# An Evaluation of Range Floodwater Spreaders[1]

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### Highlight

**Range floodwater spreaders are systems of dikes constructed to automatically divert flood flows from gullies and spread them over adjacent range land. The primary purpose of the investigation was to determine what factors influence vegetal response to this supplemental moisture. Forage was established and produced only on sites that received at least one flooding per year. Forage production per unit of water was less when water was ponded and could not drain completely from the soil surface. The total moisture retention capacity of the A and B horizons had more influence than soil texture on the amount of forage produced.**

Range floodwater spreaders are systems of dikes that are designed to divert floodwater from a gully onto adjacent range land. Many range lands were naturally flooded meadows prior to the capture of floodwaters by gullies (Fig. 1, left), but after floodwater is captured by a gully, previously verdant meadows become barren waste land (Fig. 1, right).

A manual on spreaders prepared jointly by U.S. Soil Conservation Service (SCS), Bureau of Land Management (BLM), and Forest Service (FS) personnel (Stokes, Larson, and Pearse, 1954) states that the purpose of the spreaders is "to obtain the maximum vegetal response to supplemental moisture." The SCS, BLM, and FS have designed and constructed most of the spreaders in the Western United States. The SCS is responsible for application of the practice on private lands; while BLM and the FS are responsible for the spreaders on public lands.

The primary purpose of this investigation was to determine the factors that influence maximum vegetal response to supplemental moisture.

This investigation was initiated in 1961. It was extended and intensified in 1964 at the request of, and with financing from, the Bureau of Land Management. Most of the spreaders they had constructed were included in this study. Field personnel of the BLM provided invaluable information regarding the location and history of spreaders. The constructive review given to initial drafts of this report by members of BLM technical staff proved to be quite helpful. We would especially like to thank G. T. Turcott and M. E. Noble for their critical reviews of the manuscript.

## Concepts of Range Floodwater Spreading

The literature was searched for information pertinent to the practice of range floodwater spreading. Much of the available information is opinion based on experience. This type of information is presented for consideration of the reader. Various concepts are also illustrated with photographs taken at sites included in the present investigation.

### Annual Precipitation

Bennett (1939) reported that: "Areas having an annual rainfall of less than 8 inches, or a growing season rainfall less than 4 to 5 inches, may not produce sufficient runoff to justify the installation of a water spreading system." Data assimilated from previous investigations is summarized in Table 1. Yield data indicate that in areas with less than 9 inches of mean annual precipitation the increase in grass yields from water spreading was generally small while in areas receiving 11 inches or more the increase was large.

### Floodwater Supply

Factors that influence water supply could not be given adequate consideration in the limited time available for this study; so criteria based on the experience of the U.S. Soil Conservation Service, Bureau of Land Management and Forest Service is presented instead. Miles (1944) of the U.S. Soil Conservation Service indicated that: "The relationship between acreage in a spreader system to acreage in a drainage system is of prime importance." He further stated that: "Care is needed to avoid over-developing a large spreader area which does not have sufficient drainage above to provide adequate flows for spreading; or, on the other extreme, has too small a spreading area compared with the drainage, with the result that too much water running back into the drainage below the spreader causes erosion. Stokes et al. (1954) support Miles (1944) and suggest that the planner needs information on two points to decide on the sufficiency of the water supply: (1) The rate of peak flow per second; (2) the total volume available in a flow event which will occur often enough to justify building the system. They list topography, rainfall, soils, vegetation, and available runoff records as factors to consider when potential water supply is estimated. Excerpts from their discussion of each subject follow.

On the subject of topography they state: "If the drainage area consists of many small, narrow valleys with steep slopes at right angles to the streams,

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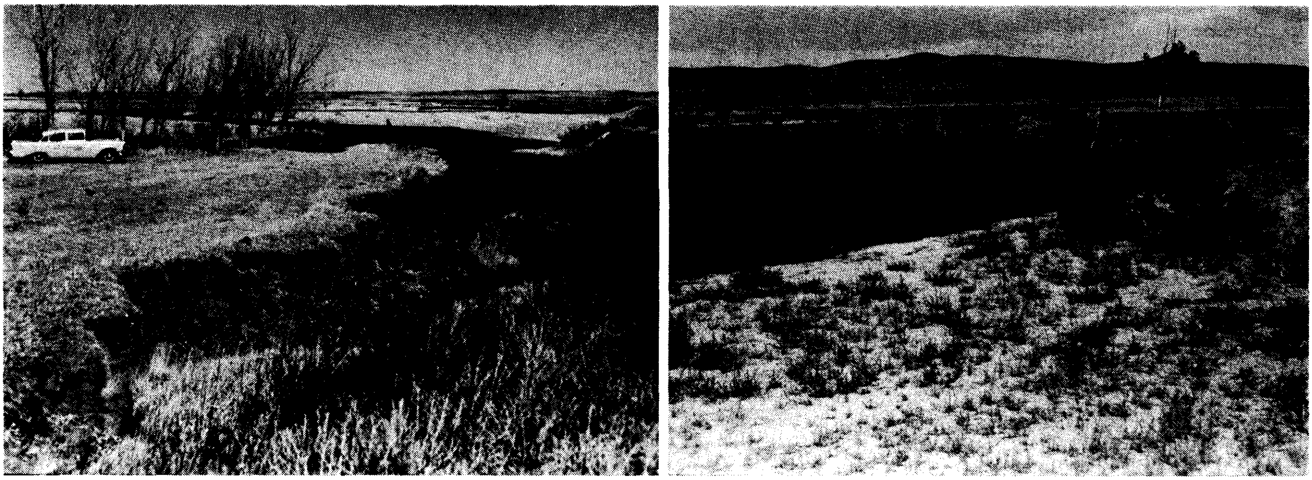

FIG. 1. Capture of floodwaters by a gully migrating up through a valley turned a meadow of western wheatgrass (*Agropyron smithii*) (left) into a weed covered waste land (right).

the runoff will probably be rapid and total time of runoff short. With broad, flat valleys the period of runoff will be much longer. The stream grades themselves will also affect period of runoff and peak flows. A long narrow drainage will have a larger runoff period and a lower peak than one which is wide and relatively short."

On the subject of soils they state: "The soils of the runoff area should be carefully examined. Most clay soils absorb water slowly. Deep sandy soils and soils with good structure will absorb water rapidly . . . ." These statements can be interpreted to mean that higher runoff can be expected from fine-textured soil; and that the potential for runoff decreases as soil becomes coarser.

On the subject of vegetation they state that: "Watersheds with a heavy cover of grass, shrubs or trees seldom produce sudden heavy runoff." General observations made during the present investigation support this statement.

