Effects of Converting Sagebrush Cover to Grass on the Hydrology of Small Watersheds at Boco Mountain, Colorado

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1532-J

Prepared in cooperation with the U.S. Bureau of Land Management

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By GREGG C. LUSBY

HYDROLOGIC EFFECTS OF LAND USE

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UNITED STATES GOVERNMENT PRINTING OFFICE: 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

Library of Congress Cataloging in Publication Data

Lusby, Gregg C.
Effects of converting sagebrush cover to grass on the hydrology of small watersheds at Boco Mountain, Colorado

(Hydrologic effects of land use) (Geological Survey water-supply paper 1532-J)
Bibliography: p. J24.
1. Hydrology–Colorado–Boco Mountain. 2. Sagebrush. 3. Grasses–Colorado–Boco Mountain. 4. Botany–Ecology–Colorado–Boco Mountain. 5. Range management–Environmental aspects–Colorado–Boco Mountain. I. United States. Bureau of Land Management. II. Title. III. Series. IV. Series: United States. Geological Survey. Water-supply paper 1532-J.
TC801.U2 no. 1532-J [GB705.C6] 553'.7'0973s [551.4'8] 78-32149

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C. 20402
Stock Number 024-001-03154-0

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CONVERSION TABLE

For use of those readers who may prefer to use U.S. customary rather than metric units, the conversion factors for the terms used in this report are listed below

Multiply metric unit	*By*	*To obtain U.S. customary unit*
millimeters (mm)	0.0394	inches (in.)
centimeters (cm)	.3937	inches (in.)
meters (m)	3.281	feet (ft)
kilometers (km)	.622	miles (mi)
square meters (m^2)	10.76	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
hectares (ha)	2.47	acres
square kilometers (km^2)	.386	square miles (mi^2)
kilograms (kg)	2.205	pounds (lb)

EFFECTS OF CONVERTING SAGEBRUSH COVER TO GRASS ON THE HYDROLOGY OF SMALL WATERSHEDS AT BOCO MOUNTAIN, COLORADO

By GREGG C. LUSBY

ABSTRACT

Changes in runoff and sediment yield caused by changing sagebrush cover to grass cover were studied at four small watersheds in western Colorado during a 9-year period, from 1965 to 1973. Measurements of runoff and sediment yield from the four watersheds were made for 3 years, at which time two watersheds were plowed and seeded to beardless bluebunch wheatgrass. The same measurements were then continued for an additional 6 years.

Measurements indicated that conversion to grass caused a reduction in runoff from summer rainstorms of about 75 percent. Runoff from spring snowmelt increased about 12 percent, and annual runoff from treated watersheds decreased about 20 percent when compared to control watersheds. Sediment yield from the seeded watersheds was reduced by about 80 percent; most of this reduction is related to the decrease in runoff from summer rainstorms.

The size of barren interspaces between plants was reduced on the converted watersheds to about 30 percent of those on the untreated watersheds. Linear regression analysis indicates that a reduction of 38 percent in the amount of bare soil resulting from planting grass would result in a decrease of 73 percent in sediment concentration.

INTRODUCTION

One of the primary factors affecting the surface hydrology of land masses is the vegetal cover. The vegetal cover not only affects the timing of runoff and the percentage of precipitation that becomes runoff, but it also drastically affects erosion. Langbein and Schumm (1958) showed a relationship between annual precipitation and weight of vegetation per acre and also between annual sediment yield and effective precipitation, which is defined as the amount of precipitation required to produce the known amount of runoff. The highest erosion rates measured in the United States occurred on areas which had an annual effective precipitation of from 250 to 350 mm. This amount of precipitation occurs on millions of hectares of land in the Western United States.

Sediment production is not only dependent on the amount of precipitation but also is dependent on the type of vegetation growing on the watershed. Several different vegetative communities in the United States are adapted to the effective precipitation range of 250 to 350 mm. These include Pinyon-Juniper forest, grassland, and desert shrubs, each of which has its own intrinsic values. Included in the shrub category is the sagebrush community, which is dominant on over 400,000 km^2 of land in the Western United States. Many sites in the United States have been treated to eradicate the sagebrush and promote the growth of grass. Although many sites have already been treated, a greater area remains untouched. Little is known about the effects of these conversions on the hydrology of the sites where the work was done.

ACKNOWLEDGMENTS

Many thanks are due numerous coworkers in the Geological Survey who helped collect and compute the data. Special thanks to Lynn M. Shown who helped collect and analyze the data on soil moisture and Farrel A. Branson who did the work on vegetation.

The Bureau of Land Management administered the lands on which the study was done, fenced the entire area, constructed the measurement reservoirs, and plowed and seeded the study watersheds.

PURPOSE AND SCOPE

Very few quantitative data are available on the hydrologic effects of changing sagebrush cover to grass, although it is generally believed that a substantial grass cover provides better watershed protection than sagebrush because of the closer spacing of plants. Sagebrush tends to inhibit the growth of understory and leaves barren interspaces, providing avenues for runoff and attendant erosion. It is the objective of this study to determine the hydrologic effects of changing sagebrush to grass at a specific location.

The scope of the study includes the determination of rainfall, runoff, sediment yield, infiltration, soil moisture, and productivity of natural sagebrush sites and the comparison of these factors with those from nearby sites that have been converted to grass.

LOCATION

The study area is located in west-central Colorado about 5 km north of Wolcott, lat 39°44′, long 106°41′, at an altitude of about 2,200

m. The drainage is tributary to Alkali Creek, which flows into the Eagle River about 3 km downstream. The general location is shown in plate 1.

METHODS OF STUDY

In 1965, four small drainage basins at the study area were chosen for instrumentation and calibration. These basins ranged in size from 2.06 to 3.92 ha. A small reservoir was constructed at the lower end of each drainage basin to measure runoff and sediment. The reservoirs were equipped with continuous water-stage recorders for the measurement of runoff, and permanent monumented cross sections were established for stage-capacity and sediment-yield computations. One of the water-stage recorders is shown in figure 1. A precipitation recorder was installed in each drainage basin. Two basins were provided with digital recording gages which measured rainfall only (fig. 2). The other two basins were provided with weighing-type recorders which measured both rain and snow (fig. 3). Four sampling stations were established in each basin where soil samples were obtained periodically (usually monthly during summer months) for the gravimetric determination of soil moisture (fig. 4). Permanent vegetation transects (fig. 5) were established at 10 locations in each basin for measurement of vegetation type and density.

FIGURE 1.—Water-stage recorder installed in reservoir for measuring runoff.

The aforementioned measurements were made in all four basins from July 1965 to October 1967, at which time two of the basins were plowed using a disc (fig. 6), and beardless bluebunch wheatgrass (*Agropyron inerme*), was planted using a rangeland drill (fig. 7.) The same measurements were then continued until October 1973. Effects of the vegetation change were determined by comparing measurements before and after treatment.

Drainange basins and instrumentation are as shown in plate 1.

FIGURE 2.—Digital recording rain gage.

Prior to the beginning of the study, the area was used for sheep grazing. The entire area was fenced in 1965 and has not been used by domestic livestock since that time. Some use of the area has been made by big game animals during the winter months.

DESCRIPTION OF THE AREA

TOPOGRAPHY

The Boco Mountain watersheds are located in the low hills bordering Alkali Creek. Average basin slope ranges from about 6 to 9 percent. Each basin contains a central drainage channel leading to the

FIGURE 3.—Weighing-type recording precipitation gage.

measurement reservoir. Except for the main channel, the basins are not greatly incised.

GEOLOGY AND SOILS

The Boco Mountain watersheds are located on Pierre Shale of Late Cretaceous age (Tweto and others, 1976). Pierre Shale is a dark-gray marine shale containing a few thick beds of fine-grained sandstone. In the area of study no sandstone is exposed.

The soil on the watersheds is residual weathered parent material

FIGURE 4.—Acquisition of soil samples for determination of soil moisture.

and contains no A horizons. Fractured bedrock lies from 60 to 200 cm below the surface, but over most of the area it averages about 100 cm below the surface. Soil material has a silty clay texture, is quite uniform in structure, and is very dense. Below 10 cm depth a bulk density greater than 2.0 is common. The density of the upper 10 cm varies depending on the time of year and moisture content.

CLIMATE

The climate at Boco Mountain is semiarid. The nearest long-term weather station is at Eagle, about 13 km west of and 210 m lower than the study area. The average annual precipitation for 30 years of record at Eagle was 259 mm (U.S. Weather Bureau, 1943–73). Of this amount, about 165 mm occurred as rain and 94 mm as snow. Precipitation at Boco Mountain during the study period averaged about 30 percent more than that at Eagle. This is probably the normal situation caused by the higher altitude. The monthly distribution of rain and snow appears to be similar at the two stations. The largest average monthly precipitation was 27 mm in August, and the smallest was 15 mm in February. Rainstorms in the summer are characterized

FIGURE 5.—Vegetation transect for determination of vegetation type and density.

by numerous small events in addition to an occasional large event. The larger events often constitute most of the monthly precipitation. Snowfall during the winter accumulates to some extent and provides a snow cover generally from November until March. Summer temperatures are usually cool at night and warm during the day. The average time between the last spring and first fall freezing temperature at Eagle was 76 days. However, freezing temperatures have been recorded in every month of the year.

