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EFFECTS OF DIVERTING SEDIMENT-LADEN RUNOFF FROM ARROYOS TO RANGE
HUBBELL, D.S., GARDNER, J.L.   1 OF 1

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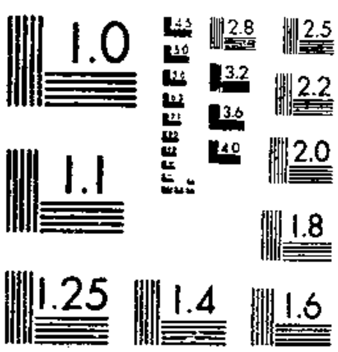

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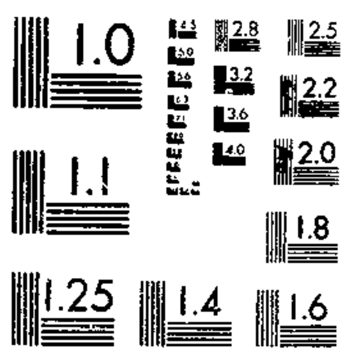

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Effects of Diverting Sediment-Laden Runoff From Arroyos to Range and Crop Lands [1]

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CONTENTS

SUMMARY

Water spreading is the practice of diverting flows from ephemeral streams and distributing the water over permeable soils of valley floors. Its effects were investigated at the Navajo Experiment Station in northwestern New Mexico during a 9-year period, 1935–43. Water was spread on 14 areas of native range land, otherwise untreated, by plugging the arroyos with earthen dams. The effect of water spreading was studied intensively on three of these sites and observed in less detail on the others. Additional studies were made on plots seeded with range grasses and field crops, and on lysimeter plots seeded with the same grasses and watered with water-sediment mixtures carrying sediment of known quantity and quality.

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[2] Acknowledgment is made of the work of L. R. Rich, formerly in charge of hydrologic work, and I. E. Chapman, in charge of laboratory work, at the Navajo Experiment Station.

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Information was obtained on the responses of soil and vegetation to water spreading, and on the quantity of sediment carried away by runoff from eroded uplands. The results of the study indicate, also, the extent to which sediment, if not controlled by some such means as water spreading, will obstruct normal stream flow and reduce the capacity of reservoirs.

The proportion of sediment by weight in the runoff ranged from less than 1 to more than 60 percent and averaged 13 percent. The sediment deposited in the channels lessened the channel gradients for distances of at least 2,000 to 2,800 feet above the dams. Deposition in the channels occurred chiefly in the first 3 years, but continued throughout the study period.

On the flood plains, sediment deposit just below the spillways averaged more than 2 feet in depth. It decreased in depth with distance below the spillway, and became negligible at distances that averaged about 3,700 feet, the limit of deposition depending upon the configuration of the spreading area and other factors. During the 9 years a total of approximately 300 acre-feet of sediment was stored above and below the dams of the three study areas.

Deposition markedly lightened the soil texture in the upper reaches of the field flooding areas. Just below the lightened areas the texture became heavier. The clay fraction of the soil increased greatly in the controlled plots irrigated with arroyo water, since much of the coarser sediment was dropped in the 2,000-foot ditch that conveyed the water to the plots. In the field areas and in the controlled plots that received no cultivation, the percentage of organic matter in the soil increased when heavy-textured sediment was deposited. Organic-matter percentage did not change in the soil of cultivated plots. In the lysimeter plots, it was dependent on the amount of buried vegetation or the amount of organic matter present in the deposited material.

Flooding increased the grass density of field plots where not more than 1 inch of sediment was deposited. Rapid deposition of more than 5 inches of sediment greatly damaged all grasses except western wheatgrass (*Agropyron smithii*). Shallower sediment, or relatively slow deposition of sediment to depths as great as 10 inches, caused heavy damage to blue grama (*Bouteloua gracilis*), red threeawn (*Aristida longiseta*), and sand dropseed (*Sporobolus cryptandrus*), and moderate damage to galleta (*Hilaria jamesii*) and creeping muhly (*Muhlenbergia repens*). In plot experiments, deposition of 9 inches of heavy-textured sediment in 2 years resulted in moderate damage to alkali sacaton (*Sporobolus airoides*). Western wheatgrass increased on medium to deep deposits, owing to reduction of competition with other plants.

Forage production on lightly silted portions of flooded areas, as determined from clipped quadrats, was three to nine times that on comparable unflooded areas, the difference varying with the amount of flood water diverted. The gain on the lightly silted and unsilted portions more than balanced the loss due to damage from sediment, which extended over approximately 20 percent of each flooded area.

Yields of corn and oats on plots irrigated with arroyo water were greater than yields on comparable dry-land plots. Application of flows selected on the basis of low sediment content and plant needs proved more consistently beneficial than application of all flows. Yield of beans was increased by irrigation with selected flows but was sharply reduced where every flow was used.

Except under the highly controlled conditions of lysimeter plots, application of water and sediment produced few consistent changes in the chemical characteristics or bacterial activity of the soil material deposited or of the soil underlying the deposits. In the field areas and controlled plots, the chemical characteristics of the deposits and original soils were similar, except for the concentration of sulfates and potassium. The sulfates were considerably higher in the added material, the potassium lower.

Observations indicate that, under the conditions of climate and topography prevailing within the experimental area, drainage areas of less than 2,000 acres are likely not to produce runoff often enough to make water spreading practical if the chief purpose is to increase production of forage and crops. The effect on silting of stream channels and reservoirs, however, may justify the cost of spreading water from small drainage areas. The maintenance requirement for control of water and sediment from a drainage area of 45,000 acres was disproportionately large, and the water from this area could not be used so advantageously.

For the safe handling of runoff from drainage basins of 2,500 to 4,700 acres, the required ratio of drainage area to spreading area was found to be about 20:3.

Water spreading is an effective means of transporting sediment to places where it can be stored and thus keeping it from downstream water-storage reservoirs and areas of flood hazard. On an area so large that the sediment is held on a relatively small part of it, water spreading is beneficial from the standpoint of crop yield, forage production, and grazing use.

INTRODUCTION

In arid and semiarid sections of the southwestern United States, much of the precipitation occurs in the form of short, intense storms. The characteristically high rate of runoff from such storms has been augmented in many areas as the result of depletion of the protective cover of vegetation, largely through overgrazing. As a consequence, much water needed for forage and crop production on range and valley lands is lost. Uncontrolled runoff results in excessive soil erosion on semibarren slopes and in serious arroyo development in alluvial valleys. The channeling of innumerable valleys in the Southwest has lowered the ground water, destroyed irrigation diversions, interfered with the maintenance of water rights, and greatly increased the quantities of soil eroded from headwater areas.

Sediment not held back in upstream areas is carried down and deposited in the channels of large perennial streams in the lower reaches of drainage areas. This may cause serious damage to farm lands by raising the water table and increasing floods. The sediment carried into irrigation reservoirs not only curtails the useful life of these costly installations but increases evaporational losses by extending the area of free water surface. Reservoir silting, furthermore, wastes a limited natural resource—reservoir sites, an essential of the irrigated agriculture upon which depends the economic survival of much of the West (*6*).[3]

Conservation of water and control of sediment are among the most urgent needs of western agriculture. Nature conserves water for production of vegetation by dissipating the concentrated runoff from higher terrain on valley floors and other nearly level areas. Man similarly conserves water in his irrigation projects. Water spreading is a kind of irrigation aimed at restoring conditions under which water is conserved and sediment held in check in valleys that have not lost their protective cover of vegetation.

The problem area to which the results of the investigations discussed here apply comprises a large part of northwestern New Mexico and adjacent parts of Arizona, Utah, and Colorado. It is a plateau region broken by mesas, canyons, and low mountains. The geology of the region has been treated by Gregory (*19*). For the most part, the problem area lies within the Colorado River drainage basin above Hoover Dam and Lake Mead. The consequences of silting in this reservoir, the largest in America, and the menace to future developments on the Colorado River through silting have been forcefully treated by J. C. Stevens (*36*).

EXPERIMENTAL AREA

The investigations discussed here were made at the Navajo Experiment Station, a 43,000-acre portion of the Navajo Indian Reservation situated about 20 miles north of Gallup, in northwestern New Mexico (fig. 1). The elevation at Mexican Springs, the station headquarters, is 6,437 feet. The station lay within the Figuerido Creek drainage basin, a semicircular area in the Chusca Valley and Chusca Mountain subprovinces of the Colorado Plateau (*31*) surrounded by a watershed having altitudes of 7,000 to 8,800 feet.

The vegetation, topography, soils, and erosion conditions in the experimental area were representative of the general problem area. The surface characteristics include many variations in slope, numerous rock outcrops, rough broken shale hills, and valleys channelled by arroyos. The western and higher end is steep and mountainous (fig. 2); the eastern end is a rolling plain with broad alluvial valleys broken by old mesa remnants that grade into the alluvial deposits on the valley floor (fig. 3). The alluvium in the valleys was formed of outwash material from the sandstones and shales of the Mesaverde formation (*31*). All streams on the area are ephemeral, flowing only when there is runoff from melting snow or heavy rain.

The station was operated from February 1934 until December 1943.

SOILS

The soils of the Figuerido Creek drainage basin are alluvial, colluvial, and residual. They were derived principally from the sandstones and shales of the Mesaverde and Tohatchi formations. The following

[3] Italic numbers in parentheses refer to Selected References on Water Spreading, p. 67.

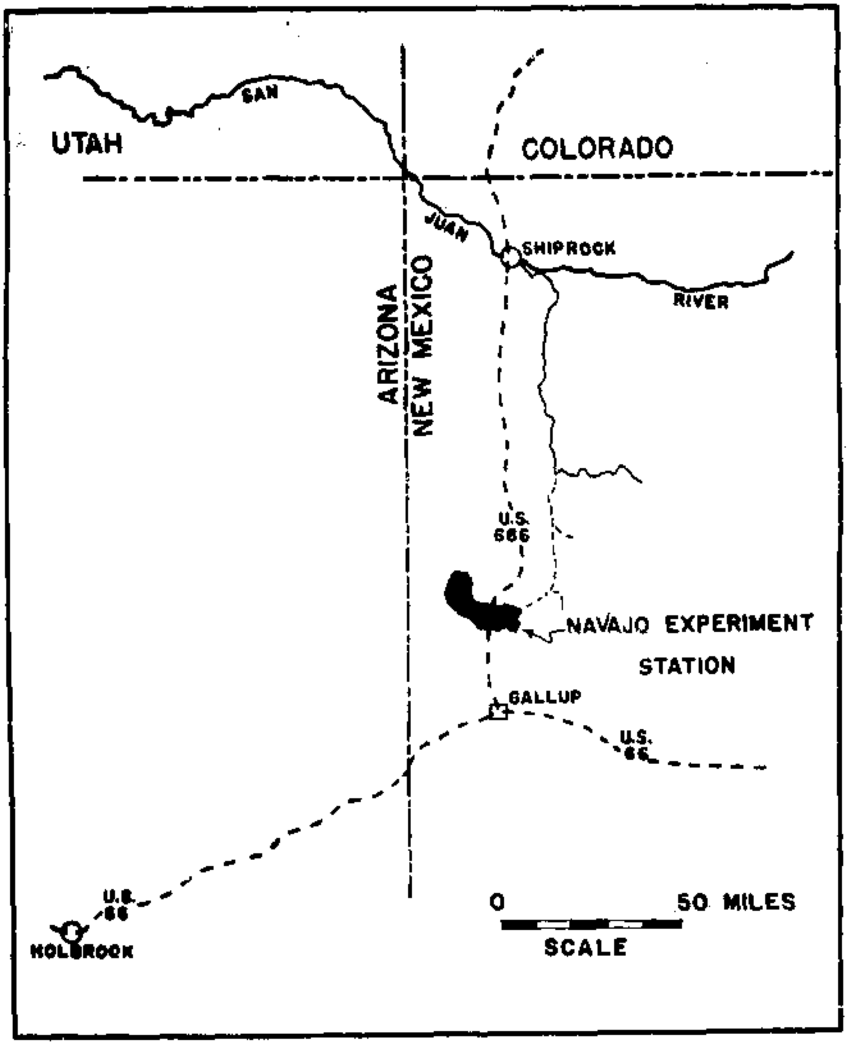

FIGURE 1.—Location of central part of problem area and of Navajo Experiment Station.

soil series are distinguished, on the basis of state of development and physical characteristics: Alluvial—Crown, Oraibi, Wepo, and Concho; colluvial—Crown; residual—Buell, Pinedale, Hopi, Chuska, and Floy. These series are further separated according to surface texture into five soil types—clay, clay loam, sandy clay, sandy clay loam, and sand.

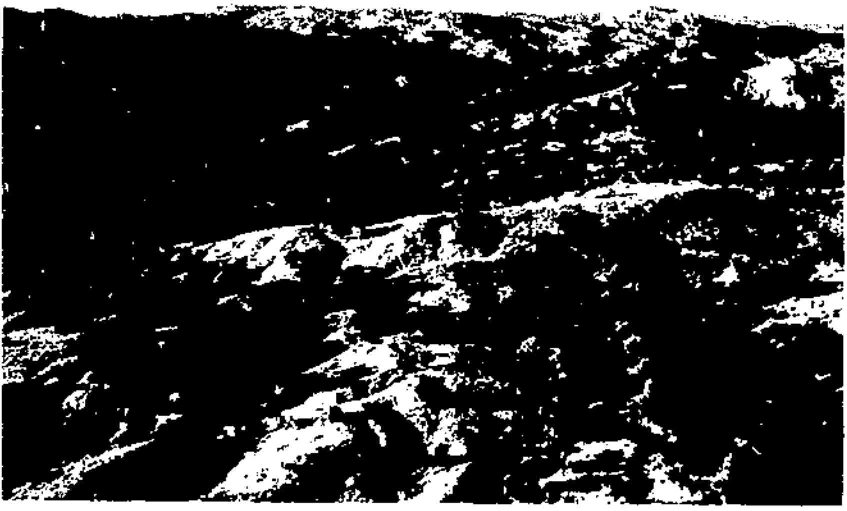

FIGURE 2. Foothill and mountain topography within station area.

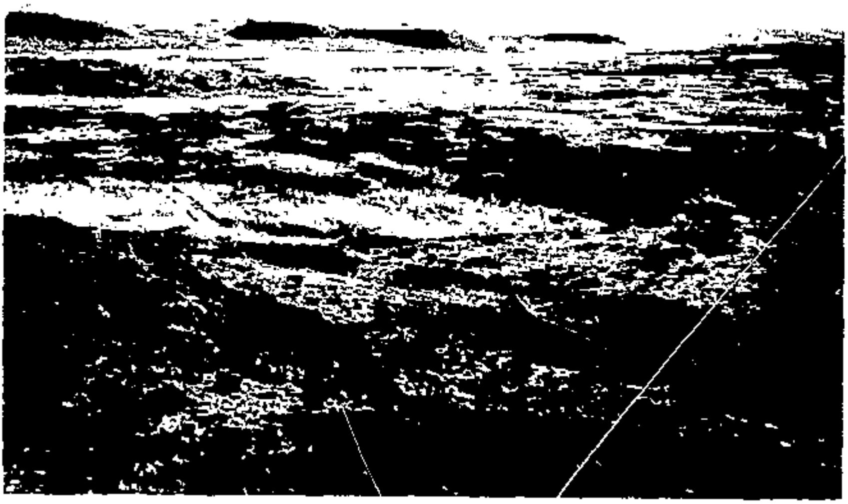

FIGURE 3. Plain and valley topography within station area.

CLIMATE

Monthly averages of climatic data at the Navajo Experiment Station for the study period are presented in table 1. Annual precipitation on the experimental area varied widely. Extremes at headquarters were 20.08 inches (1941) and 6.02 inches (1942). Annual precipitation averaged approximately 11.3 inches at an elevation of 6,437 feet; 9.5 inches at 6,200 feet; and 17.5 inches at 8,400 feet. Temperatures were moderate, average hourly wind movement rather high, and relative humidity low. The high average wind movement and low relative humidity caused high evaporation rates. Evaporation from the 48-inch pan of a class A weather station during the period April through October averaged 71.8 inches. The precipitation-evaporation ratio for these months was 1:9. The climate of the Southwest has been discussed in some detail by Thornthwaite and others (*40*).

TABLE 1.—*Monthly averages of weather factors and soil temperature, Navajo Experiment Station, 1934–48*

[Elevation 6,437 feet]

Month	Air temperature			Soil temperature at 6-inch depth	Relative humidity	Hourly wind movement	Precipitation	Evaporation[1]
	Mean daily maximum	Mean daily minimum	Mean					
	°F.	°F.	°F.	°F.	*Percent*	*Miles*	*Inches*	*Inches*
January	42.0	17.7	29.9	33.8	47.6	3.4	0.57	....
February	44.5	21.0	32.8	33.8	46.4	4.3	.78	....
March	53.5	26.0	39.8	38.6	35.4	5.0	.81	....
April	62.0	33.4	48.2	49.0	32.3	6.1	.54	8.59
May	74.3	41.7	58.0	58.1	28.2	5.3	.99	12.24
June	84.2	48.9	66.5	68.3	21.9	5.3	.60	12.50
July	88.3	56.3	72.3	75.8	30.6	3.9	1.16	12.72
August	85.3	55.8	70.5	76.0	35.2	3.4	2.10	10.70
September	77.2	47.3	62.2	69.0	38.4	3.2	1.79	7.57
October	67.5	36.4	52.0	58.8	33.2	3.6	.72	6.40
November	53.6	26.5	40.1	46.0	37.0	3.6	.38	....
December	44.7	21.1	32.9	38.5	44.4	3.1	.82	....
Year	64.9	36.0	50.5	54.2	36.1	4.3	11.26	....

[1] Record was begun Aug. 1, 1936.

The growing season for most of the native grasses at the lower elevations is from May to late September; at the higher elevations, from early June to early September.

RUNOFF AND EROSION

On the steep, sparsely vegetated slopes of this section an intense storm, even though brief, results in a large volume of runoff heavily burdened with sediment. Rainfall and runoff figures for parts of the experimental area for 1941 and 1942, years of exceptionally heavy and exceptionally light rainfall, are given in table 2. The record for a single storm that occurred July 23, 1941, in a 1,300-acre drainage basin within the area is as follows:

Rainfall:		
Total [1]	inches	0.79
Maximum 5-minute intensity	inches per hour	1.99
Total runoff	inches	.34
Flow duration	hours	7
Soil loss:		
Maximum runoff content, by weight	percent	32.4
Average per acre	inches	.04
	tons	6.9
Total	do	9,142

[1] Weighted average, computed by Thiessen's method.

TABLE 2.—*Averages of rainfall* [1] *and runoff in 1941 and 1942 for four drainage areas of graduated size within experimental area*

Size of drainage area (acres)	1941 Rainfall	1941 Runoff	1942 Rainfall	1942 Runoff
	Inches	*Inches*	*Inches*	*Inches*
187	15.65	0.53	3.97	0
1,300	16.29	2.41	6.31	.05
5,550	15.89	1.16	5.37	0
20,910	18.20	1.10	5.94	0

[1] Rainfall figures are weighted averages, computed by Thiessen's method.

Erosion is severe on the experimental area particularly in the western part, where mountain and foothill topography prevails and the soil is generally shallow. The valleys and plains at the foot of the hills are only slightly affected by sheet erosion, but are dissected by deep arroyos. The soils of lighter texture on the plains are subject to wind erosion.

A soil survey of 65,000 acres within the Figuerido Creek drainage basin showed that a total of about 36,000 acres had been severely eroded and dissected. From most of the severely eroded portion all of the topsoil had been removed, and over large parts of it the surface is soft shale or sandstone. On the remaining 29,000 acres, the erosion is roughly classed as slight to moderate; here approximately 25 percent of the surface soil has been removed. Abnormal erosion in some degree prevails on practically the entire area.

VEGETATION

The vegetation of the experimental area varies with elevation. Up to an elevation of approximately 6,600 feet, galleta (*Hilaria jamesii*) and blue grama (*Bouteloua gracilis*) are the dominant species of stabilized areas. In the valleys, galleta is the dominant grass, with varying admixtures of western wheatgrass (*Agropyron smithii*). Red three-awn (*Aristida longiseta*) is found throughout the grassland belt where overgrazing has been moderate to fairly heavy. In a few of the valleys the vegetation is dominated by alkali sacaton (*Sporobolus airoides*). The conspicuous species above the grassland belt to elevations of approximately 7,500 feet are piñon (*Pinus edulis*) and junipers (*Juniperus utahensis* and *J. monosperma*). Among these trees are found the grasses of the grassland, although galleta drops out at the higher elevations. Ponderosa pine (*Pinus ponderosa*) is present in scattered stands above 7,500 feet. Where they have not been grazed out, grama, western wheatgrass, and other grasses grow among the pines and in open areas. Badland areas, which occur in the upper part of the grassland and in the piñon-juniper belt, support a few piñons, junipers, and xeric shrubs and forbs, with galleta and western wheatgrass in the more stable valleys.

Scope of Experiments

The work comprised quantitative observations of the effects on soils and native vegetation of diverting all the water and sediment from three arroyos to the adjacent valley floors; determination of the effects of diverting known amounts of arroyo water to plots having stands of four range grasses and three field crops; and experimental isolation and integration of factors involved in the effects of application of known amounts of sediment-laden water on grass and soil in lysimeters containing stands of the same grass species. The lysimeter studies included analysis of the effects of sediment deposits according to (1) differences in depth and (2) differences in texture representing those that result not only from differences in the soils of drainage areas but from segregation of soil fractions as the sediment is deposited.

PLAN AND PROCEDURE

In 1934 and 1935, 14 sites were selected for diverting arroyo water, and an earthen dam was constructed at each site. The dams across the arroyos were extended as dikes on the flood plains for various

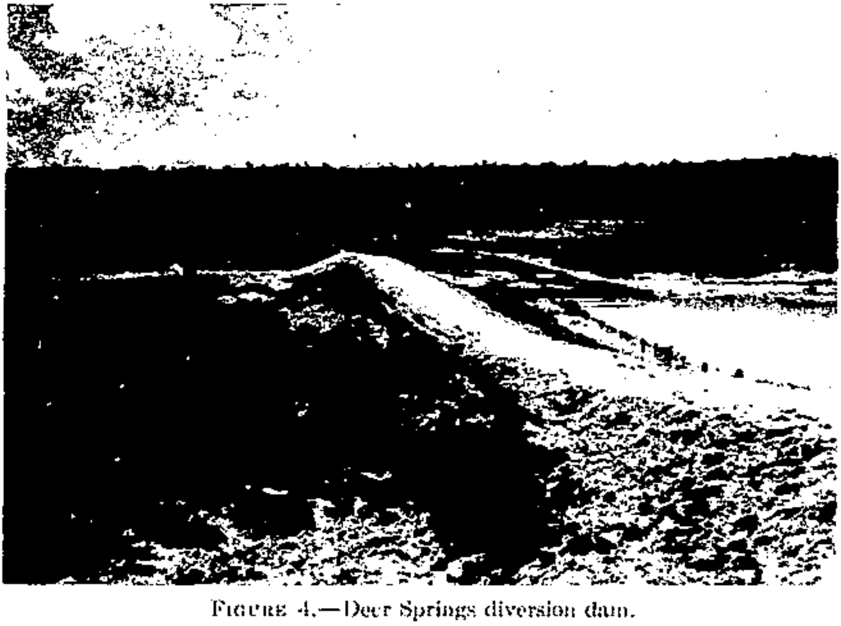

Figure 4.—Deer Springs diversion dam.

distances (fig. 4). The edges of the arroyo banks were typically higher than the valley floors. Where breaks occurred in these natural levees, dikes were built. At places on the flood plains where, owing to a narrowing of the valley or an increase in slope, cutting occurred or was expected, wire-bound rock sausages were buried or spreader fences were erected. Observations of deposition and studies of the effect of flooding on the vegetation and soil were made at three of the sites—Deer Springs, Norcross, and Muddy Creek. The principal characteristics of the drainage basins and flood plains of these areas are presented in table 3.

Field Areas

Fenced plots 100 feet square, for use in sampling soil and vegetation, were established at intervals down each flood plain in the course of the water flow. Similar plots just outside the course of flow served as checks. These fenced plots are referred to as field plots to distinguish them from controlled plots that were flooded with known amounts of water.

The Deer Springs flood plain was 3 miles long and one-fourth mile wide, and comprised 450 acres. Exceptionally large flows may have covered as much as 550 acres. There were nine flooded plots, the lowest of which was 3 miles below the spillway. Of the three check plots, one lay on each side of the course of flow 0.25 mile below the spillway and one approximately 2 miles farther down.

The studied portion of the Norcross flood plain was approximately 0.6 mile long by 0.4 mile wide and comprised about 150 acres. Flows frequently went beyond the studied area. Seven plots lay in the course of flow, the lowest being 0.59 mile below the spillway. Two check plots lay in the valley immediately above the dam and two 0.25 mile below it.

Muddy Creek flood plain consisted of two parts having a combined area of about 250 acres. Heavy flows covered another 200 acres; very large ones reached a depression, where the water lay until it seeped away. Arroyo flows were diverted to a dry lake bed of about 25 acres by means of a dike. Weeps in the dike allowed water to pass to the part of the area containing plots 1 to 5. Water spilled from the lake bed to the part containing plots 6 and 7. Plots 8 and 9 received flows from both sources. Plot 9 lay 0.66 mile below the dam. There were two check plots, one in the valley above the dam and the other 0.3 mile below the dam.

Within each plot five 1-meter-square permanent quadrats were laid out in quincuncial arrangement. The vegetation on the quadrats was charted with a pantograph in 1935, 1938, 1941, and 1943. Grasses were charted at ground level. A single grass stem, or a clump occupying a ground area of approximately 1.5 square centimeters or less, was assigned a value of 1 square centimeter. Bare areas of 1 square centimeter or more within clumps were delineated. Forbs were recorded in terms of number of plants; the annuals were counted in the field by species, and the perennials were charted and the numbers on each quadrat determined from the charts.

A record was kept of the number and extent of floodings of the field areas. In 1940 and 1941, depth of penetration of floodwater and rain was determined in or near the study plots after each flow.

TABLE 3.—*Description of Deer Springs, Norcross, and Muddy Creek study areas as of 1935*

[Geology: Drainage basins, Mesaverde formation; flood plains, alluviated valleys]

Area	Size	Elevation	Average annual precipitation, 1931-43	Topography	Slope		Major soil type	Major vegetative type
					Maximum	Average		
	Acres	*Feet*	*Inches*		*Percent*	*Percent*		
Deer Springs:								
Drainage basin	3,360	6,400-7,600	11.3 to 13.5	Rough, stony, and broken	100	18	60 percent clay and shale	Sparse piñon-juniper woodland.
Flood plain	[1] 450	6,240-6,400	9.3 to 11.3	Flat to gently sloping	5	.2	Clay to clay loam	Galleta.[2]
Norcross:								
Drainage basin	2,550	6,400-7,640	11.3 to 13.5	Rough, broken	50	19	70 percent clay and shale	Sparse piñon-juniper woodland.
Flood plain	[3] 150	6,350-6,400	11.3	Flat to gently sloping	3	2	Clay to clay loam	Galleta.[2]
Muddy Creek:								
Drainage basin	3,560	6,390-8,400	From slightly less than 11 to 17.5.	Rough, broken Badlands.	150	25	85 percent clay and shale	Sparse piñon-juniper woodland.
Flood plain	[4] 250	6,380-6,390	Slightly less than 11.	Flat to gently sloping	2	.2	Clay to clay loam	Galleta.

