07	0	.07	3.18	.06
Oct. 7	.30	.21	0	.21	9.55	.18
Oct. 9	.51	.06	0	.06	2.73	.05
1955						
July 25	1.29	1.20	0	1.20	54.5	1.03
July 31	.11	.01	0	.01	.45	.01
Aug. 2	.11	.01	0	.01	.45	.01
Aug. 7	.40	.19	0	.19	8.64	.16
Aug. 8	.07	.01	0	.01	.45	.01
Aug. 24	.36	.08	0	.08	3.64	.07
Sept. 18	.20	.01	0	.01	.45	.01
1956						
Aug. 15	.46	.03	0	.03	1.36	.03
1957						
May 16	.40	.01	0	.01	.45	.01
May 19	.33	.07	0	.07	3.18	.06
May 24	.35	.04	0	.04	1.82	.03
June 15	.68	.21	0	.21	9.55	.18
Aug. 5	.54	.14	0	.14	6.36	.12
Aug. 8	.60	.49	0	.49	21.8	.42
Aug. 20	.64	.05	0	.05	2.27	.04
Aug. 26	.17	.01	0	.01	.45	.01
Aug. 30	.37	.02	0	.02	.91	.02
Do	----------	.16	0	.16	7.27	.14
Oct. 12	.56	.12	0	.12	5.45	.10
Oct. 13	----------	.03	0	.03	1.36	.03
Oct. 20	.29	.15	0	.15	6.82	.13
Oct. 22	.18	.01	0	.01	.45	.01
1958						
Nov. 12	----------	.03	0	.03	1.36	.03

TABLE 23.—*Storm runoff measured in observation reservoirs in Badger Wash, April 1954 to October 1958*—Continued

Observation reservoir 4–B

Location.—Lat 39°19′, long 108°56′, in sec. 36, T. 8 S., R. 104 W., near Mack, Mesa County, Colo.
Drainage area.—0.019 sq mi (12 acres).
Records available.—April 1954 to October 1958, summer months only.
Gage.—Water-stage recorder. Elevation of reference mark is 4,969.96 ft above mean sea level.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow computed from a stage-capacity curve of the reservoir.
Capacities.—Original capacity 4.52 acre-ft at spillway (gage height of 68.5 ft), survey of December 1953; capacity 4.26 acre-ft, surveys of July 1955 and November 1956; capacity 4.18 acre-ft, surveys of October 1957 and November 1958.
Maxima.—Maximum inflow 48.0 cfs, 5:45 p.m., July 25, 1955. Maximum storm inflow volume 0.77 acre-ft, or 40.5 acre-ft per sq mi, July 25, 1955.
Remarks.—Records good.

Date [1]	Precipitation (inches)	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow	
					Acre-ft per sq mi	Inches
1954						
Sept. 12	0.97	0.22	0	0.22	11.6	0.22
Sept. 23	.67	.30	0	.30	15.8	.30
Sept. 25	.31	.04	0	.04	2.11	.04
Oct. 7	.30	.17	0	.17	8.95	.17
Oct. 9	.45	.07	0	.07	3.68	.07
1955						
July 25	1.31	.77	0	.77	40.5	.77
Aug. 7	.41	.11	0	.11	5.79	.11
Aug. 24	.38	.04	0	.04	2.11	.04
1957						
May 19	.34	.01	0	.01	.53	.01
May 24	.37	.02	0	.02	1.05	.02
June 15	.72	.06	0	.06	3.16	.06
Do	------	.03	0	.03	1.58	.03
June 16	.10	Tr	0	Tr	------	Tr
Aug. 5	.52	.04	0	.04	2.11	.04
Do	------	.06	0	.06	3.16	.06
Aug. 8	.53	.30	0	.30	15.8	.30
Aug. 20	.66	.01	0	.01	.53	.01
Aug. 26	.20	.04	0	.04	2.11	.04
Aug. 29	.35	Tr	0	Tr	------	Tr
Aug. 30	.37	.02	0	.02	1.05	.02
Do	------	.01	0	.01	.53	.01
Do	------	.10	0	.10	5.26	.10
Aug. 31	.07	Tr	0	Tr	------	Tr
Oct. 12	.61	.13	0	.13	6.84	.13
Oct. 13	------	.01	0	.01	.53	.01
Oct. 18	.25	.01	0	.01	.53	.01
Oct. 20	.29	.04	0	.04	2.11	.04
Do	------	.08	0	.08	4.21	.08
Oct. 21–22	.21	.02	0	.02	1.05	.02

[1] No runoff in 1956 and 1958.

Runoff into all reservoirs during the 5-year period 1954–58 is shown in table 24. Storm runoff into the reservoirs located in the eight paired watersheds and a station description for each reservoir are given in table 23. Table 25 contains information on precipitation, runoff, and runoff ratios for paired watersheds during the 1954–58 summer seasons. The runoff ratio in table 25 is computed by dividing unit runoff from the grazed area by that from the ungrazed area. The pairs of watersheds in which the reservoirs are equipped with continuous water-stage recorders show a general increase in this ratio from year to year, ranging from 1.04 to 1.99 in 2–A and 2–B and 1.15 to 1.32 in 4–A and 4–B. The watersheds in which reservoir contents are measured manually do not indicate a continual increase in the ratio. The runoff ratio 1–A to 1–B was 1.14 in 1954, 1.29 in 1955, and 0.89 in 1957. The ratio 3–A to 3–B was 1.08 in 1954, 1.00 in 1955, 0.82 in 1956, and 1.29 in 1957. This difference in ratios may be partly attributable to the lower accuracy in determining runoff in reservoirs without recorders.

