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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1532-I

Prepared in cooperation with the Bureau of Land Management

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By GREGG C. LUSBY

HYDROLOGIC EFFECTS OF LAND USE

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CONVERSION FACTORS

Over the period of study covered in this report, data were collected in U.S. customary units. For use of those readers who prefer to use metric units, the conversion factors for the terms used in this report are listed below:

Multiply U.S customary unit	*By*	*To obtain metric unit*
acres	4.047×10^{-3}	km^2 (square kilometer)
acre-ft (acre-foot)	1,233	m^3 (cubic meters)
ft (feet)	0.3048	m (meter)
in. (inch)	25.4	mm (millimeters)
in. (inches)	2.54	cm (centimeter)
in^3 (cubic inches)	16.4	cm^3 (cubic centimeter)
mi (mile)	1.609	km (kilometers)
lb (pounds)	0.455	kg (kilogram)
lb (pound)	453.6	g (grams)
mi^2 (square mile)	2.59	km^2 (square kilometers)

EFFECTS OF GRAZING ON RUNOFF AND SEDIMENT YIELD FROM DESERT RANGELAND AT BADGER WASH IN WESTERN COLORADO, 1953-73

By GREGG C. LUSBY

ABSTRACT

Four different systems of livestock management were compared hydrologically during a 20-year study (November 1953-November 1973) in western Colorado. These systems were grazing by cattle and sheep from November 15 to May 15 each year, complete elimination of grazing, grazing by sheep from November 15 to February 15 each year, and grazing by sheep from November 15 to February 15 every other year. Grazing by both cattle and sheep from November 15 to May 15 each year was the standard grazing practice in the area at the beginning of the study.

Complete grazing exclusion resulted in a reduction in runoff of about 20 percent during the period 1953-65 and an additional 20 percent during 1966-73. During the same periods sediment yield was reduced by 35 and 28 percent, respectively, for a total of 63 percent.

A change in grazing use from cattle and sheep, November 15-May 15 each year, to sheep only at approximately the same utilization rate, November 15-February 15 each year, was accompanied by a reduction in runoff and sediment yield of about 29 percent. The same change in use, except that grazing was allowed every other year during the sheep grazing period, resulted in a reduction in runoff and sediment yield of about 20 percent.

Recurrence intervals of annual runoff occurring on three soil types at Badger Wash are provided. These data may be applied to similar soils in areas of like climate and physiography shown on accompanying maps.

INTRODUCTION

In many of the arid areas of the Western States, the works of man are jeopardized by the runoff from rangeland. Some of the aspects of arid-land hydrology that concern the land manager are (1) the reduced productivity of land due to erosion of great quantities of soil material each year, with attendant low infiltration rates; (2) the rapid filling of downstream storage structures with sediment; and (3) the damage to manmade structures, such as bridges and canals, by high peak flows in ephemeral stream channels. An example of this type of arid rangeland is the Colorado Plateaus, in western Colorado and eastern Utah, that include thousands of square miles of land with sparse vegetal cover and underlain by highly erodible rock.

In general, a reduction in runoff and erosion is desirable so that vegetation production on rangeland can be increased. Attempts to reseed lands in arid areas have generally failed, and expensive mechanical treatments, such as terracing, pitting, or contour furrowing are usually not justified or are impractical because of the terrain. One aspect of management that merits attention is the evaluation of the effects of livestock grazing—or of the exclusion or regulation of livestock—on runoff, sediment yield, and plant growth.

The Colorado Plateau contributes a large part of the sediment but only a small part of runoff to the Colorado River. A need for quantitative data on the effect of treatment practices has long been recognized, and in 1953 the Sedimentation Subcommittee of the Pacific Southwest Interagency Committee made a concerted effort to locate a site for the study. The Badger Wash basin, in western Colorado, was chosen by the subcommittee because it was considered to be typical of a large part of the Colorado Plateau, and because numerous small reservoirs were available in which to measure runoff and sediment yield.

PURPOSE AND SCOPE

The primary purpose of the study is to compare runoff and sediment yield from grazed and ungrazed watersheds. Other objectives are to determine (1) the amount and rate of runoff and sediment yield from storms of various magnitude and duration; and (2) the relative infiltration and erosion rates on different soils and their response to grazing treatment.

The study area is limited to the Badger Wash basin, which contains several well-defined tributary watersheds. In the fall of 1953, four of those watersheds were fenced to exclude livestock, and four were left as open range to be grazed by sheep and cattle during the winter and spring months. Also, records were kept of runoff and sediment yield at 10 other grazed watersheds in the Badger Wash basin to supply additional data at sites where future investigations might be made.

Runoff data obtained from the study area is extrapolated to areas of like physiography and climate farther west.

Five Federal agencies cooperated in the study. Their responsibilities were as follows: The Bureau of Land Management (BLM) was responsible for administration of the area and construction and maintenance of dams, fences, and roads. Also, BLM helped in making some vegetation measurements as well as providing some financial assistance. The Bureau of Reclamation 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 measured precipitation, runoff, erosion, and sedimentation, and made periodic measurements of vegetal cover and utilization during 1967–73. The Forest Service prepared soils maps and made vegetal measurements during the period 1953–66. The Fish and Wildlife Service, which entered the study in 1955, determined trends in populations of small rodents and lagomorphs (rabbits) on the study areas. The only items covered in this report are the result of Geological Survey measurements on precipitation, runoff, erosion, and sedimentation.

The study was coordinated by a committee composed of one member from each agency. During the 20-year study period covered by this report, committee membership was as follows: U.S. Geological Survey, H. V. Peterson (1954), K. R. Melin (1955–60), and G. C. Lusby (1961–73); U.S. Forest Service, G. T. Turner (1954–64) and O. D. Knipe (1965–66); Bureau of Land Management, J. S. Andrews (1954–65), R. K. Miller (1966–72), and T. Heller (1973); Bureau of Reclamation, W. H. Hirst (1954–67), and J. O. Langford (1968–73); and U.S. Fish and Wildlife Service, V. B. Scheffler (1956) and V. H. Reid (1957–73). This report was prepared under the supervision of R. F. Hadley. The report was reviewed by the technical staffs of the Bureau of Land Management and the Geological Survey.

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 under study is at an elevation of about 5,000 feet. 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. Although Badger Wash does not extend into the Book Cliffs, the larger streams in the area do. The upper end of the drainage basin is separated from the base of the cliffs by a valley that is about 1 mile wide.

METHODS OF STUDY

Prior to 1953, 22 small reservoirs whose storage capacities range from 0.9 to 22.4 acre-feet were constructed in the Badger Wash basin by the Bureau of Land Management. Field representatives of the various cooperating Federal agencies involved in the proposed study selected watersheds upstream from eight of the reservoirs; intensive study was made of the effect of grazing exclusion on runoff, sediment yield, vegetation, and infiltration. The watersheds were chosen to include four adjoining pairs, with each pair being as similar as possible in slope, soil type, vegetation, and size. Runoff measurements were begun in the fall of 1953 and precipitation measurements were begun in the spring of 1954. Determination of effects of grazing exclusion was necessarily done by trend studies of watershed pairs because a calibration period was not provided. One watershed of each pair was fenced to exclude livestock grazing, and the other was allowed to receive normal grazing use for the area. Watersheds were designated by numbers and letters. The designation for one pair of watersheds contained the same number and the letters "A" and "B" denote grazed and ungrazed, respectively. Locations of the watersheds studied are shown on plate 1.

Originally, each of the watersheds contained one reservoir, except for watersheds 2-A and 3-A, each of which contained two reservoirs. However, during the winter of 1955-56, 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. It is used to retain any spill from the main reservoir, as well as runoff from a small area adjacent to the reservoir. In 1959 the dam for the main reservoir in 2-A was raised to provide additional capacity. Spillage did not occur during the study period so the runoff and drainage area considered in this report is that from the main watershed only.

Methods used to measure precipitation, runoff, erosion, and sediment yield are described under "Observation Network."

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. Shale in the western and upper parts of the basin contains a number of thin sandstone layers (less than 1 ft thick). Because of their greater resistance to erosion, these sandstone layers cause an alternation of steep and gentle slopes. The gently sloping areas are those which overlie 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 east side of the basin, the sandstone layers are absent, and the topography is more nearly uniform, with very steep hillslopes merging with gentle colluvial slopes at their bases. Channels are incised into the shale. Figure 1 is a view of terrain at Badger Wash showing typical plants and erosion characteristics.

SOILS

Soil in the study area is poorly developed and consists mainly of a shallow weathered mantle overlying the Mancos Shale. 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 area, four types of soil are recognized—that derived from shale, that derived from sandstone, a mixture of the two, and alluvium. The mixed type derived from 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 generally 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 commonly occur on steep slopes. The mixed type is intermediate between the shale and the sandstone

FIGURE 1.—General view of terrain in Badger Wash showing typical plants and erosion characteristics.

soils in these characteristics, but it more nearly resembles the shale soil. The alluvial soils are extremely variable in all characteristics. For this reason and because of their limited extent, they are not described, nor were they sampled in this study.

CLIMATE

The climate of Badger Wash is arid to semiarid. At Fruita, Colo., about 16 miles southeast of the study area, the average annual precipitation is 8.8 inches, based on 48 years of record. Precipitation from April to October occurs generally as thunderstorms, which characteristically produce high-intensity rainfall. Average monthly precipitation ranges from a minimum of 0.44 inch in June to a maximum of 1.02 inches in August.

Summer temperatures at Fruita are generally high during the day and low at night; the average maximum temperature during July is in the mid-nineties, and the average minimum temperature is in the midfifties. Yearly average temperature is 51.2°F (Fahrenheit), and the average for the period from April to October is 64.1°F. The number of days with a minimum temperature greater than 32°F averages about 130, from about May 15 to September 20.