VEGETATION

The dominant vegetation on the watersheds before conversion was big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) (Shown and others, 1972). It averaged about 0.6 m in height, and the shrub canopy cover varied from 45 to 55 percent of the watershed areas. The spacing of the sagebrush trunks was 0.6 to 0.9 m (fig. 8). The generally sparse understory was composed of western wheatgrass (*Agropyron smithii*), bottlebrush squirreltail (*Sitanion hystrix*), and several other grasses and forbs. Usable forage production from shrubs, grasses, and forbs was estimated to be about 111 kg/ha.

A few stunted juniper trees grow at the upper end of two of the watersheds, and aspen grow at a slightly higher altitude on some of the nearby hills.

RESULTS

PRECIPITATION

Precipitation was measured at four locations during the course of

FIGURE 6.—Disc plow being used at Boco Mountain to remove sagebrush.

FIGURE 7.—Rangeland drill used to seed bluebunch wheatgrass at Boco Mountain.

FIGURE 8.—Sagebrush cover at Boco Mountain showing the bare interspaces and sparse understory.

the study. Gages 1 and 3 (pl. 1) were installed in November 1964 and were operated continuously until September 1973. These were weighing-type recorders that measured snow and rain. Digital recording gages were installed at sites 2 and 4 in June 1966. These gages were used to measure rain only and were operated each summer until 1973. Monthly and annual amounts are shown in table 1.

As noted elsewhere in this report, the Boco Mountain watersheds annually received about 30 percent more precipitation than Eagle during the study period. Figure 9 shows a frequency curve for annual precipitation at Eagle based on 30 years of record. A second frequency curve is shown that represents annual precipitation amounts which are 30 percent larger. The recurrence of annual precipitation measured at Boco Mountain that was computed from the short-term record fits the upper curve on figure 9 very closely. Using the upper curve, the recurrence interval of annual precipitation at Boco Mountain is as follows:

	Annual precipitation, in millimeters	*Recurrence interval, in years*
1965	411	5.4
1966	288	1.4
1967	319	1.8
1968	280	1.3
1969	446	8.7
1970	343	2.3
1971	312	1.7
1972	261	1.2

Shown on figure 10 is a frequency curve of maximum daily precipitation at Eagle for the summer months. Also plotted on this curve is maximum daily precipitation at Boco Mountain at recurrence intervals computed from the short-term record. The data fit the curve for Eagle quite well except for one day in 1969, which was apparently an extreme event. The frequency of maximum daily precipitation at Boco Mountain obtained from this curve is as follows:

	Maximum daily precipitation, in millimeters	*Recurrence interval, in years*
1965	26.4	5.2
1966	12.7	1.3
1967	15.5	1.6
1968	13.0	1.3
1969	49.5	*120.0
1970	15.5	1.6
1971	23.4	3.5
1972	22.4	3.1
1973	16.2	1.7

*This value is too far beyond available data for reliability.

RUNOFF

The effect of vegetative conversion on runoff will be considered separately for both rainstorms and snowmelt because it appears that the effects were different. The treated watersheds, 2 and 4, were plowed and planted to beardless bluebunch wheatgrass (*Agropyron inerme*) in October 1967. The control watersheds, 1 and 3, remained in sagebrush throughout the study period 1965–73. The grass did not become well established until late in the growing season of 1968. In

TABLE 1.—*Precipitation at Boco Mountain watersheds, in millimeters*

Year	Gage	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for year
1964	1	----	----	----	----	----	----	----	----	----	----	36.1	43.7	----
	2	----	----	----	----	----	----	----	----	----	----	----	----	----
	3	----	----	----	----	----	----	----	----	----	----	34.0	41.1	----
	4	----	----	----	----	----	----	----	----	----	----	----	----	----
1965	1	28.7	10.4	40.4	17.8	25.7	26.4	67.6	43.2	83.6	6.6	51.8	20.3	422.5
	2	----	----	----	----	----	----	----	----	----	----	----	----	----
	3	25.7	9.4	38.1	16.3	19.8	21.8	57.9	45.5	82.8	6.6	52.1	23.4	399.4
	4	----	----	----	----	----	----	----	----	----	----	----	----	----
1966	1	5.6	13.7	4.6	26.2	36.1	22.4	14.5	41.4	21.1	24.9	25.7	54.6	290.8
	2	----	----	----	----	----	22.1	16.5	47.5	21.6	----	----	----	----
	3	7.6	11.2	5.3	23.6	32.5	22.4	15.2	43.7	18.3	24.1	27.4	54.1	285.4
	4	----	----	----	----	----	22.6	18.0	45.0	21.6	----	----	----	----
1967	1	22.1	20.1	20.6	8.1	23.1	36.6	30.0	43.9	62.7	15.0	14.0	34.0	330.2
	2	----	----	----	4.8	24.4	38.1	37.1	38.9	57.4	----	----	----	----
	3	21.8	20.3	19.3	10.7	24.6	33.8	29.7	38.6	51.8	15.0	11.4	31.2	308.2
	4	----	----	----	6.4	25.1	42.2	35.3	46.5	54.4	----	----	----	----
1968	1	10.2	21.3	7.4	29.2	33.8	1.7	43.7	62.0	24.1	22.6	20.1	17.0	293.2
	2	----	----	----	----	28.4	2.8	41.9	56.6	23.6	20.1	----	----	----
	3	9.4	17.3	6.4	28.4	28.2	1.5	36.1	51.8	21.1	18.8	31.2	17.3	267.5
	4	----	----	----	----	30.5	3.6	44.5	59.4	23.6	20.8	----	----	----
1969	1	67.8	15.0	5.8	26.4	27.4	104.1	39.1	19.1	16.0	71.9	18.0	25.1	435.7
	2	----	----	----	----	24.6	98.3	41.9	22.4	21.8	63.2	----	----	----
	3	67.1	11.2	5.3	22.9	24.4	94.2	39.6	19.1	17.5	74.7	15.5	25.1	456.2
	4	----	----	----	----	25.1	97.8	42.4	24.4	20.6	67.1	----	----	----
1970	1	20.1	4.3	20.8	35.8	9.9	25.7	23.6	37.3	54.1	49.3	31.0	26.6	338.5
	2	----	----	----	----	10.7	26.7	25.7	57.4	60.5	49.8	----	----	----
	3	15.2	3.3	23.4	38.9	10.4	23.9	21.3	41.7	56.1	48.8	34.0	30.0	347.0
	4	----	----	----	----	10.7	26.4	24.9	51.8	61.2	49.8	----	----	----
1971	1	27.9	21.6	23.4	22.6	29.2	2.8	38.9	26.9	52.8	19.6	9.7	45.7	321.1
	2	----	----	----	----	27.9	3.6	37.1	26.9	47.2	----	----	----	----
	3	17.3	22.1	22.4	21.6	27.2	2.0	37.6	26.4	51.1	19.6	10.9	43.7	301.9
	4	----	----	----	----	29.5	3.6	36.8	29.5	48.3	----	----	----	----
1972	1	7.4	6.6	16.0	33.8	17.8	26.2	8.6	14.7	48.0	39.1	11.2	28.7	258.1
	2	----	----	----	----	16.3	34.0	13.7	16.3	47.5	43.2	----	----	----
	3	6.4	6.6	15.0	32.0	18.3	28.2	12.4	15.0	46.0	42.9	12.7	27.7	263.2
	4	----	----	----	----	16.0	32.0	14.2	16.8	48.8	47.0	----	----	----
1973	1	12.2	6.9	11.7	35.8	33.0	49.8	57.4	17.8	10.4	----	----	----	----
	2	----	----	----	----	37.6	49.3	53.6	16.0	11.4	----	----	----	----
	3	12.7	6.6	13.0	36.3	33.8	47.0	52.1	17.5	11.4	----	----	----	----
	4	----	----	----	----	36.8	48.5	52.1	18.8	10.7	----	----	----	----

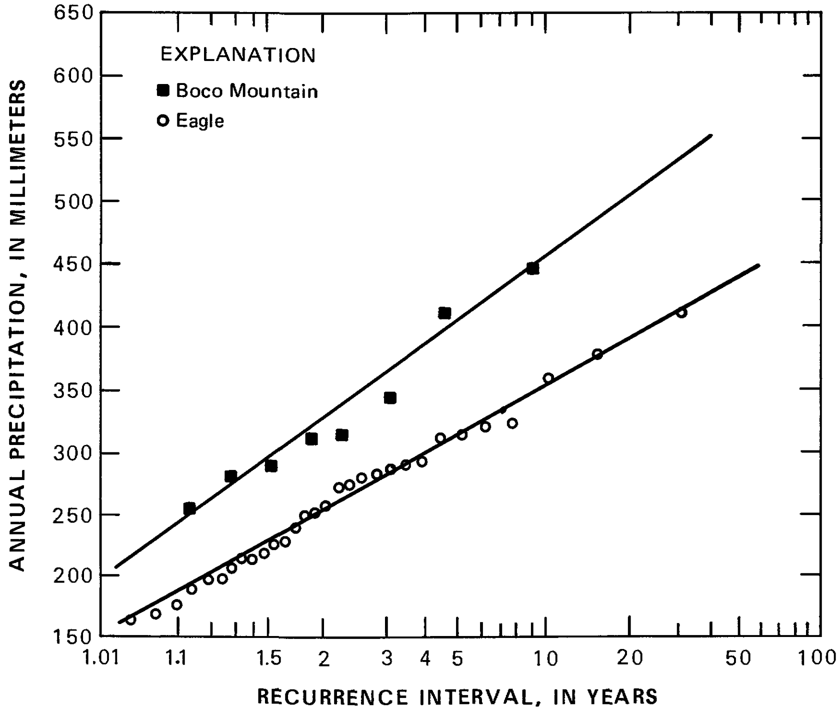

FIGURE 9—Frequency curve of annual precipitation at Eagle and an estimated curve for Boco Mountain, where the precipitation is 30 percent greater.

comparing pretreatment and posttreatment periods, 1968 is omitted because it is considered a transition period.