TABLE 24.—*Runoff and sediment yield*

Watershed	Drainage area (sq mi)	Runoff (acre-ft)					Sediment yield		
							1954–58		Average annual
		1954	1955	1956	1957	1958	Acre-ft	Acre-ft per sq mi	Acre-ft per sq mi
1-A	0.066	3.81	3.75	0	4.05	0	0.95	14.4	2.88
1-B	.084	4.25	3.70	0	5.79	0	.63	7.50	1.50
2-A	.167	9.90	10.78	0.15	12.05	0.13	2.76	16.5	3.30
2-B	.158	9.03	8.12	0	5.72	0	2.51	15.9	3.18
3-A	.059	2.83	3.32	.05	7.40	0	.84	14.2	2.84
3-B	.048	2.14	2.71	.05	4.64	0	.45	9.38	1.88
4-A	.022	1.07	1.51	.03	1.51	.03	.66	30.0	6.00
4-B	.019	.80	.92	0	.99	0	.36	18.9	3.78
5	.055	2.21	1.95	0	2.18	.08	.21	3.82	1.27
6	.220	9.55	8.30	0	10.4	0	2.71	12.3	2.46
7	.094	3.41	3.72	0	3.83	0	.75	7.98	1.60
8	.109	3.63	4.84	0	5.19	0	.92	8.44	1.69
9	.313	11.29	19.09	1.41	18.2	0	2.40	7.67	1.53
10	.100	2.64	2.63	0	2.65	Tr	.55	5.50	1.10
11	.089	4.39	6.16	1.35	10.5	.26	.75	8.43	1.69
12	.092	4.47	8.15	5.14	10.3	1.14	1.56	17.0	3.40
13	.484	13.44	14.3	15.5	22.9	1.44	3.89	8.04	1.61
14	1.53	--------	--------	--------	85.2	1.74	2.17	1.42	1.14

TABLE 25.—*Seasonal precipitation and runoff for paired watersheds*

Watershed	Season precipitation (inches)	Runoff		
		Acre-ft	Acre-ft per sq mi	Ratio (grazed / ungrazed)
1954				
1-A	4.97	3.81	57.7	1.14
1-B	4.68	4.25	50.6	
2-A	5.04	9.90	59.3	1.04
2-B	4.80	9.03	57.2	
3-A	4.76	2.83	48.0	1.08
3-B	4.79	2.14	44.6	
4-A	4.61	1.07	48.6	1.15
4-B	4.60	.80	42.1	
1955				
1-A	3.24	3.75	56.8	1.29
1-B	3.10	3.70	44.0	
2-A	3.82	10.78	64.6	1.26
2-B	3.64	8.12	51.4	
3-A	3.71	3.32	56.3	1.00
3-B	3.48	2.71	56.5	
4-A	3.49	1.51	68.6	1.42
4-B	3.50	.92	48.4	
1956				
1-A	2.12	0	0	0
1-B	1.94	0	0	
2-A	1.90	.15	.90	--------
2-B	2.09	0	0	
3-A	1.90	.05	.85	.82
3-B	1.82	.05	1.04	
4-A	2.28	.03	1.36	--------
4-B	2.29	0	0	
1957				
1-A	8.03	4.05	61.4	.89
1-B	7.58	5.79	68.9	
2-A	8.17	12.05	72.2	1.99
2-B	7.81	5.72	36.2	
3-A	7.02	7.40	125	1.29
3-B	7.18	4.64	96.7	
4-A	7.48	1.51	68.6	1.32
4-B	7.88	.99	52.1	
1958				
1-A	2.95	0	0	0
1-B	2.95	0	0	
2-A	2.74	.13	.78	--------
2-B	2.69	0	0	
3-A	2.69	0	0	0
3-B	2.71	0	0	
4-A	2.41	.03	1.36	--------
4-B	2.54	0	0	

Figures 16–19 are double-mass curves of precipitation and runoff and were compiled from information given in tables 25 and 26. The double-mass curve is drawn by plotting the sum, year by year, of amounts of runoff and precipitation on grazed versus ungrazed area. If the runoff and precipitation for each pair of watersheds were equal, the points would plot on the line of equal runoff and precipitation. Curves for all watershed pairs except 1–A and 1–B indicate an increasing divergence between runoff and precipitation lines in the direction of the grazed watersheds.

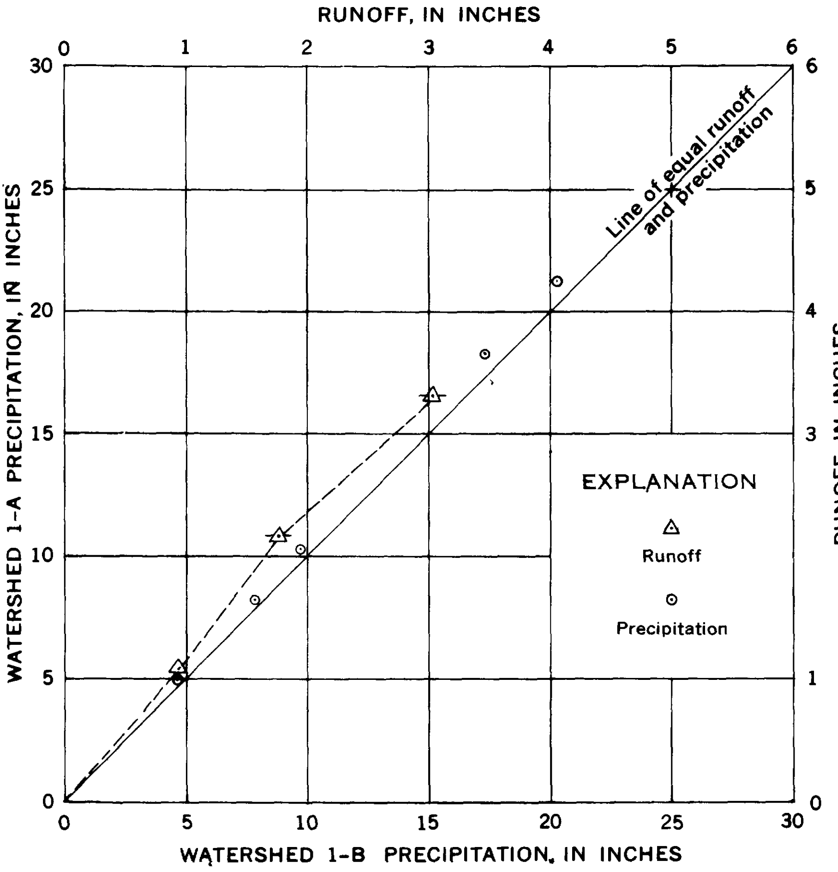


FIGURE 16.—Mass diagram of runoff and precipitation, watersheds 1–A and 1–B.

Table 26 indicates the amounts of precipitation in inches received during runoff events, the runoff in inches, and a ratio of runoff to precipitation. This ratio, which in effect is a percentage of actual storm precipitation that occurs as runoff, is included to show any inequities because of difference in rainfall between watersheds. Although some slight differences are apparent, the general trend is the same as indicated in table 25.