Stokes et al. (1954) further concluded: "Runoff records when available are the best source of information on water supply, particularly records which are continuous over a 20-year period or longer." Very few spreaders have been built, however, in areas where such records are available. When reliable records are not available they suggest the alternative of estimating peak runoff by the "slope area method." This computation is based on water marks and drift lines left by high flows observed at several points along a reasonably straight, smooth portion of stream channel. The method is described in detail by Stokes et al. (1954). They recommend that the spreader not be built if one good flood cannot be expected at least once a year on the average.

### Sedimentation

Stokes et al. (1954) state that: "Frequent and heavy deposits of sediment may interfere with the effective operation of the spreader system. Such deposits will retard plant growth and may kill younger plants." This is confirmed by the research results of Hubbell and Gardner (1950). They

**Table 1. Data from previous waterspreader investigations.**

| Investigators | Date | Mean annual precipitation (inches) | Soil | Grasses | Yield of grass |
|---|---|---|---|---|---|
| Valentine | 1947 | 8.68 | Coarse | Black grama | Slight increase |
| | | | Fine | Tobosa | Large increase |
| Hubbell and Gardner | 1950 | 11.26 | Fine | Alkali sacaton | 1.21 T/acre |
| | | | | Western wheatgrass | Large increase |
| | | | | Galleta | Large increase |
| | | | | Vine mesquite | Large increase |
| Hubbard and Smoliak | 1953 | 11.18 | Medium | Western wheatgrass | 1.89 T/acre |
| Branson | 1956 | 8.92 | Fine | Western wheatgrass | 0.62 T/acre |
| Houston | 1960 | 12.90 | Fine | Western wheatgrass | 1.69 T/acre |
| | | | Medium | Western wheatgrass | 3.84 T/acre |
| Hadley and McQueen | 1961 | 13.74 | Fine | Western wheatgrass | Large increase |

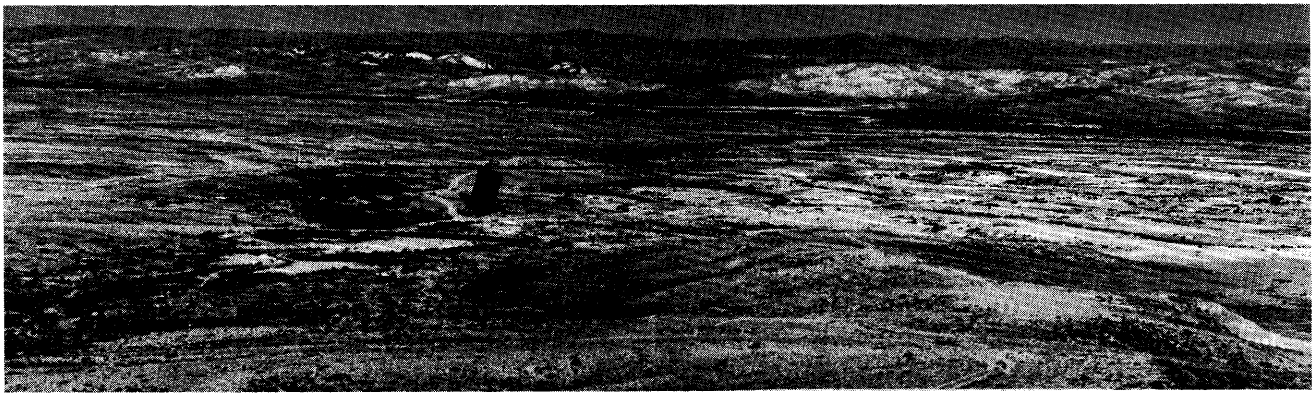

FIG. 2. Little Robber Spreader near Baggs, Wyoming is typical of the type of spreader that has frequently been constructed in Montana and Wyoming.

found that sediment carried by floodwater had an adverse effect on the yield of all grasses studied except western wheatgrass. Of the other grasses studied by them, alkali sacaton (*Sporobolus airoides*) was least adversely affected by sedimentation. It was damaged only slightly by deposition of 9 inches of sediment in 2 years. They also found that galleta grass (*Hilaria jamesii*) is quite readily killed by sedimentation. Further investigation of this problem was not deemed necessary, because of the comprehensive study already conducted.

To avoid excessive sediment deposition, Miles (1944) suggested ". . . construction of the diversion dam at a point where it will provide a silt storage reservoir." He also suggested that "Where the problem appears to be serious, the first dam may be built at the lower of two or more alternate sites with the expectation of later building at another site when the first dam becomes filled with sand and silt."

### Design Factors

Monson and Quesenberry (1958) stated that "Diversion dams, ditches, and control structures should be designed so as to divert the water and distribute it automatically with a minimum of supervision during the time the water is flowing." Therefore, to operate successfully under such conditions an irrigation system must qualify in three ways:

(1) It must be adapted to the control of large volumes of water;
(2) It must be automatic in operation, because intermittent streams flow for only a short period at a time—often without warning; and
(3) It must be low in initial cost and maintenance because the uncertain water supply will not justify a large investment.

Information presented by Bennett (1939) indicated that a spreader should also be designed and constructed in a manner that eliminates ponding. He recommended that "The soil should be capable of absorbing all the water applied within 48 hours; otherwise, crops are likely to be injured." Ponding, as used in this report, refers to water being held in such a manner that it cannot flow off the surface of the soil.

No quantitative information regarding the influence of design and construction-related factors on forage production was found in the literature. Photographs taken during the present investigation provide some additional qualitative information.

The Bureau of Land Management has used several arrangements of dikes and drains to spread floodwater on range land. The Little Robber spreader near Baggs, Wyoming is pictured in Fig. 2. It is typical of many that have been constructed in Montana and Wyoming. The dike that diverts floodwater from the channel onto the flatland adjacent to it is visible under the arrow to the left of the picture. This small structure is protected by a larger dam upstream that detains flood flows and releases the water at a controlled rate. Dikes are placed across the area to be flooded in a manner that causes the water to flow back and forth until it is dissipated into the soil. The dikes are placed on a contour to prevent ponding.

Ponding is prevalent in many spreaders where no drainage through the dikes is provided. This results in barren areas or the production of weeds or foxtail barley (*Hordeum jubatum*). This water might have produced useable forage if ponding had been prevented.

The practice of taking earth for the construction of dikes from the upslope side also results in ponding and the susbsequent waste of floodwater. The results of this practice are evident in Fig. 3, left. Drainage of water through culverts into borrow pits downstream from the dike can also result in ponding and barren soil (Fig. 3, right).