The average relative humidity at Grand Junction from June to September is about 59, 20, 30, and 40 percent for the hours of 5 a.m., 11 a.m., 5 p.m., and 11 p.m., respectively. These values were obtained by averaging the average monthly values of humidity published by the U.S. Dept. of Commerce, National Weather Service (1956–66).

Because of the high daytime temperatures and the low relative humidity, potential evaporation rates in the area are very high. The average evaporation measured in a National Weather Service class-A evaporation pan at the Grand Junction, Colo., Airport for the months April–October during the years 1954–60 was 92.1 inches. The highest monthly average was 18.3 inches in July. In 1962 the evaporation equipment was located at a new site within the irrigation project in Grand Valley. The average April–October evaporation from 1962 to 1973 was 61.1 inches, and the monthly maximum, in July, was 11.6 inches. Evaporation rates at the airport are perhaps more indicative of the rates farther west on the desert at Badger Wash.

During 1954–73 annual precipitation at Fruita ranged from 4.64 to 18.08 inches. The long term mean (48 years) was exceeded five times, and precipitation was less than the mean 15 times.

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 in available soil moisture.

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

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

Except in local areas, the plant cover on the drainage basins is sparse; crowns of living perennial plants cover perhaps 10 to 20 percent of the surface. In wet years the vegetal cover is usually increased somewhat by cheatgrass brome *(Bromus tectorum)* and other annuals. Although flowers of woody aster *(Aster venustus)* and milkvetch *(Astragalus* sp.) may be conspicuous during wet periods, these plants contribute relatively little to watershed cover.

HISTORY OF RANGE USE

According to verbal statements made by pioneers who settled in the vicinity of Badger Wash, domestic livestock were first brought into the area during the decade 1880–90, when thousands of cattle were imported from Texas. Many early settlers stated that the Badger Wash area and adjacent lands supported a much better vegetal cover than at present.

For many years, beginning about 1915, large flocks of migratory sheep were 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 it was near a railway shipping point, and large numbers of both cattle and sheep were kept in the area pending shipment.

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

WATERSHED CHARACTERISTICS

SOILS DESCRIPTION AND DISTRIBUTION

The areas underlain by each soil type on the eight experimental watersheds are listed in table 1 and are outlined in figures 2–6.

Description of soil profiles present in the three major soil types were made by U.S. 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 soil-moisture tension, and a loose sample was taken from the same general layer for tests of texture by the hydrometer method, for tests of pH by the Truog reaction method, and for tests of phosphorous content by the sodium bicarbonate method.

A short description of soil and soil horizons follows. A more complete description may be obtained from "Agriculture Handbook 18" (U.S. Department of Agriculture, 1951).

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.

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

Watershed number	Shale		Mixed		Sandstone		Alluvium		Total
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres
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 (A) watersheds	25	12	134	67	31	15	11	6	201
Ungrazed (B) watersheds	41	21	110	55	30	15	17	9	198

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 are very similar. Sandstone soils have a deeper A_1 horizon, a higher pH, higher phosphorous, and less pore space than shale or mixed soils. The shallow shale soil is highest in pore space, and lowest in pH and phosphorous. The mixed soil is intermediate between the shale and sandstone soils (table 2).

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 U.S. Geological Survey to make an investigation of the drainage network characteristics for each watershed. However, a field check showed that many of the smaller streams were not shown on the maps, and these channels were added to the maps by additional mapping done in the field before the features of the watersheds, such as stream-channel lengths and watershed areas, were designated.

The streams on each map were classified by order number. First-order drainage channels are defined as those having recognizable drainage areas

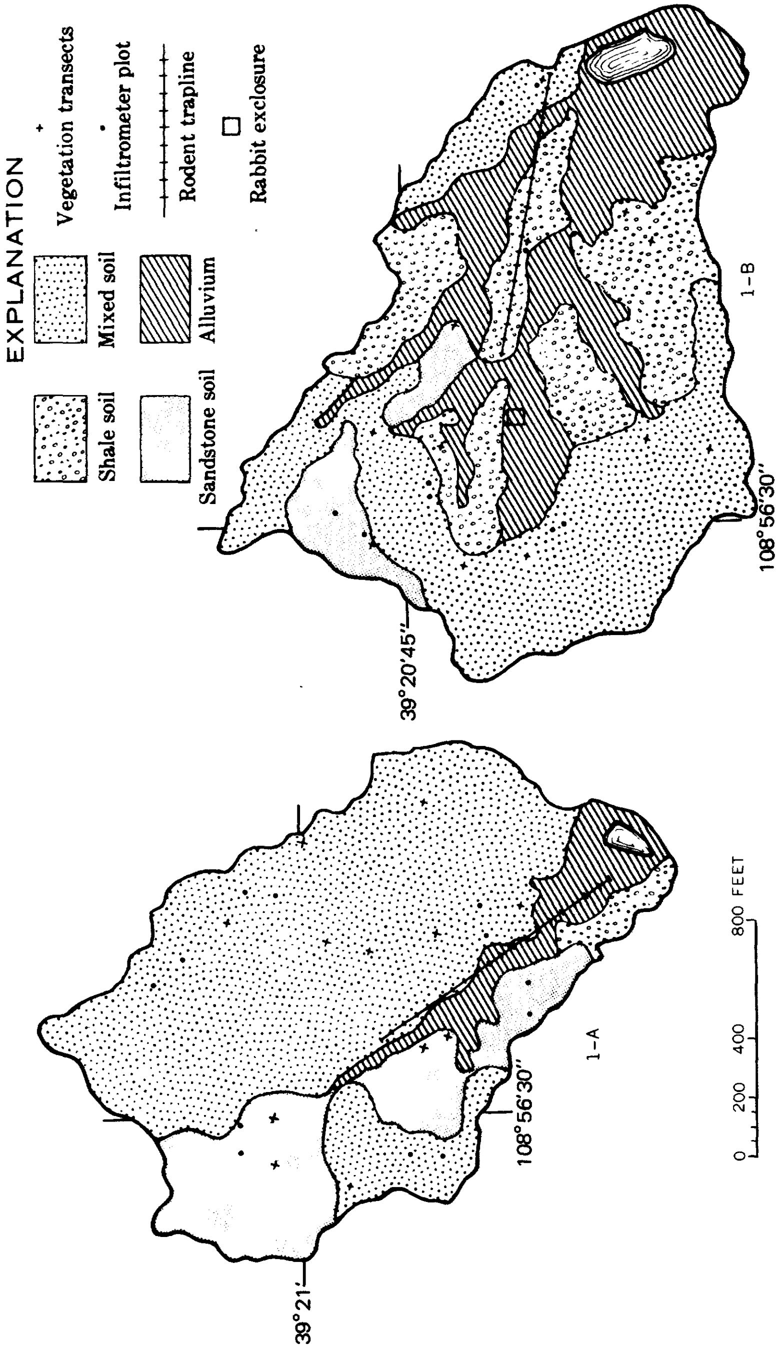

FIGURE 2.—Areas of soil types and observation points, watersheds 1-A and 1-B.

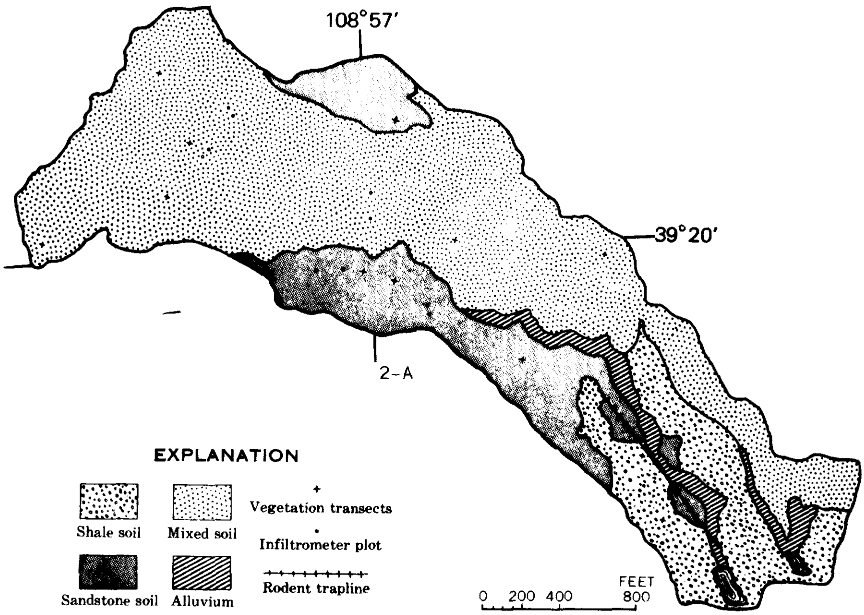

FIGURE 3.—Areas of soil types and observation points, watershed 2-A.

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

[Values in parentheses represent the number of samples]

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

A_1 horizon	Consistency	pH[1]	Phosphorous as P_2O_5 (lb/acre)	Water loss at 50 cm tension[2] (percent)	Saturated pore space[2] (percent)	Bulk density[2] (g/cm^3)
Shale	Loose	8.1 (10)	2.99 (2)	17 (27)	53 (27)	1.31 (35)
Mixed	Loose	8.5 (31)	3.19 (8)	16 (94)	48 (95)	1.35 (127)
Sandstone	Loose	9.3 (6)	6.88 (2)	12 (18)	47 (20)	1.31 (28)

[1]Difference between soil types is significant at 5-percent level.

[2]Difference between soil types is not significant at 5-percent level.