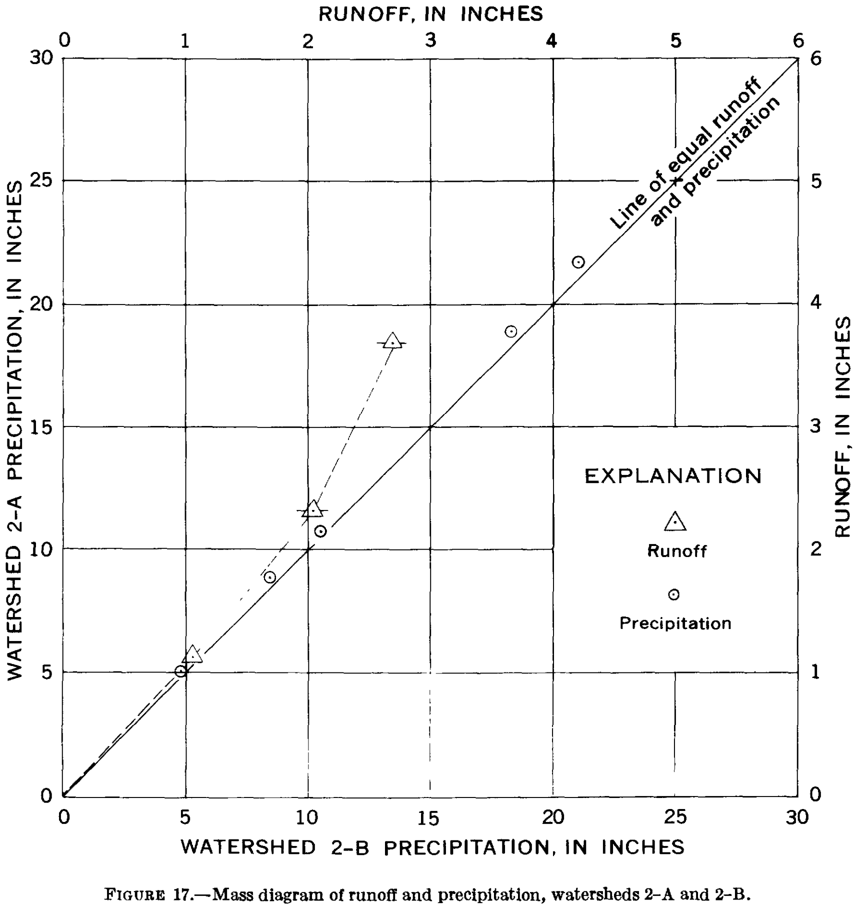


FIGURE 17.—Mass diagram of runoff and precipitation, watersheds 2-A and 2-B.

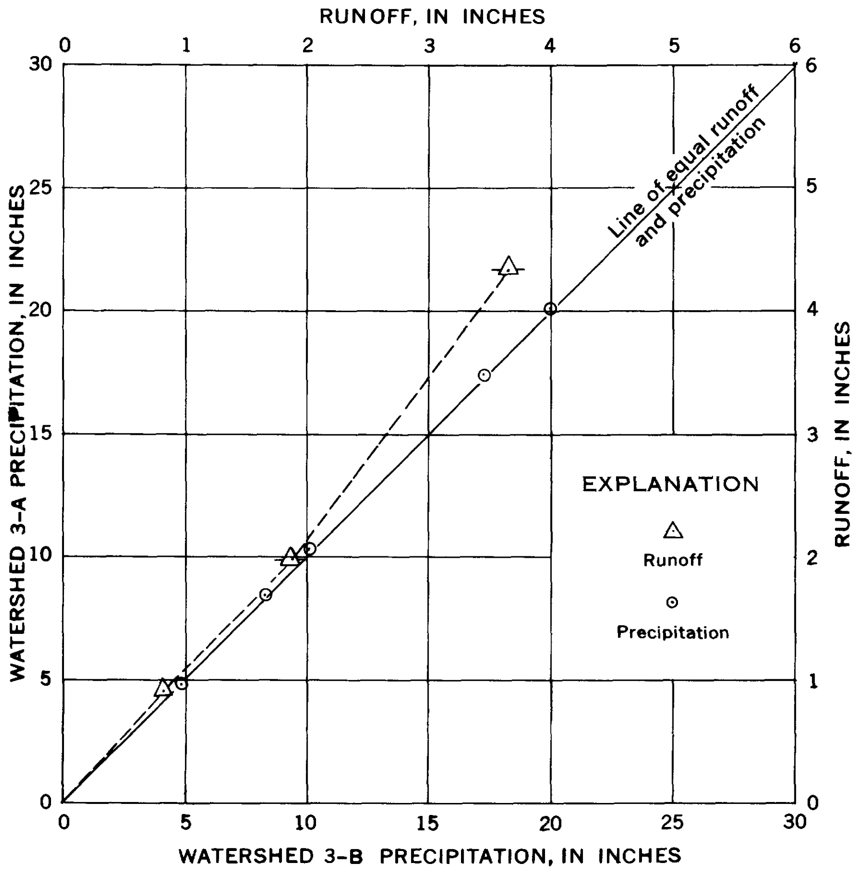


FIGURE 18.—Mass diagram of runoff and precipitation, watersheds 3-A and 3-B.

TABLE 26.—*Ratio of runoff to precipitation*

[Values for precipitation are the parts of total seasonal precipitation that occur during runoff events]

Watershed	Precipitation (inches)	Runoff (inches)	Ratio (runoff / precipitation)
1954			
1-A	3.32	1.08	0.328
1-B	2.95	.95	.322
2-A	3.47	1.11	.320
2-B	3.30	1.07	.303
3-A	2.18	.90	.408
3-B	2.21	.84	.376
4-A	2.71	.91	.339
4-B	2.70	.79	.296