Ponding was prevented in the Coal Creek spreader near Terry, Montana by obtaining the earth for

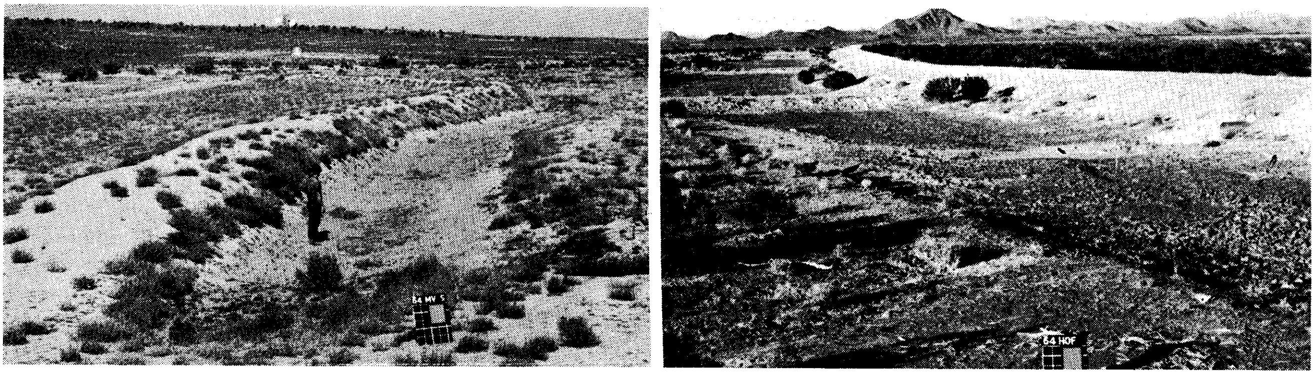

FIG. 3. Water ponded in borrow pits either above (left), or below dikes (right) resulted in barren soil and wasted water.

dikes outside the area to be flooded (Fig. 4, left). Earth for dikes was, however, obtained from within the area to be flooded where storage of drinking water for cattle was desired (Fig. 4, right).

Refilling of gullies with sediment is desirable, but can occur only if structures cause water to accumulate in the void to be filled with sediment. In areas like the San Simon Valley in Arizona, large earth and concrete structures (Fig. 5, left) were constructed across the channel to arrest erosion, control flood flows, and induce sedimentation in the channel upstream. Water flows through the dikes in culverts onto the valley floor at some distance from the gully (Fig. 5, right). This prevents water from re-entering the gully. Tobosa grass (*Hilaria mutica*) now grows in the areas that are flooded as it did prior to gullying.

**Maintenance**

Maintenance of earthen structures must be considered a continuing process. This was dramatically emphasized when a site previously described in glowing terms by Bennett (1939) was visited. He described plant response on the water spreader in the "Freeman Flat" experimental area at Safford, Arizona as follows: "Three years ago, before treatment, the flat was practically bare of grass. A sparse growth of burroweed, saltbush, creosote bush, and mesquite covered some areas. After water was spread, some annual grasses and weeds appeared the first year, then much saltbush, followed by perennial grasses that had been broadcast behind the spreaders. It is estimated that two years after seeding, the grass will yield 1.5 tons to the acre and pasture for 30 cows for the four spring months." The productive potential of Freeman Flat was still evident (Fig. 6, left) above one dike that still receives water from a side slope. Most of the land in the spreader has, however, reverted back to its original condition. This has happened because the main diversion structure was washed out and has not been repaired (Fig. 6, right).

Peterson and Branson (1962) have summarized the effects of lack of maintenance on structures built by the Civilian Conservation Corps in the late 1930's and early 1940's. They report that many range floodwater spreading systems are no longer productive because the main diversion structure has failed and has not been repaired.

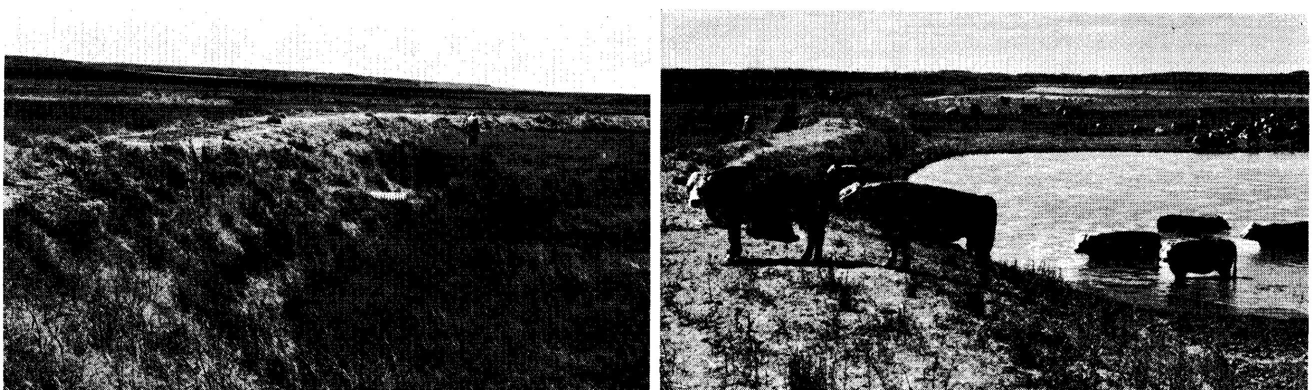

FIG. 4. Ponding has been eliminated in the Coal Creek Spreader near Terry, Montana by draining water through culverts in the dikes (left). Earth for the carryall-built dikes was borrowed outside the flooded area except at sites (right) where water storage for livestock was desired.

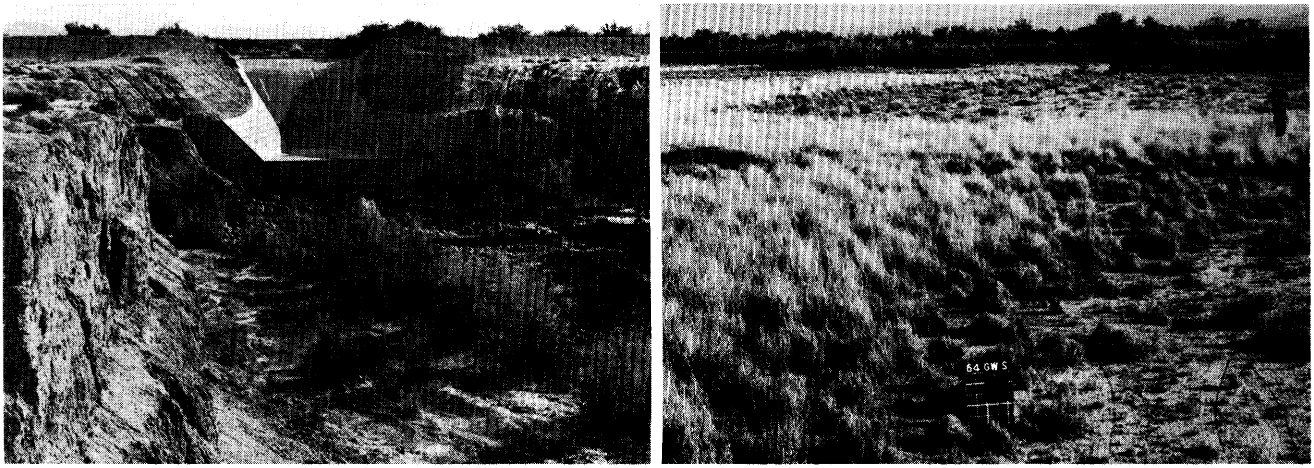

FIG. 5. The concrete drop structure (left) protects the large earth dike across Goat-Well Wash, south of Solomon, Arizona; while water is drained through the dike in culverts at a distance from the gully (right) to prevent re-entry into the gully.