Three methods were used to determine the statistical significance of changes noted in runoff from treated watersheds and the magnitude of these changes. These methods are variance analysis, determination of predicting equations by regression of runoff events between watersheds during the calibration period, and the regression of precipitation against runoff for individual events.

RAINSTORM RUNOFF

Inflow to the reservoirs at Boco Mountain by individual event is shown in table 5 at the end of the report. Annual runoff from rainstorms is shown in table 2.

A three-way analysis of variance was performed on runoff data for the Boco Mountain watersheds to test the significance of any measured differences. This type of analysis was done for both individual rainstorm runoff events and annual runoff from rainstorms for each watershed. This analysis determines the portion of the total variance in runoff data that is attributable to different factors. In this case the

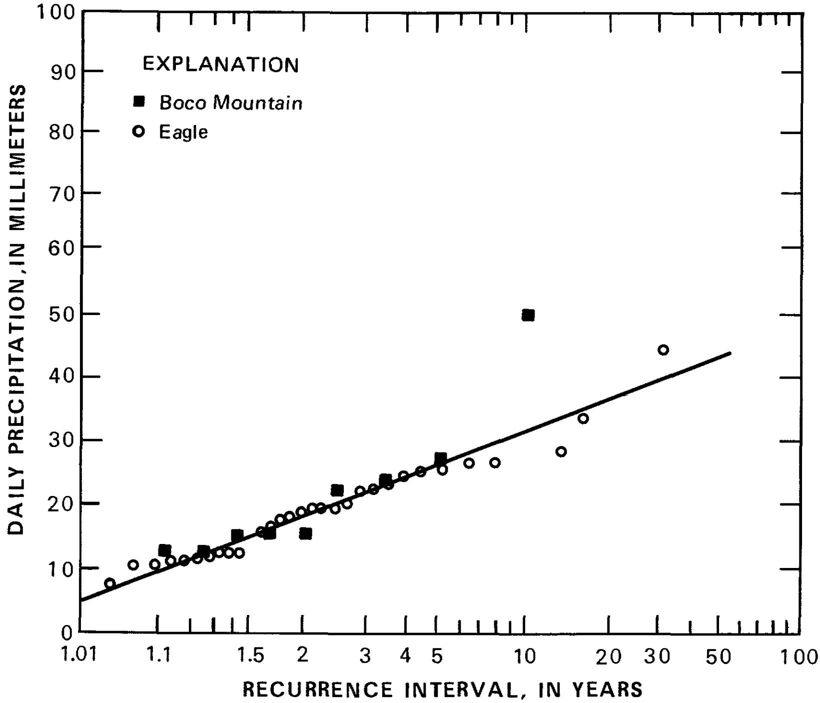

FIGURE 10—Frequency curve of maximum daily precipitation at Eagle for the summer months and maximum daily precipitation recorded at Boco Mountain.

factors considered were differences in watersheds, differences in years, and differences in cover. Differences in runoff caused by differences in watershed cover as measured by the "F" statistic were significant at the 1 percent level for both individual runoff events and annual runoff.

In order to determine the magnitude of changes that were indicated, regression equations were developed between runoff from con-

TABLE 2.—*Annual rainstorm runoff from watersheds at Boco Mountain, in millimeters*

[1968 is considered a transition year from sagebrush to wheatgrass and so is not considered]

Year	Watershed 1	Watershed 2	Watershed 3	Watershed 4
1965	28.7	41.9	33.8	31.8
1966	.5	7.1	2.7	3.7
1967	6.6	16.6	10.4	9.3
1969	14.8	9.8	27.9	11.0
1970	.8	.4	4.1	0
1971	6.4	1.2	8.6	.8
1972	3.0	0	3.3	0
1973	.1	.5	.8	.1
Total	60.9	77.5	91.6	56.7

trol and converted watersheds during the pretreatment period. The resulting equations are as follows:
For annual rainstorm runoff,

$$Y = 3.5 + 1.08X;$$

for individual rainstorm runoff,

$$Y = 0.24 + 1.07X$$

where

Y = runoff from watersheds before conversion, and
X = runoff from control watersheds, both in millimeters.

The standard error for these two equations was 1.9 mm for annual amounts and 0.4 mm for individual events.

Predicted annual runoff from rainstorms for the converted watersheds during 1969 to 1973 was 11.1 mm, whereas 2.4 mm was measured. Predicted runoff using the individual event equation was 9.2 mm per year. Indicated reduction in runoff for each of the equations was 78 percent and 74 percent, respectively.

Shown in figure 11 are the results of plotting precipitation (X) against runoff (Y) for watersheds 1 (control) and 4 (treated) during both the pretreatment and posttreatment periods. The least-squares fit of the regression lines in this figure indicate that in the control watershed, runoff from rainstorms was slightly less during the posttreatment period, but the slope of the regression line remained essentially the same. In the treated watershed the slope of the regression line declined from 0.28 to 0.21.

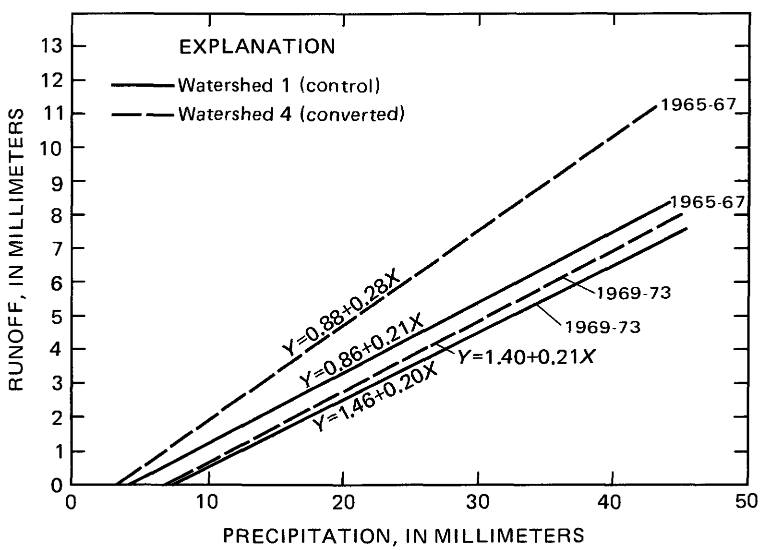

FIGURE 11.—Regression of precipitation versus runoff from rainstorms at watersheds 1 and 4, Boco Mountain.

The same relationship for watersheds 3 (control) and 2 (treated) is shown in figure 12. Essentially the same result is indicated for these watersheds as was seen in watersheds 1 and 4. The slope of the regression was almost the same in pretreatment and posttreatment periods for the control watershed, whereas the slope for the treated watershed declined from 0.35 to 0.16.

SNOWMELT RUNOFF

The response of the converted basins to snow was somewhat different from what it was to rain. Runoff derived from snowmelt for all basins is shown in table 3. An analysis of variance showed that after adjustment for differences in watersheds and years, no significant difference in runoff from converted and control watersheds was measured.

The relationship between runoff from the control watersheds (1,3) and the converted watersheds (2, 4) was established by regression of values obtained during the calibration period. The resulting equation is

$$Y = -9.7 + 1.65X$$

where

Y = annual snowmelt runoff from converted watersheds, and
X = annual snowmelt runoff from control watersheds, both in millimeters.