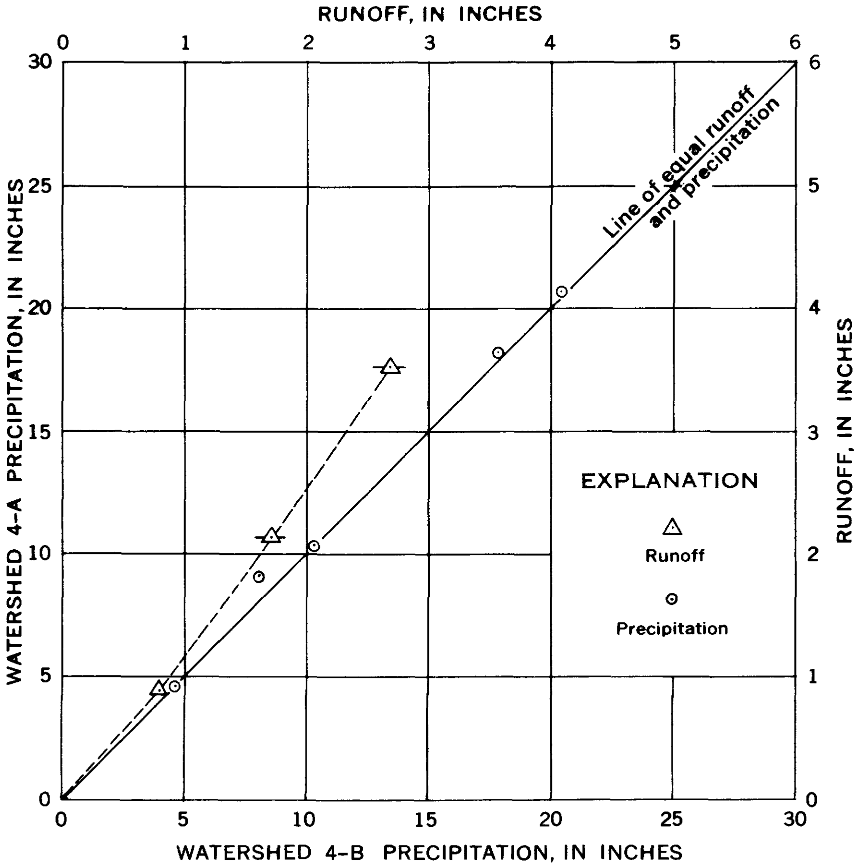


FIGURE 19.—Mass diagram of runoff and precipitation, watersheds 4-A and 4-B.

TABLE 26.—*Ratio of runoff to precipitation*—Continued

[Values for precipitation are the parts of total seasonal precipitation that occur during runoff events]

Watershed	Precipitation (inches)	Runoff (inches)	Ratio (runoff / precipitation)
	1955		
1–A	1.56	1.06	0.692
1–B	1.56	.82	.526
2–A	2.93	1.21	.413
2–B	2.90	.96	.334
3–A	2.01	1.06	.517
3–B	1.93	1.06	.544
4–A	2.54	1.29	.512
4–B	2.60	.91	.354

TABLE 26.—*Ratio of runoff to precipitation*—Continued

[Values for precipitation are the parts of total seasonal precipitation that occur during runoff events]

	Precipitation (inches)	Runoff (inches)	Ratio (runoff / precipitation)
1956			
1-A	0	0	0
1-B	0	0	0
2-A	-----------	.02	-----------
2-B	-----------	0	-----------
3-A	.34	.02	.059
3-B	.38	.02	.053
4-A	.46	.03	.065
4-B	.46	0	0
1957			
1-A	3.39	1.15	0.345
1-B	3.26	1.29	.393
2-A	6.72	1.35	.201
2-B	6.42	.68	.104
3-A	4.59	2.34	.508
3-B	4.76	1.81	.376
4-A	5.80	1.29	.224
4-B	5.56	.98	.178
1958			
1-A	0	0	0
1-B	0	0	0
2-A	-----------	.01	-----------
2-B	-----------	0	-----------
3-A	0	0	0
3-B	0	0	0
4-A	-----------	.03	-----------
4-B	-----------	0	-----------

Maximum rates of inflow for the period of record were determined for reservoirs equipped with water-stage recorders by computing change of volume with time. These rates were as follows: 2-A, 284 cfs, or 1,920 cfs per square mile; 2-B, 165 cfs, or 1,050 cfs per square mile; 4-A, 27.3 cfs, or 1,240 cfs per square mile; 4-B, 36 cfs, or 1,890 cfs per square mile. Each of these runoff events occurred on July 25, 1955. Although the inflow rates mentioned are the maximum recorded during the 5-year period, all runoff events have been characterized by high rates of inflow for short periods.

EROSION AND SEDIMENT YIELDS

Nine reservoirs in the paired watersheds were surveyed during the winter of 1953 by Bureau of Reclamation personnel, and the remainder were surveyed in June 1954 by Geological Survey personnel. No runoff occurred between these surveys. Reservoirs were resurveyed in July 1955, November 1956, October 1957, and November 1958. Table 27 indicates dates of surveys and amounts of sediment received by the reservoirs.

Maximum unit sediment yield of 30.0 acre-feet per square mile for the 5-year period occurred in watershed 4–A. Minimum 5-year yield in the paired watersheds was 7.41 acre-feet per square mile in watershed 1–B.

TABLE 27.—*Sediment yield during periods between surveys*

Watershed	April 1954 to July 1955		July 1955 to November 1956		November 1956 to October 1957		October 1957 to November 1958		April 1954 to November 1958	
	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi	Acre-ft	Acre-ft per sq mi
1-A	0.71	10.8	0	0	0.25	3.80	0	0	0.96	14.5
1-B	.63	7.41	0	0	0	0	0	0	.63	7.41
2-A	2.35	14.1	0	0	.41	2.46	0	0	2.76	16.5
2-B	2.40	15.3	0	0	.11	.70	0	0	2.51	16.0
3-A	.74	12.5	0	0	.10	1.70	0	0	.84	14.2
3-B	.41	8.37	0	0	.04	.82	0	0	.45	9.18
4-A	.45	20.4	0	0	.21	9.55	0	0	.66	30.0
4-B	.28	14.7	0	0	.08	4.21	0	0	.36	18.9
5	--------	--------	[1].21	3.82	--------	--------	0	0	.21	3.82
6	--------	--------	[1]1.63	7.41	1.08	4.91	0	0	2.71	12.3
7	--------	--------	[1].67	7.13	.08	.85	0	0	.75	7.98
8	--------	--------	[1].69	6.33	.23	2.11	0	0	.92	8.44
9	--------	--------	[1]2.25	7.20	.14	.45	0	0	2.39	7.64
10	--------	--------	[1].45	4.50	.10	1.00	0	0	.55	5.50
11	--------	--------	[1].53	5.96	.22	2.47	0	0	.75	8.43
12	--------	--------	[1]1.07	11.6	.49	5.33	0	0	1.56	17.0
13	--------	--------	[1]2.40	4.97	1.41	2.92	0	0	3.81	7.88
14	--------	--------	--------	--------	--------	--------	[2]2.17	1.42	--------	--------

[1] Sediment in acre-feet for period April 1954 to November 1956.
[2] Sediment in acre-feet for period July 1957 to November 1958.