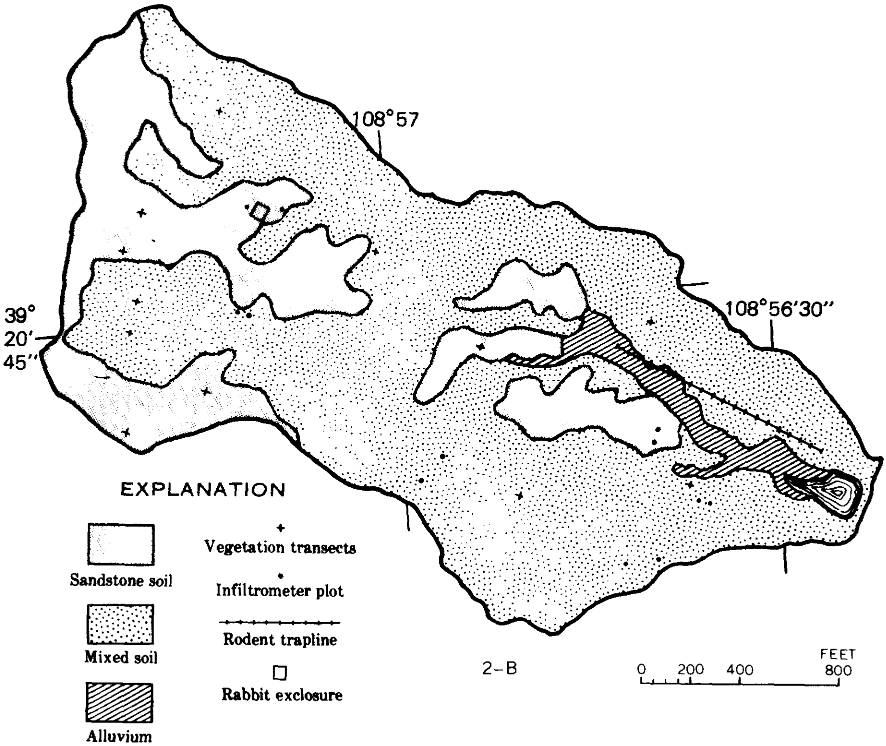

FIGURE 4.—Areas of soil types and observation points, watershed 2-B.

and well-defined valley-side slopes. This definition eliminates all rill channels that may not be permanent features. The junction of two first-order streams forms a second-order stream, and so forth (Strahler, 1957). Each stream of each order was numbered on the map so that measurements could be checked and additional information could be obtained from the same watershed without confusion. Drainage divides were then outlined, and the stream lengths and watershed areas were then measured.

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

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

1. Relief ratio (h/l) 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, as measured parallel to the main channel (Schumm, 1955).

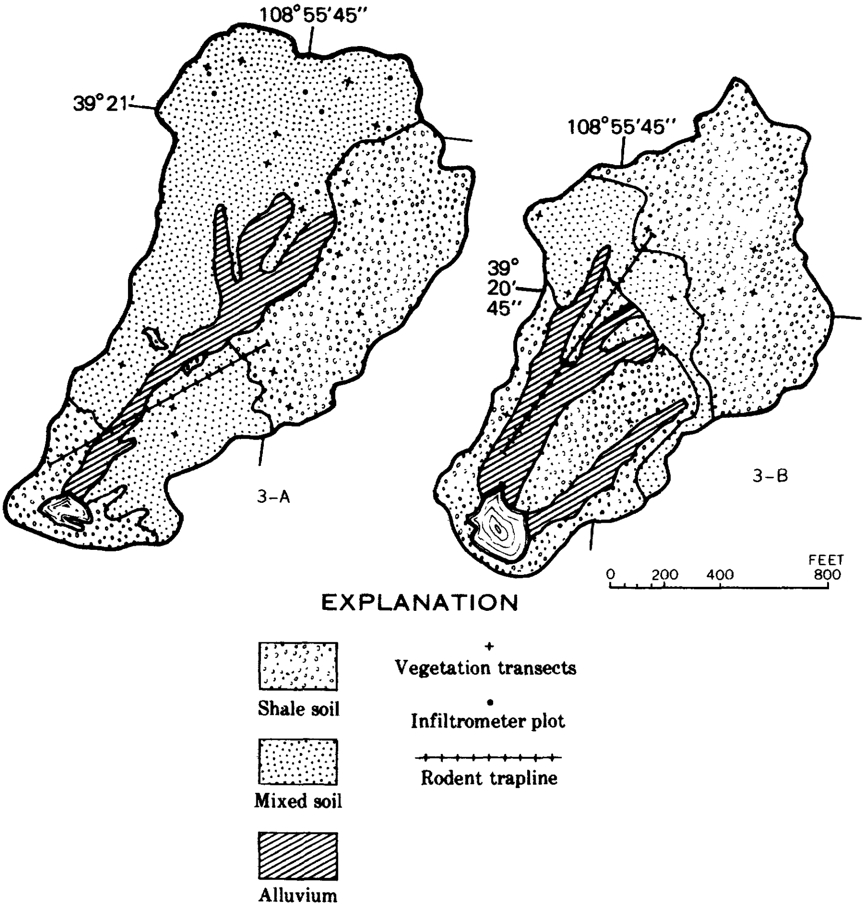

FIGURE 5.—Areas of soil types and observation points, watersheds 3-A and 3-B.

2. Mean slope of a drainage basin is obtained by weighting the main 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 the angles measured between the major tributaries and the 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. Table 3 indicates that the

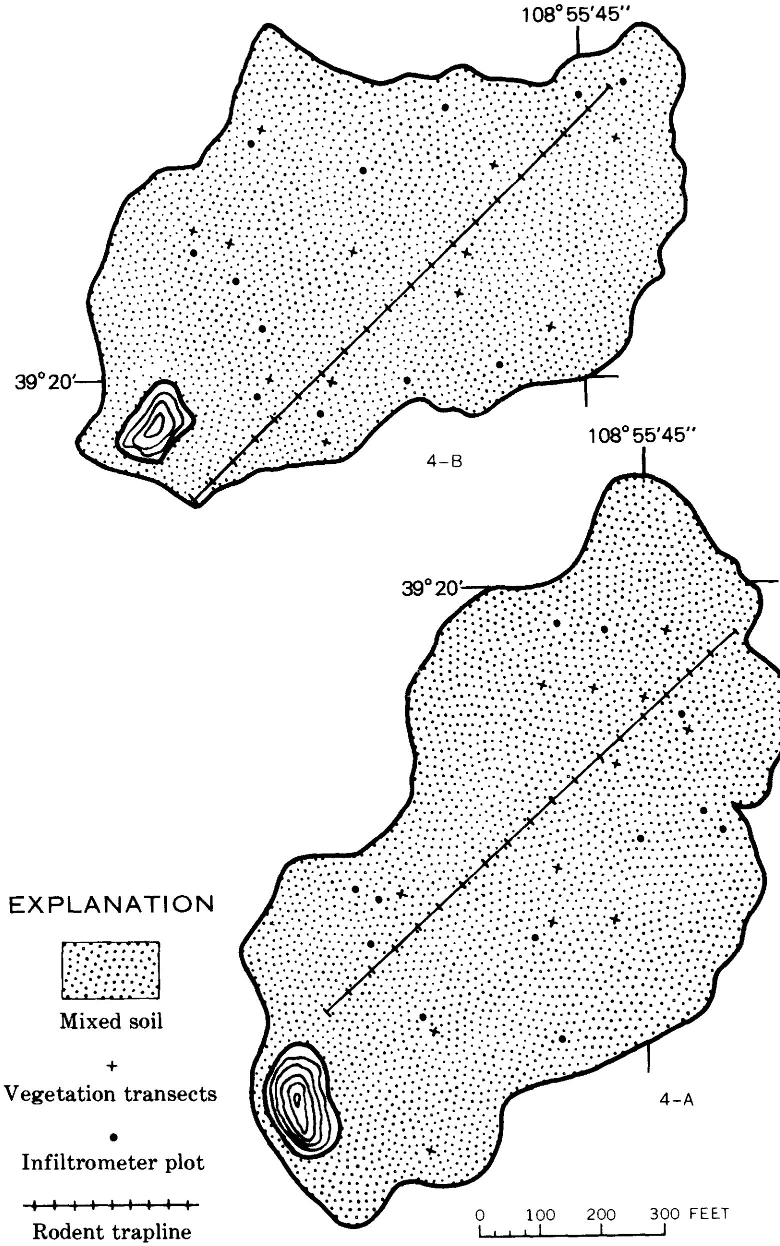

FIGURE 6.—Areas of soil types and observation points, watersheds 4-A and 4-B.

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 of individual watersheds*

Watershed number	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.

INFILTROMETER PLOT RECORDS

The original study plan for Badger Wash included the determination of the effect of livestock exclusion on infiltration and sheet erosion by the application of rainfall to selected plots. This work was done during the fall of 1953 and the fall of 1954, and repeat measurements were made in the fall of 1958. After the 1958 measurements were made, it was decided that the results obtained did not warrant the expenditure of funds necessary to continue the measurements, and they were discontinued. A complete description of the methods used and of the results obtained was made by Lusby, Turner, Thompson, and Reid (1963). Some of their conclusions bear repeating here.

At the start of the present study (1953), the average infiltration rates on the mixed-type soil for the last 20 minutes of the wet and dry runs were slightly higher on the grazed watersheds than they were on the ungrazed watersheds. This difference remained practically unchanged in 1958, which is an indication that grazing had no appreciable effect on the infiltration rates during the latter stages of extended rains. However, after 5 years of protection the initial water-absorbing capacity of soils in ungrazed watersheds became as much as twice as great as that of soils in grazed watersheds.