[1] Dimensions, 3 miles by 0.25 mile. A few flows may have covered 550 acres.
[2] With slight mixtures of western wheatgrass and blue grama.
[3] Length about 0.6 mile; average width 0.4 mile. Large flows often reached beyond studied portion; maximum flooded area measured was 325 acres.
[4] Two subareas totaling 250 acres, plus a dry lake bed of 25 acres with a spillway at lower end. Heavy flows covered approximately 450 acres; exceptionally large ones extended to a natural depression that ponded the water until it seeped away.

Samples of soil for moisture-content determination were taken from the field plots in the spring and the fall of each year. Soil analyses were made on composite samples taken from each plot in the fall of every third year. The methods of analysis are indicated in table 42, appendix.

The course of deposition on the flood plains was followed by means of measurements, along permanent lines, surveyed before any flows occurred and annually thereafter, from reference points situated at intervals below the spillways. Volume and extent of deposition and changes in channel gradient in the arroyos above the dams were similarly determined when time permitted. In 1943, measurements of cut and fill in the channels were not made, but changes of elevation in midchannel were determined. The survey lines were established normal to the flow; and deposition was measured by determining elevations at 10-foot intervals and at abrupt changes in slope, plotting these data on cross-section paper, planimetering the resulting areas, and applying the prismoidal formula. The extent of the survey in the channel was 2,821 feet at Deer Springs, 2,146 feet at Norcross, and 2,445 feet at Muddy Creek.

Until the end of the 1937 flooding season the amount of water that flowed onto the flood plain was determined from current-meter measurements and records were taken in a stabilized section at or above the dam with a Stevens type E water-stage recorder. In addition, plane-table maps of the areas over which the water spread were made after each major flow, and after some of the smaller ones, on seven flooding areas. All measurements of flow onto the flood plain were discontinued after the 1937 flooding season, because in that year, after sediment filled the basins behind the dams, silting over of the control sections made further collection of reliable data impracticable.

Grass Plots

The design of the grass plots was based on randomized blocks replicated four times. It comprised 60 plots 18 x 25 feet, inside measurement. Of these, 20 were flooded with 6 inches of water diverted through a 2,000-foot ditch from an arroyo each time it flowed, 20 were flooded at each of these times with a like amount of clear water from a well, and 20 were not flooded. Owing to space limitations, the unflooded plots were laid out in a rectangle, close to the flooded ones. A dike 6 feet wide supported a flume and formed one side of each flooded plot (fig. 5). Earthen dikes 3 feet wide at the base and 1 foot high were built on the three other sides of these plots and on all sides of those not flooded. The flume was equipped with automatic gates—one for each plot—and aliquot samplers (*18*) which simultaneously measured and sampled the irrigation water as it entered the plot. Each sampler was calibrated to deliver sufficient water to cover the plot to a depth of 6 inches before shutting off the flow. The sample was taken continuously and amounted to slightly less than 20 gallons. After an irrigation with arroyo water, this large sample was thoroughly stirred and a small sample was withdrawn by means of a pipe sampler, which sampled the reser-

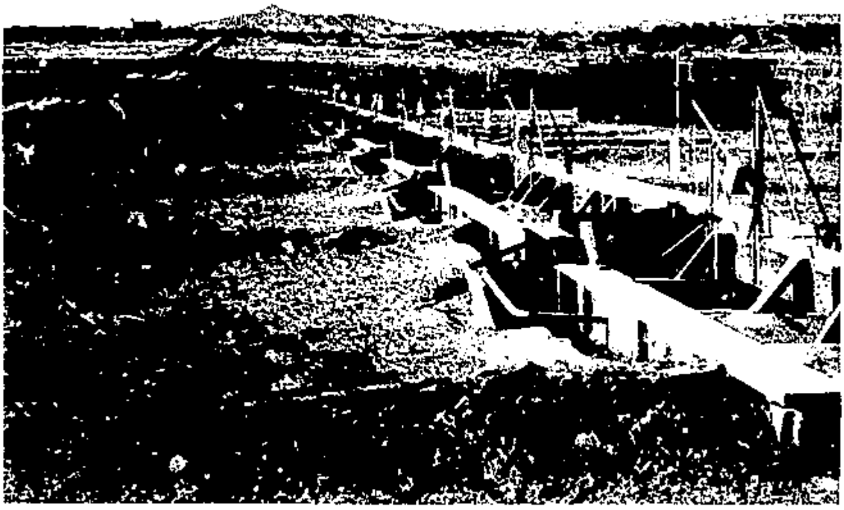

FIGURE 5.—General view of irrigation flume and grass plots before planting.

voir throughout its depth. The small sample was then analyzed in the laboratory for percentage of sediment by weight.

The irrigated plots were divided into four blocks of 10 plots each, 5 on one side of the flume and 5 on the other. One-half of each block was designated to receive sediment-laden water and the other to receive clear water. The unirrigated plots were divided into four blocks, each of which contained a row of five plots, with 2-foot paths between the blocks.

In each block one plot, selected at random, was seeded with western wheatgrass, one with blue grama, one with galleta, one with alkali sacaton, and one with a mixture of these species. Sufficient weights of seed of each species, as determined by germination tests of 10 samples of each, were sown to produce approximately the same number of plants in each plot. The seeds were sown in August 1937, and the plots were watered until the seedlings were well started. Forbs and extraneous grasses were removed during the summers of 1938 and 1939. Original soil data were obtained from samples taken in the summer of 1939. By the spring of 1940 the grasses in all plots had become well established, and the first measurements of the vegetation were made then. The water treatments began during the summer of 1940.

For determination of soil characteristics, composite soil samples taken from each plot were analyzed by methods indicated in table 43, appendix.

Vegetational responses were determined as changes in basal areas of grasses and in numbers of forbs. Sampling was done with 10-foot line transects. Each plot was divided into front and back and right and left halves, and three transects were located at random annually in each quarter plot. Measurements were made annually in early July.

Crop Plots

The influence of water spreading on crop production was studied on 60 experimental plots 18 x 25 feet, inside measurement, established in the fall of 1937. Of these, 48 were irrigated and 12 were dry-farmed. The dry-land plots, owing to space limitations, were laid out in a rectangle, as four rows of three plots, near the plots that were to be irrigated. Arroyo water was delivered to the irrigated plots through a 2,000-foot ditch and a flume, as described for the grass plots, in the amount of 6 inches per irrigation. Half this amount was used in a few instances when flows followed each other so rapidly that another 6-inch irrigation could not be added. Water samples were taken and analyzed as described for the grass plots.

Of the 48 irrigated plots, 12 received water from the arroyo each time it flowed and 12 corresponding plots were watered with clear water within a day's time of each irrigation; 12 were watered with arroyo flows selected on the basis of low sediment content and the moisture need of the crop, and a corresponding group of 12 received clear water within a day's time. The entire group was divided into 4 blocks, each comprising 6 plots on each side of the flume. Each block was divided into 4 sub-blocks, and among the sub-blocks the water treatments were randomized. There were four replications of the treatments.

Flows of low sediment content were selected by means of a test devised by the writers.[4]

The crops used were pinto beans obtained locally, a locally adapted strain of yellow soft corn, and Brunker oats obtained commercially. The three crops were randomized annually within each sub-block. The plots were spaded in November of each year to a depth of 7 inches. Planting was done as nearly as possible on May 20 and crops were harvested in early October. After the first year the beans in the irrigated plots were planted on ridges about 8 inches high to eliminate or reduce the "burning" effect of sediment on the leaves (*18*).

Soil samples taken in late May of each year were analyzed by methods indicated in table 44, appendix.

Lysimeters

The lysimeters were concrete receptacles 22 inches square and 36 inches deep. In November 1937 they were filled with a thoroughly mixed sandy clay loam. The following July they were seeded with a mixture of western wheatgrass, blue grama, galleta, and alkali sacaton. Weighed amounts of seed with approximately equal numbers of viable caryopses of the component species were sown in each lysimeter. Although this method gave good results in the grass plots, in the limited space of the lysimeters the numbers of seedlings of the individual species differed rather widely from those expected, perhaps because of the adverse influence of one species on another during germination and early growth (*11*). The vegetation was charted with a pantograph in May 1939.

Samples of the surface 6-inch layer of soil were analyzed in June 1939 before irrigation was begun. The factors determined and the analyti-

[4] Gardner, J. L., and Hubbell, D. S. CONSERVATION OF RUNOFF FOR CROP AND FORAGE PRODUCTION. Soil Conserv. Serv. Regional Bul. 94, 20 pp., illus. 1944. [Processed.]

cal methods used were: Total bacteria, by plate count (*17*); nitrifying power, by ammonium salt conversion (*17*); water-soluble nitrates, by Harper's phenoldisulfonic acid (*21*); calcium carbonate, by Emersons' carbonate carbon (*15*); pH, by glass electrode (*1*); water-soluble salts, by salt bridge (*13*); organic matter, by Schollenberger's chromic acid (*32*); and colloids, by official method (modified) (*1*).

After the vegetation had been charted, the lysimeter plots were subjected to 22 different irrigation treatments. Twenty of these were of water-sediment mixtures in which the sediment varied in kind and amount. The percentages of sediment, by weight, were 5, 20, 35, and 50. For each of these percentages, there were five treatments with different qualities of sediment, as follows: 100 percent sand; 80 percent sand, 20 percent clay; 60 percent sand, 40 percent clay; 40 percent sand, 60 percent clay; and 20 percent sand, 80 percent clay. One of the two treatments lacking sediment was of clear well water; the other, of water decanted from a soil-and-water mixture that had been thoroughly stirred and allowed to settle for 12 hours.

The 80-percent clay and the 100-percent sand came from natural deposits near the experimental area. Quantities of each obtained at the beginning of the experiment proved sufficient for 3 years, and material was taken from the same sources for the fourth year. For the intermediate treatments, weighed amounts of these base materials were mixed. The soil material used on each plot was mixed with the required amount of water at the time of application.

There were 264 lysimeters at the beginning of the experiment. These were divided into three blocks, and each of these blocks was divided into four sub-blocks that received replications of the 22 treatments. Each of the sub-blocks was in turn divided into 4 groups of plots, and among these the 5-, 20-, 35-, and 50-percent sediment treatments were randomized. In each of these groups, plots for measuring the effects of the different kinds of sediment were selected at random. The clear-water and the decanted-water treatments were randomized among the 5-percent treatments. Each year one sub-block from each of the major blocks was sampled and dismantled.

One foot of each water-sediment mixture, or 1 foot of water in the treatments without sediment, was applied annually in three equal portions—one the 1st of July, one the 1st of August, and one the 1st of September. Annual deposit in the different groups amounted to approximately 6 inches for the 50-percent sediment treatments, 3.5 inches for the 35-percent, 2 inches for the 20-percent, and 0.75 inch for the 5-percent. As the surfaces of the plots rose with the addition of sediment, the sides were built up to hold subsequent applications (fig. 6). After 4 years of treatment, the depth of accumulated sediment amounted to approximately 3.5 inches in the 5-percent-suspension plots, 9 inches in the 20-percent, 15 inches in the 35-percent, and 23 inches in the 50-percent.

In June of 1940, 1941, 1942, and 1943 the vegetation in all the plots of the current year's replications was charted and soil samples were taken. Except in the 5-percent plots, samples of the deposit were taken only after the accumulation of approximately 6 inches of sediment. Thus the 50-percent plots were sampled every year, the 35-

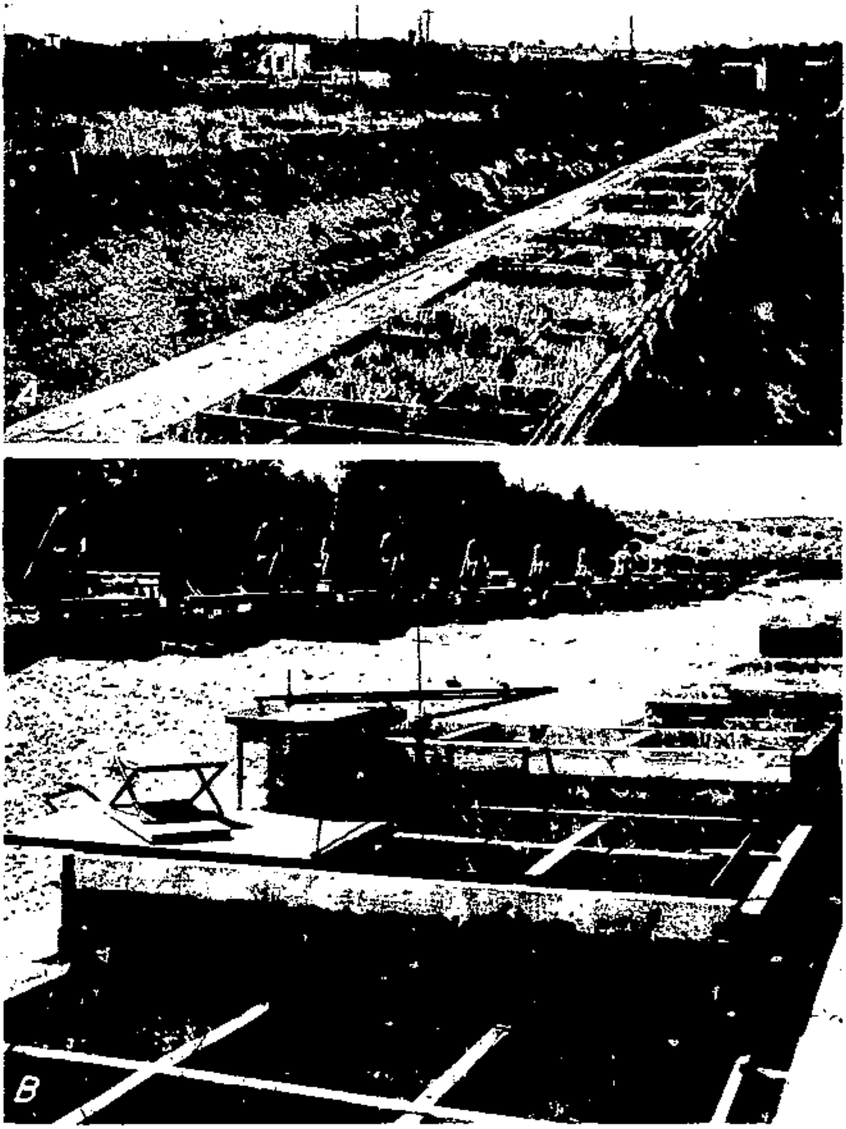

FIGURE 6.—Lysimeters (*A*) before treatment and (*B*) after 4 years of treatment. Instrument is pantograph set-up used in charting vegetation.

percent plots in 1941 and 1943, and the 20-percent plots in 1942. Sampling of the deposit was at 6-inch depth intervals or to the nearest fraction of this interval. The original underlying soil was sampled to a depth of 6 inches. The 0-percent and the 5-percent plots were sampled each year to a depth of 6 inches from the existing surface.

RESULTS

The record of floodings received by the field plots (table 4) reveals wide variations in number and extent of floodings from year to year and from flood plain to flood plain. In 1941 the three flood plains, respectively, received 8, 9, and 12 flows; in 1942 none of them received any. Owing to distribution of storms, the Norcross area, with the smallest drainage basin, received more floodings than either of the others. Many flows went beyond the studied parts of the Norcoss and Muddy Creek areas, while only a few extended the full length of the longer Deer Springs area.

Flows reached the flood plains only during or just before the growing season. Flooding was heaviest in August and September and lightest in June. The floodings of 1940 and 1941 were well distributed from April to October; in 1937, on the other hand, four of the six largest flows at Deer Springs came in the period August 26 to September 4 (table 5).

As determined from hundreds of samples taken during the operation of the station, the sediment content of arroyo flows, by weight, averaged approximately 13 percent. It ranged from less than 1 percent in runoff from melting snow, which constituted a very small part of the annual runoff, to more than 60 percent in the runoff from heavy summer storms occurring on badland areas.

CHANNEL SEDIMENTATION

Deposition in the channel above the dam was measured to a distance of 2,821 feet at Deer Springs, 2,146 feet at Norcross, and 2,445 feet at Muddy Creek (table 6). The upper limits of the surveys were approximately 500, 2,000, and 100 feet, respectively, from the points where the channels emerged from the foothills. By 1943, at the upper end of the survey, the channel had filled to a depth of 3 feet at Deer Springs and 4.5 feet at Norcross; the Muddy Creek channel had cut and partly refilled, resulting in a net cut of 1.5 feet. Little or no channel deposition occurred in the foothills, where the channel slopes were perceptibly steeper.

TABLE 4.—*Number of floodings and depth of deposit in field plots, 1936–43, and an example of moisture penetration*

Plot	Distance of plot from spillway	Floodings								Average depth of sediment					Extremes of depth of sediment [1] in 1941		Moisture penetration [2] April 26, 1941	
		1936	1937	1938	1939	1940	1941	1942	1943	1937	1938	1939	1940	1941	Maximum	Minimum	Flooded plots	Unflooded plots
	Feet	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Deer Springs:																		
1	120	1	6	4	1	9	12	0	3	4.4	9.5	10.8	17.2	28.0	34.2	22.8	96+	43
2	740	1	6	5	1	9	12	0	3	4.7	7.1	8.9	10.8	10.5	19.8	3.4	96+	41
A	(3)																	
B	(3)																	
3	1,580	1	6	3	1	8	8	0	3	7.6	7.2	8.5	9.5	24.5	34.5	16.6	46	30
4	2,130	1	6	3	1	7	10	0	3	3.0	3.8	5.5	4.8	7.6	10.5	5.8	96+	46
5	3,330	1	7	3	1	8	10	0	3	3.1	3.8	5.5	7.1	14.8	22.2	6.4	84	40
6	6,280	1	6	3	1	5	8	0	3	.2	.4	.7	1.4	.2	1.4	−8.5	96+	39
7	9,880	0	4	0	0	3	6	0	3								35	24
C	(3)																	
8	12,900	0	0	0	0	3	2	0	3								47	25
9	15,900	0	0	0	0	3	4	0	3								54	20
Norcross:																		
A	(3)																	
B	(3)																	
1	150	1	11	9	1	11	8	0	4	7.9	12.3		16.6	20.9	26.4	7.4	86	42
2	500	1	11	7	0	11	8	0	4	7.0	12.2		12.7	16.8	29.4	12.0	96+	40
3	950	1	11	7	0	11	8	0	3	3.4	5.3		6.8	5.6	11.4	4.0	42	17
C	(3)																	
D	(3)																	
4	1,500	1	9	7	1	10	8	0	3	1.7	4.9		5.3	11.3	12.6	9.0	49	20
5	2,100	0	8	7	0	9	7	0	3	1.3	2.9		3.4	5.5	6.0	4.4	46	22
6	3,100	0	7	6	1	8	7	0	3	.2	.7		2.2	8.3	9.6	7.0	67	25
Muddy Creek:																		
A	(3)																	
1	100	0	4	2	0	3	2	0	3	3.5	0.9	(4)	13.7	20.2	23.4	15.0		
2	700	0	4	1	0	2	1	0	3	5.2	5.6	(4)	8.5	8.5	9.6	4.2		
3	1,300	0	2	0	0	0	0	0	2	.7	0	(4)	0	0	1.5	0		
B	(3)																	
4	1,500	0	3	0	0	3	2	0	3	2.0	2.1	(4)	2.6	5.3	6.0	3.6		
5	1,800	0	3	0	0	0	0	0	3	.7	.9	(4)			2.4	.4		
6	200	0	4	8	0	10	9	0	3	6.4	13.0	(4)	21.9	21.9	30.6	14.4	96+	41
7	1,500	0	4	7	0	9	7	0	2	1.5	2.7	(4)	5.2	12.2	19.8	16.2	70	40
8	2,000	0	4	7	0	10	7	0	3	2.2	4.9	(4)	−2.5	1.5	6.0	−6.0	96+	37
9	3,500	0	4	4	0	8	6	0	3	1.5	1.9	(4)		2.9	4.4	2.0	67	33

[1] A minus sign signifies a cut below the original level.
[2] Borings were made no deeper than 8 feet. The determinations made averaged 71.8 inches for flooded plots, 33.4 inches for unflooded plots.
[3] Check.
[4] Not flooded.

TABLE 5.—*Date and volume of each flow from Deer Springs and Norcross drainage basins in 1936–37, with acreage flooded*

Name and acreage of drainage basin	Average slope		Date of flow	Volume of flow	Area flooded	Ratio of acreage flooded to acreage of drainage basin	Average application
	Drainage basin	Flood plain					
	Percent	*Percent*		*Acre-feet*	*Acres*		*Inches per acre*
Deer Springs, 3,360	18	0.2	1936 Sept. 1	14.6	83.4	1:40.3	2.1
			1937 July 27	12.5	87.0	1:38.6	1.7
			Aug. 5	1.2	2.5	1:1,344.0	5.5
			Aug. 26	35.2	110.0	1:30.5	3.8
			Aug. 29	11.0			
			Aug. 30	11.9			
			Sept. 1	16.4	152.0	1:22.1	1.3
			Sept. 3	.3			
			Sept. 4	88.8	183.0	1:18.4	5.7
			Sept. 29	22.8			
			Sept. 30	2.5	165.0	1:20.4	.2
Norcross, 2,552	19	2.0	1936 Aug. 5	.5	3.0		2.0
			Aug. 6	9.9	10.0	1:255.0	1.1
			1937 May 27	18.1	325.0	1:7.9	.7
			July 7	3.3	37.0	1:69.0	1.1
			July 11	6.6	85.0	1:30.0	.9
			July 27	8.1	121.0	1:21.1	.8
			Aug. 15	3.9	44.0	1:58.0	1.1
			Aug. 18	.5	10.0	1:255.2	.6
			Aug. 24	.4	11.0	1:232.0	.4
			Aug. 30	8.0	150.0	1:17.0	.6
			Sept. 1	1.0			
			Sept. 2	11.6	138.0	1:18.5	1.0
			Sept. 29	12.4			
			Sept. 30	5.1	160.0	1:16.0	.4

TABLE 6.—*Amounts of sediment deposited in stream channels, 1934–38, and changes in channel gradients, 1934–43*

DEER SPRINGS

Stations Nos.	Distance above Ian. (feet)	Sediment				Gradient				
		1934–35	1935–37	1937–38	Total 1934–38	1934	1935	1937	1938	1943
		Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0–1	46	25,647	0	943	26,590					
1–2	216	138,856	19,400	880	159,136	1.00	0.31	0.67	0.29	0.16
2–3	446	143,670	77,368	4,680	225,718	.82	.26	.12	.22	.16
3–4	646	100,279	49,000	3,130	152,409	.29	.33	.32	.27	.28
4–5	1,016	125,970	48,850	5,970	180,790	.13	.56	.11	.03	.18
5–6	1,516	136,675	66,650	10,890	214,215	.85	.25	.23	.62	.51
6–7	1,716	47,609	33,890	9,900	91,399	2.05	.15	.68	.70	.47
7–8	1,921	17,178	9,040	4,940	31,158	.37	.58	.01	.19	.33
8–9	2,321	28,588	17,095	8,760	54,443	.87	.45	−.07	.45	.35
9–10	2,821	10,124	22,400	15,100	47,624	1.85	1.63	1.45	1.00	.77
Total surveyed		774,636	344,503	64,613	1,183,752					
		[1](17.8)	(7.9)	(1.5)	(27.2)					

TABLE 6.—*Amounts of sediment deposited in stream channels, 1934–38, and changes in channel gradients, 1934–43*—Continued

NORCROSS

Stations Nos.	Distance above dam (feet)	Sediment				Gradient				
		1934–35	1935–37	1937–38	1934–38	1934	1935	1937	1938	1943
		Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0-1	100	4,100	4,190	1,415	9,705					
1-2	200	6,399	7,830	2,166	16,395	0.40	0.67	0.89	0.37	0.71
2-3	300	3,696	5,660	1,267	10,623	.50	.27	.25	−.33	.07
3-4	400	3,072	5,550	1,478	10,100	−.99	−.32	.06	−.27	.05
4-5	500	4,300	4,010	1,770	10,080	.31	−.30	.03	.24	.14
5-6	636	9,412	19,210	7,536	36,159	.67	.41	.88	.61	.87
6-7	736	6,818	17,360	7,054	31,232	−.01	.42	.38	.44	.87
7-8	1,062	3,450	9,220	5,443	18,113	.27	.23	.10	.18	.40
8-9	1,516	5,805	23,900	10,746	40,451	.21	.10	.14	.11	−.40
9-10	1,716	10,010	38,650	25,733	74,393	.50	.30	.85	1.02	1.36
10-11	1,916	15,637	38,650		54,287	.48	.80	.29	.30	.50
11-12	2,016	7,977	27,240	11,290	46,507	.48	.52	1.00	1.22	1.14
12-13	2,116	9,541	14,300	6,009	29,850					
Total surveyed		90,217	216,670	81,908	388,795					
		[1](2.1)	[1](5.0)	[1](1.9)	[1](8.9)					

MUDDY CREEK

Stations Nos.	Distance above dam (feet)	1934–35	1935–37	1937–38	1934–38	1934	1935	1937	1938	1943
0-1	200	14,850	65,920	18,980	99,750					
1-2	600	37,400	188,364	53,230	278,994	0.44	0.53	0.51	0.35	1.47
2-3	800	38,030	179,470	67,633	285,133	.50	.53	.09	.35	.46
3-4	1,100	14,720	37,206	20,785	72,711	.55	.19	.25	.10	−.20
4-5	1,315	18,090	93,050	32,795	143,935	.21	.57	−.29	0	.59
5-6	1,915	18,030	33,766	44,610	96,406	.74	−.14	.52	.52	.29
6-7	2,215	279	29,713	61,925	91,917	.33	.29	.16	.19	.48
7-8	2,415	4,782		24,897	29,115	2.10	1.95	.87	.77	.48
8-9		5,375			5,375	1.98	2.01	.87	.77	.88
Total surveyed		141,932	627,509	327,875	1,097,316					
		[1](3.3)	[1](14.4)	[1](7.5)	[1](25.2)					

[1] Acre-feet.

The average channel gradient for the measured distance above the dam in 1934 was 0.92 percent at Deer Springs, 0.71 percent at Muddy Creek, and 0.26 percent at Norcross. By 1943 the average had decreased to 0.39 and 0.53 percent at Deer Springs and Muddy Creek, respectively, but had increased to 0.35 percent at Norcross. In 1943 the deposits behind the Deer Springs and Muddy Creek Dams sloped almost uniformly except for the lowest 200 feet at Muddy Creek (fig. 7); at Norcross the slope was uneven, owing to channel plantings.

The deposited material could be distinguished from the original material of the channel, by its finer texture, for a distance of approximately 1,200 feet at Deer Springs and Muddy Creek, and for a greater distance at Norcross—probably owing to the lower gradient and the planting there.