Table 28 compares runoff and sediment yield in paired watersheds for periods between reservoir surveys. A ratio of sediment to runoff is indicated for each of the reservoirs. This ratio, which is in effect a sediment concentration, illustrates the effect of different size and type of storm on sediment yield. Most of the sediment deposited in the reservoirs during the period April 1954 to July 1955 was deposited during the storm of July 25, 1955. Although runoff during the period November 1956 to October 1957 was somewhat less than that during the period April 1954 to July 1955, the difference in sediment yield was greater. This difference was caused mainly by the type of storms that occurred during each period. A few fairly large storms occurred during the first period, the largest of which was the storm of July 25, 1955. On the other hand, many small storms occurred during the 1957 season, but these storms, although they produced considerable runoff, did not produce a large amount of sediment.

Samples of sediment deposited in 10 reservoirs were obtained in July 1958 and checked for density and grain-size distribution. Results of tests for four reservoirs are shown in table 29.

TABLE 28.—*Runoff and sediment yield, in acre-feet, during periods between surveys*

[Sediment accumulation not measurable where 0 is shown in sediment column]

Watershed	April 1954 to July 1955			July 1955 to November 1956			November 1956 to October 1957			October 1957 to November 1958		
	Runoff	Sediment	Ratio (sediment/runoff)	Runoff	Sediment	Ratio (sediment/runoff)	Runoff	Sediment	Ratio (sediment/runoff)	Runoff	Sediment	Ratio (sediment/runoff)
1-A	7.08	0.71	0.100	0.48	0	0	4.05	0.25	0.062	0	0	0
1-B	7.55	.63	.083	.40	0	0	5.79	0	0	0	0	0
2-A	17.61	2.35	.133	3.22	0	0	12.05	.41	.034	.13	0	0
2-B	15.32	2.40	.157	1.83	0	0	5.72	.11	.019	0	0	0
3-A	5.81	.74	.127	.39	0	0	7.40	.10	.014	0	0	0
3-B	4.52	.41	.091	.38	0	0	4.64	.04	.009	0	0	0
4-A	2.27	.45	.198	.34	0	0	1.51	.21	.139	.03	0	0
4-B	1.57	.28	.178	.15	0	0	.99	.08	.081	0	0	0

TABLE 29.—*Density and grain-size distribution of reservoir sediments*

Hole	Sample	Depth below surface (feet)	Density (lb per cu ft)	Percent moisture by weight	Percent			
					Clay	Silt	Sand	Gravel
Watershed 2-A								
1	1	0.5	77.95	20.18	34	60	6	0
1	2	1.5	90.96	18.62	18	79	3	0
2	1	0	90.36	8.16	13	53	34	0
2	2	1.0	83.84	17.45	18	64	18	0
Average			85.8		21	64	15	0
Watershed 2-B								
1	1	0.5	93.39	21.61	39	57	4	0
1	2	1.5	85.18	14.12	12	33	55	0
2	1	.25	71.23	17.59	25	46	29	0
2	2	1.3	79.27	18.58	23	44	33	0
Average			82.3		25	45	30	0
Watershed 4-A								
1	1	0	91.99	.88	7	23	59	11
1	2	.75	89.34	4.98	15	42	42	1
2	1	.25	86.17	18.17	37	60	3	0
2	2	1.3	87.25	12.10	28	57	15	0
Average			88.69		22	46	30	3
Watershed 4-B								
1	1	0.3	82.30	15.31	37	63	0	0
1	2	1.3	91.04	8.49	19	47	34	0
2	1	.175		4.55	38	57	5	0
Average			86.67		31	56	13	0

The procedure by which density values were obtained was as follows:

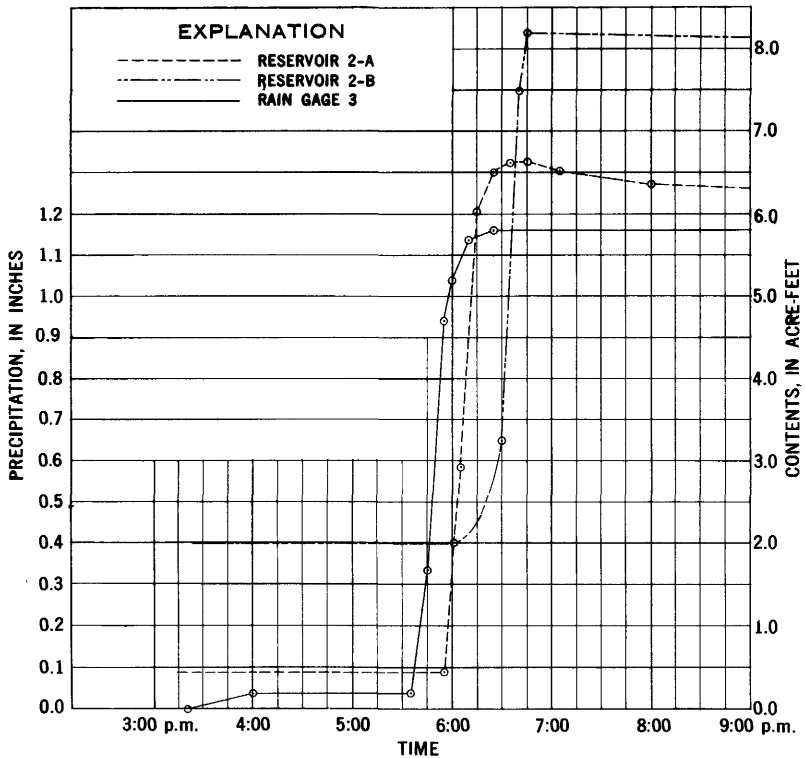
A sample of deposited sediment was removed from the bottom of the reservoir and retained in a moisture-tight container. A flexible diaphragm was placed over the cavity formed by removal of the sample. The diaphragm was then forced outward by water under pressure from a reservoir until it filled the hole so that all air spaces were occupied. The volume of the cavity was read directly from a graduated scale on the water reservoir. The sediment samples were then weighed, all the moisture was removed by heating in an oven, and the samples were weighed again. Percent moisture by by weight and density in pounds per cubic foot were computed from these figures.

Grain-size distribution in the sediment samples was obtained by mechanical sieve analysis for the coarse fraction and hydrometer analysis for the fine.[5] Samples were taken in reservoirs at locations that were intended to give an average value for the total sediment deposit. For the four reservoirs sampled (table 29), sediment deposits were composed of 69 to 79 percent silt and sand and 21 to 31 percent clay. A small amount of gravel was obtained from the upper end of the reservoir in watershed 4–A.