## Concepts of Soil Moisture Retention

After 9 years of study, Bouyoucos (1928) concluded that "Water affords probably the best index of the physical characteristics of the soil. The behavior of soil toward water probably gives truer and more comprehensive composite information concerning the physical characteristics of that soil than the behavior of the same soil toward any other agent. This is probably due to two main factors: First, water, besides being the most natural and universal reagent, is also the chief natural agent by which the soil has been formed; second, most of the physical properties of the soil run parallel with its behavior toward water—for instance, the finer the texture of a soil, the greater is its hygroscopic water, absorption-adsorption of water, water holding capacity, capillary movement of water, evaporation of water, unfree water, wilting coefficient of plants, and shrinkage of soils. In the same parallel direction the greater the organic matter content is in a soil, the greater will be its hygroscopic water, absorption-adsorption of water, water holding capacity, capillary movement of water, evaporation of water, unfree water, wilting coefficient of plants, and shrinkage of soils. Here, therefore, the texture of mineral soils and the content of organic matter are not opposed in the behavior of natural soil toward water."

One method that provides an index of the moisture retention characteristics of soils is the centrifuge moisture equivalent test (ASTM, 1958). This method is frequently used to determine the amount of moisture that will be retained in soil materials after drainage. Prill and Johnson (1959) tested this method and concluded that "Results obtained in the centrifuge studies indicated that reproducible centrifuge moisture content may be obtained with the control of temperature and humidity. The nonreproducibility of centrifuge moisture contents, a cause of criticism for this test for a number of years, may be attributed to the testing of duplicate samples at different temperatures. This method was investigated further by McQueen and Miller (1963). They reported that: A low-cost evaporative cooler-humidifier capable of cooling and humidifying standard centrifuges has been developed and tested. Soil moisture retention characteristics as measured in centrifuges modified in this manner are equivalent to those measured on identical soil in a refrigerated humidified centrifuge. Soil initially loses moisture

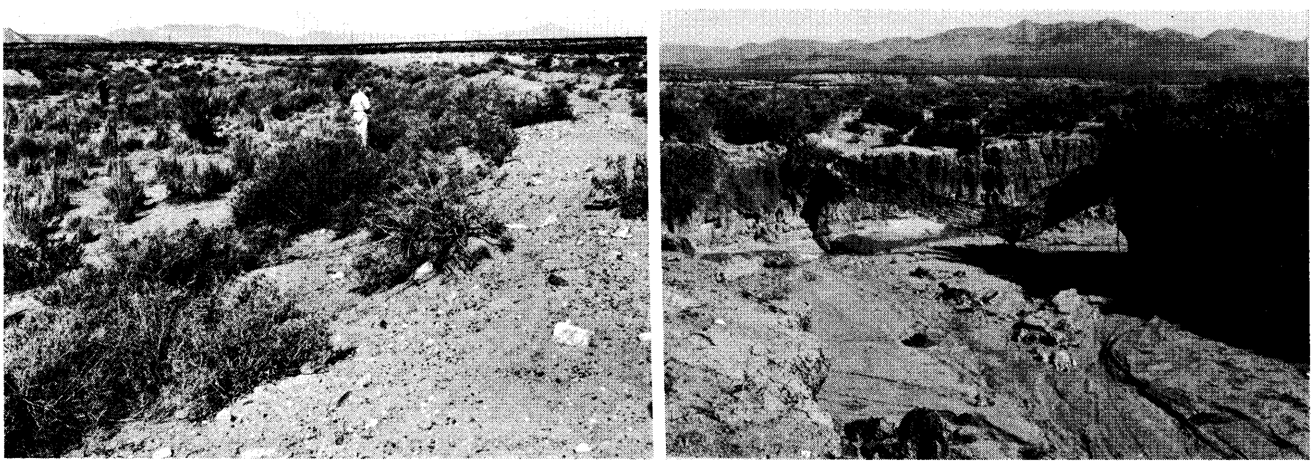

FIG. 6. The productive potential of the Freeman Flat waterspreader built by the Civilian Conservation Corps, is evident in an area (left) above one dike that still receives water from a side hill. Remnants of a wire-reinforced concrete structure that once diverted floodflows onto Freeman Flat waterspreader are stil visible (right).

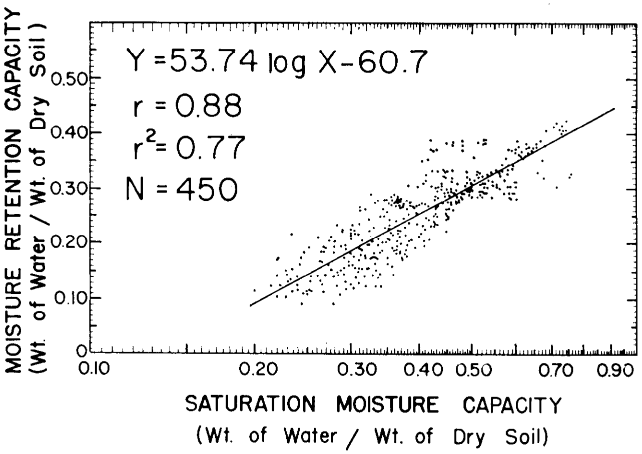


FIG. 7. Relationship between the saturation moisture capacity and moisture retention capacity of 450 soil samples at moisture equilibrium in a cooled humidified centrifuge at 1,000 times the force of gravity.

with time, but after equilibration has been attained, it retains the same moisture content for periods as long as 24 hr. Coarse-textured soils attain equilibrium quickly, while up to 6 hr are required to attain equilibrium in fine-textured soils. Details of the method and equipment used are described in a patent obtained by McQueen (1963).

Modification of the standard centrifuge method (ASTM, 1958) as recommended by McQueen and Miller (1963) provides results that can be used as an index of the relative amounts of moisture that soil materials can retain after drainage. Moisture equilibrium is probably achieved when the only moisture retained in the soil is the moisture adsorbed as films on soil surfaces. Clay and humus, for all practical purposes, provide most of the surface available in soils for adsorption of moisture.

The moisture content of soil at saturation, according to Richards et al. (1954) ". . . is directly related to the field moisture range." Stiven and Khan (1966) presented results indicating that the moisture content of soil at saturation is quantitatively related to the clay content of the soil. They concluded that the moisture content of saturated soil samples "could be used as a means for classifying a soil quantitatively." They also report that this type of data "can be measured easily both in the field and in the laboratory."