Penetrometer readings made in 1958 indicated a significantly higher average reading at a 1-inch depth on the grazed plots than on the ungrazed plots. No significant difference was found to exist below the 1-inch depth.

PRECIPITATION, RUNOFF, EROSION, AND SEDIMENT YIELD

OBSERVATION NETWORK

The objectives of the U.S. Geological Survey in the study, as stated in the original agreement between cooperators, include determination of the rates of runoff and of sediment yield from storms of varying intensity and magnitude and determination of the effect of total elimination of livestock grazing on runoff and erosion. Also included are determination of the extent and character of erosion, runoff, and sediment yield under different conditions of vegetative cover and soil types on grazed and ungrazed watersheds.

A relatively dense network of rain gages was installed in the Badger Wash basin to compensate for the great areal variability in rainfall during summer thunderstorms. A total of nine recording precipitation gages were operated in the paired basins, with at least two gages in each pair. Locations of these gages are shown on plate 1.

Runoff and sediment were measured in the reservoirs at the lower end of each watershed. Continuous water-stage recorders (A-35) were operated in the reservoirs in watersheds 2-A, 2-B, 4-A, and 4-B for the full 20-year period of record, and in August 1960 continuous water-stage recorders were installed in reservoirs 1-A, 1-B, 3-A, and 3-B. Before that time, periodic measurements were made of water stage in these latter reservoirs. Both the continuous and periodic measurements of stage were converted to volume of water stored in the reservoir by application of stage-capacity tables. Stage-capacity values were adjusted periodically to compensate for sediment deposition. The water-stage recorders were operated at a chart speed so that time intervals of 5 minutes could be defined and used to convert change in stage to inflow rate. Accuracy of inflow records is estimated to be between 5 and 10 percent. Sediment yield from each watershed was measured by successive topographic surveys of the reservoirs. In addition to measurements made in the 8 paired watersheds, runoff and sediment were measured in the 10 reservoirs in adjacent grazed areas.

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

PRECIPITATION

The possibility of changes in runoff and sediment yield being caused by differences in precipitation was investigated using long-term weather records at Grand Junction and Fruita, Colo. (U.S. Dept. of Commerce, National Weather Service, 1914-73) as well as records obtained during the study period at Badger Wash. Summaries of data used for these comparisons are shown in tables 4 and 5.

In order to determine whether precipitation received during the study period was comparable to that received during prior years, analyses of variance were done using both annual precipitation and precipitation that occurred during the summer months at Grand Junction and Fruita. Both these analyses indicated there was no significant difference at the 1 percent level between precipitation during the period 1914-53 and during the period 1954-73. Climatic conditions controlling plant growth have remained essentially the same for the last 60 years.

Even though annual and summer-season precipitation have remained constant, an investigation was made of the occurrence of storms of a size likely to cause runoff. This was done by comparing the number of storms at Badger

TABLE 4.—*Long-term and study-period averages of annual and seasonal precipitation at Badger Wash area, in inches*

	Fruita	Grand Junction	Badger Wash
Average annual — long term	8.79*	8.62*	......
1954-73	8.30	8.06	......
1954-65	8.19	8.23	......
1966-73	8.46	7.81	......
Average seasonal (Apr.-Oct.) — long term	5.44†	5.45†	......
1954-73	5.09	5.13	5.03
1954-65	4.74	5.08	4.76
1966-73	5.62	5.21	5.44

*Fifty years of record.
†Fifty-seven years of record.

TABLE 5.—*Average number of storms per year by size class during long term and study period*

Size class (inches)	0.25-0.50	0.51-1.00	1.01-1.50	1.51-2.00	2.01-3.00
Grand Junction:					
1914-53	4.9	1.6	0.15	0.02	0
1954-73	5.4	1.7	.10	0	0
1954-65	5.5	1.8	.08	0	0
1966-73	5.4	1.5	.13	0	0
Fruita:					
1914-53	5.4	1.7	.15	.05	.02
1954-73	4.4	1.6	.25	0	0
1954-65	3.8	1.7	.25	0	0
1966-73	5.2	1.6	.25	0	0
Badger Wash:					
1954-73	4.3	1.7	.29	0	0
1954-65	4.2	1.6	.32	0	0
1966-73	4.5	1.8	.25	0	0

Wash in each size class shown in table 5 with those at both Grand Junction and Fruita from 1914-53. A χ^2 test (Dixon and Massey, 1957) was performed to test the hypothesis that the distribution of the number of storms in each size class was comparable for the long term period 1914-53 at both Grand Junction and Fruita and for the study period 1953-73 at Badger Wash. Results indicated that at the 5 percent level the value of χ^2 was not large enough to reject the hypothesis.

Because of the change in grazing treatment that occurred in 1966, a χ^2 test was performed on data for the number of runoff-producing storms at Badger Wash for the periods 1954-65 and 1966-73. This test indicated less than a 1 percent chance of the distribution of the number of storms in each size class being unequal for the two periods.

To determine the comparability of rainfall on paired watersheds, an analysis of variance of seasonal precipitation received on each watershed was performed. These data indicated that after adjusting for differences in years, watersheds, and periods, no significant difference existed between rainfall received on paired watersheds at the 1 percent level. Also, rainfall received on grazed watersheds in total was not significantly different than on ungrazed watersheds. The analysis of variance also showed that summer season rainfall during the period 1954-65 was significantly different than that during 1966-73. As shown in table 4, about 0.7 inch more rainfall was received during the latter period.

The statistical analyses performed on the precipitation data indicated in general that precipitation at the study area has remained essentially unchanged and that paired watersheds received the same amount of precipitation. These statements will be referred to later in the discussion on runoff.

Statistical tests performed and results obtained are as follows:

Hypothesis	Test	Result
That at Grand Junction and Fruita, mean annual precipitation from 1914-53 is equal to that from 1954-73 (accepted).	Variance	$F = 1.24$ $F_{.95}(1,46) = 4.06$ $F_{.99}(1,46) = 7.24$
That at Grand Junction and Fruita, mean Apr.-Oct. precipitation from 1914-53 is equal to that from 1954-73 (accepted).	Variance	$F = 0.97$ $F_{.95}(1,49) = 4.04$ $F_{.99}(1,49) = 7.21$
The distribution of the number of runoff-producing storms at Badger Wash, 1954-73, was the same as the number at Grand Junction, 1914-53 (accepted).	χ^2	$\chi^2 = 1.30$ $\chi^2_{.95}(4\ \mathrm{df}) = 9.49$
The distribution of the number of runoff-producing storms at Badger Wash, 1954-73, was the same as the number at Fruita, 1914-53 (accepted).	χ^2	$\chi^2 = 2.47$ $\chi^2_{.95}(4\ \mathrm{df}) = 9.49$
The number of runoff-producing storms at Badger Wash was the same during 1954-65 and 1966-73 (accepted).	χ^2	$\chi^2 = 0$ $\chi^2_{.95}(3\ \mathrm{df}) = 7.81$
That seasonal precipitaton on paired grazed and ungrazed watersheds was the same (accepted).	Variance	$F = 1.52$ $F_{.95}(3,136) = 2.65$ $F_{.99}(3,136) = 3.90$
That seasonal precipitation on grazed watersheds in total was the same as on ungrazed watersheds (accepted).	Variance	$F = 0.44$ $F_{.95}(1,136) = 3.90$ $F_{.99}(1,136) = 6.80$
That seasonal precipitation during 1954-65 was the same as during 1966-73 (rejected).	Variance	$F = 334$ $F_{.95}(1,136) = 3.90$ $F_{.99}(1,136) = 6.80$

RUNOFF

METHODS OF STUDY

At the beginning of the study, measurements of runoff and sediment yield were made in 4 sets of paired watersheds and 10 additional nearby watersheds. One of each of the paired watersheds was fenced during the winter of 1953 and was not grazed afterward. From 1954 through 1965 the remainder of the watersheds were grazed by cattle and sheep from November 15 to May 15 each year.

Starting with the 1966 grazing season, three changes were made in the grazing system. Livestock were changed to sheep only, the season of use was changed to November 15-February 15, and part of the watersheds were grazed every other year instead of each year. The livestock change was necessitated because the rancher allottee changed to a sheep only operation. The season of use change came about because Lusby and others (1971) theorized from previous work that the critical period for damages done by grazing at Badger Wash was in the spring when the soil was loose and friable. The grazing period from February 15 to May 15 was therefore eliminated. The alternate year grazing was done to test the effects of this rest type of grazing system in an arid environment. Table 6 is a summary of all the watersheds and the periods in which various treatments were applied to each.

TABLE 6.—*Watersheds at Badger Wash and periods during which various grazing treatments were applied*

Treatment 1: Ungrazed.
2: Grazed by cattle and sheep Nov. 15 to May 15 each year.
3: Ungrazed.
4: Ungrazed, but previously grazed from 1954-65.
5: Grazed by sheep Nov. 15 to Feb. 15 each year.
6: Grazed by sheep Nov. 15 to Feb. 15 in alternate years.

Watershed	Treatment					
	1	2	3	4	5	6
1-A		1954-65			1966-73	
1-B	1954-65		1966-73			
2-A		1954-65		1966-73		
2-B	1954-65		1966-73			
3-A		1954-65			1966-73	
3-B	1954-65		1966-73			
4-A		1954-65		1966-73		
4-B	1954-65		1966-73			
5		1954-65				
6		1954-65				
7		1954-65				1966-73
8		1954-65				1966-73
9		1954-65				1966-73
10		1954-65				
11		1954-65				1966-73
12		1954-65				1966-73
13		1954-65				

In order to measure the statistical significance of changes in runoff from the different watersheds, analyses of variance were made on annual runoff values to test hypotheses about the mean runoff between treatments and periods.