During the 5-year period of greatest deposition, 1934–38, sediment accumulation in the surveyed segments of the Deer Springs, Norcross, and Muddy Creek channels amounted to 27, 9, and 25 acre-feet, respectively (table 6).

The deposit behind the Figuerido Creek diversion dam, within the experimental area, is illustrated in figure 8.

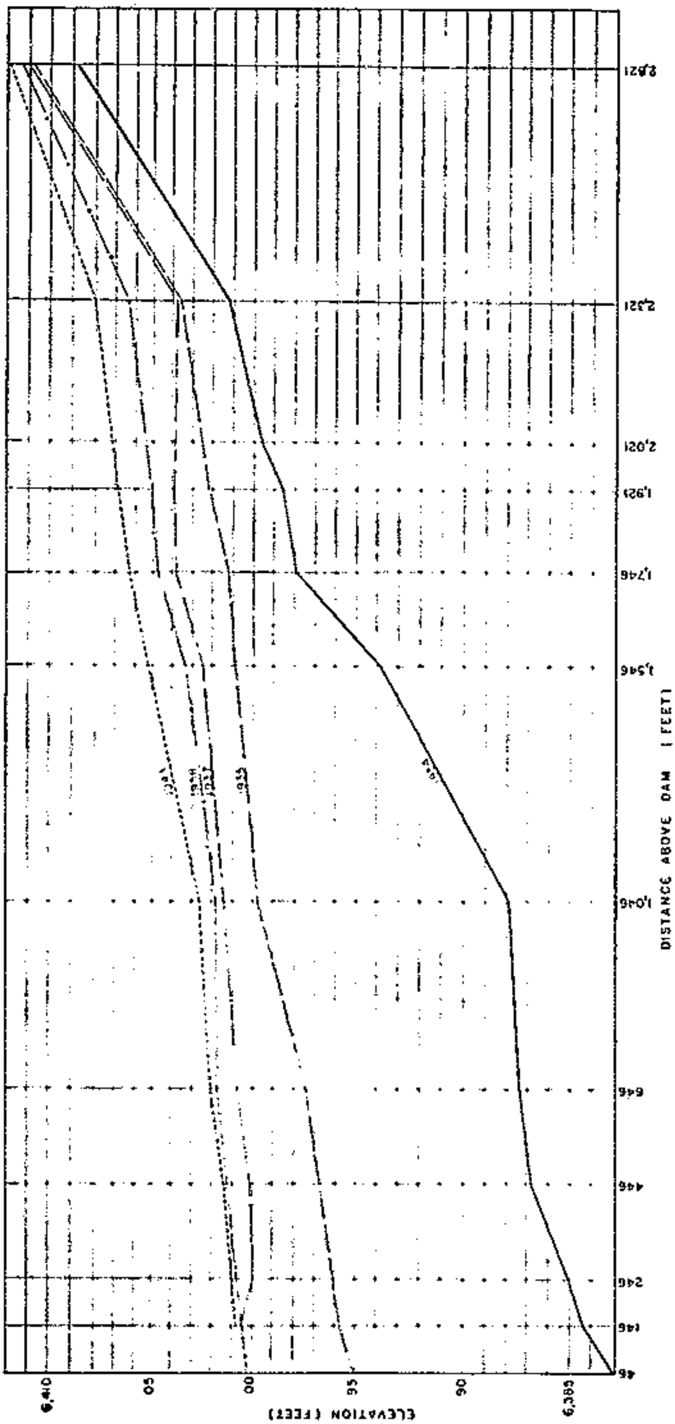

FIGURE 7.—Course of channel filling in first 2,821 feet of arroyo above Deer Springs diversion dam.

FIGURE 8.—A, View [illegible] 1936 of [illegible] Creek, 35-foot-deep arroyo cut by runoff from 15,000 acres [illegible] B, View from [illegible]

EXTENT OF SPREAD OF DIVERTED WATER

After leaving the spillway, water spreads in a sheet over the flood plain (fig. 9). The extent to which comparable quantities of water spread on the study areas varied from flow to flow and from flood plain to flood plain (table 5). Among the factors that determine the size of the area flooded by a given amount of runoff diverted from an arroyo are the rate at which the runoff flows onto the flood plain and the slope, configuration, soil texture, vegetation, and current soil moisture content of the plain. Deposition of sediment and trash in some instances so changes the configuration of the plain that

FIGURE 9.—Water spreading over range land in Norcross flood plain: *A*, Flow at spillway; *B*, flow 0.1 mile below spillway; *C*, flow 0.3 mile below spillway; *D*, general view of flow.

waters of a succeeding flow may reach hitherto unflooded areas and bypass areas previously flooded.

Comparison of data from Deer Springs and Norcross (table 5) illustrates the influence of slope of flood plain. Vegetation and soil texture in the two areas were similar; current soil moisture data are lacking. Because of steeper channel gradient in the first half-mile above the Deer Springs Dam, it may be assumed that velocities at which comparable amounts of water reached the flood plain were higher at Deer Springs than they were at Norcross. Yet the amount of water in inches per acre absorbed by the Deer Springs flood plain, the slope of which averaged only 0.2 percent, was considerably greater than that absorbed by the Norcross flood plain, which had an average slope of 2.0 percent.

An instance of variation of spread with rate of flow appears in the 1937 records for the Norcross area. On May 27, 18.1 acre-feet of runoff flowed onto the Norcross flood plain in 4.75 hours, at rates reaching a maximum of 240 cubic feet per second, and covered 325 acres. On September 29 and 30, 17.5 acre-feet of runoff flowed onto this flood plain in 9 hours, at rates reaching a maximum of 83 cubic feet per second, and covered 160 acres.

A 3-year record for seven drainages disclosed little or no direct relation between size of drainage area and size of flooded area under the climatic and topographic conditions of the station area (table 7). In 1937 the maximum area flooded below the 2,550-acre Norcross drainage basin was 325 acres; that at Black Creek, below a drainage basin nearly twice as great, was 235 acres; and that at Figuerido, below a drainage basin 17.7 times as great as the one at Norcross, was 824 acres. Since runoff-producing storms rarely covered the entire station area, larger drainage basins were less completely covered than small ones. The longer channels of large basins, as shown by unpublished hydrologic data collected at the station, absorbed more of the runoff than the shorter ones of smaller basins did; therefore, lower percentages of the precipitation falling in the larger basins reached the flood plains.

TABLE 7. *Ratio of maximum size of flooded area to size of drainage basin,[1] by year*

Location of diversion dam	Size of drainage basin	1935		1936		1937	
		Maximum area flooded	Ratio of area flooded to area of basin	Maximum area flooded	Ratio of area flooded to area of basin	Maximum area flooded	Ratio of area flooded to area of basin
	Acres	*Acres*		*Acres*		*Acres*	
Norcross	2,550	147	1:17	10.0	1:255	325	1:8
Deer Springs	3,300	435	1:8	83	1:40	183	1:18
Muddy Creek	3,560	236	1:16	0			
Black Creek	4,710	575	1:8	307	1:15	235	1:20
Coal Mine	5,100	170	1:30	268	1:20		
Upper Dye Brush	25,200	249	1:101	284	1:89		
Figuerido[2]	45,070					824	1:56

[1] All drainage basins except that above Upper Dye Brush dam had steep slopes.
[2] Dam built in 1936.

While the larger drainage basins did not serve proportionately larger spreading areas, observations indicated that drainage areas of less than 2,000 acres, otherwise suitable, were likely not to produce runoff often enough to make water spreading practical for production of forage or crops.

Flood-Plain Sedimentation

Deposition on the flood plains began in 1935; but until 1937 the sediment blanket was less than 2 inches deep, even on the more heavily silted areas. From 1937 on, deposition was heavy (table 8); annual deposit on the upper 2,650 feet at Deer Springs averaged 5 acre-feet from 1937 to 1941. Beyond 3,500 feet, the deposit was light or negligible. Changes in the topography of the Deer Springs flood plain brought about by silting between 1934 and 1942 are illustrated in figures 10 and 11.

The topography of the flood plains appears to have exerted the greatest single influence on the distribution of sediment there. Deposition was greater above points where the flow changed its course or the flood plain narrowed (fig. 10 and table 8), and also where flow widened below such points. Flood-plain deposition was least at Norcross and greatest at Muddy Creek. Below the portion of the Muddy Creek area that was under study, a considerable quantity of sediment accumulated where the water flowed into a large depression.

Table 8.—*Sediment deposited on flood plains below Deer Springs and Norcross diversion dams, 1934–42*

DEER SPRINGS

Stations Nos.	1934–35	1935–36	1936–37	1937–42	Total
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
9–10	2,705	380	5,260	42,662	51,007
10–11	2,607	825	3,550	12,746	19,728
11–12	2,847	1,362	2,150	21,731	28,090
12–24	2,115	1,634	952	11,629	16,330
24–25	4,400	479	2,277	24,845	32,001
25–26	21,188	5,360	17,100	203,264	246,912
26–27	17,520	9,424	32,320	257,928	317,192
27–28	11,984	1,286	24,000	116,390	153,660
28–29	26,040	986	52,720	152,717	232,463
29–30	21,240	416	33,960	60,688	116,304
30–31	1,195	313	1,460	8,556	17,521
Total	117,441 [1] (2.7)	22,165 [1] (0.5)	178,749 [1] (4.1)	903,156 [1] (20.8)	1,221,511 [1] (28.7)

NORCROSS

Stations Nos.	1934–35	1935–36	1936–37	1937–42	Total
20–21		1,080	12,700	27,933	41,713
21–22		1,717	13,570	24,585	39,872
22–23		1,680	11,825	18,223	31,728
23–24		3,700	18,810	19,502	42,012
24–25		3,617	18,025	56,725	78,367
25–26		1,896	13,720	66,315	81,931
26–27		2,275	19,540	64,244	86,059
27–28		3,097	17,500	52,917	73,514
28–29		2,190	11,010	22,401	35,601
29–30		1,243	7,370	21,717	30,330
30–31		978	5,000	17,028	23,006
31–32		375	3,070	20,774	24,219
Total		21,128 [1] (0.5)	155,160 [1] (3.6)	412,067 [1] (9.5)	588,355 [1] (13.6)

[1] Acre-feet.

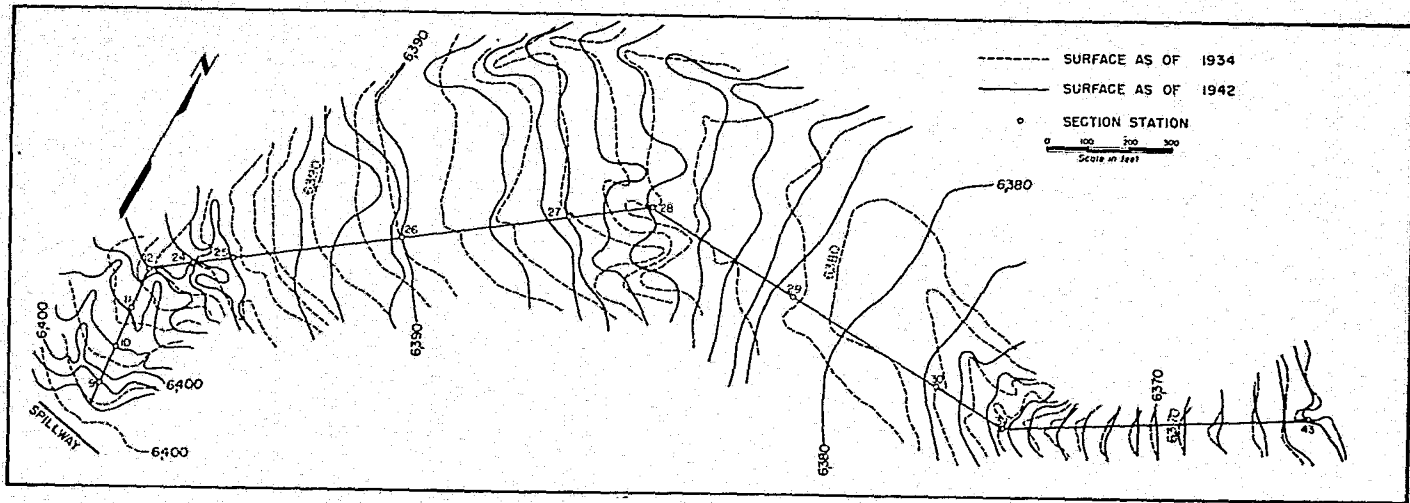

FIGURE 10.—Topographic map of upper part of Deer Springs flood plain showing 1-foot contours in 1934 and in 1942.

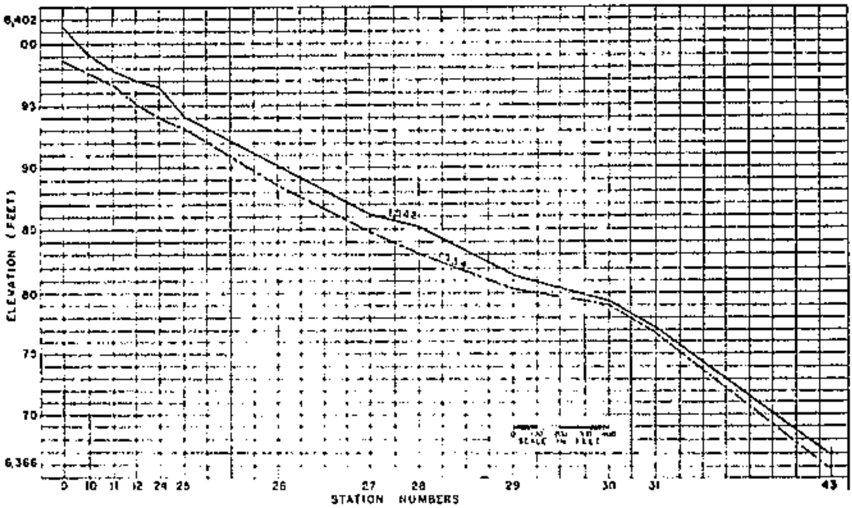

FIGURE 11.—Profile along base line on upper part of Deer Springs flood plain in 1934 and in 1942.

On the basis of the surveys and other observations, it was estimated that the sediment deposited on the three flood plains, plus that deposited in the channels, during the 9-year period of study approximated 300 acre-feet. This soil loss, if allocated evenly to the 9,470 acres of the three drainage basins and to years, amounts to 0.04 inch per year. Actual distribution of loss was, of course, far from even. Ordinarily a large part of the sediment carried by arroyo flows comes from sloughing of the arroyo walls.

Soil Moisture Content of Field Areas

Soil moisture percentages of field plots as determined for each of the four sampling depths before and after each flooding season are presented in table 9. In this discussion of soil moisture, as in table 9, the terms "flooded" and "unflooded," respectively, are used as applying in the fall of a given year to treated plots that have and have not been flooded in that year and as continuing to apply to the same plots the following spring. (Elsewhere in this bulletin, the term "flooded," when applied to field plots, is synonymous with "treated.")

Soil moisture percentages in flooded plots were usually greater in the fall than they had been the spring before, or than those in unflooded plots were in the fall. The data reflect the greater depth of water penetration in the flooded plots: spring moisture at the second- and third-foot depths was usually noticeably greater in flooded plots than in unflooded plots. In the latter it was only slightly greater than in the check plots. In contrast, spring moisture in the upper 6 inches or 1 foot of soil was less in flooded plots than in unflooded plots, where it was usually greater in the spring than it had been the preceding fall.

This moisture difference in the upper layer of soil was probably due chiefly to the greater exposure of the surfaces of flooded plots to late winter and spring winds and perhaps in part to their lighter soil

TABLE 9.—*Average moisture percentages of soils of flooded, unflooded, and check field plots* [1]

Plots, and sampling depth (inches)	1935		1936		1937		1938		1939	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Flooded:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0-6		13.3	9.8	8.9	9.4	18.2	12.7	11.4	9.8	15.8
6-12		15.1	11.9	10.0	13.3	18.8	17.1	14.1	13.3	16.5
12-24		13.5	10.0	9.1	13.8	16.1	14.7	13.3	12.9	11.4
24-36			9.6	10.4		12.1	12.3	12.3	12.0	8.9
Number of plots	0	23	24	19	10	22	22	18	18	9
Unflooded:										
0-6	6.3			10.1	13.4	12.6	15.8	7.0	11.7	10.9
6-12	8.8			10.0	14.7	9.2	15.8	9.2	12.4	10.2
12-24	8.4			9.5	13.3	7.9	10.2	8.8	9.4	10.0
24-36				8.7		7.1	8.3	6.7	7.1	9.2
Number of plots	21	0	0	14	14	2	2	6	6	15
Check:										
0-6	4.6	11.0	7.8	9.3	8.1	11.2	9.2	6.4	7.5	9.1
6-12	6.6	10.0	11.7	10.7	11.9	9.4	11.9	5.8	8.5	7.8
12-24	7.0	6.9	13.2	7.8	10.8	8.0	9.8	6.4	6.8	6.6
24-36			8.1	7.2		6.8	6.7	6.2	6.7	6.5
Number of plots	7	8	9	9	9	9	9	9	9	9

Plots, and sampling depth (inches)	1940		1941		1942		1943	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Flooded:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0-6	10.9	22.0	12.4	19.9	12.0			14.1
6-12	12.6	21.1	17.1	20.9	17.0			15.6
12-24	9.9	16.7	17.0	19.0	18.7			14.5
24-36	9.1	11.6	16.7	15.5	15.2			10.3
Number of plots	9	22	22	22	22	0	0	24
Unflooded:								
0-6	12.1	18.2	12.8	21.8	13.6	7.0	9.6	
6-12	12.3	14.0	14.4	21.8	18.6	8.4	11.4	
12-24	9.0	9.5	15.8	13.4	15.1	8.8	9.5	
24-36	8.5	6.2	11.5	13.1	9.4	8.4	8.9	
Number of plots	15	2	2	2	2	24	24	0
Check:								
0-6	9.1	13.2	8.0	14.6	8.8	6.1	7.8	7.8
6-12	5.9	11.8	11.9	14.8	13.6	6.1	7.8	11.2
12-24	7.8	8.2	13.2	14.1	15.6	5.9	7.5	8.0
24-36	6.6	6.7	13.5	10.5	13.1	6.4	6.6	6.6
Number of plots	9	9	9	9	9	9	9	9

[1] In the computation of fall averages, treated plots were classed as "flooded" if they had been flooded in the indicated year, and as "unflooded" if they had not been flooded in the indicated year; in the computation of spring averages, treated plots were classed as "flooded" and "unflooded" according as they had or had not been flooded in the preceding year.

texture in later years. The flooded group always included the heavily silted plots, upon which the cover of vegetation had been reduced. Unflooded plots lay farther down the flood plain, where silting was light or negligible and plant debris protected the surface. Moisture conditions in the upper soil layer of the check plots resembled those in the unflooded plots.

The soil moisture content of all three groups of plots was high in the fall of the very wet year 1941, and, except in the surface 6-inch layer, had diminished only a little by the spring of 1942. In 1942 only 2.6 inches of rain fell during the growing season, and there was no flooding. In the autumn of 1942, after 9 months of severe drought and an entire year without flooding, soil moisture content to a depth of 3 feet had diminished in all the plots approximately to the preflooding percentages of 1935. The drought continued until late July of 1943, and the soil had gained little moisture by the spring of that year. Precipitation slightly greater than average and heavy floodings occurred during August and September. At the fall sampling, all plots had regained some moisture, but the flooded plots were not as moist as would normally have been expected from the amount of runoff they had received.

Auger borings taken 24 hours after flooding, to afford comparison of depth of penetration in flooded plots with that in nearby areas receiving only rain, gave averages of 12.0 inches in the former and 2.3 inches in the latter for all floodings in 1940. Corresponding averages in 1941 were 48.7 and 11.7 inches. After the storm of April 26, 1941 (table 4), depth of penetration averaged 71.8 inches in flooded plots, 33.4 inches in areas not flooded.

Water and Sediment in Grass and Crop Plots

The grass plots designated for irrigation received added water in the summers of 1940 and 1941 and in the spring of 1942. Owing to low precipitation on the contributing drainage area, they received no irrigation during the summer of 1942 or the spring of 1943. The record of precipitation and irrigation on these areas follows:

Period:	*Precipitation (inches)*	*Irrigation water (inches)*	*Sediment (inches)*
July 1, 1939, to June 30, 1940	9.11	0	0
July 1, 1940, to June 30, 1941	19.94	36	2.5
July 1, 1941, to June 30, 1942	12.76	72	6.7
July 1, 1942, to June 30, 1943	6.74	0	0

Of the total precipitation during the year beginning July 1, 1941, 10.15 inches occurred before November 1.

Except for three 6-inch irrigations given the "all flow" plots during the fall of 1941, the crop plots received all their irrigations just before or during the growing season. Total yearly applications of water in the "all flow" plots ranged from 18 inches in 1938 to 114 inches in 1941; those in the "selected flow" plots, from 18 inches in 1938 to 36 inches in 1941 (table 10). These values include the sediment load. The average percentage of sediment was within the measuring error for sediment-laden water.

Average sediment content, by weight, of arroyo water received by "all flow" crop plots at one irrigation ranged from 0.30 percent for runoff from melting snow to 30.95 percent for that from a heavy rain. For the selected arroyo flows, sediment percentage varied from 0.30 to 15.80. Five-year averages of sediment content of water given the "all flow" and the "selected flow" plots were 7.01 and 3.46 percent, respectively. Annual averages for the "all flow" plots ranged from 0.55 percent in 1942 to 8.88 percent in 1940; those for the "selected flow" plots, from 0.47 percent in 1942 to 8.55 percent in 1938. Depth of deposit after 5 years averaged 20.8 inches in plots receiving all arroyo flows and 4.3 inches in those receiving selected ones.

TABLE 10.—*Amounts of water and sediment received by crop plots treated with arroyo water, and resulting deposits*

Year	Total precipitation	Plots irrigated with all flows				Plots irrigated with selected flows [1]			
		Irrigation water		Deposit		Irrigation water		Deposit	
		Amount	Sediment load, by weight	Amount per acre	Depth	Amount	Sediment load, by weight	Amount per acre	Depth
	Inches	*Inches*	*Percent*	*Tons*	*Inches*	*Inches*	*Percent*	*Tons*	*Inches*
1938	9.63	18	3.10	179	1.5	18	8.55	191	1.7
1939	8.35	[2] 33	7.15	353	3.1	18	2.59	47	.4
1940	15.26	[3] 78	8.88	889	7.7	24	5.85	165	1.4
1941	20.08	[4] 111	6.51	975	8.4	36	1.89	80	.7
1942	6.02	21	.55	15	.1	21	.47	13	.1
Total			7.01	2,411	20.8		3.40	496	4.3

[1] In 1938 these plots were irrigated with all flows, a total of 3.
[2] Includes three 3-inch irrigations.
[3] Includes two 3-inch irrigations.
[4] Includes three 6-inch irrigations applied after crop growth was checked by a freeze.

Samples of sediment-laden water taken at different stages of a flow in the arroyo from which water was diverted to the crop plots are shown in figure 12. At the peak stage of flow, the sediment content was 26 percent; approximately 2 hours later, it had dropped to 7 percent. This instance was by no means unique.

Water percolation in the crop plots irrigated with selected arroyo flows was no different from that in the two sets of plots irrigated with clear water. In the plots irrigated with all arroyo flows, percolation varied with soil conditions and the sediment content of the water. In these plots the comparatively clear water of the spring flows, put on soil disturbed by spading, disappeared as rapidly as the waters of the spring irrigations in the other plots. When the soil was dry and cracked, percolation was similarly rapid. When the soil was wet, the water often stood in the plots for several days (*18*).

Water containing much sediment, especially if the sediment was high in the clay fraction, took considerably longer to enter the ground than water with less or coarser sediment, even though the soil was dry at the time of application. During the very wet summer of 1941 the floodings were so closely spaced that, at times, the plot surfaces did not dry out between them; and, owing to the fine texture of the deposits in the plots irrigated with arroyo water, percolation in these plots was retarded to such an extent that water lay on them for several days at a time.

SOIL RESPONSES

TEXTURE

The prevailing texture of the soil of the flooded field areas at all sampling distances below the spillways was clay in 1935. By 1943 it had changed to sandy loam at 125 feet below the spillways, to sandy clay loam at 650 feet, and to clay loam at 1,000 feet and at 2,000 feet (table 11). At a distance of 1,500 feet below the spillways, the soil was still clay, but the sand content had risen from 34.8 to 48.9 percent. Through 1941 heavy deposition of sand was limited to the first 1,500

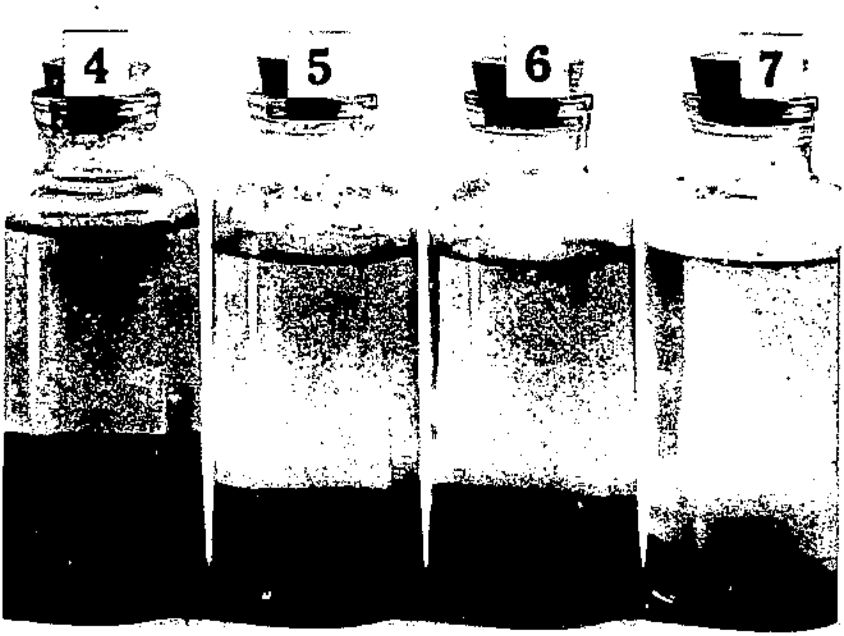

FIGURE 12.—Samples of sediment-laden water from successive stages of an arroyo flow: No. 4, from peak of flow, 2:30 p. m., 26 percent sediment by weight; No. 5, 2:45 p. m., 14 percent sediment; No. 6, 3:10 p. m., 13 percent sediment; and No. 7, 4:35 p. m., 7 percent sediment.

feet below the spillways, but by 1943 it reached approximately 500 feet farther down the flood plains.

The sediment-laden water used to irrigate the grass and crop plots dropped a considerable part of its sand fraction in the 2,000-foot ditch through which it flowed to them from the arroyo. This loss of sand caused the deposits on the plots to be of very heavy texture.