An attempt was made to determine the infiltration rate in four of the watersheds in which the reservoirs are equipped with water-stage recorders. This was done by determining an infiltration index (Langbein and others, 1947), also called the ϕ index, which is defined as the average rate of rainfall such that the volume of rainfall at greater rates equals the total direct runoff. An example of this determination is shown in figure 20. The precipitation during selected time intervals was determined from recording rain gages representative of the area. The precipitation excess (P_e) for each of several assumed infiltration rates (f) was then computed as the sum of the volumes of precipitation in each time interval at rates greater than the assumed rate. The precipitation-excess values so computed were plotted against the assumed infiltration rates. A smooth curve drawn through these points was then used to determine the infiltration index as the rate corresponding to the actual precipitation excess—the direct runoff—for the storm. This infiltration index, or ϕ index, differs from an infiltration rate in that it includes the effects of interception and surface storage.

Values of the ϕ index for all storms on which good records were available are given in table 30. It is apparent from this table that the ϕ index is extremely variable for different storms in the same watershed and for the same storm in different watersheds. Each storm

[5] Size classification is as follows: Clay, smaller than 2 microns; silt, 2 to 50 microns; sand, 50 to 2,000 microns; and gravel, larger than 2,000 microns.



Period (minutes)	Precipitation: Inches	Precipitation: Inches per hour	Precipitation minus f: f=0.90	f=0.70	f=0.50	f=0.20
10	0.30	1.80	0.150	0.183	0.217	0.267
10	.60	3.60	.450	.483	.517	.567
5	.10	1.20	.025	.042	.058	.083
10	.10	.60	0	0	.017	.067
15	.02	.08	0	0	0	0
Totals	1.12	------	.625	.708	.809	.984

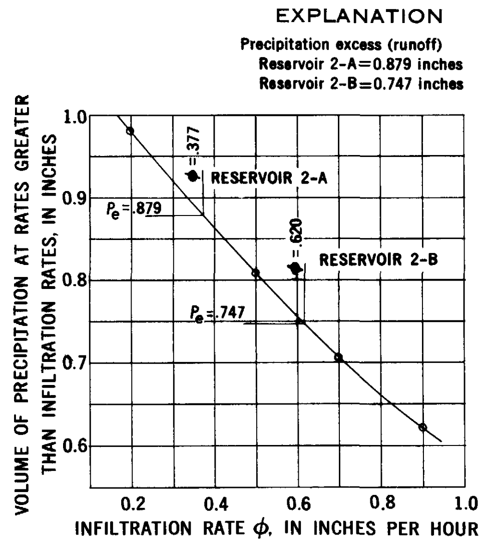


FIGURE 20.—Example of determination of infiltration index.

has its own characteristics, and runoff is determined by several variables. An effort was made to relate the ϕ index to the effects of grazing. The indexes for each watershed were averaged by years, and the average for each watershed was divided by the average for the adjacent grazed watershed. This ratio for watersheds 2–A and 2–B was 1.10 in 1954, 1.63 in 1955, and 1.40 in 1957, and for watersheds 4–A and 4–B was 1.13 in 1954, 1.71 in 1955, and 1.50 in 1957.

TABLE 30.—*Infiltration index (ϕ index)*

Date of storm	Watershed		Ratio $\left(\frac{\text{Ungrazed}}{\text{grazed}}\right)$
	2–A	2–B	
Sept. 23, 1954	0.42	0.46	1.10
July 25, 1955	.38	.62	1.63
July 18, 1957	.51	.59	1.16
Aug. 5, 1957	.35	.43	1.23
Do	.14	.19	1.36
Aug. 8, 1957	1.84	3.08	1.67
Aug. 20, 1957	.15	.18	1.20
Aug. 26, 1957	.24	.29	1.21
Aug. 30, 1957	.27	.26	.96
Do	.07	.10	1.43
Oct. 12, 1957	.29	.29	1.00
	4–A	4–B	
Sept. 12, 1954	0.62	0.86	1.39
Do	.28	.30	1.07
Do	1.06	.86	.81
Sept. 23, 1954	.12	.21	1.75
Do	.16	.31	1.94
July 25, 1955	.30	.68	2.26
Aug. 7, 1955	.28	.37	1.32
Aug. 24, 1955	.34	.58	1.70
Aug. 20, 1957	.30	.37	1.23
Aug. 26, 1957	.45	.64	1.42
Aug. 30, 1957	.13	.30	2.31
Do	.06	.06	1.00
Oct. 12, 1957	.14	.28	2.00

Cross sections marked by monuments were established in 1954 on main channels at 49 locations in the 8 paired watersheds. (See pl. 1.) These cross sections were resurveyed in 1958 in order to determine any erosion trend. Steel rods were driven into the ground at the ends of each cross section, and elevations of the ground surface at measured stations in the cross sections were determined. The area bounded by a line drawn from one end stake to the other and along the ground surface was then computed. Of the 49 cross sections, 75 percent showed an increase in area. Selected cross sections are shown in figures 21 and 22. Erosion along the sections appears to consist of both a change in shape of the channel and a change in the channel depth. Although in some sections the channel has deepened, in others