Shown et al. (1964) reported that "For rangeland soils, a nearly straight-line relationship was found between the saturation percentages and the centrifuge moisture equivalents determined in a cooled, humidified centrifuge. The above-mentioned relationship permits the use of the saturation percentage instead of the centrifuge moisture equivalent in evaluating soil moisture-holding capacities. The standard centrifuge moisture equivalent test does not evaluate the effect of coarse material on moisture retention. The saturation percentage test indirectly provides a measure of the influence of coarse material on soil moisture retention."

Since the moisture content of soil at saturation is related to the moisture content of soil after drainage, and can be measured easily both in the field or laboratory, it was selected as the means to characterize the soils on range floodwater spreaders. Soils were classified either on the basis of their moisture content at saturation or their probable moisture content after drainage as determined from the relationship presented in Fig. 7. This relationship is based on analyses from 450 soil samples of various textures and geological origins. The coefficient of correlation for the relation between saturation moisture capacity (moisture content of saturated soil) and the moisture retention capacity (moisture content after drainage to moisture equilibrium in an evaporation-cooled centrifuge at 1,000 times gravity) is 0.88, significant at the .01 level (Snedecor, 1953). An even better correlation was obtained when only 96 samples, but all of similar geologic origin were used to determine the relationship. The $r$ value was 0.95. This indicates that, in an area where soils are derived from materials of similar geologic origin, moisture retention capacity can be determined from saturation moisture capacity with relatively little error.

For the present investigation, the depth of moisture retained per unit depth of soil was computed, using approximations of the relative bulk density determined from the saturation moisture capacity data.

It can be shown that in a unit volume of saturated soil the moisture content ($M_s$) expressed as a decimal fraction of the dry weight is equal to the ratio of the density of water ($d_w$) to the bulk density ($d_b$) minus the ratio of the density of water ($d_w$) to the density of the soil particles ($d_s$).

The equation is as follows:

$$M_s = \frac{d_w}{d_b} - \frac{d_w}{d_s}$$

If the density of the water is assumed to be 1 gm/cc, and an average of 2.65 gm/cc (Richards, et al., 1954) is assumed for the density of the soil particles[2], then a relative bulk density can be computed for each soil sample from the saturation percentage by the following equation:

$$M_s = \frac{1}{d_b} = \frac{1}{2.65} \quad \text{or} \quad d_b = \frac{1}{M_s + 0.37735}$$

The depth of moisture that a soil will retain per unit of depth can be estimated by multiplying values of moisture-retention capacity from Fig. 7 by relative bulk density obtained using the above formula. A single curve, Fig. 8, was drawn using the latter products to show the relation between saturation moisture capacity and the depth of moisture per unit depth that each soil will retain.

### Sampling and Analyses

Saturation moisture capacity was determined for soil samples obtained from the A, $B_2$, and $B_3$ horizons of the profile at each sampling site. Horizon boundaries were determined as designated in the supplement to the soil survey manual (USDA, 1951, p. 212).

Textural class of the soil samples from each horizon was determined in the field by feeling the soil with the fingers, as defined in U.S. Department of Agriculture Handbook 18 (USDA, 1961, p. 212).

The saturation moisture capacity was determined by adding distilled water to samples that had been previously dried for 24 hr at 110 C. The amount of water required to saturate each soil sample was determined by reading the number of milliliters used from a self-zeroing burette. Saturation was defined as the moisture content at which the addition of

[2] The assumption of an average specific gravity of 2.65 would be valid for all soils encountered in this study. Peat soils and pumice soils may have lower specific gravities but their occurrence in water spreaders would be unusual.

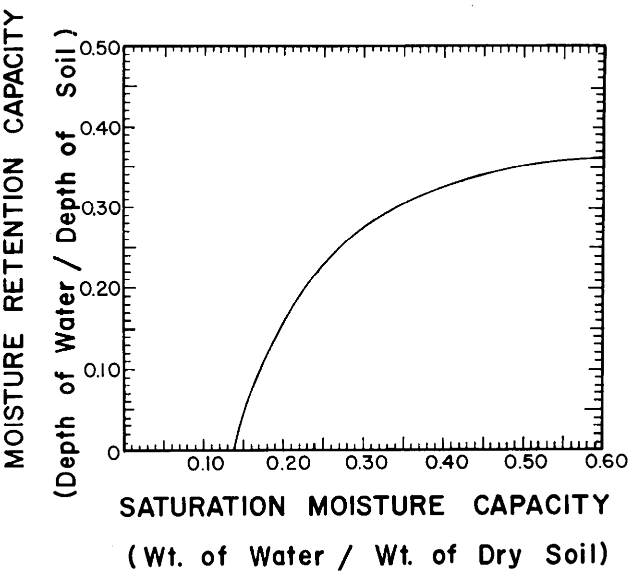


FIG. 8. Relationship between saturation moisture capacity, a fraction of dry weight, and moisture-retention capacity of soil profiles expressed as a fraction of depth.

more water would result in moisture standing on the surface of the sample. The amount of moisture added to the dry soil was then determined and is reported as saturation moisture capacity (weight of water/weight of dry soil).

The pH and electrical resistivity of each saturated sample of soil was also determined. This was done to determine if levels of alkalinity or salinity existed that might deter plant growth or establishment. The pH of saturated soil samples was determined using a Beckman Model H2 glass-electrode pH meter. The electrical resistivity of the saturated soil samples was determined using cigar-shaped metal electrodes having a cell constant equivalent to that of the standard Bureau of Soils electrode cup (Richards et al., 1954, method 5). The resistance in ohms between the electrodes, when in full contact with the saturated soil, was determined with a 1,000 cycle alternating current Wheatstone bridge.

Visible differences in plant response to flooding were used to determine the number and location of sample sites at each range floodwater spreader or naturally flooded area visited during the investigation. Forage yields were measured by clipping grass from two rectangular plots having areas of 9.6 ft$^2$. The average of the yields measured at two plots was converted to lb/acre and reported for each sampling site.

## Results and Discussion

The approximate locations of the range floodwater spreaders and naturally flooded areas investigated during 1961, 1962, and 1964 are shown in Fig. 9.

### Climate

Range floodwater spreaders have not been constructed in areas mapped by the U.S. Weather Bureau as having less than eight inches of normal annual precipitation (Fig. 9). Some productive spreaders are, however, located very near the boundaries of such areas.

The vegetation in naturally flooded areas provides evidence of the possible influence of climate on the kind and quantity of vegetation that could possibly be grown on artificially flooded areas.