In the grass plots irrigated with sediment-laden water, at the end of 2 years of treatment, the sand fraction of the soil had decreased from 70 to 33 percent and the clay fraction had increased from 18 to 45 percent (table 12). Because of the heavy texture of the deposits, the soil data and the vegetation data from these plots are comparable to those from the lower portions of the heavily silted field areas and to those from the lysimeters in which intermediate treatments were applied. No changes of soil texture appeared in the grass plots irrigated with clear water or in those not irrigated.

In 1938, before treatment, the sand content of the soil of the crop plots was high, ranging from 54 to 74 percent, and the clay content was medium, ranging from 16 to 25 percent. By 1943, the sand fraction had decreased to an average of 37 percent in the plots treated with all the arroyo flows and to one of 39 percent in those treated with selected arroyo flows, and the clay fraction of the soil of each of these groups of plots had risen to an average of more than 38 percent (table 13).

TABLE 11.—*Texture*[1] *of soil on the 3 flood plains at different distances from spillway during 9 years of flooding, 1935–43*

Plots	Sampling sites	Sand				Silt				Clay			
		1935	1938	1941	1943	1935	1938	1941	1943	1935	1938	1941	1943
Treated plots at indicated distance from spillway:	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
125 feet	4	43.8	53.3	71.2	67.0	23.0	20.4	14.7	13.1	33.2	24.3	14.1	19.9
650 feet	3	20.8	37.9	66.1	57.5	32.9	33.8	16.5	22.1	37.3	29.3	17.5	20.4
1,000 feet	1	21.0	25.8	30.3	43.6	41.8	40.0	38.4	33.2	37.2	34.2	31.0	23.2
1,500 feet	5	34.8	37.9	52.2	48.9	28.0	27.6	13.5	16.3	37.2	34.5	34.3	34.8
2,000 feet	4	39.0	32.4	20.7	37.7	21.1	29.9	33.1	32.5	39.0	37.7	46.2	29.8
3,000 feet	1	16.4	15.4	7.3	12.4	50.6	31.0	33.1	49.6	33.0	53.6	59.6	38.0
3,500 feet	2	45.3	34.5	7.8	29.6	22.6	29.7	35.2	20.0	32.1	35.8	57.0	41.4
6,000 feet	1	40.4	41.6	14.5	30.0	23.2	23.0	29.2	30.0	36.4	35.6	56.3	40.0
10,000 feet	1	15.4	21.4	22.9	23.5	9.6	12.8	16.9	16.5	65.0	65.8	60.2	60.0
13,000 feet	1	18.0	17.8	13.5	16.0	18.6	16.0	11.6	23.4	63.4	66.2	74.9	60.6
16,000 feet	1	32.0	28.8	10.7	23.5	10.7	11.6	13.8	18.5	57.2	59.6	75.5	58.0
Check plots:													
Soil texture, heavy	5	38.9	41.1	31.1	39.3	21.3	21.8	27.9	23.3	39.8	37.1	41.0	37.4
Soil texture, light	4	65.8	68.4	67.9	64.2	15.7	11.8	12.2	14.2	18.5	20.1	19.9	21.6

[1] Diameter ranges, in millimeters, represented by soil classification: Sand, 0.05 to 2; silt, 0.005 to 0.05; clay, <0.005.

TABLE 12.—*Texture* [1] *of surface 6 inches of soil in grass plots subjected to irrigation beginning in 1940*

Water treatment	Sand			Silt			Clay			Colloids		
	1939	1942	1943	1939	1942	1943	1939	1942	1943	1939	1942	1943
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sediment-laden	69.9	33.3	37.4	11.7	21.7	21.2	18.4	45.0	41.4	16.1	41.1	38.2
Clear	71.9	71.8	71.5	10.6	11.6	11.0	16.7	16.8	16.5	14.0	14.4	14.2
None	66.8	68.3	67.2	13.3	13.2	13.0	19.4	18.5	18.7	17.2	17.3	17.2

[1] Diameter ranges, in millimeters, represented by classification: Sand, 0.05 to 2; silt, 0.005 to 0.05; clay, <0.005; colloids, <0.002.

TABLE 13.—*Soil texture,*[1] *as determined from samples taken in the spring, of crop plots subjected to irrigation in 1938–43*

Year	Texture class	Soil of "all flow" plots irrigated with— Sediment-laden water	Soil of "all flow" plots irrigated with— Clear water	Soil of "selected flow" plots [2] irrigated with— Sediment-laden water	Soil of "selected flow" plots [2] irrigated with— Clear water	Soil of unirrigated plots
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
1938	Sand	67.98	65.99	65.04	67.68	57.37
	Silt	13.68	14.75	15.24	14.33	18.13
	Clay	18.34	19.26	19.63	18.73	24.49
	Colloids	15.41	16.08	16.21	15.53	20.45
1939	Sand	59.63	66.70	52.93	66.22	59.51
	Silt	19.83	14.38	19.49	15.12	18.78
	Clay	20.54	18.92	27.58	18.66	22.55
	Colloids	23.92	15.72	22.00	15.72	19.87
1940	Sand	29.23	67.95	52.42	66.20	62.03
	Silt	27.88	15.37	21.04	15.35	16.37
	Clay	42.87	16.68	26.13	18.55	21.58
	Colloids	35.64	13.30	20.48	15.03	18.14
1941	Sand	13.64	65.78	33.63	67.33	61.50
	Silt	35.40	15.36	27.07	14.77	16.95
	Clay	50.96	18.86	39.26	17.90	21.53
	Colloids	39.52	15.56	29.89	11.57	18.26
1942	Sand	32.05	66.38	35.37	68.13	61.78
	Silt	22.73	14.52	22.61	13.62	16.37
	Clay	45.22	19.11	41.92	18.22	21.83
	Colloids	41.33	17.44	37.61	16.50	18.70
1943	Sand	37.60	66.70	39.10	67.00	61.53
	Silt	21.90	14.40	22.30	14.25	16.92
	Clay	38.50	18.90	38.60	18.73	21.53
	Colloids	37.60	16.30	33.20	15.30	18.40

[1] Diameter ranges, in millimeters, represented by classification: Sand, 0.05 to 2; silt, 0.005 to 0.05; clay, <0.005; colloids, <0.002.
[2] In 1938 the "selected flow" plots were irrigated with all flows, a total of 3. In 1942 there were no summer irrigations. Since the soil samples analyzed were taken in the spring, data for a given year reflect the influence of the previous year's treatment.

Floodings of 1939, the first year when selection of flows was practiced, caused no soil-texture change in the crop plots treated with selected arroyo flows. A marked decrease in the sand fraction and increases in the silt and clay fractions occurred in the plots that received all of the arroyo flows. In 1940, treatment with arroyo water caused a gain in clay in the "all flow" plots and a marked gain in clay in the "selected flow" plots. In 1941 it brought about a lightening of the soil in the "all flow" plots but little or no change in the others. The apparent changes in 1943, a year when no irrigations were made, and the small differences in the clear-water plots and in the unirrigated plots are attributed to sampling errors.

Although by the end of the fourth year of treatment the soil texture was similar in the two sets of crop plots irrigated with arroyo water, differences were observable in the field. Deep cracks were conspicuous in the soil of the "all flow" plots but not in that of the other set. The cracking was probably due to puddling of the soil caused by the standing of the water on the surface for long periods. In 1942, when there were no summer irrigations, puddling may have resulted from the rapid succession of the spring irrigations coupled with the much greater depth of heavy-textured material.

In the lysimeters, mechanical analyses before and after treatment showed no significant change in colloids in the first 6-inch layer of soil underlying the 4-year deposit accumulations (table 14). This indicates that colloidal material had not penetrated the original soil perceptibly.

TABLE 14.—*Percentage of colloids in top 6 inches of original lysimeter soils underlying deposits resulting from treatment with water having a 50-percent (by weight) content of sediment and in lysimeter soils treated with decanted water and clear water*

Treatment	1939	1940	1941	1942	1943
100 percent sand	17.7	18.2	18.1	17.6	17.9
80 percent sand, 20 percent clay	17.7	18.2	17.7	18.2	18.0
60 percent sand, 40 percent clay	17.7	18.1	18.5	18.0	18.1
40 percent sand, 60 percent clay	17.7	19.5	18.3	18.6	18.8
20 percent sand, 80 percent clay	17.7	18.5	18.8	18.7	18.6
Decanted water	17.7	18.9	20.4	18.1	18.7
Clear water	17.7	18.1	19.1	18.0	17.5

ORGANIC MATTER

Diverted arroyo water carried to the spreading areas large quantities of organic debris consisting of branches, cones, leaves, and minute fragments. In general, the large, heavy pieces settled out near the spillway; but fine, light material was carried much farther down. A large flow carried much of its debris well onto the flood plain, whereas a flow covering only a few acres left its entire load in the upper part of the plain.

Changes in the organic-matter content of the soil of treated field areas (table 15) were apparently governed by several factors including distance from spillway, amount and texture of sediment deposit, and regularity of flooding.

TABLE 15.—*Changes in organic-matter content of soil of field areas in relation to distance from spillway*

Plot classification	Plots	Organic-matter content of topsoil: Average 1935 value	Changes from 1935 value: 1938	1941	1943
Treated, at indicated distance from spillway:	*No. 1st*	*Percent*	*Percent*	*Percent*	*Percent*
120–1,000 feet	8	1.08	0.23	0.60	+0.03
1,500–2,000 feet	9	1.02	−.16	+.05	+.19
3,000–3,500 feet	3	1.16	+.12	+.83	+.57
6,000 feet	1	1.79	−.77	+.26	−.12
10,000–16,000 feet	3	1.27	−.22	+.13	.00
Check:					
Soil texture heavy	7	1.08	−.17	−.01	−.12
Soil texture light	1	.73	+.03	+.16	+.11

In soil samples taken on the three flood plains in 1935, percentage of organic matter was correlated to some extent with soil texture, since the sandier the soil, the lower was the percentage of organic matter. This correlation persisted in later years in the check plots, although the lighter textured soils gained and the heavier textured ones lost organic matter (table 15). In the flooded plots 3,000 or 3,500 feet below the spillway, organic-matter content of the soil increased considerably; at greater and less distances, gains were much smaller and some losses were apparent. In the first 1,000 feet, where the soils became much sandier, the percentage of organic matter was less in 1938 and in 1941 but regained its original value by 1943. Slight gains were recorded in the 1,500–2,000-foot zone, where the texture of the deposit was about the same as that of the original soil. At 6,000 feet there was a loss of 0.77 percent in organic matter by 1938, but the 1941 and 1943 values were slightly higher than that recorded in 1935. Only small changes took place below this point, where flooding occurred in only 4 of the 9 years of the study and the flood water, having been filtered through relatively heavy grass for distances of from 0.5 to 1.5 miles, no longer carried any but the finest material in suspension.

Percentages of organic matter in the surface 6 inches of soil of the grass plots treated with clear water and those treated with sediment-laden water differed in 1942 and 1943 (table 16). Organic-matter content of the soil of the clear-water plots showed trends similar to those in the dry plots from 1939 to 1943. The increase in the plots treated with arroyo water is attributed to decomposition of buried grasses and of organic debris carried to the plots by the applied runoff; and the increases in the unirrigated plots and the clear-water plots in 1942, to decomposition of vegetational debris under the influence of the very wet weather of 1940 and 1941. The decrease from 1942 values observed in all plots in 1943 is ascribed to the 18-month drought that preceded the 1943 sampling.

Although large amounts of organic debris were carried to crop plots by arroyo water, increases of organic matter in the surface 6 inches of deposit in the "all flow" plots were slight (table 17). This contrasts with results in the field and the grass plots, where, with heavy-textured deposits, organic matter increased. In the crop plots where sediment eventually became 20.8 inches deep, organic matter in soil underlying the deposit diminished from 1.62 percent in 1938 to 0.82 percent in 1943. The corresponding percentages for the plots receiving similar amounts of clear water were 1.15 and 1.16.

The organic-matter content of the sand component of the mixtures applied to lysimeters was 0.08 to 0.15 percent; that of the clay component, 1.05 to 1.14 percent. Basal area of vegetation in these plots was high in 1939, averaging 20 percent cover, and consequently top growth was short. In plots receiving annual 6-inch deposits, this short vegetation was entirely buried the first year. In subsequent years, the density of plant cover was greatly reduced in these plots, the plants grew taller, and proportionately less plant material was buried. In all but the two heaviest clay treatments of the 50-percent series, burying of leaves and stems was accompanied by a marked increase of organic matter in the oldest deposit during the first 3

TABLE 16.—*Organic-matter content and some chemical characteristics of the surface 6 inches of soil in grass plots, 1939–43*

Water treatment and grass	Organic matter			Total water-soluble salts			Calcium carbonate			Soil reaction		
	1939	1942	1943	1939	1942	1943	1939	1942	1943	1939	1942	1943
Sediment laden:	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*pH.*	*pH.*	*pH.*
Galleta	0.84	1.35	1.21	0.11	0.14	0.14	1.00	1.00	0.99	8.68	8.55	8.41
Alkali sacaton	1.03	1.20	1.10	.11	.14	.12	1.28	1.06	1.06	8.73	8.48	8.53
Western wheatgrass	.93	1.32	1.12	.11	.14	.14	1.24	1.03	1.00	8.76	8.48	8.45
Blue grama	.90	1.36	1.12	.11	.13	.14	1.27	1.01	1.22	8.70	8.44	8.47
Mixture	.80	1.29	1.25	.09	.13	.14	1.05	.98	.94	8.79	8.46	8.38
Average	.90	1.32	1.16	.11	.14	.14	1.17	1.02	1.04	8.74	8.48	8.45
Clear:												
Galleta	1.10	.95	1.00	.10	.09	.09	.97	.99	.94	8.84	8.57	8.99
Alkali sacaton	1.07	1.04	.78	.10	.10	.06	.98	.95	1.03	8.73	8.55	8.98
Western wheatgrass	.81	.92	.79	.09	.09	.08	1.07	1.08	1.11	8.81	8.58	8.85
Blue grama	.84	1.03	.86	.10	.09	.08	.74	1.04	1.01	8.82	8.62	8.89
Mixture	.96	1.05	.80	.10	.09	.07	1.07	1.02	1.04	8.74	8.73	8.78
Average	.95	1.00	.85	.10	.09	.08	.97	1.02	1.03	8.79	8.75	8.88
None:												
Galleta	.70	.81	.77	.13	.09	.08	.75	.75	.76	8.60	8.51	8.85
Alkali sacaton	.77	.76	.70	.13	.09	.07	.75	.70	.71	8.56	8.53	8.70
Western wheatgrass	.79	.89	.77	.13	.09	.08	.74	.75	.70	8.57	8.41	8.80
Blue grama	.76	.81	.70	.13	.08	.07	.75	.70	.79	8.55	8.47	8.92
Mixture	.78	.80	.64	.13	.09	.06	.75	.71	.72	8.61	8.50	8.90
Average	.78	.81	.72	.13	.09	.07	.75	.72	.75	8.58	8.50	8.83

years, but increases were smaller or lacking in later deposits. Organic-matter content of the oldest 60-percent-clay deposit increased only during the first 2 years; that of the oldest 80-percent-clay deposit decreased generally. Similar responses were observed in the deposits of the 35-percent and the 20-percent series of water-soil mixtures, except that small increases of organic matter appeared in the 60-percent-clay and the 80-percent-clay deposits in 1941 and 1942.

When the deposit was as shallow as 6 inches, the chief factor influencing organic-matter content of the soil was the amount of buried vegetation. The organic-matter content of the surface soil of deep deposits was dependent chiefly on the amount of organic matter in the freshly deposited sediment.

TABLE 17.—*Organic matter and nitrates in surface soils of crop plots, 1938–43*

Item	Year	Plots irrigated with— All flows: Sediment-laden	Plots irrigated with— All flows: Clear	Plots irrigated with— Selected flows: Sediment-laden	Plots irrigated with— Selected flows: Clear	Unirrigated plots
Organic matter .... percent	1938	1.16	1.15	1.32	1.23	0.80
	1941	1.22	1.21	1.38	1.21	.76
	1943	1.32	1.18	1.42	1.33	.81
Nitrates .... p. p. m.	1938	12.75	12.61	13.11	17.67	8.44
	1939	9.90	10.28	7.30	9.72	4.30
	1940	7.54	7.41	7.07	8.44	7.30
	1941	3.46	3.65	7.06	6.05	2.26
	1942	3.55	5.10	5.76	3.62	3.79
	1943	17.05	18.75	19.26	16.97	6.14

Owing to decay of heavy vegetation in the lysimeter plots receiving no sediment, organic-matter content of their soil increased with the years.

Organic-matter content of the original soil underlying all deposits in the lysimeters, unlike that in the crop plots, remained almost constant.

Detailed data on organic matter in lysimeter soils appear in tables 45 and 46, appendix.

BACTERIA

In field areas, numbers of bacteria decreased similarly in flooded and check plots during the 9 years of observation (table 18).

Samples taken in 1938 indicated that bacterial populations in the soil of drainage basins were low--20,000 to 620,000 per gram of dry soil--but that those in the runoff and in deposits that had lain for 24 hours were many times higher (table 19). Sediment that had lain for 8 months in its new environment contained 750,000 bacteria per gram of dry soil, which was comparable to the number in the soil of the check plots. This relatively low number indicates that, with respect to numbers of bacteria, sediment rapidly became adjusted to its new environment.

Flooding produced no discernible effect on the nitrifying power of the soil in field plots (table 18).

The nitrifying power of soils of the drainage basins, as determined in 1938, was low. That of the transported sediment sampled 24 hours after deposition averaged only 17.2 percent. After the sediment had lain for 8 months, the percentage of ammonium radical converted had risen to 91.4--further evidence that the deposit rapidly assumed some characteristics of the underlying soil.

TABLE 18.—*Bacterial population and nitrifying power of surface soil of 3 flood plains in relation to distance from spillway during 9 years of flooding, 1935–43*

Plots	Sampling sites	Total bacteria per gram of dry soil				Nitrifying power ammonium radical converted			
		1935	1938	1941	1943	1935	1938	1941	1943
	Number	*Millions*	*Millions*	*Millions*	*Millions*	*Percent*	*Percent*	*Percent*	*Percent*
Treated plots at indicated distance from spillway:									
125 feet	4	1.57	0.60	0.70	0.89	74.8	31.5	14.3	52.5
650 feet	3	2.53	.61	1.09	.79	63.7	53.1	12.5	58.5
1,000 feet	1	1.30	1.76	.59	.36	76.0	90.7	9.2	42.2
1,500 feet	5	2.88	.98	1.80	.94	87.2	32.3	10.5	42.2
2,000 feet	4	3.22	.97	1.25	.90	89.1	53.2	7.8	60.0
3,000 feet	1		1.61	.36	.59		12.8	10.8	46.2
3,500 feet	2	4.17	.60	1.41	1.03	74.0	15.0	12.0	45.5
6,000 feet	1	.83	.51	.99	.92	60.7	14.9	27.1	60.5
10,000 feet	1	3.76	.53	.45	.67	100.0	39.4	28.6	29.2
13,000 feet	1	2.85	.74	.60	.56	93.0	36.9	31.5	28.1
16,000 feet	1	1.12	.71	.85	.55	91.6	39.6	15.1	44.0
Check plots:									
Soil texture, heavy	5	3.03	.98	1.30	1.02	59.7	50.8	23.0	37.7
Soil texture, light	4	1.18	.74	1.13	.92	54.8	7.7	10.6	25.8
Average, check plots	9	2.20	.87	1.22	.98	57.5	31.6	17.5	32.4
Average, treated plots	24	2.61	.84	1.08	.83	81.0	38.5	13.2	40.1

TABLE 19.—*Bacterial population of floodwater and deposits*

Sample	Sediment content, by weight	Total bacteria per gram of dry sediment	Nitrifying power (ammonium radical converted)
	Percent	*Number*	*Percent*
Water at peak of flow	9.50	5,320,000	
Water at subsiding stages of same flow	5.46	7,530,000	
Water at end of same flow	4.60	10,700,000	
Deposit after 24 hours		22,800,000	17.2
Deposit after 8 months		750,000	91.4

Numbers of aerobic bacteria in the soil were lower in the grass plots flooded with arroyo water than in those flooded with clear water (table 20). The numbers in the unirrigated plots differed little from those in the clear-water plots. Highly significant differences in this respect appeared among plots seeded with different kinds of grass, except where arroyo water had been applied. As the differences were not consistent under clear-water treatment and the period of treatment was short, the writers hesitate to draw inferences from these results.

Neither water nor sediment affected nitrifying power in the grass plots (table 20).

TABLE 20.—*Bacterial population and nitrifying power of surface soil of grass plots, 1939–43*

Water treatment and grass	Total aerobic bacteria per gram of dry soil				Nitrifying power (ammonium radical converted)			
	1939	1941	1942	1943	1939	1941	1942	1943
	Millions	*Millions*	*Millions*	*Millions*	*Percent*	*Percent*	*Percent*	*Percent*
Sediment-laden:								
Galleta	1.92	0.92	0.34	2.38	81.9	89.6	66.4	61.2
Alkali sacaton	1.99	1.14	.25	2.60	82.9	90.8	68.8	51.0
Western wheatgrass	1.61	1.23	.32	2.47	83.1	88.8	67.7	61.4
Blue grama	1.43	1.35	.30	2.26	79.9	89.1	66.1	72.0
Mixture	1.49	1.28	.23	2.26	83.3	93.5	53.2	68.3
Average	1.69	1.19	.29	2.39	82.2	90.4	64.4	62.8
Clear:								
Galleta	2.08	1.90	.64	3.86	83.0	82.0	70.6	72.3
Alkali sacaton	1.93	1.63	.56	3.48	85.6	83.5	76.8	62.3
Western wheatgrass	1.74	2.55	.74	4.45	81.5	82.0	70.9	80.2
Blue grama	2.01	1.56	.68	3.08	83.9	82.3	68.2	65.6
Mixture	1.88	1.75	.72	3.58	81.3	82.1	70.4	82.8
Average	1.93	1.90	.67	3.69	84.3	82.4	71.4	72.6
None:								
Galleta	1.39	1.37	.37	3.45	80.4	83.7	83.5	66.7
Alkali sacaton	1.20	1.32	.29	3.11	83.8	83.3	83.7	45.5
Western wheatgrass	1.35	2.42	.86	4.43	80.0	81.9	70.7	66.5
Blue grama	1.08	1.24	.45	3.11	78.7	81.5	76.4	60.7
Mixture	1.33	1.42	.53	3.21	83.3	82.0	74.9	65.8
Average	1.27	1.55	.50	3.48	81.2	83.1	79.6	61.0

In the crop plots, bacterial numbers were not consistently affected by either kind or amount of irrigation water (table 21). In 1941, the numbers in plots treated with all arroyo flows were lower than those in other irrigated plots. This may have been due to the fact that in 1941 water had lain on this group of plots for several days a week before the sampling. Comparison of these results with those in field areas

TABLE 21.—*Bacterial population and nitrifying power of soils of crop plots, 1938–43*

Item	Year	Plots irrigated with—				Plots not irrigated
		All flows		Selected flows		
		Sediment-laden	Clear	Sediment-laden	Clear	
Bacteria per gram of dry soil—millions	1938	1.15	1.12	1.28	1.18	0.85
	1939	.75	.70	.63	.97	.92
	1940	2.03	2.57	3.04	2.70	2.11
	1941	.53	1.63	1.87	2.51	1.08
	1942	.11	.26	.15	.15	.18
	1943	2.48	2.30	2.04	2.29	1.76
Nitrifying power in terms of ammonium radical converted—percent	1938	73.67	80.00	78.80	77.55	68.91
	1939	85.73	81.90	86.35	82.46	81.24
	1940	81.48	81.75	82.63	79.38	83.36
	1941	85.02	83.32	87.92	77.55	83.86
	1942	64.08	65.23	68.70	72.36	76.42
	1943	50.34	68.72	60.78	66.60	57.52

and grass plots indicates that cultivation had little or no effect on bacterial numbers.

Differences in kind of irrigation produced no significant difference in nitrifying power of the soil of the crop plots until 1943 (table 21), when the value for the plots irrigated with all arroyo flows was significantly lower than those for the other plots. The explanation of this 1943 difference is not apparent, since there had been no irrigation for more than a year, and the "selected flow" and the "all flow" plots had received the same treatment in the spring of 1942.

In sediment applied to lysimeters, numbers of bacteria were low at the time of application. They did not vary consistently with proportion of either sand or clay. Compared with the numbers of bacteria present at the time of application in water-sediment mixtures in which the sediment amounted to more than 5 percent and was 20, 80, or 100 percent sand, the numbers in the resulting deposits were markedly greater. In comparable deposits that were 40 or 60 percent sand, the corresponding differences were much less. No such differences were apparent after the prolonged drought of 1942–43. Numbers of bacteria present in the 100-percent-sand deposits were the highest except in 1943.

Only in the fourth year did number of bacteria in the deposits in lysimeters appear to be correlated with depth. In 1943, number of bacteria varied inversely with depth in the 23-inch deposit of the 50-percent series. In soil underlying deposits, numbers fluctuated from year to year; but in that under the two deeper deposits, they were higher in 1943 than they had been in 1939.

Increases in bacterial numbers resulted from application of sediment in small amounts, irrespective of its quality. In plots receiving annual deposits of 3.5 inches or more, numbers were lower than in plots receiving less sediment or none. The differences tended to be greater where the deeper deposits were high in the clay fraction.

In the lysimeters receiving clear or decanted water, bacterial numbers consistently remained high throughout the study. In those treated with decanted water, which received small amounts of colloidal matter and of organic matter, the numbers were higher than in the clear-water plots in all but the first year.

The original nitrifying power of the sand applied to lysimeter plots was 0 to 3 percent; that of the clay ranged from 25 to 55 percent. With a few exceptions the nitrifying power of the deposit increased, the degree of increase depending on the quantity of clay in the sediment. In all the years and throughout the depth of the deposit, the nitrifying power of the 100-percent sand remained very low, never rising above 7.3 percent. An admixture of as little as 20 percent clay allowed the value to increase markedly. Additional increases in nitrifying power, considerably smaller in proportion, were associated with additional admixtures of clay. Nitrifying power was lower in the sediment deposited on lysimeter plots than in the original soil. Where 0.75 inch of sediment low in nitrifying power was deposited annually, the nitrifying power of the surface 6 inches of soil remained high at the end of 4 years. Annual deposits 2 inches deep, sampled after 3 years' accumulation, had a nitrifying power lower than the average of those they had immediately after being laid down. Depth of sediment had no influence on the nitrifying power of the underlying original soil.

Detailed data on bacterial populations and nitrifying power of lysimeter soils are presented in tables 47, 48, 49, and 50, appendix.

SOIL REACTION

Flooding and deposition of sediment produced no change in pH values of surface soil in the field areas; values for the flooded plots averaged 8.42 in 1935 and 8.43 in 1943 (table 22). No change in pH was observed in original surface soils underlying 9-year deposits (table 23); the average pH of such soils underlying deposits with mean depths of 6 inches or more was 8.50 in 1943.