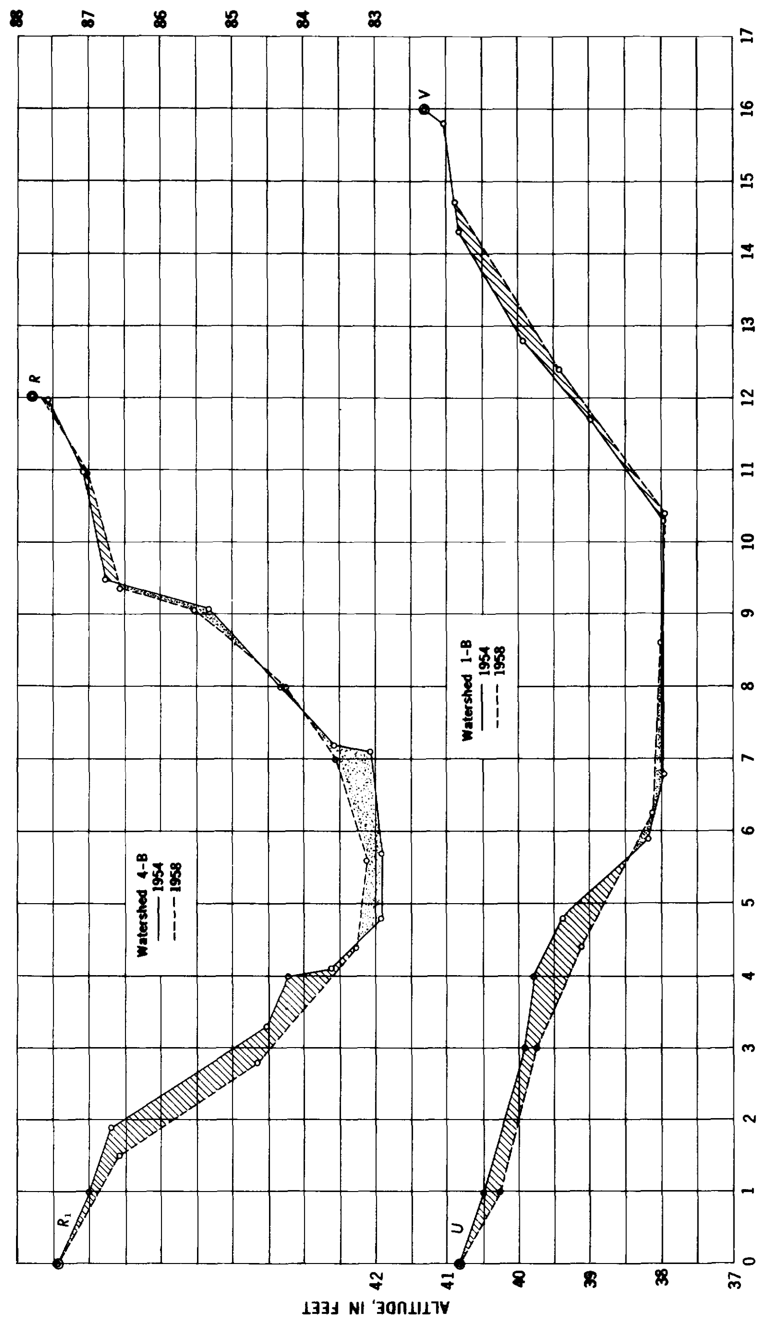


FIGURE 21.—Selected gully cross-sections in watersheds 1-B and 4-B.

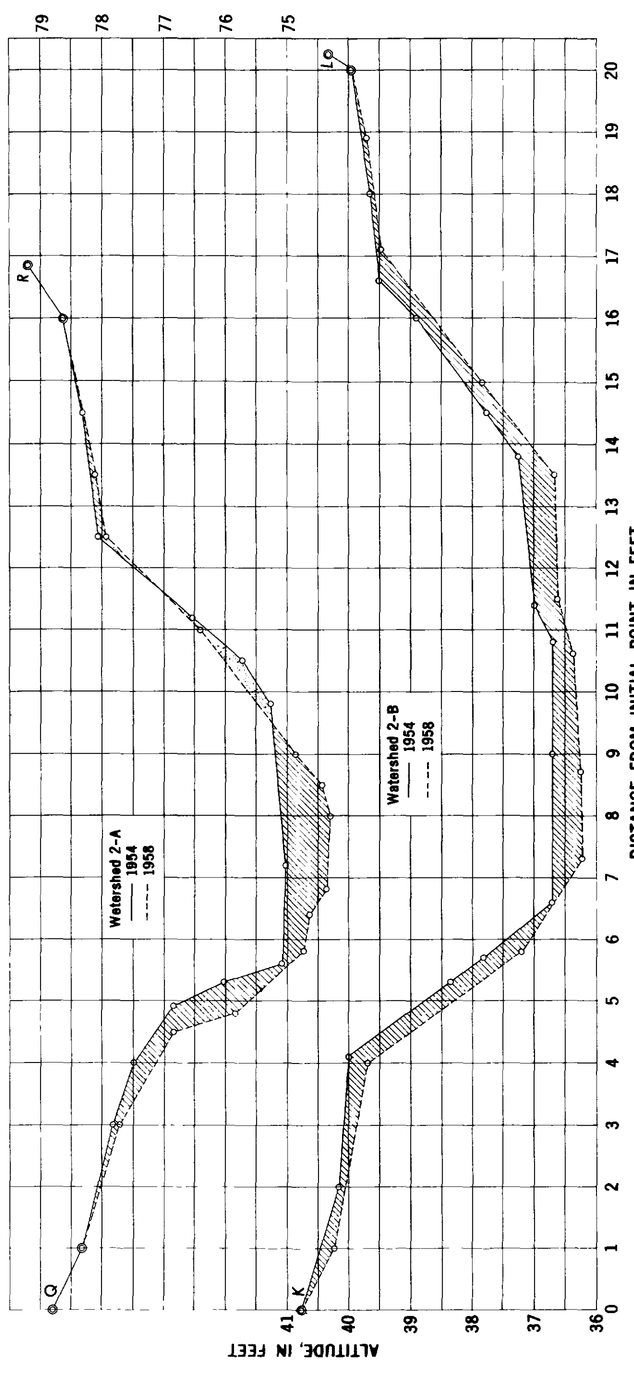


FIGURE 22.—Selected gully cross-sections in watersheds 2-A and 2-B.

it has filled slightly. The change in shape of the channel was caused either by erosion of the banks by water which flowed into the channel over the banks or by slumping of bank material into the channel. Water flowing in the stream channels did not reach an elevation high enough to cause bank erosion directly.

Transects for measuring sheet erosion were established in 1954 on hillslopes in each of the paired drainage areas. Ground-surface elevations were determined at fixed locations along the transect. All transects were resurveyed in November 1958. Although some slight differences in elevation were noted, most changes were no larger than the limits of accuracy of this type of survey.

In view of the foregoing facts, it seems likely that most of the sediment deposited in reservoirs is at the present time being derived from stream channels.

EFFECT OF RESERVOIRS ON RUNOFF AND SEDIMENT YIELD

Because runoff records were not obtained before the construction of reservoirs in Badger Wash, no definite relationships can be stated regarding runoff and sediment yield before and after construction of reservoirs, but some qualitative data is available for comparison.

Reservoir 14, which was completed in May 1957, has an uncontrolled drainage area of 1.53 square miles. Reservoirs located upstream from this dam have a combined drainage area of 1.696 square miles. Water has not spilled from the upstream reservoirs during the period of record.