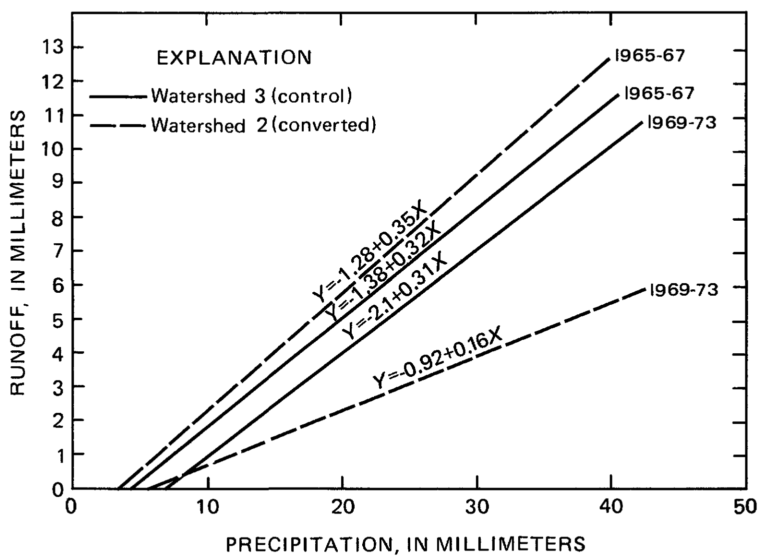

FIGURE 12.—Regression of precipitation versus runoff from rainstorms at watersheds 2 and 3, Boco Mountain.

The correlation coefficient is 0.98 with 2 degrees of freedom, and the standard error is 1.8 mm. Average annual snowmelt from the converted watersheds obtained by using this predicting equation and runoff values from the control watersheds during 1969–73 was 36.0 mm. Measured average annual snowmelt from the converted watersheds was 35.1 mm, which again indicates no appreciable difference in snowmelt runoff because of conversion.

A large part of the annual runoff at Boco Mountain is derived from snowmelt. This proportion on the control and converted watersheds is as follows:

	Proportion of annual runoff occuring from snowmelt, in percent	
	Control	*Converted*
1966–67 (pretreatment)	83	69
1969–73 (posttreatment)	80	91

The percentage remained about the same for the two periods in the control watersheds, but in the watershed changed to grass, the percentage increased from 69 to 91 percent. This was caused primarily by the reduction of runoff from summer rainstorms, although for these particular periods runoff from the converted watersheds increased from 110 percent of that from the control watersheds during the pretreatment period to 123 percent during the posttreatment period.

Figures 13A and 13B show a comparison of the snowpack at one of the sagebrush watersheds and a grassed watershed. A meaningful measure of the snowpack on sagebrush-covered watersheds is difficult to obtain. Athough the snowfall measured on all watersheds was nearly the same, it is not known how much redistribution by wind took place prior to melting. Snow-tube measurements in the watersheds indicated that distribution on the converted watersheds was quite uniform but distribution on the control watersheds was highly variable. Density of the snow within shrub crowns is generally much less than that in the interspaces. During the spring period prior to the start of runoff, snow within the shrub crowns is either melted or

TABLE 3.—*Runoff from snowmelt at Boco Mountain, in millimeters*
[1968 is considered a transition year from sagebrush to grass and so is not considered]

Year	Watershed 1	2	3	4
1966	29.7	29.7	23.5	38.8
1967	19.0	18.5	18.3	23.3
1969	40.7	67.2	36.5	65.6
1970	25.8	24.5	20.4	31.6
1971	43.5	39.9	50.6	57.5
1972	26.9	21.5	21.3	30.2
1973	0	.2	0	13.1
Total	185.6	201.5	170.6	260.1

FIGURE 13.—Snow cover at Boco Mountain. *A*, Sagebrush area. *B*, Grassed area.

evaporated as shown in figure 14A. Hutchison (1965) described this same effect at a study site in northern Wyoming. It is not known whether this moisture enters the ground as stemflow around the plants or is evaporated, but it is not available for runoff. According to Shown and others (1972), the soil moisture is recharged slightly more during the winter period in the sagebrush watersheds than in the grass. This water may come from the snowpack around the plants. In contrast, the snowpack on the grassed watersheds is a nearly uniform depth over the area and is evenly exposed to solar radiation, which may induce a quicker melt and thus provide less opportunity for infiltration.

Regression of annual runoff between control and converted watersheds during the pretreatment period resulted in a predicting equation:

$$Y = -5.8 + 1.54X$$

where

Y = annual runoff from converted watersheds, and

X = annual runoff from control watersheds, both in millimeters.

The correlation coefficient was 0.79 with 2 degrees of freedom. The standard error of this regression is 2.8 mm. Annual runoff during the posttreatment period for the converted watersheds using this equation was 46.8 mm, whereas 37.5 mm was actually measured, resulting in a reduction of 20 percent.

SEDIMENT YIELD

Total annual sediment yield was determined for each watershed by measuring the sediment deposit in the outlet reservoir after each summer runoff season. Computations were done from permanently established cross sections in the reservoirs to determine the accretion during the intervening period. Sediment yields for each period are shown in table 4. The sediment yields for pretreatment and posttreatment periods are also shown in table 4.

TABLE 4.—*Sediment yield at Boco Mountain, in cubic meters per square kilometer*

[1968 is considered a transition year from sagebrush to grass and so is not considered]

Period	Watershed			
	1 (Control)	2 (Treated)	3 (Control)	4 (Treated)
July 25, 1965–Nov. 2, 1965	1,069	3,616	2,509	1,110
Nov. 2, 1965–Oct. 31, 1966	0	0	0	0
Oct. 31, 1966–Nov. 1, 1967	329	1,855	1,016	288
Nov. 6, 1968–Nov. 6, 1969	41	31	896	411
Nov. 6, 1969–Nov. 3, 1970	164	31	358	0
Nov. 3, 1970–Oct. 27, 1971	247	0	1,135	82
Oct. 27, 1971–Nov. 6, 1972	206	0	0	0
Nov. 6, 1972–Oct. 2, 1973	0	0	0	0
July 25, 1965–Nov. 1, 1967	1,398	5,471	3,525	1,398
Nov. 6, 1968–Oct. 2, 1973	658	62	2,389	493

An analysis of variance indicated that after adjusting for differences in watersheds and periods no significant difference could be detected between the mean values for converted and control watersheds that could be related to treatment. The extreme variation in observed values between years probably masked any such changes which may have occurred.

Three secondary methods were used to determine quantitatively the effect of treatment on sediment yield.

The regression of annual sediment yield values from control areas against those from areas to be converted during the pretreatment period resulted in a predicting equation:

$$Y = -49 + 1.45X$$

where

Y= annual sediment yield from areas to be converted, and
X = annual sediment yield from control areas, both in cubic meters per square kilometer.

Points on this regression were obtained by pairing watersheds 1 and 4 and 2 and 3. The regression was forced through zero because during the period November 2, 1965, to October 31, 1966, a slight amount of sediment was deposited in each of the reservoirs, but the amount was too small to measure. The equation resulting from the six points has a coefficient of determination of 0.96 with 4 degrees of freedom and a standard error of 319. Prediction of sediment yield for converted areas during the posttreatment period resulted in an average value of 408 m^3/km^2 instead of 55.5 m^3/km^2 actually measured.

Average annual sediment yield from the control and converted areas were as follows. All values are weighted for watershed size.

	Average annual sediment yield, in cubic meters per square kilometer per year	
	Control	*Converted*
1965–67 (pretreatment)	755	1,204
1969–73 (posttreatment)	273	52

If the same relationship existed between sediment yield from control and converted watersheds during the posttreatment period as existed during the pretreatment period, 435 $(m^3/km^2)/yr$ might have been expected from the converted watersheds after treatment instead of the 52 $(m^3/km^2)/yr$ which occurred, or a reduction of 88 percent.

Sediment yield at Boco Mountain appears to be highly correlated with rainstorm runoff. Very little sediment was contributed to the reservoirs from snowmelt runoff. As shown in figure 14, an ice layer usually formed over frozen ground in late spring. Observations during this period showed the water to be running over the ice and creating very little erosion. The slow release rate from melting also created prolonged flows of low discharge which produced little erosion in channels.

FIGURE 14.—Snow cover at Boco Mountain showing ice layer over soil which inhibits erosion.

A comparison of rainstorm runoff and sediment yield follows:

	Average annual rainstorm runoff, in cubic meters per square kilometer per year	
	Control	*Converted*
1965–67 (pretreatment)	13,400	19,900
1969–73 (posttreatment)	6,600	3,200

	Ratio of sediment yield to rainstorm runoff	
	Control	*Converted*
1965–67 (pretreatment)	0.056	0.060
1969–73 (posttreatment)	.041	.016

These data indicate that if the ratio of runoff in the pre- and post-treatment periods which was observed in the control watersheds had occurred in the converted watersheds, annual runoff for the post-treatment period would have been 9,800 $(m^3/km^2)/yr$ instead of the 3,200 measured. This indicates a reduction of 67 percent.

The ratio of sediment yield to rainstorm runoff, which in effect is a sediment concentration, is quite similar for the three periods when sagebrush was present on the watersheds. However, if the ratios observed in the control watersheds had occurred in the treated watershed, a sediment concentration ratio of 0.044 would have been measured in the posttreatment converted watershed instead of the 0.016 measured. This indicates a reduction of 64 percent in sediment concentration.