Table 22.—*Total soluble salts, hydrogen ion concentration, and calcium carbonate in surface soil of three flood plains in relation to distance from spillway during 9 years of flooding, 1935–43*

Plots	Sampling sites	Total water-soluble salts				Calcium carbonate				Hydrogen ion concentration			
		1935	1938	1941	1943	1935	1938	1941	1943	1935	1938	1941	1943
Treated plots at indicated distance from spillway:	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*pH*	*pH*	*pH*	*pH*
125 feet	4	0.14	0.12	0.10	0.14	0.727	0.863	0.848	0.765	8.47	8.52	8.61	8.38
650 feet	3	.15	.12	.11	.13	.772	.882	.979	.808	8.12	8.48	8.56	8.62
1,000 feet	1	.16	.13	.14	.13	1.273	1.240	1.144	.966	8.47	8.48	8.51	8.46
1,500 feet	5	.15	.14	.13	.13	.561	.907	.923	.531	8.40	8.45	8.57	8.42
2,000 feet	4	.13	.14	.15	.13	.576	.917	.932	.581	8.40	8.41	8.50	8.38
3,000 feet	1	.16	.14	.14	.13	1.087	1.073	1.008	.919	8.31	8.40	8.32	8.44
3,500 feet	2	.14	.14	.13	.13	1.088	.846	.936	.501	8.38	8.25	8.40	8.33
6,000 feet	1	.14	.13	.14	.14	.739	.741	1.001	.539	8.53	8.42	8.28	8.53
10,000 feet	1	.16	.14	.14	.13	.353	.370	.378	.346	8.45	8.48	8.61	8.44
13,000 feet	1	.15	.14	.14	.13	.240	.262	.327	.257	8.32	8.43	8.50	8.33
16,000 feet	1	.14	.13	.14	.13	.473	.478	.201	.384	8.53	8.56	8.58	8.40
Check plots:													
Soil texture, heavy	5	.14	.12	.12	.12	.652	.709	.816	.707	8.55	8.62	8.66	8.56
Soil texture, light	4	.08	.06	.07	.06	.406	.665	.415	.547	8.53	8.77	8.55	8.76
Average, check plots	9	.11	.09	.10	.09	.583	.689	.638	.680	8.51	8.69	8.61	8.65
Average, treated plots	24	.15	.13	.12	.13	.695	.840	.850	.621	8.42	8.45	8.51	8.43

TABLE 23.—*Total water-soluble salts, calcium carbonate, and hydrogen ion concentration in original surface soil of 3 flood plains in relation to distance from spillway after 9 years of flooding, 1935–43*

Plots	Total water-soluble salts		Calcium carbonate		Hydrogen ion concentration	
	1935	1943	1935	1943	1935	1943
Treated plots at indicated distance from spillway:	*Percent*	*Percent*	*Percent*	*Percent*	*pH*	*pH*
125 feet	0.14	0.14	0.727	0.580	8.47	8.52
650 feet	.15	.13	.772	.892	8.42	8.49
1,000 feet	.16	.13	1.273	.962	8.47	----
1,500 feet	.16	.14	.561	.790	8.40	8.54
2,000 feet	.14	.14	.570	.691	8.40	8.47
3,000 feet	.16	.14	1.087	.893	8.31	8.48
3,500 feet	.14	.13	1.088	1.013	8.38	8.51
6,000 feet	.14	.13	.739	.793	8.53	8.47
10,000 feet	.16	.13	.353	.368	8.45	8.44
13,000 feet	.16	.13	.240	.209	8.32	8.46
16,000 feet	.14	.14	.473	.561	8.53	8.48
Check plots:						
Soil texture, heavy	.14	.12	.652	.761	8.55	8.52
Soil texture, light	.08	.06	.496	.648	8.53	8.82
Average, check plots	.11	.09	.583	.711	8.54	8.65
Average, treated plots	.15	.14	.695	.782	8.42	8.50

The data indicate that the pH values of sediment carried from the drainage basins and deposited on the three flood plains were very uniform and differed little if at all from those of the original soils of the flood plains.

The average pH of the surface soil of the grass plots irrigated with arroyo water decreased to a highly significant extent, from 8.74 in 1939 to 8.45 in 1943 (table 16). During this period the average pH of the soil of the unirrigated plots increased, and that of the clear-water plots did not change.

Among the crop plots, the pH of the soil of those irrigated with arroyo water underwent highly significant decreases between 1938 and 1943. The pH of the soil of the "all clear" plots did not decrease until 1943, and that of the soil of the "selected clear" plots did not change (table 24).

In the original soil underlying the deposits in the crop plots irrigated with arroyo water, there was no change in pH at depths of 3 feet or less (table 25).

In the lysimeter data, there was little evidence of response of soil reaction to the treatments. The pH of the sand component of the sediment mixtures applied ranged from 9.10 to 9.71; that of the clay component, from 8.55 to 8.60. Except in 1943, the pH of the deposit in plots receiving 60 percent or more of sand decreased from the original value, the decrease being most noticeable in the all-sand deposit. In 1943, the pH of the all-sand deposit remained unchanged in the top 6-inch layer but increased from the 1942 values at lower depths. In the deposits of the 80-percent-sand and the 60-percent-sand treatments, the pH increased from the 1942 values in the top 6-inch layer as well as at lower depths. Values in the plots receiving 50-percent suspensions of the 40-percent-sand and 20-percent-sand mixtures increased steadily at all depths, but corresponding increases

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TABLE 24.—*Soil reaction and percentage of calcium carbonate and of total water-soluble salts in surface soils of crop plots, 1938-43*

Year	Calcium carbonate					Total water-soluble salts					Soil reaction				
	Plots irrigated with—				Unirrigated plots	Plots irrigated with—				Unirrigated plots	Plots irrigated with—				Unirrigated plots
	All flows		Selected flows			All flows		Selected flows			All flows		Selected flows		
	Sediment-laden	Clear	Sediment-laden	Clear		Sediment-laden	Clear	Sediment-laden	Clear		Sediment-laden	Clear	Sediment-laden	Clear	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*pH*	*pH*	*pH*	*pH*	*pH*
1938	1.28	1.31	1.33	1.30	0.89	0.11	0.11	0.11	0.11	0.12	8.93	8.81	8.86	8.81	8.56
1941						.14	.11	.12	.11	.09	8.58	8.75	8.68	8.82	8.70
1942	1.10	1.34	1.09	1.41	.86	.14	.13	.14	.12	.11	8.48	8.67	8.56	8.76	8.67
1943	1.15	1.26	1.17	1.23	.85	.14	.13	.14	.11	.10	8.42	8.56	8.51	8.82	8.62

TABLE 25.—*Soil reaction and total water-soluble salts in original soils of crop plots in 1938 and in 1943*

Item	Year	Depth (inches)	Plots irrigated with— All flows: Sediment-laden	Plots irrigated with— All flows: Clear	Plots irrigated with— Selected flows: Sediment-laden	Plots irrigated with— Selected flows: Clear	Unirrigated plots
Total water-soluble salts ... percent	1938	0–12	0.10	0.11	0.11	0.11	0.12
		12–24	.13	.13	.13	.13	.13
		24–36	.13	.13	.14	.14	.13
	1943	0–12	.09	.12	.09	.11	.10
		12–24	.10	.12	.09	.11	.11
		24–36	.11	.11	.10	.11	.11
Soil reaction ... pH	1938	0–12	8.93	8.81	8.86	8.81	8.56
		24–36	8.46	8.45	8.40	8.43	8.48
	1943	0–12	8.72	8.50	8.73	8.82	8.62
		24–36	8.50	8.63	8.57	8.57	8.53

took place in the clear-water plots and in the original soil under all deposits.

Detailed data on pH of lysimeter soils are presented in tables 51 and 52, appendix.

CALCIUM CARBONATE

No changes of calcium carbonate in the soil could be attributed to flooding; changes that appeared in flooded plots were overshadowed by those in check plots (tables 22, 23, and 24). Detailed data on calcium carbonate content of lysimeter soils are presented in tables 53 and 54, appendix.

TOTAL WATER-SOLUBLE SALTS

Flooding had no discernible effect on the total water-soluble-salt content of the soils of the field areas (tables 22, 23). In the three other sets of plots, total salt content was higher in the deposit than it had been in the original soil when the experiment began (tables 16 and 24, and tables 55 and 56, appendix). In the grass plots and the crop plots it decreased in the soil underlying the deposits but decreased similarly in the check plots.

WATER-SOLUBLE IONS

Of the water-soluble anions, the nitrate, chloride, carbonate, bicarbonate, and phosphate ions were apparently unaffected by flooding in the field areas (tables 26, 27, 28, and 29). The relatively high concentration of nitrates in 1943, which was strikingly apparent except in the lysimeters (tables 57 and 58, appendix), is attributed to the fact that plant growth was low during the summers of 1942 and 1943, owing to prolonged droughts. (The lysimeter plots received some extra water during these two seasons.) Although bicarbonates increased considerably in flooded plots, they increased more in the check plots having heavy-textured soil.

The deposit on the flood plains was high in sulfates, and there was considerable leaching into the underlying original soil.

TABLE 26.—*Water-soluble nitrates, phosphates, potassium, and calcium*[1] *in surface soil of 3 flood plains in relation to distance from spillway during 9 years of flooding, 1935–43*

Plots	Sampling sites	Nitrates				Phosphates				Potassium				Calcium			
		1935	1938	1941	1943	1935	1938	1941	1943	1935	1938	1941	1943	1935	1938	1941	1943
Treated plots at indicated distance from spillway:	*Number*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
125 feet	4	1.52	2.48	1.06	2.44	0.22	0.08	0.15	T	69	50	24	89	171	103	69	146
650 feet	3	1.65	1.92	.73	2.06	.17	.13	.20	T	66	50	27	80	185	106	75	121
1,000 feet	1	1.18	1.66	0	0	.20	.10	.10	T	54	36	21	88	227	101	90	86
1,500 feet	5	2.46	1.39	.74	3.01	.22	.12	.14	T	78	53	35	82	158	112	71	128
2,000 feet	4	2.12	1.39	.76	3.88	.22	.10	.15	T	89	75	42	93	183	129	88	127
3,000 feet	1	--------	2.28	.81	0	.20	.10	.20	T	63	68	35	95	201	134	125	122
3,500 feet	2	2.69	1.70	0	.90	.15	.10	.25	T	92	54	36	66	157	135	93	144
6,000 feet	1	.22	1.84	0	3.90	--------	.10	.30	T	--------	56	58	35	176	102	115	150
10,000 feet	1	5.67	4.84	0	16.39	--------	.10	.30	T	--------	65	88	28	--------	89	104	139
13,000 feet	1	5.52	8.21	0	8.20	--------	.10	.30	T	--------	63	83	30	--------	97	112	135
16,000 feet	1	7.91	5.38	0	8.00	--------	.10	.40	T	--------	72	54	62	--------	88	103	150
Check plots:																	
Soil texture, heavy	5	3.62	4.08	.62	3.54	.32	.30	.53	0.19	69	55	54	102	156	89	81	123
Soil texture, light	4	3.23	1.94	0	2.05	.37	.17	.55	T	60	65	74	91	131	82	61	115
Average, check plots	9	3.45	3.13	.34	2.88	.34	.24	.54	.12	65	59	63	97	145	86	72	119
Average, treated plots	24	2.51	2.33	.58	3.53	.20	.10	.19	T	76	58	39	77	175	112	86	132

[1] T=Trace.

TABLE 27.—*Water-soluble carbonates, bicarbonates, chlorides, and sulfates in surface soil of 3 flood plains in relation to distance from spillway before and after 9 years of flooding, 1935–43*

Plots	Sampling sites	Carbonates		Bicarbonates		Chlorides		Sulfates	
		1935	1943	1935	1943	1935	1943	1935	1943
Treated plots at indicated distance from spillway:	*Number*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
125 feet	4	7	0	775	1,100	23	25	83	555
650 feet	3	12	0	764	1,066	21	30	83	406
1,000 feet	1	5	0	788	1,140	26	30	70	240
1,500 feet	5	12	0	737	1,058	28	37	112	344
2,000 feet	4	6	0	770	1,080	32	42	78	40
3,000 feet	1	12	0	710	1,360	10	30	61	355
3,500 feet	2	0	0	770	1,060	38	30	155	240
6,000 feet	1	0	0						
10,000 feet	1	0	0						
13,000 feet	1	0	0						
16,000 feet	1	0	0						
Check plots:									
Soil texture, heavy	5	12	0	787	1,056	28	21	60	45
Soil texture, light	4	2	0	720	963	16	12	55	45
Average, check plots	9	8	0	757	1,010	23	31	63	55
Average, treated plots	24	7	0	760	1,091	27	33	95	320

TABLE 28.—*Water-soluble phosphates, potassium, and calcium* [1] *in original surface soil of 3 flood plains in relation to distance from spillway before and after 9 years of flooding, 1935–43*

Plots	Phosphates		Potassium		Calcium	
	1935	1943	1935	1943	1935	1943
Treated plots at indicated distance from spillway:	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
125 feet	0.22	T	69	72	171	141
650 feet	.17	0.13	66	85	185	116
1,000 feet	.20	T	54	95	227	110
1,500 feet	.22	T	78	113	158	137
2,000 feet	.22	T	89	92	183	126
3,000 feet	.20	.30	63		201	114
3,500 feet	.15	T	92	88	157	139
Check plots:						
Soil texture, heavy	.32	.20	69	97	156	126
Soil texture, light	.72	.22	60	84	131	113
Average, check plots	.35	.21	65	90	145	120
Average, treated plots	.21	T	76	92	175	130

[1] T=Trace.

The water-soluble cations measured were calcium and potassium. Although flooding seemed to affect water-soluble potassium, other factors overshadowed this apparent effect in 1943. Amount of soluble potassium declined steadily in the flooded field plots from 1935 to 1941, with no change in the check plots. In 1943 it increased in both the flooded and the check plots. In the original soil, which was sampled in 1935 and 1943, similar increases occurred in both the flooded and the check plots.

Flooding had no apparent effect on amount of water-soluble calcium: both in the flooded plots and in the check plots, the amount decreased

TABLE 29.—*Water-soluble carbonates, bicarbonates, chlorides, and sulfates in original surface soil of 3 flood plains in relation to distance from spillway before and after 9 years of flooding, 1935–43*

Plots	Carbonates		Bicarbonates		Chlorides		Sulfates	
	1935	1943	1935	1943	1935	1943	1935	1943
Treated plots at indicated distance from spillway:	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
125 feet	7	0	775	977	23	30	83	215
650 feet	12	0	764	710	21	33	83	370
1,000 feet	5	0	788	1,122	26	30	70	320
1,500 feet	12	0	737	823	28	37	112	316
2,000 feet	6	0	770	1,040	32	45	78	350
3,000 feet	12	0	710	1,215	19	40	61	40
3,500 feet	0	0	770	760	38	40	155	250
Check plots:								
Soil texture, heavy	12	0	787	1,056	28	36	69	68
Soil texture, light	2	0	720	743	16	25	55	40
Average, check plots	8	0	757	899	23	31	63	55
Average, treated plots	7	0	760	909	27	37	95	202

steadily from 1935 to 1941 and increased in 1943. Calcium decreases in the original soil were recorded, but cannot be attributed to flooding.

Among the grass plots, owing to limitations of time, only the soil of those having a mixed cover was analyzed for water-soluble ions other than nitrates. Increases in calcium and bicarbonate ions and decreases in chloride and carbonate ions could not be attributed to water treatment (table 30). Findings with regard to the soil underlying the deposit were similar.

TABLE 30.—*Water-soluble ions* [1] *in original soil and in deposit in grass plots having a mixed cover, 1939 and 1943*

Water treatment	Calcium			Potassium			Phosphate			Sulfate		
	Original soil		Deposit	Original soil		Deposit	Original soil		Deposit	Original soil		Deposit
	1939	1943	1943	1939	1943	1943	1939	1943	1943	1939	1943	1943
	P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
Sediment-laden	150	232	231	62	80	69		2.5	T	69	82	77
Clear	149	205		80	68			4.3		75	68	-----
None	141	196		67	82			3.9		160	21	-----

TABLE 30.—*Water-soluble ions* [1] *in original soil and in deposit in grass plots having a mixed cover, 1939 and 1943*—Continued

Water treatment	Chloride			Carbonate			Bicarbonate		
	Original soil		Deposit	Original soil		Deposit	Original soil		Deposit
	1939	1943	1943	1939	1943	1943	1939	1943	1943
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
Sediment-laden	35	5	4	9	0	0	574	961	841
Clear	45	2		3	0		551	863	----
None	27	4		11	0		376	778	-----

[1] T = Trace.

Nitrate content of the soil in grass plots irrigated with sediment-laden water differed from that in plots irrigated with clear water in 1941 and 1943 (table 31). The lack of significant difference in 1942 is attributable to the overshadowing effects of differences in development of vegetation. In the unirrigated plots, but not in those irrigated, soil under western wheatgrass had a higher nitrate content than that under the other grasses in 1941, 1942, and 1943.

TABLE 31.—*Nitrates in soil of grass plots*

Grass seeded	1939			1941		
	Plots irrigated with—		Unirrigated plots	Plots irrigated with—		Unirrigated plots
	Sediment-laden water	Clear water		Sediment-laden water	Clear water	
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
Western wheatgrass	2.0	2.2	1.3	1.1	1.0	1.3
Blue grama	2.4	1.3	1.0	.9	.5	.1
Galleta	1.4	1.8	.8	1.0	.2	.1
Alkali sacaton	1.4	1.9	.4	1.4	.8	0
Mixture	.9	.8	.5	.7	.5	.1
Average	1.6	1.6	.8	1.0	.6	.4

Grass seeded	1942			1943		
	Plots irrigated with—		Unirrigated plots	Plots irrigated with—		Unirrigated plots
	Sediment-laden water	Clear water		Sediment-laden water	Clear water	
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
Western wheatgrass	0.6	0.2	0.6	3.1	1.1	3.2
Blue grama	.5	.4	.1	6.7	.6	1.4
Galleta	.4	.4	.5	7.1	.7	.5
Alkali sacaton	0	.6	.1	3.8	1.0	.5
Mixture	.2	.2	.5	8.2	1.1	.9
Average	.3	.4	.3	4.8	.9	1.3

In the crop plots, nitrates were determined each year under all treatments but other water-soluble ions were determined only in the "all flow" plots and the check plots. Chlorides diminished to traces in the surface soil irrespective of treatment (table 32). In the original surface soil underlying the 21-inch deposit they dropped from 42 parts per million in 1938 to 8 in 1943. Carbonates disappeared from the soil of all sampled plots. Originally, there was a trace of water-soluble phosphate in the soil of every plot. This increased slightly in the clear-water plots and the unirrigated plots and in the original soil of the plots irrigated with arroyo water; but in the deposit only a trace was present in 1943. Sulfate content increased in the surface soil of the irrigated crop plots sampled but remained approximately unchanged in the original soil underlying the deposit, and dropped in the soil of the unirrigated plots. Bicarbonate content was considerably higher in the deposited material than it was in the soil of the plots originally; but it increased in 1943 under all treatments and also in the check plots. The behavior of these anions is comparable to their behavior in the field areas and the grass plots.

TABLE 32.—*Water-soluble ions*[1] *in surface soils of crop plots*

Ions	Plots irrigated with—					Unirrigated plots	
	All arroyo flows			All clear flows			
	Original surface soil		Deposit				
	1938	1943	1943	1938	1943	1938	1943
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
Sulfate	111	64	140	90	208	192	67
Chloride	42	8	T	54	T	39	T
Carbonate	17	0	0	29	0	15	0
Bicarbonate	499	554	1,032	491	638	361	568
Phosphate	T	6	T	T	8	T	3
Potassium	130	82	86	132	56	46	60
Calcium	107	145	303	130	200	148	135

1 T=Trace.

Over the 5-year experimental period neither kind nor amount of irrigation water affected nitrates in the surface soil of the crop plots (table 17). In 1941, after the wet summer of 1940 and a wet spring, the soil of the "selected flow" plots was higher in nitrates than that of the "all flow" plots. In 1943, after more than a year of very dry weather, the soil of the plots irrigated with arroyo water was higher in nitrates than that of the clear-water plots. In general, however, effect of flooding on nitrate content of the soil was negligible.

Water-soluble potassium diminished under irrigation and increased in the unirrigated plots. The decrease in the clear-water plots was greater than that in the arroyo-water plots. In the silted plots the underlying soil had approximately the same content of soluble potassium as the deposits. Although the response of potassium in the irrigated crop plots was different from that in the grass plots or in the field, the final values were similar.

Water-soluble calcium increased in the irrigated crop plots, both in the surface soil and in the soil underlying deposits. Similar response occurred in the irrigated grass plots. In unirrigated crop plots, water-soluble calcium decreased slightly. The reason for the gains, at variance with the response in the field areas, is not apparent.

TOTAL NITROGEN, PHOSPHORUS, POTASSIUM, AND CALCIUM

Flooding produced no apparent effect on the total amounts of nitrogen, phosphorus, and calcium present in the Norcross and Deer Springs flooding areas. The amount of potassium decreased to a greater extent in the heavily silted plots than in the check plots (table 33). Determinations of these elements were not made for the soils of the grass or crop plots or the lysimeters.

TABLE 33.—*Total nutrients in surface soil of 8 flood plains before and after 9 years of flooding, 1935–43, in relation to distance from spillway*

Plots	Sampling sites	Nitrogen		Phosphorus		Potassium		Calcium	
		1935	1943	1935	1943	1935	1943	1935	1943
Treated plots at indicated distance from spillway:	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
125 feet	2	0.068	0.070	0.093	0.088	2.57	1.77	1.67	1.63
650 feet	2	.070	.062	.105	.106	2.48	1.93	1.73	1.57
1,000 feet	1	.058	.052	.076	.097	2.83	1.79	2.03	1.36
1,500 feet	2	.079	.065	.096	.107	2.86	2.13	1.35	1.35
2,000 feet	2	.069	.068	.089	.102	2.58	1.79	1.12	1.39
3,000 feet	1	.098	.094	.102	.120	2.89	2.04	2.10	1.62
3,500 feet	1	.094	.090	.105	.103	2.74	2.24	1.25	1.42
Check plots:									
Soil texture, heavy	3	.068	.066	.098	.127	2.79	2.56	1.67	1.52
Soil texture, light	4	.041	.039	.074	.093	3.01	2.84	1.24	1.22
Average, check plots	7	.053	.051	.084	.108	2.92	2.72	1.42	1.35
Average, treated plots	18	.076	.070	.095	.102	2.68	1.94	1.56	1.48

SUMMARY OF SOIL RESPONSES

Responses of the soils of the field areas and the grass and crop plots are summarized in tables 34, 35, and 36.

TABLE 34.—*Summary of soil responses*[1] *on 8 flood plains in 9 years of flooding*

Analysis		Flooded plots			Check plots	
		Original surface		Deposit, 1943	1935	1943
		1935	1943			
Physical						
Organic matter	percent	1.13		1.28	0.93	0.91
Texture:						
Upper plain	class	(2)		(3)	(2)	(2)
Lower plain	do	(2)		(3)	(3)	(3)
Microbiological:						
Total aerobic bacteria	millions	2.61		.83	2.21	.98
Nitrifying power	percent	81.0		49.1	57.5	32.4
Chemical						
Water-soluble salts	do	.15	0.14	.13	.11	.09
Soil reaction	pH	8.42	8.50	8.43	8.51	8.65
Calcium carbonate	percent	.70	.78	.62	.58	.68
Nitrates	p. p. m.	2.51		3.53	3.45	2.88
Water-soluble phosphate	p. p. m.	.20	T	T	.34	.12
Water-soluble potassium	p. p. m.	76	92	77	65	97
Water-soluble calcium	p. p. m.	175	130	132	145	119
Sulfates	p. p. m.	95	292	320	63	55
Chlorides	p. p. m.	27	37	33	23	19
Carbonates	p. p. m.	7	0	0	8	0
Bicarbonates	p. p. m.	760	909	1,091	757	1,010
Total nitrogen	percent	.076		.070	.053	.051
Total phosphorus	do	.095		.102	.084	.108
Total potassium	do	2.68		1.94	2.92	2.72
Total calcium	do	1.56		1.48	1.42	1.35

[1] T=Trace.
[2] Clay.
[3] Sandy loam.

TABLE 35.—*Summary of soil responses[1] in grass plots*

Analysis		Plots irrigated with arroyo water: Original surface, 1939	Plots irrigated with arroyo water: Original surface, 1943	Plots irrigated with arroyo water: Deposit, 1943	Clear-water plots: 1939	Clear-water plots: 1943	Unirrigated plots: 1939	Unirrigated plots: 1943
Physical:								
Texture	class	(2)		(3)	(2)	(2)	(2)	(2)
Organic matter	percent	0.90		1.16	0.95	0.95	0.78	0.72
Microbiological:								
Total aerobic bacteria	millions	1.69		2.39	1.93	3.69	1.27	3.48
Nitrifying power	percent	82.20		62.8	84.3	72.6	81.2	61.0
Chemical:								
Total water-soluble salts	do	.11		.14	.10	.08	.13	.07
Soil reaction	pH	8.74		8.45	8.79	8.88	8.58	8.83
Calcium carbonate	percent	1.17		1.04	.97	1.03	.75	.75
Nitrates	p. p. m.	1.6		4.8	1.6	.9	.8	1.3
Water-soluble phosphate	p. p. m.		2.5	T		4.3		3.9
Water-soluble potassium	p. p. m.	62	80	69	80	68	67	82
Water-soluble calcium	p. p. m.	150	232	231	149	205	141	166
Sulfates	p. p. m.	69	82	77	75	68	169	21
Chlorides	p. p. m.	35	5	4	45	2	27	4
Carbonates	p. p. m.	9	0	0	3	0	11	0
Bicarbonates	p. p. m.	574	901	841	551	863	376	778

[1] T=Trace.
[2] Sandy loam.
[3] Clay.

TABLE 36.—*Summary of soil responses[1] in crop plots*

Analysis	Plots irrigated with— All arroyo flows: Original soil, 1938	All arroyo flows: Original soil, 1943	All arroyo flows: Deposit, 1943	All clear flows: 1938	All clear flows: 1943	Selected arroyo flows: 1938	Selected arroyo flows: 1943	Selected clear flows: 1938	Selected clear flows: 1943	Unirrigated plots: 1938	Unirrigated plots: 1943
Physical:											
Texture ... class	(2)		(3)	(2)	(2)	(2)	(4)	(2)	(2)	(2)	(2)
Organic matter .. percent	1.16		1.32	1.15	1.18	1.32	1.42	1.23	1.33	0.80	0.81
Microbiological:											
Total aerobic bacteria millions	1.15		2.48	1.12	2.30	1.28	2.01	1.18	2.29	.85	1.70
Nitrifying power .. percent	73.7		50.3	80.0	68.7	78.8	69.8	77.6	66.6	68.9	57.5
Chemical:											
Water-soluble salts ... do	.11	.10	.14	.11	.13	.11	.14	.11	.11	.12	.10
Soil reaction ... pH	8.93	8.93	8.42	8.81	8.56	8.86	8.51	8.81	8.82	8.56	8.62
Calcium carbonate . percent	1.25		1.15	1.31	1.26	1.33	1.17	1.30	1.23	.89	.85
Nitrates ... p. p. m.	12.57		17.05	12.61	10.75	13.11	19.26	15.97	10.97	8.11	6.14
Sulfates ... p. p. m.	111	64	140							192	67
Chlorides ... p. p. m.	42	8	T							39	T
Carbonates ... p. p. m.	17	0	0							15	0
Bicarbonates ... p. p. m.	90	554	1,032							361	568
Water-soluble phosphate p. p. m.	T	6	T							T	3
Water-soluble potassium p. p. m.	130	82	86							46	66
Water-soluble calcium p. p. m.	107	145	303							148	135

[1] T=Trace.
[2] Sandy loam.
[3] Clay.
[4] Sandy clay loam.