RESULTS

Annual runoff from each watershed is listed in table 7, and average annual runoff for the two segments of the study period 1954-65 and 1966-73 is shown in table 8.

TABLE 7.—*Annual Runoff, in inches, from watersheds at Badger Wash*

[..., Indicates no record obtained]

Water-shed	Area mi²	Year 1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966[1]	1967	1968	1969	1970	1971	1972	1973
1-A	0.066	1.088	1.071	0	1.157	0	0.437	0.186	1.963	0.340	0.131	0.323	1.046	0.099	0.359	2.437	0	0.010	0.162	0.245	0.352
1-B	.084	.944	.822	0	1.286	0	.196	.027	1.393	.327	.080	.258	.564	.188	.524	2.201	0	0	.046	.063	.116
2-A	.148	1.108	1.118	0	1.182	.010	.551	.101	1.743	.429	.351	.640	.647	.343	.914	1.666	0	0	0	.027	0
2-B	.158	1.073	.965	0	.680	0	.388	0	1.125	.394	.170	.440	.512	.069	.598	1.667	0	0	.016	.037	0
3-A	.059	.893	1.048	.107	2.336	0	.713	.098	1.651	.502	.215	.325	.856	.503	.974	2.233	.035	.335	.367	.160	.218
3-B	.048	.828	1.049	.019	1.796	0	.538	.097	1.908	.542	.224	.306	.755	.606	1.276	2.080	.004	.347	.398	.296	.266
4-A	.022	.917	1.294	.026	1.294	.026	.591	.034	1.363	.266	.497	.737	1.243	.272	.698	1.422	0	.085	.379	.331	.005
4-B	.019	.800	.920	0	.990	0	.290	.040	1.120	.120	.190	.570	.880	.069	.416	1.570	0	0	.124	.256	.002
5	.055	.758	.669	0	.747	.027	.593	.531	1.272	.223	.175	.247	.607	.178	.398	2.640	.092	0	.306	.220	.299
6	.220	.813	.706	0	.885	0	.344	.261	1.126	.169	.066	.142	.516	.159	.287	1.996	.038	.108	.129	.043	.226
7	.094	.682	.744	0	.766	0	.238	.068	1.052	.224	.090	.298	.614	.122	.476	2.574	0	0	.180	.163	.203
8	.109	.622	.830	0	.890	0	.348	.017	1.013	.355	.140	.420	.694	.139	.420	2.261	.003	0	.181	.141	.139
9	.313	.677	1.145	.085	1.092	0	.452	.092	1.549	.167	.374	.619	.675	.684	1.400	1.209	.054	.018	.028	.035	.016
10	.100	.495	.493	0	.497	0	.341	.118	.840	.079	.092	.118	.544	.109	.146	1.376	.060	.019	.067	.017	.015
11	.089	.924	1.297	.284	2.211	.055	.842	.413	1.811	.743	.661	.931	1.257	.678	1.358	1.827	.076	.217	.394	.600	.476
12	.092	.909	1.658	1.045	2.095	.232	.502	.065	1.694	.313	.506	.777	.950	.510	1.645	1.916	.128	.310	.336	.220	.016
13	.484	.173	.556	.600	.886	.056	.577	.207	1.179	.037	.294	1.177	.403	.529	1.572	1.237	0	0	0	....	....
14	1.53	....	....	....	1.044	.021	.490	.158	1.667	.335	.423	.685	.883	.340	.987	1.813	.027	.067	.085	.207	.065

[1]All runoff in 1966 from storm on December 6.

TABLE 8.—*Average annual runoff, in inches, and sediment yield, in acre-feet per square mile, for watersheds at Badger Wash*

Watershed	Runoff		Sediment yield	
	1954-65	1966-73	1954-65	1966-73
1-A	0.645	0.458	2.78	1.98
1-B	.491	.392	1.43	1.19
2-A	.657	.369	3.18	1.43
2-B	.479	.298	2.37	1.18
3-A	.729	.603	2.77	1.84
3-B	.672	.659	2.25	2.54
4-A	.691	.399	4.69	2.06
4-B	.493	.305	2.50	1.16
5	.487	.517	1.18	1.05
6	.419	.373	1.79	1.39
7	.398	.465	1.91	1.37
8	.444	.410	1.78	1.17
9	.577	.430	1.56	1.16
10	.301	.226	.84	.45
11	.952	.703	1.68	1.51
12	.896	.635	2.48	.91
13	.512	.556	1.87	2.71
14	.634	.449	1.36	1.22

Hypotheses about the relationship between the mean runoff values for each watershed and for the various treatments along with the results of variance analyses on these values are as follows:

1. Hypothesis: That runoff from pairs of watersheds was comparable during the period 1954–65. Hypotheses was accepted. No significant difference was noted at the 5 percent level.
2. Hypothesis: That runoff from grazed watersheds was comparable to runoff from ungrazed watersheds during the period 1954–65. Hypothesis was rejected. A significant difference was noted at the 1 percent level.
3. Hypothesis: That runoff from ungrazed watersheds was the same during 1954–65 as it was from the same watersheds during 1966–73. Hypothesis was rejected. A significant difference was noted at the 1 percent level.
4. Hypothesis: That runoff from watersheds that were formerly grazed and then fenced in 1965 was the same as runoff from watersheds that were ungrazed during the entire study period. Hypothesis was accepted. No significant difference was noted at the 5 percent level.
5. Hypothesis: That runoff from watersheds grazed by sheep every year from November 15 to February 15 was the same as runoff from watersheds not grazed. Hypothesis was accepted. No significant difference was noted at the 5 percent level.
6. Hypothesis: That runoff from watersheds grazed by sheep in alternate years was the same as runoff from watersheds not grazed. Hypothesis was rejected at the 5 percent level and accepted at the 1 percent level.
7. Hypothesis: That runoff from watersheds grazed by sheep every year from November 15 to February 15 was the same as runoff from watersheds grazed during alternate years for the same period. Hypothesis was accepted. No significant difference was noted at the 5 percent level.

Several inferences may be drawn from these hypotheses. The acceptance of the first hypothesis that runoff from the different pairs of watersheds was comparable indicates that measured differences in runoff were not caused by gross differences in watersheds.

The rejection of the second hypothesis that runoff from grazed watersheds was comparable to that from ungrazed watersheds during the period 1954–65 is because there was a statistically significant difference in these values. Runoff from the ungrazed areas ranged from 73 to 92 percent of that from the grazed areas.

Rejection of the third hypothesis about runoff from ungrazed watersheds during the two periods 1954–65 and 1966–73 indicates there was a significant difference in runoff between the two periods. The average annual runoff during the 1966–73 period was only 78 percent of that in the first period. As was shown in the section on precipitation, there was no significant difference in the number of runoff-producing storms between the two periods. The difference in runoff was logically then the result of continued improvement in water absorption on the watersheds.

A significant reduction in runoff from the ungrazed watersheds was noted after about 2 years of exclusion. It was postulated at the time that this reduction was primarily the result of changes in the soil texture because of the cessation of trampling (Lusby and others, 1971). In order to further test this theory, two watersheds that received normal grazing use were fenced in 1965. Runoff from these watersheds during 1966–73 was then compared with that from watersheds that were ungrazed during the entire study period. Again, an almost immediate reduction in runoff from the formerly grazed watersheds was noted as no significant difference could be measured between the sets of data.

Hypotheses 5–7 were used to test the effect of grazing during different periods. No significant difference in runoff could be measured when comparing watersheds that were grazed by sheep from November 15 to February 15 each year and watersheds that were not grazed. Runoff from watersheds grazed by sheep in alternate years was significantly more than that from ungrazed watersheds at the 5 percent level but not at the 1 percent level. No significant difference in runoff could be measured when comparing areas that were grazed by sheep every year with areas grazed by sheep in alternate years. It would appear that elimination of grazing during the spring period, February 15 to May 15, had basically the same effect on runoff production as the complete elimination of grazing.

To determine the effect on runoff of storms of different magnitude and intensity, multiple regression analyses were run on individual storm-event data from two watersheds, 2–A and 4–A. The dependent variable (Y) was runoff, and independent variables chosen were storm precipitation (X_1), maximum 15-minute intensity during the storm (X_2), and antecedent moisture (X_3), which was defined as $0.5P_1+0.3P_2+0.1P_3$, where P_1 = precipitation on preceding day, P_2 = precipitation 2 days previously, and P_3 = precipitation 3 days previously. The resultant regression equations, multiple correlation coefficients, and variation of the dependent variable explained by the regression are as follows:

Watershed	Equation	Multiple correlation coefficient	Percent variation explained
2-A	$Y = -.08 + .287X_1 + .267X_2 + .083X_3$	0.87	76
4-A	$Y = -.10 + .309X_1 + .163X_2 + .301X_3$	.90	81

The three independent variables mentioned play an important role in affecting runoff in arid and semiarid regions. The difficulty in determining the hydrologic effects of storms of different magnitude and intensity is pointed up by the fact that the three independent variables can be present in almost limitless combinations. A frequency distribution of runoff from watersheds 2-A and 4-A was computed using the above equations. Fifteen-minute rainfall intensities were determined for 1-, 2-, 5-, 10- 25-, and 50-year recurrence intervals using National Weather Service Technical Paper No. 40 (U.S. Department of Commerce, 1961). Storm volumes of precipitation for the same recurrence intervals were determined from the long-term precipitation record at Fruita. Antecedent moisture conditions were assumed as dry and at a value of 0.3 inch. Results of these calculations, along with a frequency distribution of actual runoff from the watersheds are shown in figures 7 and 8. Inspection of these figures indicates that actual runoff was less than computed runoff for the lower frequency events. This was chiefly because 15-minute intensities appeared to be overestimated for small rainfall events. In the absence of a good statistical relationship between rainfall volume and intensity, the only reliable indicator of actual runoff peaks in this area is a long-term record. The recurrence intervals of runoff events measured (in inches) at two watersheds (2-A and 4-A) at Badger Wash are as follows:

Watershed	Recurrence interval, years					
	1	2	5	10	25	50
2-A	0	0.24	0.49	0.70	0.97	1.17
4-A	0	.25	.58	.82	1.16	1.42

EROSION AND SEDIMENT YIELD

Sediment yields from all watersheds at Badger Wash were as shown in table 9. Total sediment yield for each indicated period was computed from resurveys of reservoir capacity and represent the total yield for the period.