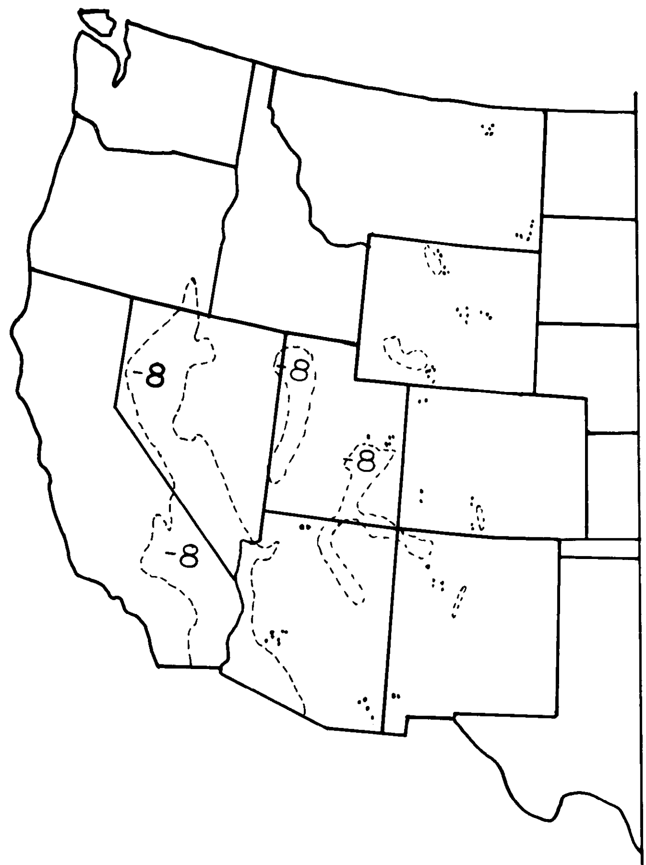


FIG. 9. Approximate locations of the range floodwater spreaders and naturally flooded areas investigated during 1961, 1962, and 1964 are indicated by black dots. Approximate locations of areas with less than eight inches average annual precipitation are indicated by dashed lines.

Plant growth in extremely dry areas like Death Valley occurs primarily in areas where runoff has been concentrated. The plants present in such areas are shrubs (Fig. 10, top). Shrubs occur both in flooded areas and on uplands in areas slightly wetter than Death Valley, but having less than eight inches of normal annual precipitation. Such areas usually drain to a flat-floored bottom of an undrained desert basin, that on occasion becomes a shallow lake. Shrubs like desert molly (*Kochia americana*) occur at the fringes of these occasionally flooded areas (Fig. 10, middle).

Grasses usually occur in naturally flooded areas at sites normally receiving more than eight inches of precipitation per year. Different grasses predominate in swales in different regions of the Western United States (Fig. 10, bottom). Western wheatgrass predominates in the portions of the Missouri, Colorado, and Rio Grande drainages that occur in Montana, Wyoming, and Colorado. Alkali sacaton predominates in swales in portions of the Colorado,

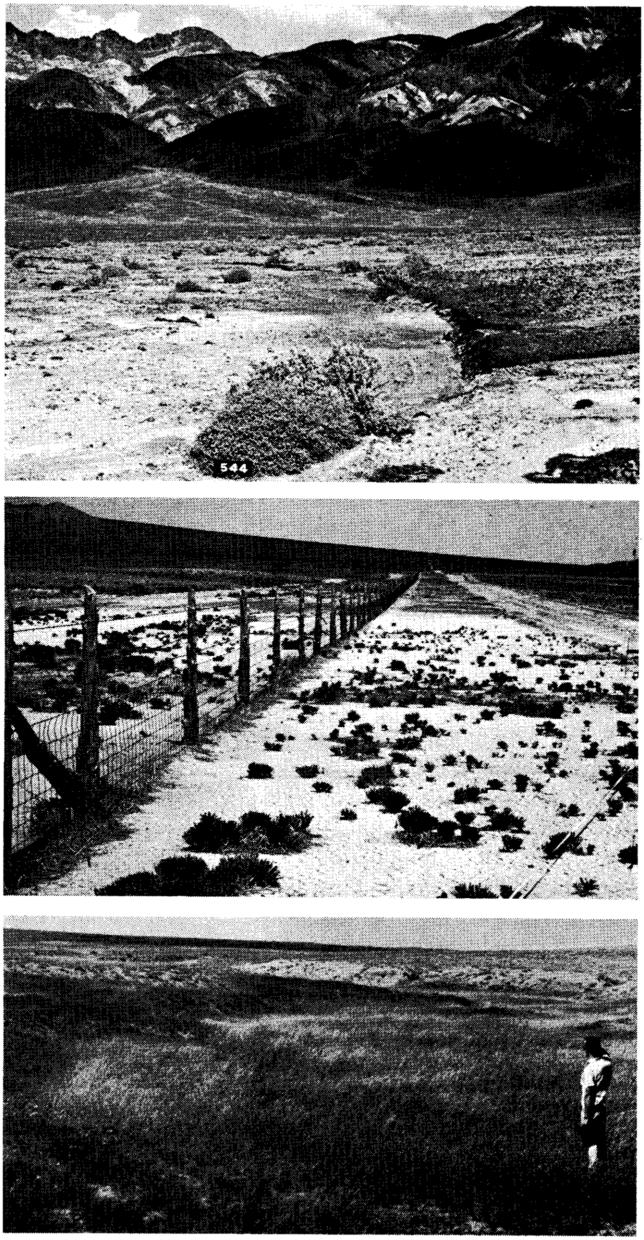


FIG. 10. In areas with less than 4 inches annual precipitation (top) vegetation occurs only in areas that flooded. Shrubs occur on both the uplands and flooded sites in areas that receive between 4 and 8 inches annual precipitation (center) while grasses predominate flooded sites with more than 8 inches (bottom).

Rio Grande, and Gila River drainages that occur in Utah, northern and southeastern Arizona, and New Mexico. Tobosa grass is present in many of the swales in the area that drains into the Gila River in southwestern New Mexico and southern Arizona. There appears to be a systematic change from western wheatgrass to alkali sacaton to tobosa from the northeast to the southwest. This suggests that factors related to temperature at least partially determine which species of grass survives in naturally flooded areas.

The same grasses that predominate in naturally flooded areas also predominate in range floodwater spreaders. Other grasses do however, occur. Where western wheatgrass predominates, streambank wheatgrass (*Agropyron riparium*), slender wheatgrass (*Agropyron trachycaulum*), giant wildrye (*Elymus cinereus*), and foxtail barley are the native grasses that occasionally occur on flooded sites. Foxtail barley, however, occurs primarily on ponded sites. Crested wheatgrass (*Agropyron desertorum*) and tall wheatgrass (*Agropyron elongatum*) have been successfully seeded and established on several spreaders in the region where western wheatgrass is predominant.