Because of the few data points available and the great variability in the sediment data, a definite statistical qualification on the effect of sagebrush conversion to grass is difficult to make. In the foregoing discussions, however, the following changes were indicated: (1) The annual sediment yield, as determined from predicting equations developed for the pretreatment period, was reduced about 86 percent by conversion to grass, (2) the relationship between average annual sediment yield for control and converted areas indicated a reduction in sediment yield of about 88 percent because of conversion to grass, and (3) not only was runoff from summer rainstorms reduced about 75 percent by conversion to grass, but the sediment concentration of runoff that did occur was reduced by about 64 percent.

In view of the foregoing observations, although a conclusive statistical statement about the effect of conversion on sediment yield cannot be made, it seems likely that a reduction in sediment yield on the order of 80 percent was caused by the conversion to grass.

Branson and Owen (1970) determined that average annual runoff from small watersheds is highly correlated with percent bare soil, but they did not find a correspondingly good relationship between average annual sediment yield and percent bare soil. As shown previously, there is a direct relationship between rainstorm runoff and sediment yield at the Boco Mountain study area. This feature has been noted at numerous other study sites in the arid west such as Badger Wash in western Colorado. It therefore seems logical that sediment yield would also be highly correlated with percent bare soil. The following values of percent bare soil were obtained in 1967, just prior to treatment, and in 1973 at the end of the study period:

	Bare soil on watersheds, in hits per 100 pins	
	Sagebrush	*Grass*
1967 (pretreatment)	56.5	61.6
1973 (posttreatment)	51.8	38.0

Shown in figure 15 is the relationship between bare soil and the ratio of volume of sediment to volume of runoff from rainstorms. This ratio is a sediment concentration based on volume. The regression equation is

$$Y = -0.0578 + 0.00194X$$

with a correlation coefficient of 0.99 and a standard error of close to zero. This relationship indicates that a 38 percent reduction in bare soil because of planting grass resulted in a 73 percent reduction in sediment concentration. The two sagebrush watersheds indicated an 8 percent reduction in bare soil and a 27 percent reduction in sediment concentration which may have been partially the result of 9 years of protection from grazing, but this was not definitely established.

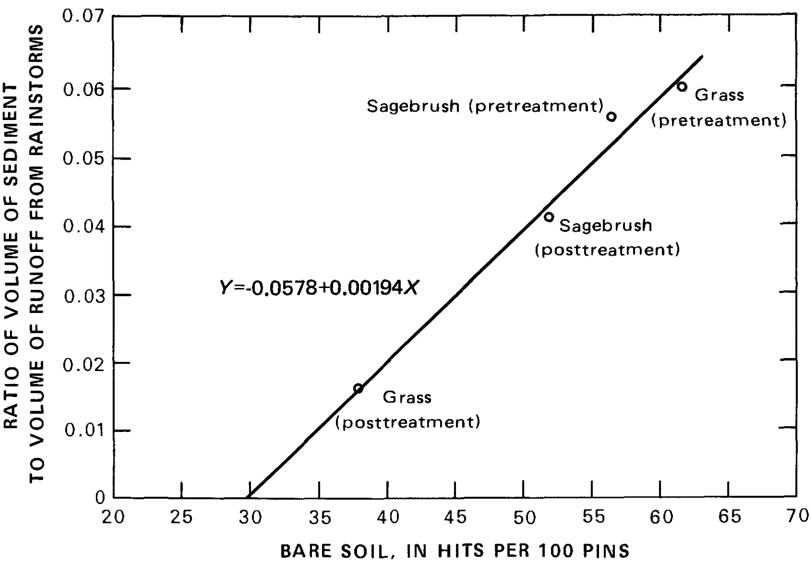

FIGURE 15.—Relationship between the ratio sediment yield/runoff (rainstorm) and bare soil.

SOIL MOISTURE

The results of the soil-moisture portion of this study were published previously (Shown, Lusby, and Branson, 1972). Some of the major findings will briefly be reviewed here.

The largest input to soil moisture at the Boco Mountain watersheds occurs during winter and early spring from snow. Summer rain rarely penetrates the soil more than 25 to 50 mm and is rapidly dissipated by evaporation. Big sagebrush appeared to use slightly more soil water than beardless bluebunch wheatgrass. The sagebrush extracted water from deeper in the soil and from the fractured shale beneath the soil, and it extracted water from the soil to a lower soil-water potential. Also, slightly more water was evaporated from the soil surface on sagebrush watersheds as determined from soil-water potential and root data.

Beardless bluebunch wheatgrass used the soil moisture more efficiently than big sagebrush. About 340 kg more usable forage per ha was produced annually by the grass.

CONCLUSIONS

The hydrologic effects of converting sagebrush-covered rangeland to grass-covered land was studied for 9 years at a site in west-central Colorado near Wolcott. Runoff and sediment yield from four small watersheds ranging in size from 2 to 4 ha were measured in small reservoirs at the outlet of each watershed. After 3 years of calibration, two of the watersheds were plowed and seeded to beardless bluebunch wheatgrass *(Agropyron inerme)*. The same parameters were then measured for an additional 6 years.

The production of usable forage on the watersheds changed from about 110 kg/ha on the sagebrush-covered watersheds to about 450 kg/ha after conversion. At the same time, the size of barren interspaces between plants was reduced on the converted watersheds to about 30 percent of those on the untreated watersheds.

One large rainstorm occurred during the study period. The remainder of the storms were small to medium in size. The effects of conversion to grass on rainstorm runoff was determined by three methods. These were: variance analysis, determination of predicting equations by regression of individual runoff events, and regression of precipitation against runoff of individual events for each watershed. The results of these determinations indicated that conversion to bluebunch wheatgrass resulted in a reduction in runoff from summer rainstorms of about 75 percent.

A large part of the annual runoff at Boco Mountain is derived from snowmelt in the spring. Although no statistical difference was measured in snowmelt runoff because of conversion, the treated watersheds did produce about 12 percent more runoff from this source when compared with control watersheds. The combination of the decrease in runoff resulting from summer rainstorms and possible increase in runoff from snowmelt resulted in an annual reduction in runoff of about 20 percent from converted watersheds.

Conversion to grass resulted in an apparent reduction in sediment yield of about 80 percent. Most of this reduction is due to reduced runoff from rainstorms. Not only was the volume of rainstorm runoff reduced by about 75 percent, but the sediment concentration was reduced by about 64 percent. Very little erosion is caused by snowmelt runoff.

Percent bare soil on the Boco Mountain watersheds was related to the ratio of sediment yield to runoff. The regression of this ratio and percent bare soil indicated that a reduction of 38 percent in the amount of bare soil resulting from planting grass effected a decrease of 73 percent in sediment concentration.

The largest recharge of soil moisture at Boco Mountain is from snowmelt in winter and early spring. Big sagebrush appeared to use slightly more soil water than beardless bluebunch wheatgrass. This was the result of using water from deeper in the soil mantle and fractured bedrock and from extracting water to a lower soil-water potential.

Hibbert, Davis, and Scholl (1974) reported that removal of deep-rooted shrubs in Arizona resulted in an increase in annual runoff. The discrepancy between these findings and those reported here are probably relatable to differences in climate and soils. Chaparral watersheds on which they reported were located on deep coarse-textured soils which were penetrated by an extensive root system. During hot, dry summers the shrubs were able to extract a large part of the annual recharge to the soil mass resulting from winter precipitation. After replacement of the deep-rooted system by shallow-rooted grasses, a much larger percentage of water entering the deep soil mantle from winter rains appeared as runoff at the watershed outlet. Soils at Boco Mountain are shallow and dense. Precipitation rarely penetrates more than a few decimeters and does not contribute to base flow of streams under either vegetation regime. Both sagebrush and grass extract most of the soil moisture from the lithosol at Boco Mountain, although sagebrush produces a lower soil-water potential and actively grows later in the fall than does grass.

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TABLE 5

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*

[SM in "precipitation" column indicates inflow was derived from snowmelt]

OBSERVATION RESERVOIR 1

Location—Lat 39°44′27″, long 106°40′49″, in NE¼NW¼, sec. 3, T. 4 S., R. 83 W., 4.5 km north of Wolcott, Eagle County, Colo.
Drainage area—29,988 m^2.
Records available—June 1965 to October 1973.
Gage—Water-stage recorder in reservoir. Altitude of gage is 2,210 meters (from topographic map).
Runoff and discharge determinations—Contents of reservoir and volume of inflow determined from a stage-capacity curve of the reservoir.
Capacity—Reservoir capacity 3,280 m^3.
Remarks—Records good except those for snowmelt periods, which are fair.