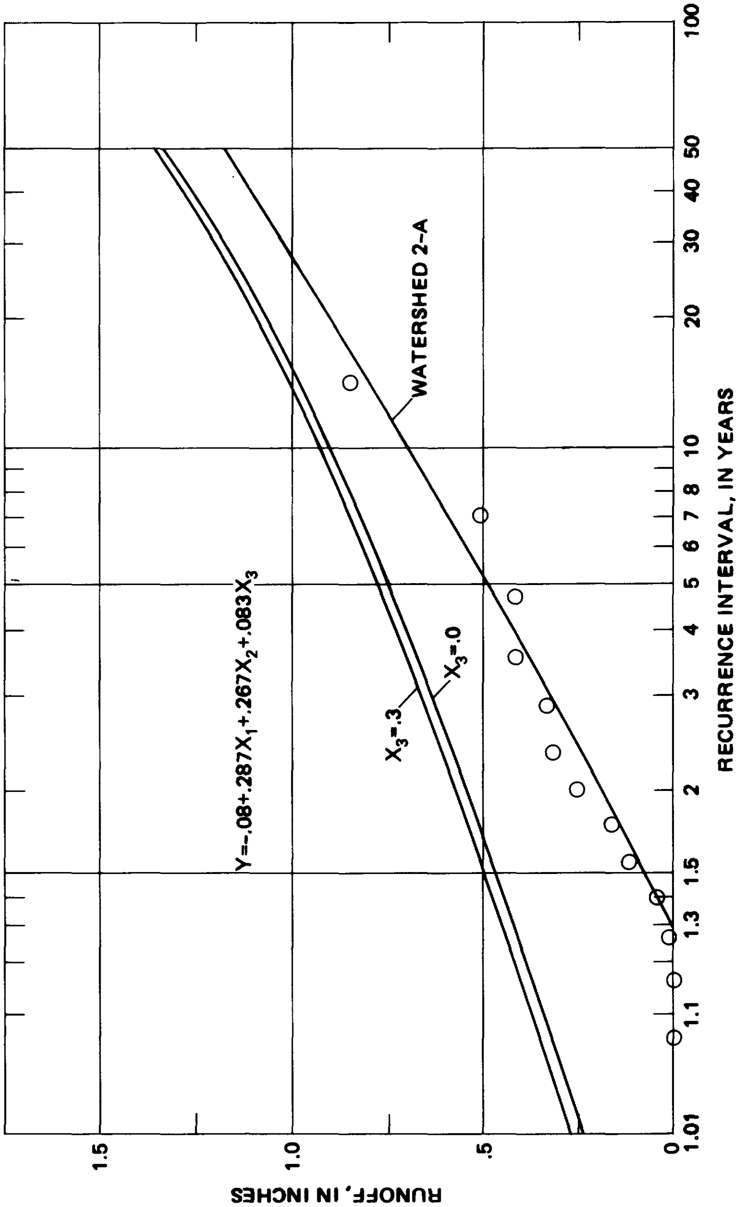

FIGURE 7.—Recurrence intervals of computed storm runoff assuming antecedent moisture of 0 and 0.3 inch and of measured storm runoff at watershed 2-A.

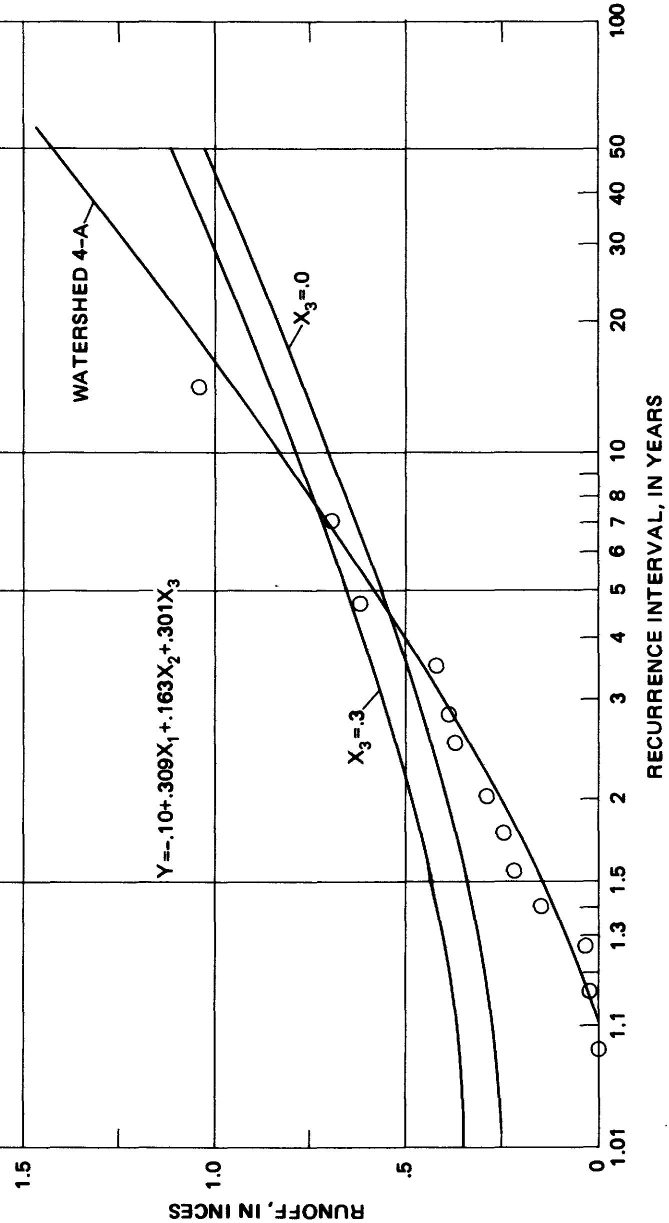

FIGURE 8.—Recurrence intervals of computed storm runoff assuming antecedent moisture of 0 and 0.3 inch and of measured storm runoff at watershed 4-A.

Sediment-yield values were quite variable from one period to another. This was probably caused by variations in the condition of the sediment deposits. At times surveys were made on fresh sediment that had not compacted, and at other times surveys were made after periods of drying which affects the density and consequently the sediment elevation. The long-term values of sediment yield are considered reliable. Average annual values of runoff and sediment yield for different treatments and periods are listed in table 10.

In order to test whether or not differences measured in sediment yield are statistically significant, an analysis of variance was performed on the data from paired watersheds. During the period 1954–65, when the area was grazed by cattle and sheep from November 15 to May 15 each year, the grazed watersheds produced 54 percent more sediment per unit area than the ungrazed watersheds. After adjusting for differences in watersheds and periods, this difference was significant at the 5 percent level.

The runoff and sediment-yield data given in table 10 indicate a relationship between the values. If runoff is plotted against sediment yield, a line may be fitted by least squares of the equation

$$Y = 0.11X - 0.85$$

where

Y = sediment yield in acre-feet per square mile, and
X = runoff in acre-feet per square mile.

The correlation coefficient for these data is 0.90. In the Badger Wash area where practically all runoff is generated from summer rainstorms, any treatment that produces a change in runoff will probably achieve a like change in erosion. Annual sediment-yield values are not available to test the statistical significance of the other treatments as was done with runoff values, but in view of the above relationship between long term runoff and sediment-yield figures, it seems likely that the same relationship would apply. Also, the relationship between runoff and sediment yield may be used to estimate sediment yield from runoff values obtained by extrapolating data from Badger Wash to other areas, as discussed in a later section.

There was considerable variation in the sediment-yield rate among the watersheds at Badger Wash, ranging from 0.45 acre-foot per square mile per year in watershed 10 (1966–73) to 4.69 acre-feet per square mile per year in watershed 4–A (1954–65). Watershed 10 is one of the flatter, more sandy areas, whereas watershed 4–A is very steep with sparse vegetation and mixed-type soil. The response to cessation of grazing was also greatest in the steeper areas. Sediment yield in area 4–A after fencing was only 43 percent of that during the period it was grazed. In the paired watershed 4–B, sediment yield during the second period of no grazing was only 25 percent of that from the paired grazed area 4–A during 1954–65.