Several other grasses also occur where alkali sacaton predominates in flooded sites. Galleta grass occurs on lightly flooded sites, but not where there appeared to have been heavy deposition of sediment. It was observed at sites in northern Arizona, Utah, southwestern Colorado, and northern New Mexico, but not in southwestern New Mexico and southeastern Arizona where alkali sacaton also occurred. In these warmer southern areas tobosa and alkali sacaton both occur. Tall wheatgrass was successfully seeded and established on spreaders in the area where galleta occurs with alkali sacaton on flooded sites. Vine-mesquite (*Panicum obtusum*) was successfully seeded and established on flooded sites in the area where tobosa occurs with alkali sacaton.

In the hot southwest portion of Arizona where tobosa predominates in flooded sites, big galleta grass (*Hilaria rigida*) also occurs naturally, but its occurrence is limited to extremely sandy sites. Blue panic (*Panicum antidotale*), Lehmann lovegrass (*Eragrostis lehmanniana*), and bermuda grass (*Cynodon dactylon*) have been successfully seeded and established on range floodwater spreaders in this hotter area.

### Soils

Forage yields and soil characteristics that were measured define the extent to which moisture retention characteristics of soils of various textures influence forage production on naturally and artificially flooded sites. Saturation moisture capacities are a useful index of the physical character of soils. Soil suitable for forage production can be identified by feeling the relative texture of soil with the fingers. Artificial flooding appears to have induced changes in the moisture retention characteristics and salinity of some soil profiles.

Saturation moisture capacity is a measure of the relative moisture retention of soil. The values of saturation moisture capacity presented in this report are the depth-weighted average for the A and $B_2$ horizons of each soil profile. This average was used, because most of the moisture available for plant growth was assumed to have been stored in

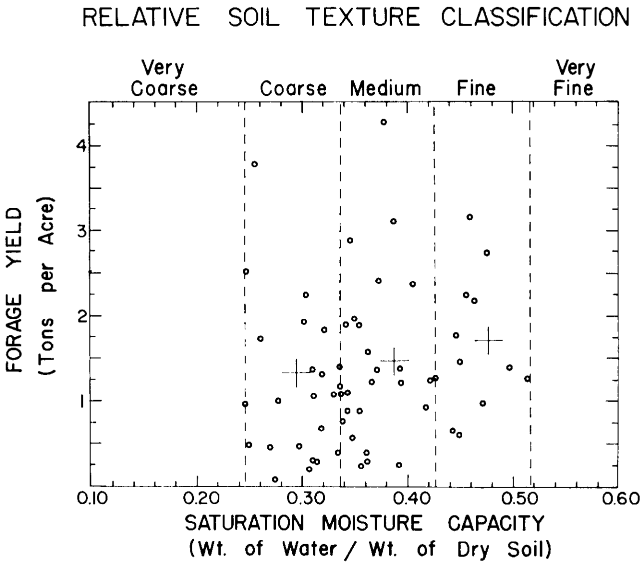


FIG. 11. Forage yields are plotted against the average saturation moisture capacity of the A and $B_2$ horizons of the soil at each sampling site. The range of saturation moisture capacities determined for each relative soil texture class is also defined. The average forage yield for each texture class is indicated by a +.

the A and $B_2$ horizons. The data obtained from the $B_3$ horizon was not included because the few roots present there are assumed to use moisture that was initially stored in the $B_2$ horizon but subsequently migrated into the $B_3$ horizon.

Comparison of forage yields with saturation moisture capacity, obtained from all the flooded sites (Fig. 11), indicates that the amount of water retained in the soil may have more influence on forage production than the moisture retention characteristics. High yields of forage were measured over most of the range of saturation moisture capacities encountered. The tendency for minimum yields to increase with saturation moisture capacity could result from progressive increases in runoff into flooded sites as the saturation moisture capacity of the soil increases. This further indicates that the quantity of water rather than the moisture retention characteristics of the soil at the flooded site determine forage yields.

Since forage yields in excess of 1 ton/acre were obtained from soils having saturation moisture capacities ranging from 0.25 to 0.52 it should be productive to construct other range floodwater spreaders on soils having similar moisture retention characteristics, but only if an adequate supply of flood water is assured.

The texture of soil profiles, on which flooding resulted in forage production, varied from sandy loam to clay. Soil classified as sand is too coarse for grass seedling establishment. The SCS criteria (USDA, 1951, p. 212) for determination of soil textural class in the field by feeling of the soil with the fingers proved to be adequate for distinguishing the difference between sand and sandy loam soils.

Sand, according to SCS criteria: "Is loose and single grained. Squeezed in the hand when dry it will fall apart when the pressure is released. Squeezed when moist, it will form a cast, but will crumble when touched." Soils with these characteristics should not be included in a range floodwater spreader.

Sandy loam according to SCS criteria: ". . . is a soil containing much sand, but which has enough silt and clay to make it somewhat coherent. The individual sand grains can readily be seen and felt. Squeezed when dry it will form a cast which will readily fall apart, but if squeezed when moist, a cast can be formed that will bear careful handling without breaking." Soils having the textural characteristics of a sandy loam, or a finer texture, should be suitable for forage production if sufficient floodwater is applied to a site and it is managed properly.

These considerations of texture have been introduced, because adequate estimates of texture can be made in the field. This permits the elimination of sites too coarse for grass establishment from the area to be flooded on the basis of field evidence alone.

A classification system relating textural differences, as they might be determined by feeling with the fingers to saturation capacity as measured in the laboratory was used to evaluate the influence of textural differences on forage production.

No forage production was measured on soils having saturation moisture capacities less than 0.25. By feeling with the fingers these soils were classified as being either gravelly fine sand, sand, or fine sand. In Fig. 11 they were classified as very coarse.

Forage production occurred and was measured on sites having saturation moisture capacities ranging from 0.25 to 0.52. This is a range of 0.27, which was divided into three equal parts.

Soils having saturation moisture capacities between 0.25 and 0.34 were classified as being coarse (Fig. 11). In the field, by feeling with the fingers, these soils were classified as being either sandy loam, fine sandy loam, or silty loam.

Soils having saturation moisture capacities between 0.34 and 0.43 were classified as being medium-textured (Fig. 11). In the field, by feeling with the fingers, these soils were classified as being either silty loam, clay loam, or silty clay loam.

Soils having saturation moisture capacities from 0.43 to 0.52 were classified as being fine-textured (Fig. 11). In the field, by feeling with the fingers, they were classified as being either fine sandy clay loam, silty clay loam, clay loam, or silty clay.

Soils having saturation moisture capacities greater than 0.52 are not reported in Fig. 11, but have been analysed in other investigations. When classified by finger feel in the field they were defined as either silty clay or clay.

Forage yields were observed only from soils that under field conditions would be classed as coarse, medium, or fine (Fig. 11). The highest average yield was computed for the 11 sites classified as having fine-textured soil. The next lowest average yield was computed for the 28 sites having medium-textured soils, while the lowest average yield was obtained for the 20 sites having coarse-textured soils. It, therefore, seems that, on the average, most forage can be produced on fine-textured soils, but yields as high as many of those obtained from fine-textured soil were obtained from medium- and coarse-textured soil. The higher average yields could well result from the fine-textured soils receiving more runoff than coarse-textured soils.