Vegetational Responses

Diversion flooding affected both the quantity and the quality of herbaceous vegetation in the field areas. The floodwater itself benefited the vegetation; but the sediment it carried had an adverse effect on all the grasses present except western wheatgrass, which it favored. Clippings from comparable flooded and unflooded sample areas showed that forage production was 900 percent greater in 1935 and 300 percent greater in 1939 in the flooded than in the unflooded areas (*23*) (figs. 13 and 14). The gains in forage produced on the lightly silted parts of the areas more than balanced the losses from deposition on the heavily silted parts. The ranker growth and greater succu-

Figure 13.—Yield of galleta grass from 10 flooded meter-square quadrats (left) and 10 comparable unflooded quadrats (right). Weight: 4,280 grams and 425 grams, respectively.

Figure 14.—Alkali sacaton meadow watered with diverted runoff.

lence of the vegetation on flooded areas caused livestock to concentrate in such places. This required some adjustment of management practices to prevent overuse of the flooded areas and to bring about adequate use of forage elsewhere on the grazing units.

In evaluating the effects of flooding, it is important to note that the heavily silted plots represented not more than 20 percent of the total area flooded, and that western wheatgrass increased markedly on parts of the Deer Springs and Norcross areas where sediment was deposited.

The value of the additional forage produced below the Deer Springs Dam equaled the cost of the dam the first year after flooding was begun. The dam, built with hand labor and horse-drawn equipment, cost approximately $3,000. A part of the flood plain was mowed for supplemental feed, and produced on an average 1.21 tons of hay per acre. It may be assumed, on the basis of the quantity of hay cut, that the 435 acres flooded produced a ton of forage to the acre. At the prevailing price of $8 a ton, this much feed was worth $3,480. If the area had not received additional water, hay could not have been produced on it.

The results of quadrat measurements are given in tables 59, 60, and 61, appendix, as averages for the five permanent quadrats in each field plot. Data on grass density in relation to depth of sediment are summarized in table 37. Owing to lack of control over the Muddy Creek area during 1942 and 1943, no data were taken there in 1943. (Average depth of deposit and number of floodings for each year are given in table 4.) Because vegetation charting was done before the flooding season and the sediment surveys were made after it, vegetation data taken in a given year are associated in the tables with deposit data taken in the preceding year. Each of the deposit data in tables 4, 59, 60, and 61 is an average of sediment depth along the portion of the permanent line of survey that fell within the indicated plot.

PRODUCTION OF GRASSES AND FORBS

Response of the vegetation to variations in rainfall is apparent. The density of grasses in the field check plots had dropped 28 percent from the original by 1938; under exceptionally heavy precipitation it had recovered this loss and gained 10 percent by 1941; and under subnormal precipitation it had lost the 10-percent gain and 58 percent of the original value by 1943. The density of grasses in flooded plots that had received from 0 to 1 inch of sediment changed little if at all until after 1941. By July 1943, after 19 months of markedly subnormal precipitation, it had diminished by approximately the same percentage as that in the check plots.

Under deposits deeper than 1 inch, total grass density decreased; the greater the depth, the greater was the decrease in density. The extent of decrease associated with any given depth seems to have varied with rate of deposition, although this variation was masked somewhat by rainfall. By 1938 the grass cover in field plots that had received from 1 to 5 inches of deposit had lost 64 percent of its original density. In 1941 the plots that had received this amount of deposit had a grass cover only 7 percent less dense than the original. By 1938

TABLE 37.—*Density of grasses (expressed as percent cover) in relation to depth of sediment deposit in field areas, in 1938, 1941, and 1943* [1]

ALL GRASSES

Depth of sediment (inches)	1938: Plots (square-meter) represented by data	1938: Average grass density: Original (1935)	1938: Current	1938: Change	1941: Plots represented by data	1941: Average grass density: Original (1935)	1941: Current	1941: Change	1943 [2]: Plots [4] represented by data	1943: Average grass density: Original (1935)	1943: Current	1943: Change
	Number	*Percent*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*
0 [3]	[4] 11	5.29	3.82	−28	9	5.40	5.92	+10	7	6.51	2.72	−58
0-1	5	4.70	4.65	−1	5	2.62	2.77	+2	4	5.04	2.24	−56
1-5	12	5.52	2.00	−64	6	6.75	6.26	−7	0	------	------	------
5-10	5	5.45	.32	−94	6	5.02	2.29	−54	4	5.43	2.45	−55
10-15	0	------	------	------	3	5.18	.91	−82	3	6.38	.88	−86
15-20	0	------	------	------	2	5.61	.81	−86	1	7.68	.93	−88
More than 20	0	------	------	------	1	5.95	0	−100	3	5.77	.34	−94
GALLETA												
0 [3]	[4] 11	3.85	2.29	−41	9	3.82	3.53	−8	7	4.48	1.75	−61
0-1	5	3.76	3.28	−13	5	2.31	2.40	+4	4	3.58	1.84	−49
1-5	12	4.53	1.45	−68	6	5.38	4.45	−17	0	------	------	------
5-10	5	4.95	.10	−98	6	4.12	1.22	−70	4	4.44	1.86	−58
10-15	0	------	------	------	3	4.21	.58	−86	3	4.19	.54	−87
15-20	0	------	------	------	2	5.27	.56	−89	1	6.13	.08	−99
More than 20	0	------	------	------	1	5.55	0	−100	3	5.36	.33	−94
WESTERN WHEATGRASS												
0 [3]	2	0.09	0.17	+89	2	0.09	0.69	+767	2	0.09	0.07	−22
0-1	0	------	------	------	0	------	------	------	0	------	------	------
1-5	5	.25	1.17	+368	2	.30	.96	+220	0	------	------	------
5-10	1	.03	.84	+2,700	3	.08	.91	+1,038	4	.15	.32	+113
10-15	0	------	------	------	2	.06	1.69	+2,717	3	.24	.19	−21
15-20	0	------	------	------	1	0	.03	------	1	.03	.78	+2,500
More than 20	0	------	------	------	0	------	------	------	1	0	(5)	--

[1] Precipitation at headquarters, which was centrally situated with respect to the 3 flooding areas, was (in inches): March through December 1934, 8.96; 1935, 11.69; 1936, 10.37; 1937, 9.95; 1938, 9.63; 1939, 8.35; 1940, 15.26; 1941, 20.08; 1942, 6.02; January through July 1943, 3.78.
[2] Muddy Creek quadrats were not charted in 1943.
[3] Check.
[4] Includes plots 8 and 9 at Deer Springs, which were not flooded in 1936-39, inclusive.
[5] Less than 0.01 percent.

the grass density in the 17 plots with from 0 to 5 inches of deposit had dropped 47 percent. The difference from the original grass cover in the 11 plots with this depth of sediment in 1941 was only 4 percent. These differences may be attributed to the rate of sediment accumulation and the heavy precipitation of 1940 and 1941. By 1943 the eight plots in the Norcross and Deer Springs areas that had received 10 inches or less of deposit had lost 55 percent of their original grass cover; but the check plots had lost a similar percentage.

Since in most of the field plots the original cover was primarily of galleta, the trend of total grass density was dominated by the response of this grass (table 37). The percentage decreases for this species were greater than those for the total cover, in both the flooded plots and the check plots. Flooding favored galleta in the plots receiving not more than 1 inch of deposit.

Density of western wheatgrass increased with deposition of sediment (table 37 and figs. 15 and 16). This grass, present in small quantities in the original cover, had increased conspicuously by 1938. By 1941 it had come to dominate rather large areas in the more heavily silted stretches of the Norcross and Deer Springs flood plains (fig. 17), and its gains were reduced but not eliminated by the ensuing drought.

FIGURE 15.—*A*, Deer Springs plot 4 in 1935, before flooding. Vegetation, galleta grass. *B*, Same plot in 1941, after 7 years of flooding. Deposit, 7.6 inches; vegetation, western wheatgrass.

The loss of density between 1941 and 1943 was less real than apparent: In the fall of 1943, after a month of above-normal precipitation, numerous new stems were observed to be arising from hitherto dormant rhizomes.

FIGURE 16. Western wheatgrass growing on 3-foot deposit on Norcross area, 1941. Forbs, Russian-thistle and Rocky Mountain bee plant (*Cleome serrulata*).

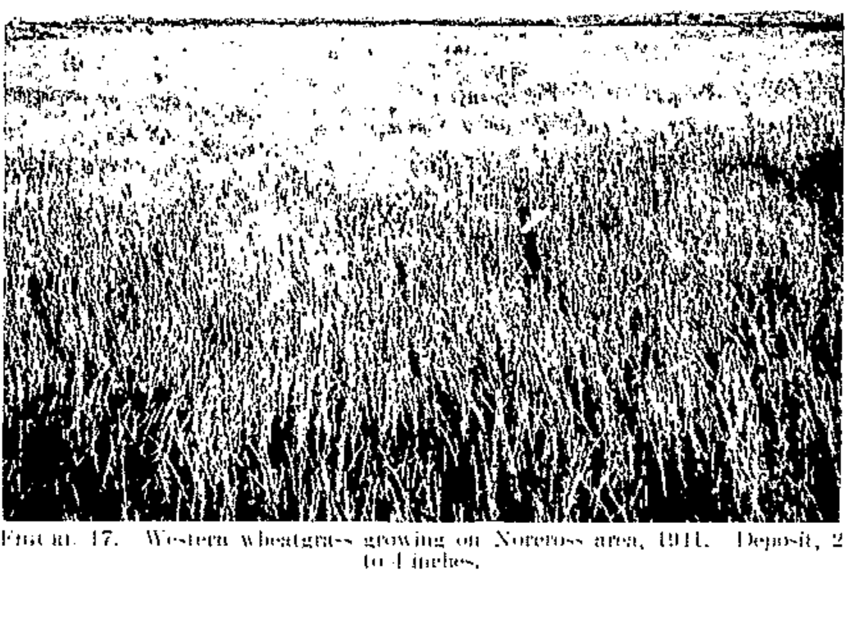

FIGURE 17. Western wheatgrass growing on Norcross area, 1941. Deposit, 2 to 4 inches.

Of the other grasses present, only two occurred generally. Red three-awn, present in the original cover of most of the plots, suffered severe losses from both silting and competition. Creeping muhly withstood moderate silting and increased considerably where deposition was light. Blue grama was originally present in appreciable amounts in only one of the flooded plots, plot 5 at Deer Springs. By 1943 its density in this plot, which then had an accumulation of nearly 15 inches of sediment, had been reduced by 97 percent.

No correlation was discernible between depth of deposit and number of annual forbs (table 38). By 1938 the number of forbs had diminished sharply from the original values in the flooded plots, but had done so irrespective of sediment depth and had changed similarly in the check plots. In 1941 the averages were greater than in 1938, but again depth of deposit seems not to have been an influencing factor. In 1943, after the drought of 1942 and 1943, annual forbs had almost disappeared.

TABLE 38.—*Number of forbs per square-meter quadrat in relation to depth of sediment deposit in field areas, in 1938, 1941, and 1943* [1]

Depth of sediment (inches)	Plots represented by data	Average number of forbs per quadrat		Plots represented by data	Average number of forbs per quadrat		Plots represented by data	Average number of forbs per quadrat	
		Original	1938		Original	1941		Original	1943 [2]
ANNUAL FORBS									
	Number			*Number*			*Number*		
(3)	[4] 11	75.6	14.0	9	68.6	23.3	7	75.0	1.1
0-1	5	63.4	35.2	5	109.8	35.2	4	40.0	0
1-5	12	137.0	31.9	6	172.2	108.0	0		
5-10	5	23.0	28.6	6	56.0	71.3	4	21.8	1.0
10-15	0			3	92.7	31.3	3	115.7	1.0
15-20	0			2	45.5	61.4	1	2.0	1.0
More than 20	0			1	10.0	4.0	3	30.3	.7
PERENNIAL FORBS									
(3)	[4] 11	[5] T	T	9	T	0.6	7	T	0.3
0-1	5	1.0	1.0	5	T	1.0	4	1.2	2.8
1-5	12	T	1.2	6	.8	1.0	0		
5-10	5	2.0	6.4	6	.7	2.5	4	1.2	0
10-15	0			3	.3	1.7	3	.3	4.0
15-20	0			2	.5	1.0	1	1.0	1.0
More than 20	0			1	5.0	0	3	1.3	0

[1] Precipitation at headquarters, which was centrally situated with respect to these areas, was (in inches): March through December 1934, 8.96; 1935, 11.69; 1936, 10.37; 1937, 9.95; 1938, 9.63; 1939, 8.35; 1940, 15.26; 1941, 20.08; 1942, 6.02; January through July 1943, 3.78.
[2] Muddy Creek quadrats were not charted in 1943.
[3] Check.
[4] Includes plots 8 and 9 at Deer Springs, which were not flooded in 1936-39, inclusive.
[5] T=Trace, less than 0.1 plant per quadrat.

Perennial forbs, on the other hand, seemed to be favored by sediment (table 38). At no time, however, did they show any tendency to dominate the cover.

The general effects of flooding on vegetation in the 14 flooding areas, the mode of recovery of the individual grasses, and some of the ecological implications have been discussed by the writers in a previous publication (*23*).

No correlation between vegetational changes and soil texture changes in the field plots is apparent.

Data showing response of grass density, expressed as percent cover, in grass plots under different water treatments are presented in table 39. Numbers of annual forbs per 10-foot line in the grass plots averaged as follows: [6]

Water treatment:	*1941*	*1942*	*1943*
Sediment-laden	1.4	3.0	T
Clear	3.5	.6	T
None	2.5	1.0	T

Moisture deficiency in the 1942–43 period was reflected by a sharp decrease of grass density in 1943 under the clear-water treatment and in the check plots, and of the number of annual forbs under all treatments.

Western wheatgrass was less sensitive to sediment in these plots than any of the other grasses. In the plots treated with sediment-laden water where it had been planted, this grass increased in 1941, held its own in 1942, and decreased only in 1943 after a year of very dry weather during which no sediment was deposited. It behaved similarly in the corresponding plots treated with clear water, except for a greater increase in 1941. In the unirrigated plots the effects of drought began to appear in 1942. Under all treatments western wheatgrass was invading the plots of the other species in 1943.

Of the three other grasses planted, alkali sacaton was the least adversely affected by deposition. By 1942 blue grama (fig. 18) and galleta had dropped out almost completely in the plots irrigated with arroyo water. Sand dropseed, a volunteer grass, was the most sensitive of the grasses observed. Its original density in all plots was low. It increased under the clear-water treatment and in the unirrigated plots, but in the plots irrigated with arroyo water it had diminished to a trace by 1941, and by 1942 it had disappeared from these plots.

Reactions of the grasses in the grass plots were similar to their reactions in the field areas. In the plots irrigated with sediment-laden water, which received an accumulation of 9 inches of sediment during a 2-year period, the densities of blue grama and galleta were severely reduced but that of western wheatgrass increased. Responses of the total cover in the clear-water plots and in the unirrigated ones were comparable, respectively, to those in the lightly silted plots and check plots of the field areas.

A surprising feature of the response of the grasses in lysimeters was the small effect of continued yearly increments of deposit. Basal area of all the grasses combined did not decrease consistently from year to year under the various treatments (table 40), although the losses under the 35- and the 50-percent treatments were somewhat greater in the fourth year than in any other. Galleta tended to show greater decreases from year to year, but did so under the clear-water treatment as well as under the others.

[6] T=Trace, less than 0.1 plant per line.

TABLE 39.—*Density of grass cover, expressed as percent cover, in grass plots*[1] *under different treatments, 1940–43*

Grass seeded	Grass species present	Plots irrigated with arroyo water				Plots irrigated with clear water				Unirrigated plots			
		1940	1941	1942	1943	1940	1941	1942	1943	1940	1941	1942	1943
Western wheatgrass	Western wheatgrass	0.8	2.6	2.4	0.5	0.9	4.0	4.1	0.8	0.8	4.8	2.7	0.4
	Blue grama	[1] T	T	0	0	.1	.1	.2	T	T	.1	.2	.1
	Alkali sacaton	T	T	T	0	T	0	.1	0	0	T	.1	T
	Sand dropseed	.4	T	0	0	.4	2.8	3.9	2.1	.2	.6	.7	.4
Blue grama	Blue grama	16.5	2.6	.1	.1	17.3	30.0	33.7	12.2	20.5	31.7	36.7	11.2
	Western wheatgrass	0	.2	.4	.2	0	0	T	T	0	T	.1	T
	Alkali sacaton	.1	T	T	T	.1	.1	.2	.2	T	.2	.4	.2
	Sand dropseed	T	0	0	0	T	.1	.2	T	T	.3	.3	0
Galleta	Galleta	5.3	1.8	.1	.1	5.2	7.2	10.3	4.9	5.4	7.6	6.7	2.4
	Western wheatgrass	T	.1	.2	.1	T	.3	.9	.3	T	.1	.2	T
	Blue grama	.2	T	0	0	.1	.6	.4	.3	.6	.8	1.0	.6
	Alkali sacaton	1.3	.5	.2	.4	.8	1.6	2.4	1.6	1.7	2.7	2.8	1.4
	Sand dropseed	.1	T	0	0	.1	.3	.3	.4	.5	1.3	1.5	.3
Alkali sacaton	Alkali sacaton	11.2	3.2	1.3	2.6	15.7	22.6	21.6	12.2	11.4	17.0	15.3	6.1
	Western wheatgrass	T	T	.2	.1	0	.1	T	T	0	0	T	T
	Creeping muhly	T	.1	T	T	0	0	0	0	0	0	0	0
	Sand dropseed	.1	0	0	0	T	.3	.6	T	.8	2.2	1.0	.2
Mixture	Western wheatgrass	.4	1.0	1.1	.5	.2	1.6	2.0	.6	.3	1.0	1.4	.2
	Blue grama	5.2	.5	T	0	5.7	10.5	8.6	2.4	4.1	10.2	10.4	2.4
	Galleta	.6	.2	T	T	.2	.7	.4	.1	.1	.3	.1	0
	Alkali sacaton	4.6	1.2	.6	1.1	6.5	9.5	10.4	5.5	4.8	7.3	7.1	3.6
	Sand dropseed	.1	0	0	0	.1	.4	.3	0	T	.1	.4	T

[1] T=Trace, less than 0.1 percent.

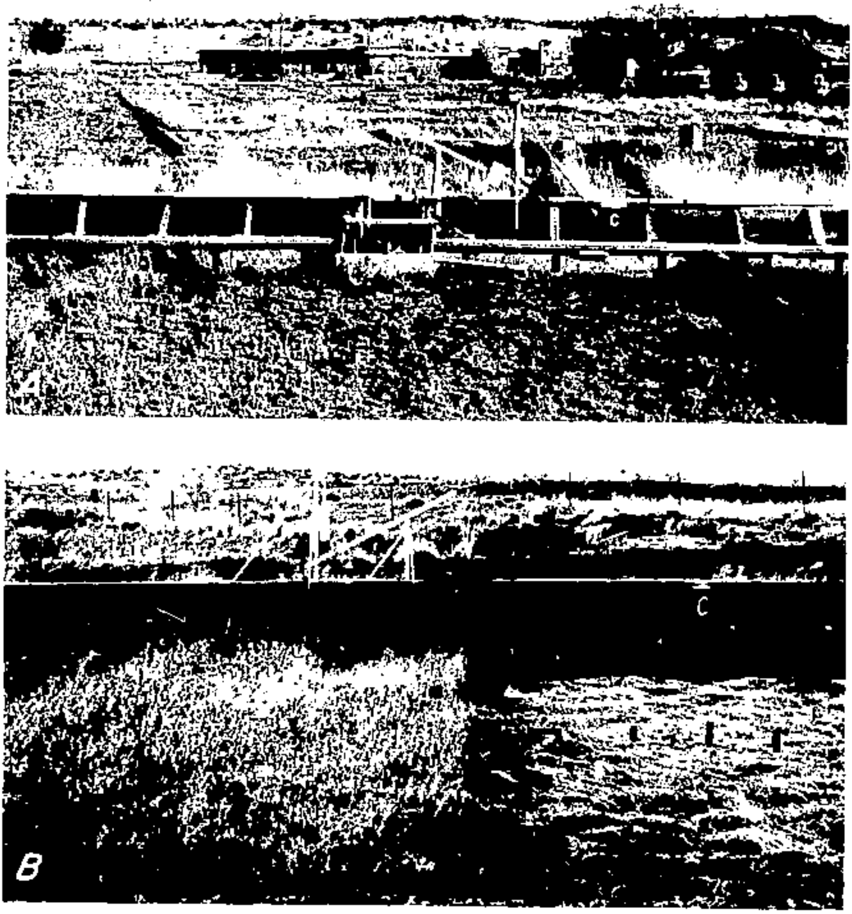

FIGURE 18.—*A*, Blue grama plot after receiving, in 3 years of irrigation, a 2-inch total deposit of heavy-textured sediment; *B*, blue grama plot after receiving clear-water irrigation for 3 years.

The influence of kind of sediment varied with grass species and with depth of increment of deposit. At the end of 1 year there was no correlation of survival with quality of sediment. After the first year, blue grama and galleta tended to suffer greater reductions under those of the 35- and the 50-percent quantity treatments in which the percentage of clay was greater. Western wheatgrass, on the other hand, tended to decrease more under treatments containing greater percentages of sand. Alkali sacaton showed no response to variations in sediment quality.

In the lysimeters, total grass cover decreased regularly as depth of sediment increased (table 10). This response was in general accord with that in the field plots. Blue grama suffered the greatest damage from sediment, and galleta the next greatest. Western wheatgrass

TABLE 40.—*Percentage changes in basal area of vegetation in lysimeters, according to quantity of sediment applied*

Year	Sediment treatment[1]	Western wheatgrass	Blue grama	Galleta	Alkali sacaton	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1940	0	−3	+60	−37	−10	+13
	5	+3	−21	−45	−29	−22
	20	−30	−35	−46	−39	−37
	35	−61	−71	−59	−60	−66
	50	76	−95	−78	−56	−80
1941	0	7	−32	−76	+10	−10
	5	−5	−32	−67	−26	−32
	20	−36	−37	−78	−61	−47
	35	−69	−77	−76	−57	−70
	50	−85	−99	−98	−62	−86
1942	0	+22	+33	−70	−2	+11
	5	−22	+1	−74	−31	−20
	20	+11	−30	−80	−45	−38
	35	+48	−73	−89	−48	−61
	50	11	−97	−96	−39	−77
1943	0	−42	+60	−84	+35	+19
	5	−34	−16	−78	−24	−28
	20	−36	−39	−81	−51	−47
	35	−33	−89	−91	−55	−76
	50	−70	−100	−99	−75	−90

[1] Sediment content, by weight, of water-sediment mixture applied.

and alkali sacaton behaved differently in different years. The response of blue grama, dominant in all plots in 1939, is well typified by its degree of survival in 1943, after 4 years of treatment. By that year its basal area had increased 60 percent in the plots that had received no sediment; had decreased 16 percent under the 5-percent treatment, which resulted in accumulation of about 3 inches of deposit; and had decreased 99.8 percent under the 50-percent treatment, which resulted in a deposit of approximately 23 inches. In the lysimeter plots subjected to the 35-percent treatment, density of blue grama decreased somewhat less than it did in the field where deposits were of comparable depth; but competition from galleta and western wheatgrass had been greater in the field.

Alkali sacaton, the next most abundant grass, increased in density one-third in lysimeter plots where no sediment was deposited. It decreased one-fourth where 3 inches of sediment was deposited in 4 years, one-half where the 4-year deposit was 9 inches or 15 inches, and three-quarters where it was 23 inches. Although its basal area was reduced by deposit of any depth, this grass showed greater percentage survival under the two heavier sediment treatments than any of the other grasses.

Western wheatgrass showed percentage decreases of 42, 34, 36, 33, and 70 under the 0-, 5-, 20-, 35-, and 50-percent treatments, respectively. These data indicate that 4-year accumulations of sediment, with depths as great as 15 inches, had less effect on survival of this species than competition where no sediment had been deposited. Deposition of 23 inches in a 4-year period reduced western wheatgrass density to approximately half what it was in plots with accumulations of 15 inches or less. This response is in contrast with increases of western wheatgrass on portions of the flooded field plots where sediment was deposited. It is thought that, owing to the limited amounts of soil in the lysimeters, soil moisture was probably more often critically low in them than it was in the field, and that this may have had a particularly restrictive effect on the growth of western wheatgrass.

Galleta in lysimeters did not compete well in the mixture, but it seemed to be less affected by depth of deposit than blue grama.

As increasing depth of sediment deposits in the lysimeters reduced plant competition, survivors of all the grass species but blue grama showed greater vigor and those of blue grama showed less.

During the very wet summer of 1941 the floodings of the grass plots were so closely spaced that, at times, the plot surfaces did not dry out between them. Owing to the fine texture of the deposits in the plots irrigated with arroyo water, percolation in those plots was retarded to such an extent that water lay on them for several days at a time. In the lysimeter plots, the surface soil usually dried out between irrigations, and percolation was always complete within a few hours. Despite this difference, the response of the grasses other than western wheatgrass was similar in the two series of plots.

CROP PRODUCTION

Crop yields (table 41) reveal no developments common to all crops under all treatments.

Corn yields in the first 3 years did not differ significantly according to irrigation treatment. In 1941, when the "all flow" plots received 96 inches of added water before the first freeze came on September 9, the average yields of corn from these plots were lower than those from the "selected flow" plots, which received 36 inches. The yields of the unirrigated plots were lower than the yields of all groups of irrigated plots except those of the two groups of "all flow" plots in 1941. In 1942 the "all flow" plots that received clear water produced a lower yield than the other irrigated plots.

In 1939, drought prevented germination of the beans, and no bean crop was produced under any treatment. In 1940 and 1941 no bean crop was produced in the plots that had been irrigated with all arroyo flows: the plants had been killed by sediment. Aside from this, no significant difference appeared among the yields of the different sets of irrigated plots. All yields of the unirrigated plots were less than those of plots treated with clear water or with selected arroyo flows.

Difference either in kind or in amount of irrigation water had no influence on yield of oat grain. In 1939, deposition of approximately 2 inches of sediment before the seed germinated, in the plots irrigated with all arroyo flows, caused these plots to produce less hay than any other set of irrigated plots. Unirrigated plots yielded crops of grain only in 1938 and 1941. The first of these crops was smaller than those produced the same year in watered plots; the second was not.

Averages for the 5 years 1938–42 show that the "selected flow" plots, irrigated with 45 percent as much water, produced yields as high as those of the "all flow" plots.