Date	Precipitation (mm)	Inflow m^3	Inflow mm
1965			
July 18	26.4	47	1.6
July 23	4.8	10	.3
July 25	5.8	12	.4
July 30	5.6	5	.2
July 31	8.1	41	1.4
Aug. 3	10.2	42	1.4
Aug. 14	19.6	143	4.8
Aug. 19	6.6	39	1.3
Sept. 3	11.7	63	2.1
Sept. 5	19.3	281	9.4
Sept. 6	----	4	.1
Sept. 18	6.8	15	.5
Sept. 19	6.1	30	1.0
Sept. 20	9.6	79	2.6
Sept. 29	9.9	39	1.3
Oct. 17	5.3	2	.1
Oct. 18	1.3	5	.2
Dec. 29–31	SM	85	2.8
Total for 1965		942	31.5
1966			
Mar. 9	SM	54	1.8
Mar. 10	SM	195	6.5
Mar. 11	SM	153	5.1
Mar. 12	SM	132	4.4
Mar. 13	SM	100	3.3
Mar. 14	SM	142	4.7
Mar. 15	SM	88	2.9
Mar. 16	SM	30	1.0
May 12	10.4	1	T
Aug. 20	6.9	2	.1
Sept. 14	10.2	6	.2
Oct. 3	9.9	6	.2
Oct. 14	9.7	1	T
Oct. 15	4.3	1	T
Total for 1966		911	30.2
1967			
Mar. 2	SM	1	T
Mar. 3	SM	2	.1
Mar. 8	SM	1	T
Mar. 9	SM	1	T
Mar. 10	SM	48	1.6
Mar. 11	SM	240	8.0
Mar. 12	SM	141	4.7
Mar. 13	SM	15	.5
Mar. 15	SM	69	2.3
Mar. 16	SM	38	1.3
Mar. 17	SM	11	.4
Mar. 19	SM	2	.1
Aug. 3	12.7	5	.2
Aug. 31	10.4	10	.3
Sept. 8	7.9	2	.1
Sept. 11	10.7	17	.6
Sept. 12	5.6	27	.9
Sept. 18–19	15.5	43	1.4
Sept. 25–26	10.4	90	3.0
Oct. 6	7.9	4	.1
Total for 1967		767	25.6

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m³	Inflow mm
1968			
Aug. 10	11.4	16	.5
Aug. 11	9.1	26	.9
Aug. 14	7.4	1	T
Sept. 3	9.7	12	.4
Total for 1968		55	1.8
1969			
Mar. 22	SM	175	5.8
Mar. 23	SM	20	.7
Mar. 27	SM	120	4.0
Mar. 28	SM	229	7.6
Mar. 29	SM	200	6.7
Mar. 30	SM	192	6.4
Mar. 31	SM	153	5.1
Apr. 1	SM	53	1.8
Apr. 2	SM	63	2.1
Apr. 3	SM	16	.5
June 15	11.2	2	.1
June 16	4.6	4	.1
June 17	12.2	39	1.3
June 23	1.5	10	.3
June 24	49.5	311	10.4
July 22	10.9	33	1.1
July 26	5.1	2	.1
Oct. 2	11.9	25	.8
Oct. 3	5.6	12	.4
Oct. 14	4.8	5	.2
Total for 1969		1,664	55.5
1970			
To Feb. 24	SM	242	8.1
Feb. 24	SM	28	.9
Feb. 25	SM	92	3.1
Feb. 26	SM	58	1.9
Feb. 27	SM	53	1.8
Feb. 28	SM	80	2.7
Mar. 1	SM	69	2.3
Mar. 2	SM	83	2.8
Mar. 3	SM	58	1.9
Mar. 4	SM	9	.3
Sept. 5	12.7	1	T
Sept. 13	15.2	16	.5
Oct. 6	15.5	2	.1
Oct. 7	11.4	4	.1
Oct. 10	10.4	4	.1
Total for 1970		799	26.6
1971			
To Feb. 23	SM	147	4.9
Feb. 23–Mar. 19	SM	147	4.9
Mar. 19–26	SM	1,011	33.7
May 14	5.3	1	T
May 23	7.6	1	T
Aug. 28	7.9	5	.2
Sept. 3	19.8	25	.8
Sept. 7	22.1	161	5.4
Total for 1971		1,498	49.9
1972			
To Feb. 16	SM	44	1.5
Feb. 21	SM	15	.5
Feb. 22	SM	136	4.5
Feb. 23	SM	43	1.4
Feb. 24	SM	49	1.6
Feb. 25	SM	4	.1
Feb. 27	SM	86	2.9
Feb. 28	SM	175	5.8
Feb. 29	SM	74	2.5
Mar. 2	SM	30	1.0
Mar. 3	SM	111	3.7
Mar. 4	SM	22	.7
Mar. 5	SM	20	.7
Apr. 12	11.9	2	.1
Sept. 19	22.4	27	.9
Sept. 20	3.3	5	.2
Sept. 23	4.1	7	.2
Oct. 15	14.2	28	.9
Oct. 23	SM	21	.7
Total for 1972		899	29.9

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m³	Inflow mm
1973			
Apr. 25	7.4	2	.1
May 6	9.9	1	T
Total for 1973		3	.1

OBSERVATION RESERVOIR 2

Location—Lat 39°44′32″, long 106°40′57″, in SW¼SW¼, sec. 34, T. 3 S., R. 83 W., 5 km north of Wolcott, Eagle County, Colo.
Drainage area—39,215 m².
Records available—June 1965 to October 1973.
Gage—Water-stage recorder in reservoir. Altitude of gage is 2,220 meters (from topographic map).
Runoff and discharge determinations—Contents of reservoir and volume of inflow determined from a stage-capacity of the reservoir.
Capacity—Reservoir capacity 1,910 m³.
Remarks—Records good except those for snowmelt periods, which are fair.

Date	Precipitation (mm)	Inflow m³	Inflow mm
1965			
July 18	21.6	117	3.0
July 23	4.8	11	.3
July 25	3.8	20	.5
July 31	8.1	89	2.3
Aug. 3	8.6	83	2.1
Aug. 14	23.4	369	9.4
Aug. 19	6.9	92	2.4
Sept. 3	12.2	184	4.7
Sept. 5	19.8	389	9.9
Sept. 18	6.6	30	.8
Sept. 19	5.8	47	1.2
Sept. 20	9.4	116	3.0
Sept. 29	8.9	67	1.7
Oct. 17	5.6	17	.4
Oct. 18	1.3	7	.2
Dec. 29–30	sm	190	----
Total for 1965		1,700	43.4
1966			
To Mar. 8	SM	247	6.3
Mar. 9	SM	259	6.6
Mar. 10	SM	259	6.6
Mar. 11	SM	174	4.4
Mar. 12	SM	102	2.6
Mar. 13	SM	60	1.5
Mar. 14	SM	57	1.4
Mar. 15	SM	10	.3
May 12	9.6	10	.3
Aug. 2	6.9	4	.1
Aug. 3	8.1	16	.4
Aug. 12	6.1	4	.1
Aug. 19	8.9	37	.9
Aug. 20	8.1	79	2.0
Sept. 14	9.4	48	1.2
Sept. 25	4.8	2	.1
Oct. 2–3	10.7	58	1.5
Oct. 13	1.5	6	.2
Oct. 14	1.5	11	.3
Total for 1966		1,443	36.8
1967			
Mar. 2	SM	9	.2
Mar. 3	SM	58	1.5
Mar. 8	SM	79	2.0

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m³	Inflow mm
1967—Continued			
Mar. 9	SM	132	3.4
Mar. 10–15	SM	404	10.3
Mar. 15	SM	43	1.1
July 31	11.9	16	.4
Aug. 2	5.3	15	.4
Aug. 3	10.2	63	1.6
Aug. 27	4.1	4	.1
Aug. 29	1.3	9	.2
Aug. 31	11.2	76	1.9
Sept. 8	8.1	23	.6
Sept. 11	9.7	69	1.8
Sept. 12	5.3	76	1.9
Sept. 18	9.9	72	1.8
Sept. 19	6.1	53	1.4
Sept. 25	7.6	22	.6
Sept. 26	8.9	143	3.6
Oct. 6	7.1	9	.2
Oct. 28	SM	2	.1
Total for 1967		1,377	35.1
1968			
Mar. 7	SM	6	.2
Mar. 17	SM	2	.1
Mar. 19	SM	2	.1
Mar. 20	SM	2	.1
Mar. 23	SM	4	.1
Mar. 24	SM	2	.1
Mar. 25	SM	12	.3
Mar. 26	SM	15	.4
Mar. 27	SM	10	.3
Mar. 28	SM	17	.4
Mar. 29	SM	28	.7
Mar. 30	SM	51	1.3
Mar. 31	SM	21	.5
Apr. 1	SM	7	.2
Apr. 6	4.6	6	.2
July 9	8.1	2	.1
Aug. 10	10.7	4	.1
Aug. 11	5.1	5	.1
Total for 1968		196	5.0
1969			
Mar. 22	SM	22	.6
Mar. 23	SM	14	.3
Mar. 27	SM	118	3.0
Mar. 28	SM	301	7.7
Mar. 29	SM	324	8.3
Mar. 30	SM	289	7.4
Mar. 31	SM	277	7.1
Apr. 1	SM	160	4.1
Apr. 2	SM	196	5.0
Apr. 3	SM	171	4.4
Apr. 4	SM	247	6.3
Apr. 5	SM	96	2.5
Apr. 6	SM	80	2.0
Apr. 7	SM	12	.3
Apr. 8	SM	17	.4
Apr. 9	SM	16	.4
Apr. 10	SM	14	.3
Apr. 11	SM	16	.4
June 11	15.7	6	.2
June 13	2.3	2	.1
June 14	10.9	10	.3
June 23	5.3	12	.3
June 24	42.4	313	8.0
July 3	3.3	4	.1
July 19	8.1	4	.1
July 20	7.6	2	.1
Aug. 12	5.3	4	.1
Aug. 28	5.1	2	.1
Oct. 2	12.2	14	.3
Oct. 3	6.4	5	.1
Total for 1969		3,018	77.0
1970			
To Feb. 24	SM	660	16.8
Feb. 24	SM	53	1.4
Feb. 25	SM	79	2.0