TABLE 9.—*Total sediment yield for period from watersheds at Badger Wash, in acre-feet per square mile*

[*, Amount included in next value, T, trace, ..., no value obtained]

Period	Watershed																	
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B	5	6	7	8	9	10	11	12	13	14
Apr. 1954-July 1955	10.7	5.12	13.0	15.2	9.78	8.48	18.8	10.9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Apr. 1954-Nov. 1956	.....	.....	.....	.....	.....	.....	.....	.....	3.89	7.41	7.12	6.33	7.20	4.50	5.93	11.6	4.97	.....
Nov. 1956-Oct. 1957	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.91	.81	2.13	.45	1.00	1.80	5.36	2.92	.....
July 1955-Oct. 1957	3.74	2.50	3.30	.67	4.05	2.27	7.00	5.32	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
July 1957-Nov. 1958	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.42
Oct. 1957-Nov. 1958	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov. 1958-Nov. 1959	4.48	0	1.47	2.13	2.00	1.42	2.59	1.36	.98	.19	2.65	1.42	1.13	0	1.22	.61	4.98	2.01
Nov. 1959-Nov. 1961	5.33	3.86	8.22	3.89	8.03	2.79	6.77	.82	*	*	*	*	*	*	*	*	*	3.85
Nov. 1961-July 1962	.....	.....	.....	.....	.....	.....	.....	.....	3.60	4.67	3.98	4.81	2.59	.11	1.58	2.92	3.04	.52
Nov. 1961-Nov. 1962	1.11	1.21	1.14	1.30	.19	2.92	0	.59	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
July 1962-Nov. 1963	.....	.....	.....	.....	.....	.....	.....	.....	1.32	1.02	1.58	.85	.78	1.98	2.60	1.14	1.64	.93
Nov. 1962-Nov. 1963	.58	.12	1.15	.54	1.00	2.90	4.82	.41	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Nov. 1963-Nov. 1964	.61	.24	7.66	2.77	.66	1.10	6.59	4.09	2.29	.03	2.37	2.29	3.51	0	2.84	1.88	4.67	1.51
Nov. 1964-Nov. 1965	6.85	4.10	2.24	1.90	7.56	5.08	9.68	6.55	2.05	3.26	4.43	3.48	3.03	2.54	4.24	6.20	.21	1.96
Nov. 1965-Nov. 1966	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*

TABLE 9.—*Total sediment yield for period from watersheds at Badger Wash, in acre-feet per square mile*—Continued

Period	Watershed																	
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B	5	6	7	8	9	10	11	12	13	14
Nov. 1966–Nov. 1967	2.42	2.02	3.92	2.34	3.05	5.62	5.00	4.21	.34	2.05	3.15	2.95	6.70	1.70	3.20	1.40	5.90	1.84
Nov. 1967–Nov. 1968	7.88	7.38	6.55	6.20	6.83	9.79	6.36	3.68	7.20	8.30	6.49	4.86	1.21	1.73	3.42	2.73	4.93	3.67
Nov. 1968–Nov. 1969	0	0	0	0	.29	0	0	0	0	0	0	.47	0	0	0	0	0	.02
Nov. 1969–Nov. 1970	0	0	0	0	2.15	1.06	1.14	0	*	*	*	*	*	*	*	*	0	0
Nov. 1970–Nov. 1971	3.88	.08	0	T	.59	2.17	2.55	.15	.89	.17	.56	0	.93	0	3.30	1.51	.....	*
Nov. 1971–Nov. 1972	T	T	.98	.17	.69	.73	1.44	.73	0	*	.79	0	0	.18	.....	.09	.....	*
Nov. 1972–Nov. 1973	1.68	.03	0	.73	1.12	.99	0	.47	0	.61	0	1.08	.41	0	.64	1.51	.....	4.24
Total, 1954–73	49.26	26.66	49.63	37.84	47.99	47.32	72.74	39.28	22.56	32.62	33.93	30.67	27.94	13.74	30.77	36.95	33.26	21.97
Acre-ft per mi² per year	2.46	1.33	2.48	1.89	2.39	2.36	3.63	1.96	1.12	1.63	1.69	1.53	1.39	.68	1.53	1.84	1.66	1.29
Total, 1954–65	33.40	17.15	38.18	28.40	33.27	26.96	56.25	30.04	14.13	21.49	22.94	21.31	18.69	10.13	20.21	29.71	22.43	12.20
Acre-ft per mi² per year	2.78	1.43	3.18	2.37	2.77	2.25	4.69	2.50	1.18	1.79	1.91	1.78	1.56	.84	1.68	2.48	1.87	1.36
Total, 1966–73	15.86	9.51	11.45	9.44	14.72	20.36	16.49	9.24	8.43	11.13	10.99	9.36	9.25	3.61	10.56	7.24	10.83	9.77
Acre-ft per mi² per year	1.98	1.19	1.43	1.18	1.84	2.54	2.06	1.16	1.05	1.39	1.37	1.17	1.16	.45	1.32	.90	1.35	1.22

TABLE 10.—*Average annual runoff and sediment yield, in acre-feet per square mile, for various periods and treatments at Badger Wash*

Treatment	Runoff	Sediment yield
1. Ungrazed, 1954–65	28.50	2.08
2. Grazed by cattle and sheep Nov. 15 to May 15 each year, 1954–65	35.01	3.21
3. Ungrazed, 1966–73	20.90	1.19
4. Ungrazed 1966–73, but previously grazed each year Nov. 15 to May 15, 1954–65	17.64	1.51
5. Grazed each year Nov. 15 to Feb. 15 by sheep, 1966–73	24.42	1.98
6. Grazed alternate years Nov. 15 to Feb. 15 by sheep, 1966–73	24.76	1.43

Monumented channel cross sections were established in 1954 at 49 locations within the paired watersheds. In addition, one 50-foot hillside transect was established in each watershed. The purpose of these measurements was to determine the rate of erosion in channels and on hillsides in each of the watersheds. The ground elevations on the cross sections and transects were measured using a level and surveying rod. From these data a cross-sectional area was determined using a standard base. Changes in ground-surface elevation appeared as a change in cross-sectional area. The relative erosion was obtained by dividing the change in area by the length of the cross section or transect. Although the value obtained using this method is not an absolute value, it is indicative of the amount of erosion taking place, especially on the flatter hillside transects. Listed in table 11 are relative amounts of erosion in channels and on hillslopes at Badger Wash for the period from October 21, 1954, to October 21, 1973. The values given are averages for all channel cross sections in a watershed. Erosion in channels ranged from 0.020 to 0.342 foot and on hillslopes form 0.037 to 0.128 foot. Conversion of these values into amounts for a watershed is not possible because of the sparsity of coverage, but they do provide some insight into the source of sediment. The larger values of erosion in channels generally are in the larger watersheds where peak flows are of greater magnitude than in the small watersheds. The greatest erosion of hillslopes occurred in the steepest watersheds, usually on mixed-type soil. In grazed watersheds there was relatively more erosion in the channels and less on the hillslopes than in the ungrazed watersheds.

TABLE 11.—*Erosion, in feet, in channels and on hillslopes at Badger Wash, 1954–73*

Watershed	Channels	Hillslopes
1–A	0.151	0.042
1–B	.020	.065
2–A	.235	.037
2–B	.212	.044
3–A	.338	.082
3–B	.342	.128
4–A	.296	.090
4–B	.155	.127

A series of measurements was made on the hillside transects during 1966–68 to determine the change in surface elevation during the year. Results of these measurements were averaged for all watersheds and are as follows:

Period	*Average elevation change, in feet* Decrease (–) or increase (+)
Dec. 10, 1966, to Feb. 15, 1967	+0.013
Feb. 15, 1967, to Apr. 26, 1967	– .014
Apr. 26, 1967, to Aug. 8, 1967	– .022
Aug. 8, 1967, to Nov. 28, 1967	– .007
Nov. 28, 1967, to Apr. 28, 1968	+ .016
Apr. 28, 1968, to Nov. 11, 1968	– .028

An analysis of variance on individual measurements showed that variations about the mean for each period were not significant at the 5 percent level.

These data confirm previous postulations that freeze-and-thaw cycles in the Badger Wash area cause a swelling of the soil followed by a subsequent compaction during the summer. During the first winter period an average rise of 0.013 foot occurred, followed by a decline in the surface of 0.043 foot during the summer. During the next winter a rise in the ground surface again occurred, followed by another decline. Although a reduction in the land-surface elevation was measured for the 19-year period from November 1954 to November 1973, the cyclic up-and-down movement of the soil surface does take place during the year.

REGIONAL RUNOFF VOLUMES

Extrapolation of conclusions obtained at Badger Wash to areas of like climate and physiography may be done by considering frequency distribution of annual runoff volumes. As part of a broader soils-mapping program, the Soil Conservation Service made a detailed soil survey of the Badger Wash basin. The drainage basins of the watersheds at Badger Wash were comprised of varying amounts of three characteristic soil groups, but in three watersheds each of these soils was represented individually. Measurements from these watersheds were used to define the runoff properties of the three soils. Frequency distributions of annual runoff for the three soils as defined by measurements at Badger Wash are shown in figure 9. The area containing similar soils within Colorado has been mapped by the Soil Conservation Service (C. F. Spears, unpublished data, 1978), but a vast area farther west in Utah that is similar in nature has not been mapped. Description of the soils for which the frequency distribution curves were defined are given to provide extrapolation of the runoff data to the west.