In the 5-year period 1938–42, irrigation with selected arroyo flows produced yields of corn averaging three times as great as those from unirrigated plots, and yields of beans, oats, and oat hay averaging about two and one-half times as great.

A comparison of the yields of corn and beans from the plots treated

TABLE 41.—*Per-acre yields of corn, beans, and oats in crop plots*

Water treatment [1]	Year	Corn	Beans	Oats	
				Grain	Hay
		Bushels	*Pounds*	*Bushels*	*Tons*
All sediment-laden	1938	28.4	809	46.9	2.36
	1939	58.3	0	0	.36
	1940	81.2	0	32.8	1.65
	1941	12.7	0	61.2	2.22
	1942	40.7	1,050	3.9	.52
	Average	44.3	372	29.0	1.42
All clear	1938	46.6	2,256	54.1	2.71
	1939	66.7	0	0	1.44
	1940	80.8	2,983	28.8	1.81
	1941	18.9	1,710	66.2	2.72
	1942	16.5	862	4.5	.64
	Average	45.9	1,578	30.7	1.87
Selected sediment-laden	1938	20.8	1,667	53.0	2.97
	1939	57.9	0	0	1.33
	1940	88.8	3,039	28.1	1.40
	1941	74.1	1,772	75.0	2.88
	1942	34.1	1,243	6.2	.79
	Average	56.9	1,532	32.5	1.80
Selected clear	1938	42.1	2,288	53.0	2.39
	1939	50.8	0	0	.82
	1940	86.5	3,115	21.9	1.49
	1941	38.6	1,939	71.1	2.73
	1942	25.2	1,167	5.1	.72
	Average	48.6	1,702	30.3	1.63
None	1938	17.7	938	7.1	.43
	1939	4.1	0	0	.28
	1940	11.1	726	0	.52
	1941	44.0	1,181	59.6	2.42
	1942	12.6	468	0	0
	Average	18.2	621	13.4	.73

[1] In 1938 the "all flow" and the "selected flow" plots alike received a total of 3 irrigations.

with selected flows and from the unirrigated plots in 1940 with those in 1942 indicates that the distribution of irrigations had a marked effect on crop yield. In each of these years, the "selected flow" plots received a total of 24 inches of irrigation water in four applications. In 1940 the first irrigation was made on May 22, just after planting; the second, on June 29; the third, on July 27; and the fourth, on August 19. In 1942 the irrigations were made on April 1, 2, 3, and 4. Although precipitation during the growing season totaled 10.23 inches in 1940 and only 2.59 inches in 1942, the yields of the two crops in the unirrigated plots were not significantly greater in 1940 than in 1942. In the "selected flow" plots, on the other hand, the per-acre yields of corn and beans, respectively, averaged 88 bushels and 3,077 pounds in 1940 in contrast with 30 bushels and 1,205 pounds in 1942.

CONCLUSION

Results of the work discussed here indicate that, in a headwater valley where channeling has destroyed natural conditions of soil moisture, restoration of such conditions can sometimes be approached by diverting the runoff from the arroyo to the valley floor. The diverted water may be used for increasing forage or producing crops, and much sediment may be kept from streams and reservoirs.

Not every gullied valley can be benefited agriculturally by water spreading. Whether desirable results may be expected depends upon the characteristics of the basin that contributes the runoff and of the area that would receive it. Among these are size, topography, vegetation, and degree of erosion. For satisfactory results in producing forage or crops on spreading areas, the drainage basin must be large enough to yield runoff in all years except those of extreme drought; it must not be so large, however, that the runoff will become unmanageable. Within these limits, suitable size varies with precipitation and slope; areas with low rainfall or gentle slopes may be expected to yield less runoff than those with high rainfall or steep slopes. Under the conditions represented by the Navajo Experiment Station, an area of at least 2,000 acres is necessary to give runoff of sufficient dependability for satisfactory water spreading. As a means of storing sediment, spreading runoff from smaller areas sometimes may be justified. The work did not reveal the maximum usable size of contributing area; but the amounts of water and sediment from the 45,000-acre Figuerido drainage area became too great for advantageous use.

Spreading of runoff from badlands and other sparsely vegetated areas is inadvisable except as a means of storing sediment and thus protecting areas and installations at lower levels. Destruction of crops or forage plants by the excessive amounts of sediment in such runoff may be disproportionate to the benefits derived from the added water. Although the soil at Muddy Creek (below a badland drainage basin) differed little if at all from that of the other areas in its response to flooding, a large mud flow there in the late fall of 1943 practically destroyed the vegetation.

Water spreading areas should be of such size that most of the sediment will settle on the upper 20 percent, and they must be large enough to accommodate exceptionally large flows if a severe erosion hazard at the lower end is to be avoided. Under the conditions prevailing at the Navajo Experiment Station (mountainous drainage basins, average annual precipitation of 11.3 inches at the lower elevations and 17.5 inches at the higher, and summer-type rainfall with short, intense storms) these requirements were met by a ratio of drainage basin to flooding area of 20:3; but the desirable ratio varies with characteristics of the contributing area and with amount and type of precipitation.

The slope of a spreading area should not be steeper than 2 percent. The tract should be as wide as possible in order to minimize the depth of deposit and to permit deposition as soon as possible after the flow leaves the spillway. The upper part of the area may safely contain small gullies. If the gullies are properly controlled, they will silt up. Severely eroded areas on which the gullies are still small may sometimes be leveled by diverting sediment-laden water to them. Gullies in the middle and lower reaches of spreading areas, which usually receive relatively clear water, require careful control. Where erosion starts or where a heavy deposit prevents the desired spread of water, no time should be lost in installing dikes, spreader fences, or—if severe erosion has already occurred—rock sausages.

It was found that under certain conditions sediment could be stored on the valley floor above the diversion dam. As an arroyo filled with sediment, the flows spilled over at one or more low points in the arroyo bank or left the bed entirely at such points. Thus, a part or all of the flow spread out and dropped sediment while still above the dam, and relatively clear water reached the spreading area below the original spillway. This process, if desired, may be hastened by raising the dam and raising the spillway as it silts out, or by constructing debris fences at suitable places above the dam.

For centuries, the Indians and their successors in the Southwest have grown crops by the practice of diverting all the runoff coming down an arroyo (*7, 37*). Under such a practice, however, crop losses are likely to occur, and depth of sediment may become a serious problem. Alternative methods are diversion of selected flows and partial diversion, either of which causes less deposition of sediment on flooded areas.

Field observations indicate that use of arroyo flows selected for low sediment content or to meet current moisture needs of crops, which gave good results in this study, is practical for farming operations.

Observations on sites outside the station area showed that it is sometimes advantageous to divert only part of each flow of an arroyo to crop or range lands. Partial diversion "skims off" the clearer water, allowing the bed load and much of the suspended sediment to pass on down the arroyo. By repeating partial diversion at different places along the arroyo, water is conserved, depth of deposit is limited, and the arroyo is made shallower by deposition of coarse sediment that the flow, lessened in volume, can no longer transport. Partial diversion usually requires more expensive installations. Even in partial diversion, certain precautions are necessary to avoid disproportionate damage to vegetation by excessive deposition. Too much of the flow must not be diverted at once, and the points of diversion must be sufficiently far apart to insure that some areas will receive little or no sediment.

The indication of this study that spreading of arroyo water causes no important changes in chemical characteristics of the soil is in agreement with results of Botkin and Shires (*4*). These investigators found that soils irrigated from a perennial stream after "forty years of irrigation showed no significant changes in nutrients * * * when compared with virgin soils within the same soil series." Studies in a cropped silting basin in the State of Washington [5] revealed similar pH values and content of water-soluble nutrients in deposit and original soil.

Despite sparseness of vegetation and extremely small numbers of soil bacteria in the drainage basins, the runoff—even from badlands—carried large amounts of organic debris and great numbers of bacteria. This may account for the presence of normal bacterial populations in the deposit on spreading areas. Wilson and Schubert (*42*), in much more extensive investigations on bacteria in runoff, likewise found greater numbers of bacteria in runoff than in the soil from which it

[5] HOUGH, J. L., and FLAXMAN, E. M. ADVANCE REPORT ON THE SEDIMENTATION SURVEY OF THE BENNETT IRRIGATION AND SILTING BASIN, WILSONCREEK, WASHINGTON, AUGUST 17–OCTOBER 17, 1936. Soil Conser. Serv. Sedimentation Studies 27. 1938. [Mimeographed.]

came. Norman and Newman (26) found, like the present investigators, that organic-matter content and bacterial activity were higher in material deposited by runoff than they were in the soil from which the runoff came.

Texture of deeper deposits differed greatly from that of original soil in flooded areas, owing to segregation of soil fractions during deposition. Chemical analyses and plant growth indicated no corresponding differences in fertility; nor was water penetration, as indicated by plant growth, markedly lessened by increase of clay in field areas. In cropped experimental plots, percolation was hampered by a 5-year accumulation of 24 inches of heavy-textured sediment; but no such effect appeared in plots with a similar accumulation of 4 inches. As evidenced by crop yields and soil analyses, fertility was not affected in any of these plots. Notwithstanding these developments, when arroyo flows with high clay content are partially diverted, the highest possible proportion of the sand fraction should be diverted to the land; Forbes (11) found that continued irrigation with water carrying very fine sediment reduced crop yield by hampering percolation.

Soils results on field areas were those logically to be expected, since original soil and newly deposited material came from the same source under comparable conditions of transport and deposit. For selection of areas to be flooded, existing vegetation and adequate samples of the soil should be used as criteria. Presence of suitable vegetation and absence of deleterious soil components (such as selenium and high concentrations of alkali salts) can be taken as indicators of areas suitable for water spreading.

In the upper half of the heavily silted portion of each flood plain, galleta and most other perennials were nearly or completely destroyed. Wind erosion resulted in places not invaded by western wheatgrass. To alleviate erosion in heavily silted situations, increase of western wheatgrass or some other sediment-enduring grass should be encouraged. If no such grass is present, one should be introduced.

The suitability of different forage plants for seeding on flooding areas depends upon the climate, soil, availability of seed, and other factors. In selecting plants for this purpose, consideration should be given to species currently growing on naturally flooded and silted areas in the vicinity. Fairly coarse grasses and grasses that reproduce vigorously by vegetative means are particularly suitable. Observations indicate that western wheatgrass, alkali sacaton, and vine-mesquite (*Panicum obtusum*) may be used to advantage within their respective ranges.

Spread of western wheatgrass below places where it had become established on flooding areas indicates that the seed was carried by the water and dropped with sediment. Establishment of sediment-enduring vegetation may be hastened by broadcasting seed on the water as it passes over the spillway or by scattering it in the spillway between flows. By this means at least part of the seed is covered with sediment, a moist seedbed is insured for germination and early growth, and the seeding process in general is simplified.

Whether seed is sown or not, heavily silted parts of spreading areas should be protected from grazing. The degree of protection needed depends on conditions of silting and of plant cover.

An alternative to seeding perennial grasses is producing corn or cane on heavily silted parts of spreading areas. This is sometimes justified even though part of the crop may be destroyed by heavy flows. If such plantings are made, the corn stalks or a high stubble of cane should be left as protection against soil blowing.

Experimental results and other observations at the Navajo Experiment Station showed that water spreading on range areas was beneficial despite a net reduction in density of vegetation due to silting. Amount of forage was increased, and the greater succulence of the vegetation made it more attractive to grazing animals. Except in deeply silted parts, moreover, the flooded areas were better fitted than unflooded ones to withstand heavy grazing. As a result, grazing pressure on less-favored areas was diminished.

These benefits together with those of sound grazing practices on the experimental area allowed a slow but important recovery of vegetation on the area as a whole.[6] Density of plant cover increased substantially in the middle reaches of the flooding areas and in other places where water was concentrated. The Navajos who used the station ranges found the undertaking profitable. Financial returns from these ranges, even though livestock numbers had been reduced by half, actually came to equal those from contiguous tracts outside where proportionately twice as many animals were grazed.[7] Erosion on the station ranges, moreover, began to show some reduction during the 9-year period of study. In contrast, erosion continued at an accelerating rate on the heavily grazed ranges outside.

These facts show the desirability of supplementing forage on upland ranges by developing floodwater areas for grazing or hay production. Reestablishment of desirable plant cover on depleted ranges is slow. Water spreading is a means of reducing the danger of overuse during the critical period of recovery.

Of perhaps greatest importance to the social economy are the sediment-storage aspects of water spreading. From less than 10,000 acres of land in the headwaters of the San Juan drainage, 300 acre-feet of sediment was stored during 9 years—sediment that otherwise would have found its way into Lake Mead. This points the way for treatment of many similar headwater valleys in the vast area contributing erosional debris to the streams that feed this great irrigation and power reservoir.

Results of work described here show that improvement of ranges may quickly compensate the cost of a water-spreading installation and the damage done to the range by sediment. Lack of such improvement would indicate that excessively large amounts of sediment were being washed from the drainage basin. In such a situation, a spreading area might well be devoted to storage of sediment because of the benefits that would accrue to downstream reservoirs and other resources.

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APPENDIX

TABLE 42.—*Methods of analysis of soils of field areas* [1]

Determination	Soil sampled	Depth	Year of sampling	Analytical methods
		Inches		
Total aerobic bacteria	Current surface	0-6	1935, 1938, 1941, 1943	Plate count (*17*).
Nitrifying power	do	0-6	1935, 1938, 1941, 1943	Ammonium salt conversion (*17*).
Water-soluble salts	do	0-6	1935, 1938, 1941, 1943	Salt bridge (*18*).
	Beneath deposit	0-12	1943	
Calcium carbonate	Current surface	0-6	1935, 1938, 1941, 1943	Emerson's carbonate carbon (*15*).
	Beneath deposit	0-12	1943	
*p*H	Current surface	0-6	1935, 1938, 1941, 1943	Glass electrode, 1:2 soil-water suspension (*1*).
Water-soluble phosphorus	do	0-6	1935, 1938, 1941, 1943	Modified Deniges colorimetric (*41*).
	Beneath deposit	0-12	1943	
Water-soluble potassium	Current surface	0-6	1935, 1938, 1941, 1943	Wright's cobaltinitrite (*43*).
	Beneath deposit	0-12	1943	
Water-soluble calcium	Current surface	0-6	1935, 1938, 1941, 1943	Permanganate titration, 1935-42 (*1*).
	Beneath deposit	0-12	1943	Photometric (*33*).
Nitrates	Current surface	0-6	1935, 1938, 1941, 1943	Harper's phenoldisulphonic acid (*21*).
Sulfates	do	0-6	1935, 1943	Gravimetric 1935 (*1*).
	Beneath deposit	0-12	1943	Photometric 1943 (*21*).
Chlorides, carbonates, and bicarbonates.	Current surface	0-6	1935, 1943	Volumetric (*15*).
	Beneath deposit	0-12	1943	
Organic matter	Current surface	0-6	1935, 1938, 1941, 1943	Schollenberger's chromic acid (*32*).
Mechanical analysis	do	0-6	1935, 1938, 1941, 1943	Bouyoucos' hydrometer (*6*).
Total nitrogen	do	0-6	1935, 1943	Kjeldahl (*1*).
Total phosphorus, potassium, and calcium.	do	0-6	1935, 1943	Volumetric (*15*).
Soil moisture	do	0-6 6-12 12-24 24-36	1935-43	Gravimetric (*1*).

[1] Samples for moisture determination were taken in October and May. All other samples were taken in October.

TABLE 43.—*Methods of analysis of soils of grass plots* [1]

Determination	Soil sampled	Depth	Year of sampling	Analytical methods
		Inches		
Total aerobic bacteria	Current surface	0-6	1939, 1941-43	Plate count (*17*).
Nitrifying power	do	0-6	1939, 1941-43	Ammonium salt conversion (*17*).
Water-soluble salts	do	0-6	1939, 1941-43	Salt bridge (*18*).
		0-12	1939	
		12-24	1939	
		24-36	1939	
	Beneath deposit	0-12	1943	
		12-24	1943	
		24-36	1943	
Calcium carbonate	Current surface	0-12	1939	Emerson's carbonate carbon (*15*).
	Deposit	0-6	1942, 1943	
	Beneath deposit	0-12	1943	
*p*H	Current surface	0-12	1939	Glass electrode (*1*).
	Deposit	0-6	1942, 1943	1:2 soil-water suspension.
	Beneath deposit	0-12	1943	
Water-soluble phosphorus.	Current surface	0-12	1939	Modified Deniges colorimetric (*41*).
	Deposit	0-6	1943	
	Beneath deposit	0-12	1943	
Water-soluble potassium	Current surface	0-12	1939	Wright's cobaltinitrite (*43*).
	Deposit	0-6	1943	
	Beneath deposit	0-12	1943	
Water-soluble calcium	Current surface	0-12	1939	Permanganate titration 1939 (*1*).
	Deposit	0-6	1943	
	Beneath deposit	0-12	1943	Photometric 1943 (*33*).
Nitrates	Current surface	0-6	1939, 1941-43	Harper's phenoldisulfonic acid (*21*).
Sulfates	do	0-12	1939	Gravimetric 1939 (*1*).
	Deposit	0-6	1943	Photometric 1943 (*33*).
	Beneath deposit	0-12	1943	
Chlorides, carbonates, and bicarbonates.	Current surface	0-12	1939	Volumetric (*15*).
	Deposit	0-6	1943	
	Beneath deposit	0-12	1943	
Organic matter	Current surface	0-12	1939	Schollenberger's chromic acid (*32*).
	Deposit	0-6	1942, 1943	
	Beneath deposit	0-12	1943	
Mechanical analysis	Current surface	0-6	1939, 1941-43	Bouyoucos' hydrometer (*6*).

[1] Samples were taken in May.

TABLE 44.—*Methods of analysis of soil of crop plots* [1]

Determination	Soil sampled	Depth	Date of sampling	Analytical methods
		Inches		
Total aerobic bacteria	Current surface	0–6	1938–43	Plate count (*17*).
Nitrifying power	do	0–6	1938–43	Ammonium salt conversion (*17*).
Water-soluble salts	do	0–6	1938, 1941–43	Salt bridge (*13*).
		0–12	1938	
		12–24	1938	
		24–36	1938	
	Beneath deposit	0–12	1943	
		12–24	1943	
		24–36	1943	
Calcium carbonate	Current surface	0–6	1938	Emerson's carbonate carbon (*15*).
*p*H	do	0–12	1938	Glass electrode (*1*). 1:2 soil:water suspension.
	Deposit	0–6	1941–43	
	Beneath deposit	0–12	1943	
Water-soluble phosphorus.	Current surface	0–12	1938	Modified Deniges colorimetric (*41*).
	Deposit	0–6	1943	
	Beneath deposit	0–12	1943	
Water-soluble potassium.	Current surface	0–12	1938	Wright's cobaltinitrite (*45*).
	Deposit	0–6	1943	
	Beneath deposit	0–12	1943	
Water-soluble calcium	Current surface	0–12	1938	Permanganate titration 1939 (*1*). Photometric 1943 (*33*).
	Deposit	0–6	1943	
	Beneath deposit	0–12	1943	
Nitrates	Current surface	0–6	1938–43	Harper's phenoldisulfonic acid (*21*).
Sulfates	do	0–12	1938	Gravimetric 1939 (*1*). Photometric 1943 (*33*).
	Deposit	0–6	1943	
	Beneath deposit	0–12	1943	
Chlorides, carbonates, and bicarbonates.	Current surface	0–12	1938	Volumetric (*15*).
	Deposit	0–6	1943	
	Beneath deposit	0–12	1943	
Organic matter	Current surface	0–12	1938	Schollenberger's chromic acid (*32*).
	Deposit	0–6	1941–43	
Mechanical analysis	Current surface	0–6	1938–43	Bouyoucos' hydrometer (*5*)

[1] Samples were taken in May.

TABLE 45.—*Organic-matter content of original soil in lysimeters*

Sediment content (by weight) of mixture applied and year of sampling	Organic-matter percentage, by quality of sediment or kind of water applied						
	Sand 100 percent	Sand 80 percent, clay 20 percent	Sand 60 percent, clay 40 percent	Sand 40 percent, clay 60 percent	Sand 20 percent, clay 80 percent	Decanted water [1]	Clear water
50 percent:							
1939	0.70	0.70	0.70	0.70	0.70		
1940	.68	.70	.69	.71	.70		
1941	.78	.72	.70	.73	.80		
1942	.66	.68	.63	.64	.68		
1943	.72	.68	.67	.69	.73		
35 percent:							
1939	.70	.70	.70	.70	.70		
1941	.73	.71	.76	.75	.75		
1943	.65	.68	.66	.70	.70		
20 percent:							
1939	.70	.70	.70	.70	.70		
1942	.72	.64	.69	.72	.73		
0 percent:							
1939						0.71	0.71
1940						.77	.74
1941						.90	.83
1942						.82	.76
1943						.95	.82

[1] Colloids present.

TABLE 46.—*Organic-matter content of deposits*[1] *in lysimeters*

Sediment content (by weight) of mixture applied,[2] and year of application	Organic-matter percentage of deposit, by quality of sediment applied and year of sampling											
	Sand 100 percent				Sand 80 percent, clay 20 percent				Sand 60 percent, clay 40 percent			
	1940	1941	1942	1943	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:												
1939	0.20	0.31	0.70	0.09	0.58	0.72	0.79	0.31	0.77	0.87	0.72	0.44
1940	...	.28	.07	.06	...	.50	.34	.19	...	.74	.58	.44
1941	...	...	.08	.05	...	...	.36	.19	...	...	.54	.54
1942	...	...	...	.04	...	...	...	.14	...	...	...	.36
35 percent:												
1939–1940	...	.32	...	.09	...	.71	...	.15	...	.80	...	.28
1941–1942	...	...	...	.04	...	...	...	.13	...	...	...	.20
20 percent:												
1939–1940	...	...	.25	...	...	...	.34	...	...	...	.81	...
1941	...	...	...	...	...	...	...	...	...	...	...	...
1942	...	...	...	...	...	...	...	...	...	...	...	...

Sediment content (by weight) of mixture applied,[2] and year of application	Organic-matter percentage of deposit, by quality of sediment applied and year of sampling							
	Sand 40 percent, clay 60 percent				Sand 20 percent, clay 80 percent			
	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:								
1939	0.97	0.99	0.74	0.70	1.13	1.16	0.84	0.91
1940	...	.92	.88	.70	...	1.22	1.01	1.04
1941	...	...	.85	.74	...	...	1.06	1.02
1942	...	...	...	.76	...	...	...	1.02
35 percent:								
1939–1940	...	1.09	...	.59	...	1.25	...	1.07
1941–1942	...	...	...	.67	...	...	...	.97
20 percent:								
1939–1940	...	...	1.26	...	...	...	1.31	...
1941	...	...	...	...	...	...	...	...
1942	...	...	...	...	...	...	...	...

[1] Depth of annual deposit, by sediment content of mixture applied: 50 percent, 6 inches; 35 percent, 3.5 inches; 20 percent, 2 inches.

[2] Organic-matter percentage of mixture at time of application:

Quality of sediment	1939	1940	1941	1942
Sand 100 percent	0.15	0.15	0.15	0.08
Sand 80 percent, clay 20 percent	.35	.35	.35	.36
Sand 60 percent, clay 40 percent	.55	.55	.55	.53
Sand 40 percent, clay 60 percent	.75	.75	.75	.86
Sand 20 percent, clay 80 percent	1.14	1.14	1.14	1.06

TABLE 47.—*Bacterial population of original soil in lysimeters*

Sediment content (by weight) of mixture applied, and year of sampling	Number of bacteria (millions per gram of dry soil), by quality of sediment or kind of water applied						
	Sand 100 percent	Sand 80 percent, clay 20 percent	Sand 60 percent, clay 40 percent	Sand 40 percent, clay 60 percent	Sand 20 percent, clay 80 percent	Decanted water[1]	Clear water
50 percent:							
1939	1.58	1.58	1.58	1.58	1.58		
1940	1.70	2.05	2.53	3.26	1.71		
1941	1.30	1.30	1.21	1.42	1.30		
1942	1.19	.97	.76	.87	1.05		
1943	1.94	1.78	1.89	2.09	2.31		
35 percent:							
1939	1.58	1.58	1.58	1.58	1.58		
1941	1.49	1.39	2.44	1.33	1.96		
1943	1.75	1.82	1.79	2.26	2.10		
20 percent:							
1939	1.58	1.58	1.58	1.58	1.58		
1942	1.33	1.40	1.22	1.53	1.57		
5 percent: 1939	1.58	1.58	1.58	1.58	1.58		
0 percent:							
1939						1.58	1.58
1940						2.27	2.44
1941						3.06	3.66
1942						3.53	2.07
1943						5.42	4.07

[1] Colloids present.

TABLE 48.—*Bacterial population of deposits*[1] *in lysimeters*

Sediment content (by weight) of mixture applied,[2] and year of application	Number of bacteria in deposit (millions per gram of dry soil), by quality of sediment applied and year of sampling											
	Sand 100 percent				Sand 80 percent, clay 20 percent				Sand 60 percent, clay 40 percent			
	1940	1941	1942	1943	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:												
1939	2.12	3.35	2.19	1.63	2.56	1.48	1.38	1.36	2.13	1.17	0.58	1.50
1940		4.16	2.72	2.13		1.39	1.01	1.56		.73	.51	1.60
1941			2.92	2.35			1.30	2.41			.47	1.71
1942				2.90				2.51				2.90
35 percent:												
1939, 1940		5.04		2.90		1.42		1.36		1.71		1.37
1941, 1942				3.87				2.03				1.67
20 percent:												
1939, 1940			4.48				2.32				2.00	
1941												
1942												
5 percent:												
1939	2.25				2.56				2.47			
1940		4.20				3.49				2.53		
1941			2.02				2.20				1.98	
1942				6.91				5.30				5.02

See footnote at end of table.

TABLE 48.—*Bacterial population of deposits*[1] *in lysimeters*—Continued

Sediment content (by weight) of mixture applied,[2] and year of application	Number of bacteria in deposit (millions per gram of dry soil), by quality of sediment applied and year of sampling							
	Sand 40 percent, clay 60 percent				Sand 20 percent, clay 80 percent			
	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:								
1939	2.12	1.55	0.98	1.74	4.12	1.13	1.23	1.57
1940		.81	.85	1.35		1.28	1.11	1.81
1941			.68	2.19			1.13	2.03
1942				2.80				2.04
35 percent:								
1939, 1940		1.25		1.21		2.26		1.60
1941, 1942				1.23				1.47
20 percent:								
1939, 1940			2.19				1.75	
1941								
1942								
5 percent:								
1939	2.46				2.78			
1940		3.18				3.70		
1941			2.70				2.76	
1942				5.23				4.37

[1] Approximate depth of annual deposit, by sediment content of mixture applied: 50 percent, 6 inches; 35 percent, 3.5 inches; 20 percent, 2 inches; 5 percent, 0.75 inch.