The largest storm during the period 1954–58 occurred on July 25, 1955. An indirect determination of discharge was made on the channel at the site of reservoir 14, and the flow was computed to be 1,400 cfs (cubic feet per second). The inflow into four upstream reservoirs equipped with water-stage recorders was computed to range from 1,050 to 1,920 cfs per square mile. Using these data as a base, it is estimated that with no reservoirs in the drainage basin a peak discharge of 3,000 cfs could have occurred at the downstream site. Since the construction of reservoir 14, the maximum flow that is likely to occur below the dam is the effluent from a 16-inch outlet pipe.

The Badger Wash reservoir system has retained runoff during the period as follows: 1954, 88.8 acre-feet, or 40.6 acre-feet per square mile; 1955, 104 acre-feet, or 47.9 acre-feet per square mile; 1956, 23.7 acre-feet, or 10.9 acre-feet per square mile; 1957, 214 acre-feet, or 58.8 acre-feet per square mile; 1958, 4.68 acre-feet, or 1.3 acre-feet per square mile. At the end of the 1958 season, runoff from about 70 percent of the total drainage area above the Highline canal was completely controlled by reservoirs. In addition to building reservoir 14, the Bureau of Land Management rebuilt an old dam located about one-half mile downstream and also built a dam on a small tributary to the main channel.

During the period 1954–58 the Badger Wash reservoirs retained 25.1 acre-feet, or 6.89 acre-feet per square mile, of sediment. This amount represents 8.4 percent of the original aggregate storage of 298 acre-feet.

If the present rate of sedimentation continues, the system of reservoirs could be expected to fill in about 60 years, but the effectiveness of the system would be reduced before that time due to loss of storage.

CONCLUSIONS

Precipitation at Badger Wash during the period 1954–58 was extremely variable and below normal for 4 of the 5 years of record. Practically all runoff was produced by convective type storms characterized by high intensity rainfall of short duration during the summer. Minimum average rainfall during a summer season was 2.19 inches in 1956, and the maximum was 7.64 inches in 1957. Maximum volume of rainfall over a study watershed in 1 storm was 1.40 inches on July 25, 1955. Runoff was produced from as little as 0.10 inch of rain.

Runoff in Badger Wash expressed as a percentage of rainfall was very high. In the storm of July 25, 1955, runoff in the 8 paired watersheds averaged 74 percent of the total rainfall in the area. Comparison of runoff amounts in grazed and ungrazed watersheds indicates a change in the relation between precipitation and runoff due to exclusion of livestock, but because of the short period of record and few runoff events during the period, no definite statement can be made regarding the relationship at this time.

Investigation of the source of sediment indicates that at present most of the sediment yield is being derived from stream channels and not from sheet erosion. Rates of sediment yield in the paired watersheds ranged from 7.41 to 30.0 acre-feet per square mile for the 5-year period, and in all cases, more sediment was derived from the grazed watershed than the ungrazed watershed in each pair. Although the data indicates a decrease in the amount of sediment yield produced from ungrazed watersheds with respect to grazed watersheds, no definite statements can be made regarding this relationship because sediment during 2 of the 4 measuring periods was not measurable in any reservoir.

TRENDS IN SMALL-RODENT AND RABBIT POPULATIONS

By Vincent H. Reid [6]

Small mammals were studied to determine population trends in relation to vegetative conditions on the grazed and ungrazed watersheds and to determine if a serious "build-up" of animals would occur on the protected or ungrazed areas. Rodents were inventoried in 1957

[6] U.S. Fish and Wildlife Service.

and 1958, and work was begun in 1958 to measure jackrabbit and cottontail-rabbit populations on the eight experimental watersheds.

SMALL MAMMALS

A permanent trap line was established in each watershed to determine small-mammal population trends. The lines were operated annually at approximately the same calendar date. Each line consisted of 20 stations spaced at intervals of 50 feet. At each station 3 traps were placed within a radius of 5 feet. The same trap-line stationing and number of traps were used each year, and traps were operated for three consecutive nights each year.

Prairie dogs are present in the Badger Wash basin, but to prevent damage to reservoir dams and watershed vegetation, these animals have been subject to control by either poisoning or shooting. No prairie dogs have been taken in the annual snap-trap inventory.

Deer mice, harvest mice, kangaroo rats, and antelope ground squirrels were taken in the trap lines. Only deer mice were captured more than once. The total catch of animals was 150 in 1957 and 162 in 1958. (See table 31.) Expressed on the basis of 100 trap nights, the catch was about 10 in 1957 and 11 in 1958.

In 1957, although the difference was small, a few more animals were taken in the ungrazed watersheds than in the grazed watersheds. Seventy-one animals, or 10 per 100 trap nights, were taken in the grazed watersheds as compared with 79, or 11 per 100 trap nights, in the ungrazed. The situation was reversed in 1958, when more animals were caught in the grazed watersheds than in the ungrazed. Ninety-six, or 13 per 100 trap nights, were caught in the grazed watersheds and 66, or 9 per 100 trap nights, were caught in the ungrazed.

The only conclusion to be reached from the foregoing figures is that no definite trend in small mammal population in relation to livestock use or nonuse can yet be determined.

JACKRABBITS AND COTTONTAILS

Blacktailed jackrabbits and desert cottontails have been observed in the study area. An initial attempt was made to determine population trends or relative use of the grazed and ungrazed watersheds by these animals from pellet counts. Pellets were tallied on 0.01-acre circular plots around the 20 permanent rodent trapping stations in each watershed.

Results of the initial counts in 1958 indicated that 58.7 percent of the plots in grazed watersheds and 77.5 percent of the plots in ungrazed watersheds contained pellets. Plots on the ungrazed watersheds contained 6.5 times the number tallied in grazed watersheds.

Results of preliminary work indicated that rabbits prefer the ungrazed watersheds. The population of these animals, however, was judged to be not high on either the grazed or the ungrazed areas.

TABLE 31.—*Small mammals catch on eight experimental watersheds, 1957–58*

[A, grazed watersheds; B, ungrazed watersheds]

Watershed	Number of animals caught			
	1957		1958	
	Total	Per 100 trap nights	Total	Per 100 trap nights
1–A	13	7. 2	18	10. 0
2–A	13	7. 2	43	23. 8
3–A	28	15. 5	22	12. 2
4–A	17	9. 4	13	7. 2
Subtotal or average	71	9. 8	96	13. 3
1–B	14	7. 7	10	5. 5
2–B	18	10. 0	25	13. 8
3–B	22	12. 2	14	7. 7
4–B	25	13. 8	17	9. 4
Subtotal or average	79	10. 9	66	9. 1
Total or average, all water sheds	150	10. 4	162	11. 2

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