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m^3	Inflow mm
1970—Continued			
Feb. 26	SM	43	1.1
Feb. 27	SM	14	.3
Feb. 28	SM	30	.8
Mar. 1	SM	28	.7
Mar. 2	SM	37	.9
Feb. 3	SM	17	.4
Oct. 7	2.8	9	.2
Oct. 8	3.0	2	.1
Oct. 9	1.0	5	.1
Total for 1970		977	24.9
1971			
To Feb. 23	SM	387	9.9
Mar. 12	SM	80	2.0
Mar. 13	SM	99	2.5
Mar. 14	SM	9	.2
Mar. 15	SM	20	.5
Mar. 16	SM	7	.1
Mar. 17	SM	75	1.9
Mar. 20	SM	7	.1
Mar. 21	SM	75	1.9
Mar. 22	SM	42	1.1
Mar. 23	SM	90	2.3
Mar. 24	SM	355	9.0
Mar. 25	SM	158	4.0
Mar. 26	SM	120	3.1
Mar. 27	SM	40	1.0
Sept. 7	23.4	44	1.1
Sept. 17	2.8	3	.1
Total for 1971		1,611	41.1
1972			
To Feb. 14	SM	2	.1
Feb. 21	SM	80	2.0
Feb. 22	SM	175	4.5
Feb. 23	SM	75	1.9
Feb. 24	SM	62	1.6
Feb. 25	SM	4	.1
Feb. 27	SM	88	2.2
Feb. 28	SM	147	3.7
Feb. 29	SM	52	1.3
Mar. 2	SM	12	.3
Mar. 3	SM	78	2.0
Mar. 4	SM	16	.4
Mar. 5	SM	32	.8
Mar. 6	SM	20	.5
Total for 1972		843	21.5
1973			
Apr. 1	SM	5	.1
Apr. 6	SM	5	.1
Apr. 15	3.3	4	.1
Apr. 25	8.9	2	.1
May 1	7.1	2	.1
May 6	9.9	5	.1
May 19	8.6	2	.1
Total for 1973		25	.6

OBSERVATION RESERVOIR 3

Location—Lat 39°44′31″, long 106°40′59″, in SW¼SW¼, sec. 34, T. 3 S., R. 83 W., 5 km north of Wolcott, Eagle County, Colo.
Drainage area—20,640 m^2.
Records available—June 1965 to October 1973.
Gage—Water-stage recorder in reservoir. Altitude of gage is 2,220 meters (from topographic map).
Runoff and discharge determinations—Contents of reservoir and volume of inflow determined from a stage-capacity curve of the reservoir.
Capacity—Reservoir capacity 1,978 m^3.
Remarks—Records good except those for snowmelt periods, which are fair.

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m³	Inflow mm
1965			
July 18	21.6	41	2.0
July 25	3.8	5	.2
July 30	5.6	2	.1
July 31	8.1	28	1.4
Aug. 3	8.6	35	1.7
Aug. 14	23.4	170	8.2
Aug. 19	6.9	32	1.6
Sept. 3	12.2	67	3.2
Sept. 5	19.8	179	8.7
Sept. 18	6.6	16	.8
Sept. 19	5.8	23	1.1
Sept. 20	9.4	54	2.6
Sept. 29	8.9	32	1.6
Oct. 17	5.6	7	.4
Oct. 18	1.3	5	.2
Dec. 29–30	SM	75	3.6
Total for 1965		771	37.4
1966			
Mar. 9–10	SM	63	3.0
Mar. 10	SM	141	6.8
Mar. 11	SM	100	4.8
Mar. 12	SM	73	3.5
Mar. 13	SM	51	2.4
Mar. 14	SM	48	2.3
Mar. 15	SM	6	.3
Mar. 25	SM	6	.3
May 12	9.6	1	.1
Aug. 19	8.9	4	.2
Aug. 20	8.1	21	1.0
Aug. 30	5.3	1	.1
Sept. 7	2.3	1	.1
Sept. 14	9.4	10	.5
Oct. 3	8.6	11	.5
Oct. 14	9.7	2	.1
Oct. 15	4.6	1	.1
Total for 1966		540	26.2
1967			
Mar. 2	SM	1	.1
Mar. 3	SM	5	.2
Mar. 8	SM	1	.1
Mar. 9	SM	2	.1
Mar. 10	SM	30	1.4
Mar. 11	SM	132	6.4
Mar. 12	SM	92	4.5
Mar. 13	SM	14	.7
Mar. 15	SM	44	2.2
Mar. 16	SM	39	1.9
Mar. 17	SM	10	.5
Mar. 18	SM	2	.1
Mar. 19	SM	1	.1
Aug. 2–3	10.9	19	.9
Aug. 31	8.4	20	1.0
Sept. 8	6.9	5	.2
Sept. 11	9.4	18	.9
Sept. 12	5.1	30	1.4
Sept. 18–19	14.0	52	2.5
Sept. 25	5.3	11	.5
Sept. 26	8.1	58	2.8
Oct. 6	6.4	4	.2
Total for 1967		593	28.7
1968			
Mar. 25	SM	18	.9
Mar. 26	SM	15	.7
Mar. 27	SM	12	.6
Mar. 28	SM	20	1.0
Mar. 29	SM	21	1.0
Mar. 30	SM	14	.7
Mar. 31	SM	2	.1
Apr. 6	4.6	1	.1
Aug. 10	10.4	19	.9
Aug. 11	5.1	6	.3

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m^3	Inflow mm
1968—Continued			
Sept. 3	8.6	14	.7
Total for 1968		142	7.0
1969			
Mar. 22	SM	69	3.3
Mar. 23	SM	15	.7
Mar. 27	SM	65	3.2
Mar. 28	SM	150	7.3
Mar. 29	SM	106	5.1
Mar. 30	SM	92	4.5
Mar. 31	SM	79	3.8
Apr. 1	SM	27	1.3
Apr. 2	SM	53	2.6
Apr. 3	SM	43	2.1
Apr. 4	SM	32	1.6
Apr. 5	SM	18	.9
Apr. 6	SM	7	.4
May 5	10.9	12	.6
May 15	4.6	4	.2
June 11	15.2	7	.4
June 14	10.4	16	.8
June 16	3.6	2	.1
June 17	13.0	60	2.9
June 24	42.4	327	15.8
July 19	7.9	7	.4
July 20	6.6	6	.3
July 22	11.4	46	2.2
July 26	7.4	18	.9
Aug. 12	5.1	5	.2
Aug. 28	5.1	4	.2
Sept. 10	4.8	1	.1
Sept. 13	3.8	2	.1
Oct. 2	12.7	42	2.0
Oct. 3	5.6	15	.7
Total for 1969		1,330	64.4
1970			
To Feb. 24	SM	154	7.5
Feb. 24	SM	32	1.6
Feb. 25	SM	44	2.2
Feb. 26 to Mar. 5	SM	185	9.0
Mar. 19	SM	4	.2
Apr. 11	10.2	5	.2
Aug. 21	9.9	12	.6
Sept. 5	12.7	15	.7
Sept. 12	7.1	2	.1
Sept. 13	13.0	27	1.3
Sept. 21	6.9	1	.1
Sept. 22	3.0	2	.1
Oct. 6	14.7	5	.2
Oct. 7	12.4	11	.5
Oct. 10	9.1	6	.3
Total for 1970		505	24.5
1971			
To Feb. 23	SM	46	2.2
Mar. 12	SM	25	1.2
Mar. 13	SM	65	3.2
Mar. 14	SM	14	.7
Mar. 16	SM	28	1.4
Mar. 20	SM	8	.4
Mar. 21	SM	80	3.9
Mar. 22	SM	45	2.2
Mar. 23	SM	106	5.1
Mar. 24	SM	323	15.7
Mar. 25	SM	199	9.6
Mar. 26	SM	107	5.2
May 14	6.1	3	.1
May 23	7.4	1	.1
Aug. 26	13.5	5	.3
Aug. 28	6.1	6	.3
Sept. 3	17.5	31	1.5
Sept. 7	23.1	129	6.3
Total for 1971		1,221	59.2
1972			
To Feb. 14	SM	49	2.4
Feb. 22	SM	41	2.0
Feb. 23	SM	25	1.2

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m^3	Inflow mm
1972—Continued			
Feb. 24	SM	25	1.2
Feb. 27	SM	35	1.7
Feb. 28	SM	95	4.6
Feb. 29	SM	36	1.7
Mar. 2	SM	9	.4
Mar. 3	SM	69	3.3
Mar. 4	SM	9	.4
Mar. 5	SM	31	1.5
Mar. 6	SM	16	.8
June 18	11.7	1	.1
Sept. 19	19.8	11	.5
Sept. 20	3.0	7	.4
Sept. 23	4.6	9	.4
Oct. 15	14.7	18	.9
Oct. 20–21	SM	21	1.0
Total for 1972		507	24.6
1973			
Apr. 15	1.6	2	.1
Apr. 25	7.6	2	.1
May 1	6.9	2	.1
May 6	9.9	7	.4
June 14–15	12.4	1	.1
July 18	6.4	1	.1
July 21	3.3	1	.1
Total for 1973		16	.8

OBSERVATION RESERVOIR 4

Location—Lat 39°44'28", long 106°41'00", in NW¼NW¼, sec. 3, T. 4 S., R. 83 W., 4.5 km north of Wolcott, Eagle County, Colo.
Drainage area—32,902 m^2.
Records available—June 1965 to October 1973.
Gage—Water-stage recorder in reservoir. Altitude of gage is 2,215 meters (from topographic map).
Runoff and discharge determinations—Contents of reservoir and volume of inflow determined from a stage-capacity curve of the reservoir.
Capacity—Reservoir capacity 2,820 m^3.
Remarks—Records good except those for snowmelt periods, which are fair.