[2] Bacterial population (millions per gram of dry soil) of mixtures at time of application:

Quality of sediment	1939	1940	1941	1942
Sand 100 percent	1.24	0.93	0.54	0.40
Sand 80 percent, clay 20 percent	1.01	.85	.49	.49
Sand 60 percent, clay 40 percent	.97	.75	.40	.58
Sand 40 percent, clay 60 percent	.83	.65	.37	.67
Sand 20 percent, clay 80 percent	.56	.48	.23	.84

TABLE 49.—*Nitrifying power of original soil in lysimeters*

Sediment content (by weight) of mixture applied and year of sampling	Nitrifying power (percentage of ammonium radical converted), by quality of sediment or kind of water applied						
	Sand 100 percent	Sand 80 percent, clay 20 percent	Sand 60 percent, clay 40 percent	Sand 40 percent, clay 60 percent	Sand 20 percent, clay 80 percent	Decanted water[1]	Clear water
50 percent:							
1939	82.7	82.7	82.7	82.7	82.7		
1940	77.0	85.1	79.5	86.0	84.5		
1941	68.0	73.0	68.4	67.3	74.2		
1942	47.4	45.7	44.2	47.3	56.4		
1943	48.3	49.4	51.4	54.6	54.2		
35 percent:							
1939	82.7	82.7	82.7	82.7	82.7		
1941	65.6	71.0	67.0	67.8	74.6		
1943	42.2	43.7	49.7	46.6	53.4		
20 percent:							
1939	82.7	82.7	82.7	82.7	82.7		
1942	46.1	26.7	27.4	32.3	44.7		
5 percent: 1939	82.7	82.7	82.7	82.7	82.7		
0 percent:							
1939						82.7	82.7
1940						77.3	76.3
1941						73.6	69.5
1942						68.7	59.8
1943						62.0	48.7

[1] Colloids present.

TABLE 50.—*Nitrifying power of deposits*[1] *in lysimeters*

Sediment content (by weight) of mixture applied,[2] and year of application	Nitrifying power (percentage of ammonium radical converted) of deposit, by quality of sediment applied and year of sampling											
	Sand 100 percent				Sand 80 percent, clay 20 percent				Sand 60 percent, clay 40 percent			
	1940	1941	1942	1943	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:												
1939	5.0	2.0	0.5	1.5	62.5	66.7	45.4	37.1	53.5	63.1	25.5	40.5
1940		2.0	1.3	4.6		33.2	20.0	28.6		52.2	27.5	34.8
1941			.2	1.3			10.6	21.2			26.7	43.5
1942				7.3				32.8				43.3
35 percent:												
1939, 1940		2.4		2.3		31.2		17.2		40.6		32.3
1941, 1942				2.6				20.1				46.8
20 percent:												
1939, 1940			1.2				7.2				16.0	
1941												
1942												
5 percent:												
1939	86.3				84.6				85.6			
1940		74.9				76.5				73.8		
1941			62.8				57.7				52.0	
1942				41.2				48.6				50.8

Sediment content (by weight of mixture applied,[2] and year of application	Nitrifying power (percentage of ammonium radical converted) of deposit, by quality of sediment applied and year of sampling							
	Sand 40 percent, clay 60 percent				Sand 20 percent, clay 80 percent			
	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:								
1939	61.9	64.1	29.5	53.2	71.5	41.9	15.1	55.6
1940		54.7	14.9	50.2		64.7	10.5	51.6
1941			21.0	51.7			14.8	51.6
1942				50.3				48.4
35 percent:								
1939, 1940		55.8		38.8		56.3		52.4
1941, 1942				37.0				50.6
20 percent:								
1939, 1940			12.5				12.5	
1941								
1942								
5 percent:								
1939	52.0				85.5			
1940		78.4				75.4		
1941			55.8				56.1	
1942				52.8				51.7

[1] Approximate depth of annual deposit, by sediment content of mixture applied: 50 percent, 6 inches; 35 percent, 3.5 inches; 20 percent, 2 inches; 5 percent, 0.75 inch.

[2] Nitrifying power (percentage of ammonium radical converted) of mixtures at time of application:

Quality of sediment	1939	1940	1941	1942
Sand 100 percent	3.1	2.7	1.0	0
Sand 80 percent, clay 20 percent	9.4	5.4	6.1	11.0
Sand 60 percent, clay 40 percent	23.2	10.2	12.2	22.2
Sand 40 percent, clay 60 percent	28.6	15.1	18.0	33.3
Sand 20 percent, clay 80 percent	34.3	25.0	29.5	55.5

TABLE 51.—*Reaction of original soil in lysimeters*

Sediment content (by weight) of mixture applied and year of sampling	pH value of soil, by quality of sediment or kind of water applied: Sand 100 percent	Sand 80 percent, clay 20 percent	Sand 60 percent, clay 40 percent	Sand 40 percent, clay 60 percent	Sand 20 percent, clay 80 percent	Decanted water [1]	Clear water
50 percent:							
1939	8.30	8.30	8.30	8.30	8.30		
1940	8.76	8.52	8.52	8.44	8.45		
1941	8.62	9.05	8.94	8.90	8.73		
1942	8.78	9.03	8.98	8.58	8.66		
1943	8.85	8.91	9.33	9.16	9.02		
35 percent:							
1939	8.30	8.30	8.30	8.30	8.30		
1941	8.63	8.78	8.93	9.02	9.07		
1943	8.79	9.05	8.96	9.10	8.96		
0 percent:							
1939						8.30	8.30
1940						8.46	8.30
1941						8.29	8.36
1942						8.53	8.70
1943						8.88	8.82

[1] Colloids present.

TABLE 52.—*Reaction of deposits* [1] *in lysimeters*

Sediment content (by weight) of mixture applied,[2] and year of application	pH value of deposit, by quality of sediment applied and year of sampling: Sand 100 percent				Sand 80 percent, clay 20 percent				Sand 60 percent, clay 40 percent			
	1940	1941	1942	1943	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:												
1939	9.27	8.87	8.74	9.23	8.80	8.53	8.93	9.23	8.64	8.81	9.05	9.35
1940		8.93	8.92	9.16		8.47	8.95	9.37		8.76	8.97	8.91
1941			8.95	9.10			8.81	9.37			8.92	9.08
1942				9.11				9.18				9.23
35 percent:												
1939, 1940		8.92		9.13		8.52		9.18		8.47		9.30
1941, 1942				9.06				9.10				9.07

Sediment content (by weight) of mixture applied,[2] and year of application	pH value of deposit, by quality of sediment applied and year of sampling: Sand 40 percent, clay 60 percent				Sand 20 percent, clay 80 percent			
	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:								
1939	8.61	8.57	8.97	9.15	8.55	8.66	8.71	8.96
1940		8.73	8.83	8.96		9.50	8.78	8.89
1941			8.93	8.92			8.79	8.82
1942				8.88				8.84
35 percent:								
1939, 1940		8.50		8.87		8.39		8.66
1941, 1942				9.00				8.89

[1] Approximate depth of annual deposit, by sediment content of mixture applied: 50 percent, 6 inches; 35 percent, 3.5 inches.
[2] Reaction (pH) of mixtures at time of application:

Quality of sediment	1939	1940	1941	1942
Sand 100 percent	9.71	9.71	9.71	9.10
Sand 80 percent, clay 20 percent	9.47	9.47	9.47	9.00
Sand 60 percent, clay 40 percent	9.24	9.24	9.24	8.90
Sand 40 percent, clay 60 percent	9.05	9.05	9.05	8.80
Sand 20 percent, clay 80 percent	8.55	8.55	8.55	8.60

TABLE 53.—*Calcium carbonate content of original soil in lysimeters*

Sediment content (by weight) of mixture applied and year of sampling	Calcium carbonate (percent) in soil, by quality of sediment or kind of water applied						
	Sand 100 percent	Sand 80 percent, clay 20 percent	Sand 60 percent, clay 40 percent	Sand 40 percent, clay 60 percent	Sand 20 percent, clay 80 percent	Decanted water [1]	Clear water
50 percent:							
1939	0.89	0.89	0.89	0.89	0.89		
1940	.90	.90	.91	.88	.93		
1941	.89	.91	.91	.88	.87		
1942	1.04	1.08	.98	.93	.87		
1943	.89	.90	.95	.94	.93		
35 percent:							
1939	.89	.89	.89	.89	.89		
1941	.90	.92	.87	.93	.88		
1943	.92	.99	1.00	.91	.90		
20 percent:							
1939	.89	.89	.89	.89	.89		
1942	.89	.92	.89	.93	.97		
0 percent:							
1939						0.89	0.89
1940						.96	.92
1941						.93	.91
1942						1.00	.96
1943						.93	.87

[1] Colloids present.

TABLE 54.—*Calcium carbonate content of deposits* [1] *in lysimeters*

Sediment content (by weight) of mixture applied,[2] and year of application	Calcium carbonate (percent) in deposit, by quality of sediment applied and year of sampling											
	Sand 100 percent				Sand 80 percent, clay 20 percent				Sand 60 percent, clay 40 percent			
	1940	1941	1942	1943	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:												
1939	0.63	0.63	1.00	0.63	0.53	0.52	0.95	0.61	0.46	0.38	0.99	0.36
1940		.57	.64	.59		.41	.67	.58		.43	.47	.46
1941			.61	.55			.49	.61			.45	.46
1942				.56				.51				.57
35 percent:												
1939, 1940		.53		.57		.42		.48		.34		.47
1941, 1942				.57				.57				.50
20 percent:												
1939, 1940			.59				.52				.51	
1941												
1942												

See footnote at end of table.

TABLE 54.—*Calcium carbonate content of deposits*[1] *in lysimeters*—Continued

Sediment content (by weight) of mixture applied,[2] and year of application	Calcium carbonate (percent) in deposit, by quality of sediment applied and year of sampling							
	Sand 40 percent, clay 60 percent				Sand 20 percent, clay 80 percent			
	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:								
1939	0.33	0.36	0.97	0.36	0.21	0.23	0.77	0.24
1940	--	.34	.36	.37	--	.20	.23	.22
1941	--		.34	.35	--		.21	.23
1942	--	--		.37	--	--	--	.20
35 percent:								
1939 / 1940	--	.30	--	.40	--	.20	--	.20
1941 / 1942	--	--	--	.41	--	--	--	.26
20 percent:								
1939 / 1940	--	--	.30	--	--	--	.21	--
1941	--	--	--	--	--	--	--	--
1942	--	--	--	--	--	--	--	--

[1] Approximate depth of annual deposit, by sediment content of mixture applied: 50 percent, 6 inches; 35 percent, 3.5 inches; 20 percent, 2 inches.
[2] Calcium carbonate (percent) in sediment at time of application:

Quality of sediment	1939	1940	1941	1942
Sand 100 percent	0.61	0.61	0.61	0.50
Sand 80 percent, clay 20 percent	.52	.52	.52	.57
Sand 60 percent, clay 40 percent	.42	.42	.42	.57
Sand 40 percent, clay 60 percent	.33	.33	.33	.31
Sand 20 percent, clay 80 percent	.15	.15	.15	.18

TABLE 55.—*Total water-soluble salts contained in original soil in lysimeters*

Sediment content (by weight) of mixture applied, and year of sampling	Water-soluble salts (percent) in soil, by quality of sediment or kind of water applied						
	Sand 100 percent	Sand 80 percent, clay 20 percent	Sand 60 percent, clay 40 percent	Sand 40 percent, clay 60 percent	Sand 20 percent, clay 80 percent	Decanted water[1]	Clear water
50 percent:							
1939	0.13	0.13	0.13	0.13	0.13	--	--
1940	.13	.15	.16	.15	.15	--	--
1941	.11	.11	.12	.12	.13	--	--
1942	.12	.13	.13	.15	.15	--	--
1943	.10	.11	.11	.13	.14	--	--
35 percent:							
1939	.13	.13	.13	.13	.13	--	--
1941	.10	.11	.11	.11	.12	--	--
1943	.12	.13	.13	.15	.14	--	--
20 percent:							
1939	.13	.13	.13	.13	.13	--	--
1942	.12	.11	.12	.12	.13	--	--
5 percent: 1939	.13	.13	.13	.13	.13	--	--
0 percent:							
1939	--	--	--	--	--	0.13	0.13
1940	--	--	--	--	--	.15	.16
1941	--	--	--	--	--	.13	.13
1942	--	--	--	--	--	.13	.13
1943	--	--	--	--	--	.12	.13

[1] Colloids present.

TABLE 56.—*Total water-soluble salts contained in deposits*[1] *in lysimeters*

Sediment content (by weight) of mixture applied,[2] and year of application	Water-soluble salts (percent) in deposit, by quality of sediment applied and year of sampling											
	Sand 100 percent				Sand 80 percent, clay 20 percent				Sand 60 percent, clay 40 percent			
	1940	1941	1942	1943	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:												
1939	0.02	0.02	0.02	0	0.10	0.10	0.11	0.08	0.14	0.13	0.13	0.12
1940		.02	.02	0		.07	.07	0		.11	.13	.14
1941			.02	0			.10	0			.13	.14
1942				0				.02				.11
35 percent:												
1939, 1940		.02		.13		.09		.11		.11		.13
1941, 1942				.02				.05				.13
20 percent:												
1939, 1940			.02				.09				.13	
1941, 1942												
5 percent:												
1939	.15				.15				.16			
1940		.11				.12				.12		
1941			.11				.13				.13	
1942				.08				.10				.11

Sediment content (by weight) of mixture applied,[2] and year of application	Water-soluble salts (percent) in deposit, by quality of sediment applied and year of sampling							
	Sand 40 percent, clay 60 percent				Sand 20 percent, clay 80 percent			
	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:								
1939	0.16	0.14	0.13	0.15	0.17	0.15	0.14	0.16
1940		.13	.15	.15		.15	.17	.17
1941			.15	.16			.17	.17
1942				.17				.19
35 percent:								
1939, 1940		.14		.13		.14		.14
1941, 1942				.15				.15
20 percent:								
1939, 1940			.14				.16	
1941, 1942								
5 percent:								
1939	.16				.17			
1940		.13				.13		
1941			.14				.14	
1942				.13				.14

[1] Approximate depth of annual deposit, by sediment content of mixture applied: 50 percent, 6 inches; 35 percent, 3.5 inches; 20 percent, 2 inches; 5 percent, 0.75 inch.

[2] Percentage of water-soluble salts in mixtures at time of application:

Quality of sediment	1939	1940	1941	1942
Sand 100 percent	0.02	0.02	0.02	0.01
Sand 80 percent, clay 20 percent	.06	.06	.06	.10
Sand 60 percent, clay 40 percent	.10	.10	.10	.12
Sand 40 percent, clay 60 percent	.13	.13	.13	.15
Sand 20 percent, clay 80 percent	.17	.17	.17	.20

TABLE 57.—*Nitrate content of original soil in lysimeters*

Sediment content (by weight) of mixture applied, and year of sampling	Nitrate content (parts per million) of soil, by quality of sediment or kind of water applied						
	Sand 100 percent	Sand 80 percent, clay 20 percent	Sand 60 percent, clay 40 percent	Sand 40 percent, clay 60 percent	Sand 20 percent, clay 80 percent	Decanted water [1]	Clear water
50 percent:							
1939	10.7	10.7	10.7	10.7	10.7		------
1940	0	7	.5	5	2.4		------
1941	.2	4	0	4	0		------
1942	6	.2	8	4	3		------
1943	.6	.3	9	6	1.8		------
35 percent:							
1939	10.7	10.7	10.7	10.7	10.7		------
1941	0	0	0	0	0		------
1943	0	0	1.1	6	6		------
20 percent:							
1939	10.7	10.7	10.7	10.7	10.7		------
1942	1	5	5	4	3		------
5 percent: 1939	10.7	10.7	10.7	10.7	10.7		------
0 percent:							
1939						10.7	10.7
1940						0	0
1941						6	0
1942						.5	.4
1943						.6	.3

[1] Colloids present.

TABLE 58.—*Nitrate content of deposits* [1] *in lysimeters*

Sediment content (by weight) of mixture applied,[2] and year of application	Nitrate content (parts per million) of deposit, by quality of sediment applied and year of sampling: Sand 100 percent				Sand 80 percent, clay 20 percent				Sand 60 percent, clay 40 percent			
	1940	1941	1942	1943	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:												
1939	0	0	0.2	0.3	2.4	0	0.4	0.3	0.3	0	0.3	0
1940		0	.5	.3		0	.4	.3		0	.5	.3
1941			.6	.8			.5	.5			.4	.6
1942				.8				.5				1.4
35 percent:												
1939, 1940		0		.3		0		2.5		0		0
1941, 1942				0				.3				.5
20 percent:												
1939, 1940			.2				.2				.1	
1941												
1942												
5 percent:												
1939	0				0				0			
1940		0				0				0		
1941			.3				.8				.4	
1942				.6				0				.3

Sediment content (by weight) of mixture applied,[2] and year of application	Nitrate content (parts per million) of deposit, by quality of sediment applied and year of sampling: Sand 40 percent, clay 60 percent				Sand 20 percent, clay 80 percent			
	1940	1941	1942	1943	1940	1941	1942	1943
50 percent:								
1939	1.7	0	0.3	0.6	0.6	1.2	0.2	1.0
1940		.3	.1	1.2		1.1	.4	1.2
1941			.4	.9			.6	4.1
1942				2.3				8.6
35 percent:								
1939, 1940		0		0		0		.3
1941, 1942				.8				.6
20 percent:								
1939, 1940			.4				.2	
1941								
1942								
5 percent:								
1939	0				0			
1940		0				0		
1941			.3				.1	
1942				.6				.9

[1] Approximate depth of annual deposit, by sediment content of mixture applied: 50 percent, 6 inches; 35 percent, 3.5 inches; 20 percent, 2 inches; 5 percent, 0.75 inch.

[2] Nitrate content (parts per million) of mixtures at time of application:

Quality of sediment	1939	1940	1941	1942
Sand 100 percent	0	0	0	1.5
Sand 80 percent, clay 20 percent	4.5	6.2	10.5	2.1
Sand 60 percent, clay 40 percent	9.0	12.4	21.1	2.8
Sand 40 percent, clay 60 percent	13.5	18.6	31.6	3.4
Sand 20 percent, clay 80 percent	22.1	31.1	52.7	4.7

TABLE 59.—*Vegetation* [1] *in study plots of Deer Springs flooding area*

[Data are averages for five permanent quadrats]

Plot No. and distance from spillway	Year	Average depth of deposit [2]	*Agropyron smithii*	*Aristida longiseta*	*Bouteloua gracilis*	*Hilaria jamesii*	*Muhlenbergia repens*	Occasional grasses [3]	Total grasses	Perennial forbs	Annual forbs
		In.	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*No.*	*No.*
1, 0.02 mile	1935	0	0	59		550		5	623	0	87
	1938	4.4	0	1		90		6	97	T	66
	1941	17.2	3	0		0		T	3	0	88
	1943	28.0	0	0		0		0	0	0	0
2, 0.14 mile	1935	0	49	31	0	385	27	30	522	0	204
	1938	4.7	94	0	0	169	15	9	288	T	37
	1941	10.8	55	0	T	2	0	T	57	T	25
	1943	10.5	10	0	0	0	T	0	11	0	3
Check A, 0.25 mile	1935	0	18		0	316	T	0	334	T	73
	1938	0	35		0	331	7	0	373	1	1
	1941	0	131		3	541	130	2	816	4	11
	1943	0	7		0	106	0	0	113	1	0
Check B, 0.25 mile	1935	0		9	334	380		40	790	T	58
	1938	0		6	485	327		41	859	0	2
	1941	0		0	717	321		5	1,046	0	5
	1943	0		0	239	186		1	427	0	0
3, 0.30 mile	1935	0	0	T		553	31	24	608	3	28
	1938	7.6	0	0		15	15	0	30	8	4
	1941	9.5	1	0		22	92	4	119	2	50
	1943	24.5	0	0		0	0	0	0	0	0
4, 0.40 mile	1935	0	57	160		407		39	673	0	174
	1938	3.0	92	0		14		3	109	0	80
	1941	4.8	193	0		3		0	196	T	8
	1943	7.6	89	0		T		0	90	0	0
5, 0.63 mile	1935	0	9	159	210	482	21	0	887	1	43
	1938	3.1	11	0	13	215	25	4	268	4	25
	1941	7.1	168	0	20	72	43	1	304	7	8
	1943	14.8	35	0	6	35	28	0	104	1	0
6, 1.19 miles	1937	0		235		463	158	37	891	5	T
	1938	.2		190		538	268	32	1,028	5	9
	1941	1.4		16		580	366	66	1,028	3	107
	1943	.2		0		194	139	2	336	0	0
7, 1.87 miles	1937	0		0		170		5	175	0	127
	1938	0		T		140		0	140	T	21
	1941	0		0		239		1	240	T	7
	1943	0		0		196		4	200	0	0
Check C, 2.40 miles	1937			0		482		37	519		93
	1938			T		237		36	273		5
	1941			0		233		14	247		5
	1943			0		240		15	255		T
8, 2.44 miles	1937	0				286		0	286	0	169
	1938	0				220		0	220	0	6
	1941	0				229		5	234	2	5
	1943	0				100		4	104	2	0
9, 3.01 miles	1937	0		29		513	4	117	664	0	66
	1938	0		20		278	2	109	409	0	7
	1941	0		0		264	0	119	383	1	8
	1943	0		0		245	0	6	251	0	0

[1] T=Trace, less than 1 unit per quadrat.

[2] Deposition data are those for preceding year. Chartings were made before current year's deposit.

[3] *Agropyron trachycaulum, Hordeum jubatum, Muhlenbergia pungens, Sporobolus airoides, Oryzopsis hymenoides, Sitanion hystrix, Sporobolus cryptandrus,* and *Schedonnardus paniculatus.*

TABLE 60.—*Vegetation in study plots of Norcross flooding area*

[Data are averages for five permanent quadrats]

Plot No. and distance from spillway	Year	Average depth of deposit [1]	*Agropyron smithii*	*Aristida longiseta*	*Bouteloua gracilis*	*Hilaria jamesii*	*Muhlenbergia repens*	Occasional grasses [2]	Total grasses	Perennial forbs	Annual forbs
		In.	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*No.*	*No.*
Check A, above dam	1935	--	--	0	--	821	--	0	821	--	13
	1938	--	--	0	--	372	--	0	372	--	0
	1941	--	--	0	--	678	--	9	687	--	17
	1943	--	--	1	--	275	--	20	296	--	0
Check B, above dam	1935	--	--	51	145	508	--	33	737	--	3
	1938	--	--	26	401	177	--	53	657	--	0
	1941	--	--	3	538	400	--	20	961	--	0
	1943	--	--	0	130	158	--	5	293	--	0
1, 0.03 mile	1935	0	0	--	--	498	0	1	499	1	4
	1938	7.9	0	--	--	35	4	1	40	2	1
	1941	16.0	0	--	--	113	26	19	158	2	40
	1943	20.9	[3]T	--	--	98	0	3	101	0	2
2, 0.10 mile	1935	0	3	3	5	613	10	132	766	1	2
	1938	7.0	81	0	0	1	6	0	88	20	6
	1941	12.7	170	0	0	6	33	2	211	5	37
	1943	16.8	76	0	0	8	9	0	93	1	1
3, 0.18 mile	1935	0	0	9	0	311	--	4	324	T	66
	1938	3.4	0	0	2	277	--	20	298	1	0
	1941	6.8	0	0	0	358	--	32	390	0	21
	1943	5.6	1	0	0	76	--	1	78	0	0
Check C, 0.23 mile	1935	--	--	43	0	404	--	2	530	T	263
	1938	--	--	0	0	173	--	T	173	0	77
	1941	--	--	T	2	255	--	3	260	1	44
	1943	--	--	0	0	164	--	0	164	1	8
Check D, 0.24 mile	1935	--	T	649	--	128	--	38	815	0	22
	1938	--	0	380		59	--	26	465	0	25
	1941	--	7	477		137		26	647	T	15
	1943	--	7	255		96		2	359	0	0
4, 0.28 mile	1935	0	15	91		399	0	0	505	0	109
	1938	1.7	38	1		68	0	6	113	3	1
	1941	5.3	103	0		282	2	127	514	6	10
	1943	11.3	13	0		126	2	6	148	11	0
5, 0.40 mile	1935	0	2	74		T	0	1	78	T	631
	1938	1.3	0	293		43	2	4	342	1	59
	1941	3.4	0	122		187	13	230	552	2	24
	1943	5.5	37	6		139	12	1	194	T	4
6, 0.59 mile	1935	0	0	0		1,068	0	20	1,088	5	0
	1938	.2	0	1		733	25	12	771	5	0
	1941	2.2	0	T		1,091	63	7	1,161	T	20
	1943	8.3	1	1		526	73	2	603	T	0

[1] Deposition data are those for preceding year. Chartings were made before current year's deposit.
[2] *Agropyron trachycaulum, Muhlenbergia pungens, Oryzopsis hymenoides, Sitanion hystrix,* and *Sporobolus cryptandrus.*
[3] T=Trace, less than 1 unit per quadrat.

TABLE 61.—*Vegetation in study plots of Muddy Creek flooding areas*

[Data are averages for five permanent quadrats]

Plot No. and distance from spillway	Year	Average depth of deposit [1]	*Agropyron smithii*	*Aristida longiseta*	*Hilaria jamesii*	Occasional grasses [2]	Total grasses	Perennial forbs	Annual forbs
		In.	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*No.*	*No.*
Check A, above dam	1935			7	228	4	239	0	33
	1938			48	248	15	311	0	20
	1941			26	368	21	415	[3] T	75
1, 0.02 mile	1935	0			285	0	285		72
	1938	3.5			0	0	0		8
	1941	13.7			0	4	4		32
2, 0.13 mile	1935	0			258	0	258	0	71
	1938	5.2			1	0	1	0	111
	1941	8.5			1	1	2	T	323
3, 0.25 mile	1935	0		1	160	0	161	0	70
	1938	.7		10	159	0	169	T	48
	1941			18	291	2	311	1	55
4, 0.28 mile	1935	0		8	502		510	1	225
	1938	2.0		0	4		4	2	110
	1941	2.0		0	0		0	0	475
Check B, 0.30 mile	1935				70	0	70		59
	1938				94	0	94		2
	1941				238	10	248		29
5, 0.31 mile	1935	0		0	25	0	25	0	120
	1938	.7		4	69	4	77	T	81
	1941			31	177	10	218	T	98
6, 0.04 mile	1935	0		4	555	36	595	5	10
	1938	0.4		0	T	0	T	2	21
	1941	21.0		0	0	0	T	0	4
7, 0.28 mile	1935	0		2	429	0	431	0	28
	1938	1.5		0	171	0	171	T	32
	1941	5.2		0	41	1	43	T	10
8, 0.38 mile	1935	0	0	10	917	74	1,001	0	11
	1938	2.2	18	0	279	1	298	3	1
	1941	−2.5	32	0	147	3	182	4	6
9, 0.66 mile	1935	0			796	3	799	0	3
	1938	1.5			410	3	413	T	9
	1941				811	8	819	T	5

[1] Deposition data are those for preceding year. Chartings were made before current year's deposit.
[2] *Oryzopsis hymenoides, Schedonnardus paniculatus, Sitanion hystrix,* and *Sporobolus cryptandrus.*
[3] T = Trace, less than 1 unit per quadrat.

END