DISTRIBUTION CURVE A—CHIPETA SERIES

The Chipeta series consists of shallow, well-drained soils. They formed in material weathered from shale on uplands. Slopes are 3–25 percent. Natural

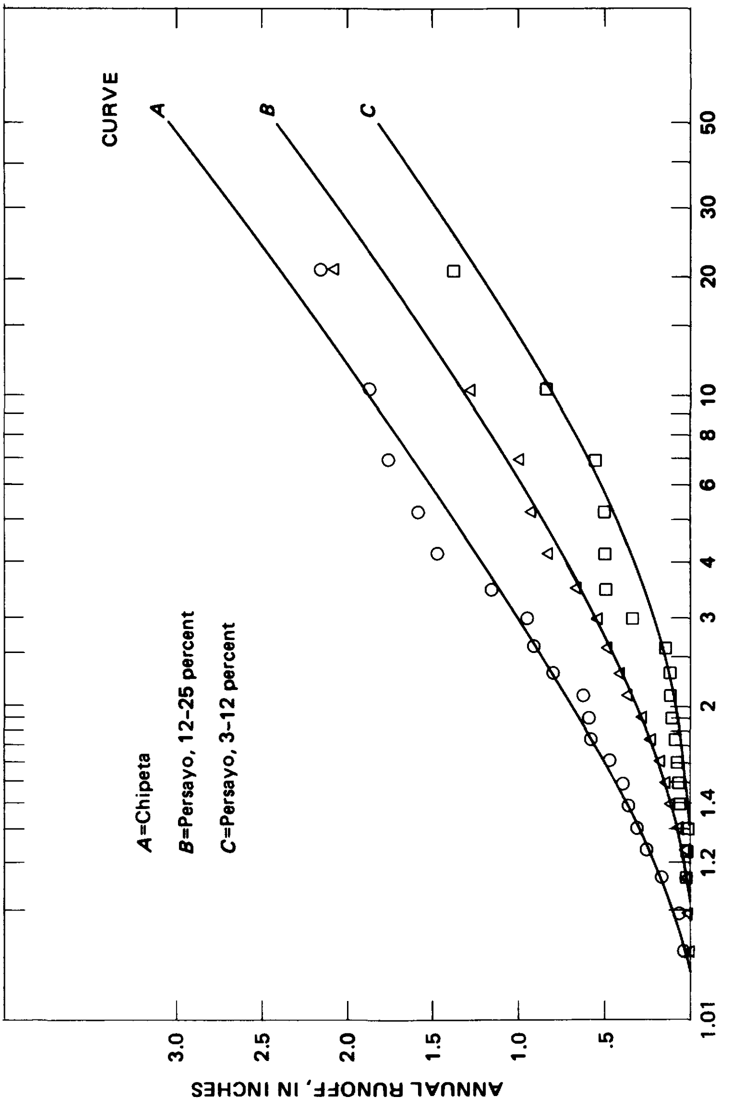

FIGURE 9.—Recurrence intervals of annual runoff for three soils types at Badger Wash.

vegetation is dominantly saltbushes, rabbitbrush, galleta, and Indian ricegrass.

In a typical profile the surface layer is light-gray silty clay about 2 inches thick. The underlying layer is very pale brown and gray silty clay about 12 inches thick, underlain by slightly weathered marine shale.

The soil is poorly permeable and has a low available water capacity. Reaction is moderately alkaline. Effective rooting depth is 12–17 inches.

DISTRIBUTION CURVE B—PERSAYO SILT LOAM 12-25 PERCENT

The Persayo series consist of shallow, well-drained soils. They formed in residium from silty shales on upland hills and ridges. Natural vegetation is dominantly saltbushes, rabbitbrush, galleta, and Indian ricegrass.

In a typical profile the surface layer is pale-yellow silt loam about 5 inches thick with small flat sandstone chips common on surface. The subsurface layer is light-brownish-gray silt loam about 11 inches thick with many shale chips and gypsum crystals in lower 4 inches. The underlying layer is yellowish-brown, firm silty shale. The soil is poorly permeable and has a low available water capacity. Effective rooting depth is about 16 inches.

DISTRIBUTION CURVE C—PERSAYO SILT LOAM 3-12 PERCENT

Description the same as for curve B except slopes are less steep.

RAINFALL DATA

An analysis of rainfall data obtained by the National Weather Service at seven stations was made to determine the area of similar climate. These seven stations were Grand Junction and Fruita, Colo., and Green River, Thompson, Hanksville, Castle Dale, and Moab, Utah. An analysis of variance of annual precipitation at these stations shows that the means and the variance about the means are homogeneous except for Green River and Hanksville. This information was used as an aid in delineating the areas shown in figure 10. Drainage basins found within these areas that are of similar soils groups to those described previously are apt to produce similar frequency distributions of annual runoff. In general, the areas outlined in figure 10 are located on Mancos Shale along the Book Cliffs westward from

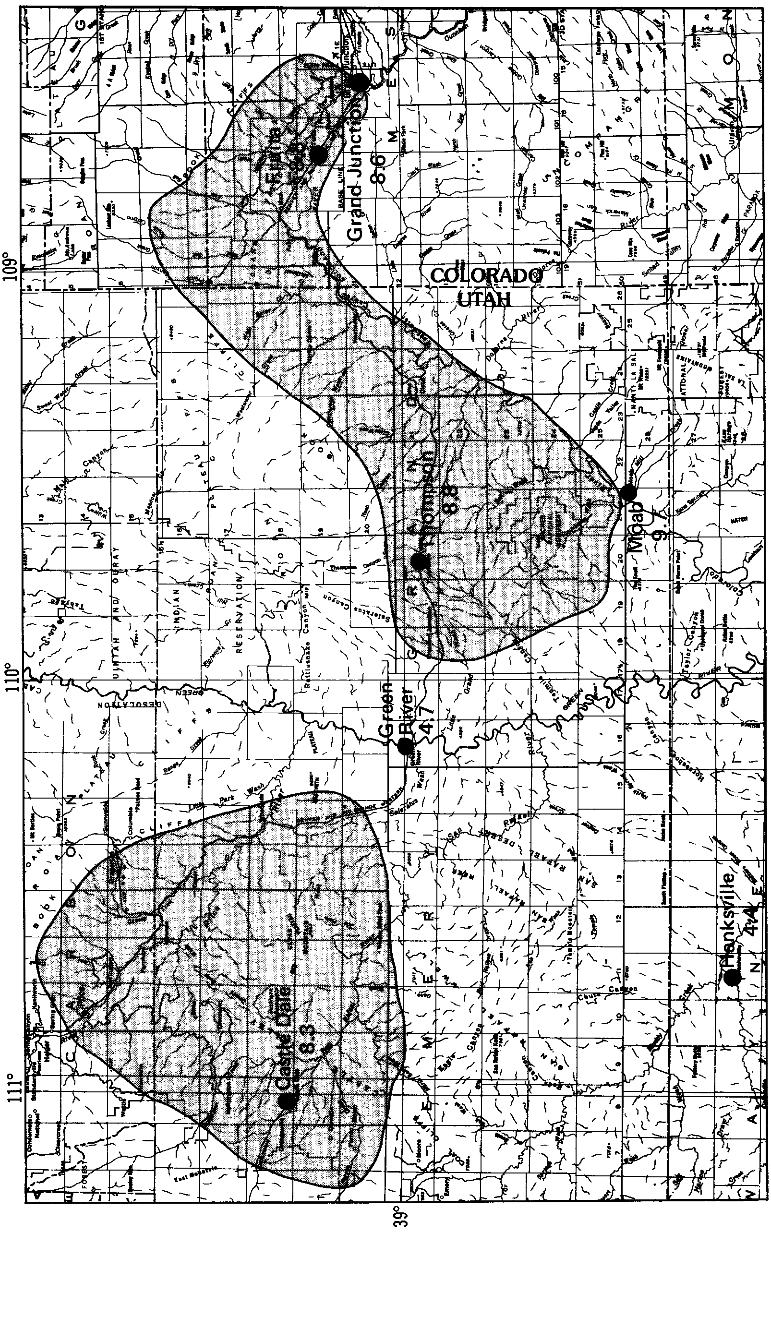

FIGURE 10.—Map showing average annual precipitation at selected weather stations and areas of similar climate and physiography.

Grand Junction. The climate for the area between Green River and Hanksville is considerably more arid, and the soil type is also different.

If an area of interest is located within the shaded areas shown on figure 10 and can be identified as one of the three soils groups described, the frequency distribution of annual runoff volumes may be estimated by the applicable curve in figure 9.

The range in size of watersheds at Badger Wash was not great enough to define the relationship between runoff and drainage area. It is generally accepted that unit runoff decreases with increase in drainage area. For this reason, the data given here should not be used to estimate runoff from areas larger than 10 square miles, which is about the size of the Badger Wash drainage area. Also, caution should be used in extending estimates beyond the time period given in figure 9.

CONCLUSIONS

Four types of grazing treatment were evaluated hydrologically by studies at Badger Wash. These treatments were: grazing by sheep and cattle from November 15 to May 15 each year, complete elimination of grazing, grazing by sheep from November 15 to February 15 each year, and grazing by sheep from November 15 to February 15 every other year. At the initiation of the project, the normal grazing practice in the Badger Wash area was winter and spring grazing by cattle and sheep from November 15 to May 15 each year. This practice was used as a baseline for evaluating the effects of the other treatments.

The elimination of grazing during the period 1953-65 resulted in a reduction of runoff by about 25 percent, which was accompanied by a simultaneous reduction in sediment yield of about 35 percent. During the period 1966-73, ungrazed areas were yielding 60 percent of the runoff and 37 percent of the sediment that was being produced under the original grazing practice.

Runoff from areas that were grazed only by sheep from November 15 to February 15 each year was 71 percent of that during the base period; whereas that from like areas grazed by sheep from November 15 to February 15 every other year was 80 percent of that during the base period. Both these reductions in runoff were accompanied by like reductions in sediment yield. The primary reason for these changes in runoff and erosion was probably the elimination of grazing during the spring period, February-May 15.

Multiple regression equations developed for storm runoff from two areas at Badger Wash explained about 78 percent of the variation in runoff and had a multiple correlation coefficient of about 0.88. Three independent variables that had a significant effect in these equations were storm volume, maximum 15-minute intensity, and antecedent moisture.

Annual sediment yield from the watersheds at Badger Wash ranged from 0.45 acre-foot per square mile in one of the flatter sandy areas, to 4.69 acre-feet per square mile in one of the areas with steep slopes. Greatest reduction in erosion because of grazing control was noted in the steeper areas.

Frequency of recurrence of annual runoff volumes were developed for three soil types at Badger Wash. Areas similar in climate and physiography to Badger Wash were outlined on maps, which may be used to develop estimates of runoff volumes for a large area in eastern Utah and western Colorado.

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