Date	Precipitation (mm)	Inflow m^3	Inflow mm
1965			
July 18	21.6	38	1.2
July 23	4.8	7	.2
July 25	3.8	9	.3
July 30	5.6	4	.1
July 31	8.1	47	1.4
Aug. 3	8.6	65	2.0
Aug. 14	23.4	231	7.0
Aug. 19	6.9	47	1.4
Sept. 3	12.2	80	2.4
Sept. 5–6	19.8	284	8.6
Sept. 18	6.6	38	1.2
Sept. 19	5.8	36	1.1
Sept. 20	9.4	96	2.9
Sept. 29	8.9	49	1.5
Oct. 17	5.6	9	.3
Oct. 18	1.3	7	.2
Total for 1965		1,047	31.8
1966			
To Mar. 9.	SM	301	9.1
Mar. 9–10	SM	10	.3
Mar. 10	SM	243	7.4
Mar. 11	SM	178	5.4

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m^3	Inflow mm
1966—Continued			
Mar. 12	SM	131	4.0
Mar. 13	SM	92	2.8
Mar. 14	SM	125	3.8
Mar. 15	SM	81	2.5
Mar. 16	SM	57	1.7
Mar. 19	SM	58	1.8
May 11	6.6	2	.1
May 12	9.6	11	.3
Aug. 19	8.1	7	.2
Aug. 20	6.4	22	.7
Aug. 30	5.3	1	T
Sept. 14	9.7	30	.9
Sept. 25	4.8	2	.1
Oct. 2–3	6.6	18	.6
Oct. 3	4.1	11	.3
Oct. 11	2.0	1	T
Oct. 13	1.3	4	.1
Oct. 14	2.0	12	.4
Oct. 16	4.8	1	T
Total for 1966		1,398	42.5
1967			
Mar. 2	SM	1	T
Mar. 3	SM	4	.1
Mar. 4	SM	7	.2
Mar. 9	SM	12	.4
Mar. 10	SM	62	1.9
Mar. 11	SM	219	6.7
Mar. 12	SM	126	3.8
Mar. 13	SM	17	.5
Mar. 15	SM	73	2.2
Mar. 16	SM	85	2.6
Mar. 17	SM	83	2.5
Mar. 18	SM	41	1.2
Mar. 19	SM	28	.9
May 2	----	1	T
May 4	3.0	1	T
May 5	1.5	2	.1
Aug. 3	11.7	28	.9
Aug. 7	3.8	1	T
Aug. 29–30	4.8	2	.1
Aug. 31	10.4	31	.9
Sept. 8	8.1	11	.3
Sept. 11	9.7	31	.9
Sept. 12	5.3	43	1.3
Sept. 18	9.7	41	1.2
Sept. 19	6.1	33	1.0
Sept. 25	8.6	21	.6
Sept. 26	5.1	52	1.6
Sept. 28	.5	4	.1
Oct. 4	2.0	1	T
Oct. 6	7.1	9	.3
Oct. 31	SM	1	T
Total for 1967		1,071	32.6
1968			
Mar. 24	SM	2	.1
Mar. 25	SM	7	.2
Mar. 26	SM	12	.4
Mar. 27	SM	4	.1
Mar. 28	SM	6	.2
Mar. 29	SM	25	.7
Mar. 30	SM	90	2.7
Mar. 31	SM	49	1.5
Apr. 1	SM	30	.9
Apr. 2	SM	6	.2
Apr. 5	SM	12	.4
Apr. 6	4.6	6	.2
Total for 1968		249	7.6
1969			
Mar. 22	SM	23	.7
Mar. 23	SM	2	.1
Mar. 27	SM	16	.5
Mar. 28	SM	112	3.4
Mar. 29	SM	169	5.1
Mar. 30	SM	211	6.4
Mar. 31	SM	268	8.1
Apr. 1	SM	168	5.1

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m³	Inflow mm
1969—Continued			
Apr. 2	SM	268	8.1
Apr. 3	SM	263	8.0
Apr. 4	SM	270	8.2
Apr. 5	SM	202	6.1
Apr. 6	SM	181	5.5
May 5	11.7	4	.1
May 15	5.1	1	T
June 17	12.7	16	.5
June 23	8.6	5	.1
June 24	42.4	289	8.8
July 19	8.6	5	.1
July 20	8.1	9	.3
July 22	11.2	17	.5
July 26	4.6	2	.1
Aug. 12	5.3	1	T
Aug. 28	5.1	2	.1
Sept. 13	4.6	1	T
Oct. 2	13.2	7	.2
Oct. 3	6.6	4	.1
Oct. 10	5.6	4	.1
Total for 1969		2,520	76.6
1970			
To Feb. 24	SM	493	15.0
Feb. 24–25	SM	47	1.4
Feb. 25	SM	80	2.4
Feb. 26	SM	42	1.3
Feb. 27	SM	30	.9
Feb. 28	SM	43	1.3
Mar. 1	SM	37	1.1
Mar. 2	SM	55	1.7
Mar. 3	SM	35	1.0
Mar. 4	SM	16	.5
Mar. 5	SM	2	.1
Mar. 6	SM	5	.1
Mar. 7	SM	9	.3
Mar. 8	SM	44	1.3
Mar. 9	SM	15	.4
Mar. 14	SM	25	.7
Mar. 15	SM	6	.2
Mar. 16	SM	11	.3
Mar. 23	SM	12	.4
Mar. 24	SM	32	1.0
Total for 1970		1,039	31.6
1971			
To Feb. 23	SM	263	8.0
Mar. 12	SM	9	.3
Mar. 13	SM	44	1.3
Mar. 14	SM	71	2.2
Mar. 18	SM	3	.1
Mar. 20	SM	3	.1
Mar. 21	SM	46	1.4
Mar. 22	SM	64	1.9
Mar. 23	SM	165	5.0
Mar. 24	SM	463	14.1
Mar. 25	SM	344	10.5
Mar. 26	SM	290	8.8
Mar. 27	SM	124	3.8
Sept. 7	23.4	24	.7
Sept. 17	2.8	5	.1
Total for 1971		1,918	58.3
1972			
To Feb. 14	SM	4	.1
Feb. 21	SM	1	T
Feb. 22	SM	104	3.1
Feb. 23	SM	84	2.5
Feb. 24	SM	74	2.2
Feb. 25	SM	12	.4
Feb. 27	SM	73	2.2
Feb. 28	SM	180	5.5
Feb. 29	SM	79	2.4
Mar. 2	SM	21	.6
Mar. 3	SM	143	4.3
Mar. 4	SM	30	.9
Mar. 5	SM	90	2.7
Mar. 6	SM	75	2.3
Mar. 7	SM	17	.5

TABLE 5.—*Runoff measured in observation reservoirs at Boco Mountain, June 1965 to October 1973*—Continued

Date	Precipitation (mm)	Inflow m^3	Inflow mm
1972—Continued			
Mar. 8	SM	7	.2
Total for 1972		994	30.2
1973			
Mar. 20	SM	6	.2
Mar. 23	SM	1	.1
Mar. 24	SM	1	.1
Mar. 25	SM	5	.1
Mar. 26–27	SM	48	1.5
Mar. 28	SM	46	1.4
Mar. 29	SM	5	.1
Mar. 31	SM	5	.1
Apr. 1	SM	17	.5
Apr. 2	SM	17	.5
Apr. 5	SM	7	.2
Apr. 6	SM	43	1.3
Apr. 7	SM	2	.1
Apr. 10	SM	10	.3
Apr. 11	SM	52	1.6
Apr. 12	SM	30	.9
Apr. 13	SM	60	1.8
Apr. 14	SM	49	1.5
Apr. 15	SM	4	.1
Apr. 16	SM	9	.3
Apr. 17	SM	14	.4
June 1	3.6	1	T
June 2	5.3	1	T
June 3	10.7	2	.1
June 4	5.6	1	T
Total for 1973		436	13.2