The structures required to control and divert flood flows from channels reduce the stream velocity, and the coarse fraction of the sediment load is deposited in the channel. Therefore, only the finer fraction of the original sediment load is deposited in range floodwater spreaders. Where fine-textured sediment is deposited, the ability of the soil to retain moisture is increased.

The texture of the A horizon was compared with the texture of the $B_2$ horizon. The comparison was made on the basis of saturation moisture capacities. Surface soils having saturation moisture capacities higher than the value for the subsoils were classified as having the surface finer; while those with saturation moisture capacities lower than the value obtained for the subsoil were classed as having the surface coarser. The moisture retention capacities of the surface soil proved to be higher than the moisture retention capacities of the subsoil at all the sites classed as having coarse soil. Finer soil was observed at the surface on 83% of the sites classed as having medium-textured soil, and at only 50% of the sites classed as having fine-textured soil.

These results indicate that a coarse-textured site might well benefit from the finer-textured sediment that is likely to be deposited on its surface. The higher moisture retention capacity of the sediment might facilitate seedling establishment on a marginal site. Shallow soils may also be benefited by an increase in the depth of soil capable of retaining moisture for plant growth. It is doubtful that fresh sediment benefits finer-textured sites unless the sediment is low in salt content.

None of the sites in the coarse, medium, or fine-textured categories had soil in the A horizon that could be classified saline. This means that the electrical conductivity of the saturated soil was less than 4 millimhos/cm at 25 C. Richards et al. (1954) indicated that yields of very sensitive crops may be restricted at this level of salinity, but the grasses that occurred on the sites investigated are not among the plants listed as sensitive.

Salinity levels that might restrict the yields of grasses were encountered in the $B_2$ horizon of some of the sampling sites. None of the $B_2$ horizons classified as being coarse, on the basis of saturation moisture capacity, were saline, but 12.5% of the $B_2$ horizons of soils classified as having medium texture, and 43% of the $B_2$ horizons classified as having fine texture were saline.

Some of the $B_3$ horizons in each texture category were classified as saline enough to restrict forage production. Twelve % of the $B_3$ horizons having coarse soil were saline, while 25% of the medium-textured sites, and 53% of the fine-textured sites were saline.

None of the $B_2$ or $B_3$ horizons had levels of salinity much higher than an electrical conductivity of 4 millimhos/cm. Thus, yields might be restricted somewhat by salinity, but it does not appear that salinity tests are essential for classifying the suitability of an area for a range flood waterspreader. Salinity tests are not considered useful if the area had been naturally flooded and produced forage prior to erosion.

### Flooding

Forage production on range floodwater spreaders is influenced by the degree of flooding and the amount of moisture retained and available from the soil after flooding. From field observations, it appeared that certain sites in range floodwater spreaders consistently received either inadequate, optimum, or excessive amounts of floodwater. The degree of flooding that each site normally received was determined when the site was visited. Sites where forage production was limited to small areas that received runoff only from areas within the spreader or received no runoff were classified as inadequately flooded (Fig. 12, top). Where forage production was stimulated across all the area designed to be flooded, the site was classified as having received optimum flooding (Fig. 12, middle). Where either foxtail barley, water plants, weeds, or bare ground occurred over parts of the area that had obviously been flooded (Fig. 12, bottom), the site was classified as having received excessive flooding.

After defining the degree to which each site had been flooded, the relative texture class of the soil was determined. The relative texture class was determined from the saturation moisture capacities of the A and $B_2$ horizons of the soil profile at each site, as previously described (Fig. 11).

Inadequate flooding occurred on 33% of the 51 sites having coarse soils, and on 11% of the 31 sites having medium-textured soils, but it was not evident on any of the 22 sites classed as having fine-tex-

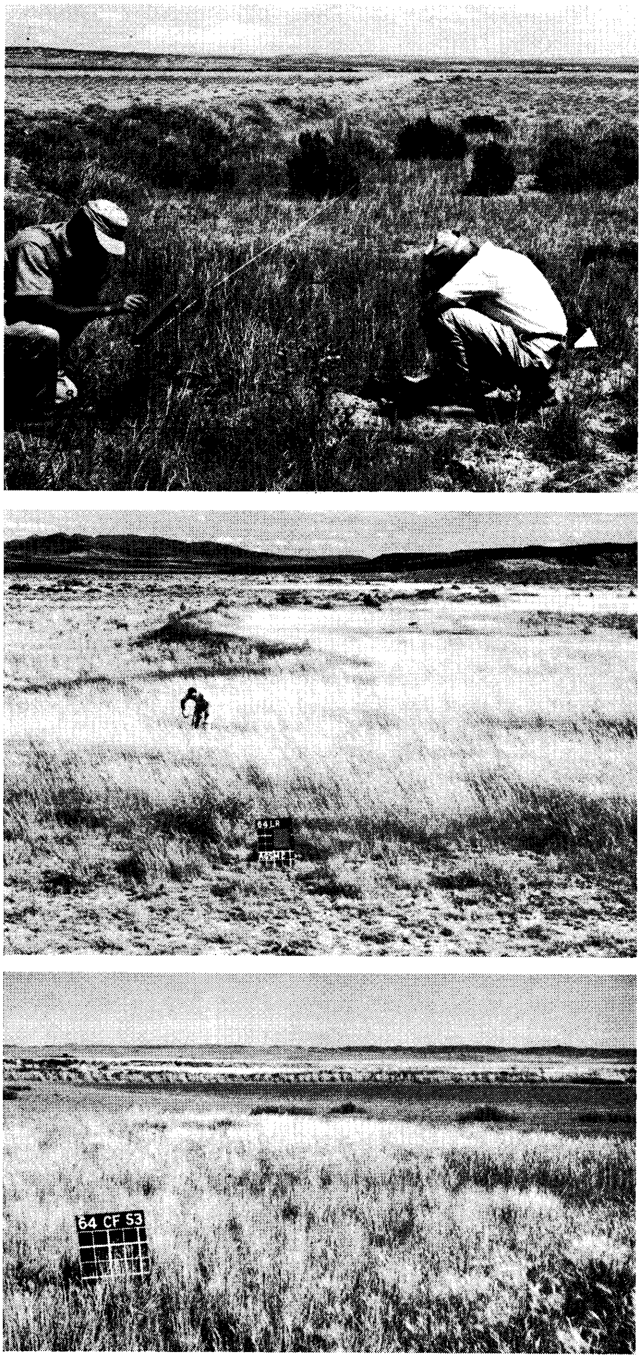

FIG. 12. Sampling sites on range floodwater spreader systems typical of those classified as having received inadequate (top), optimum (center), or excessive (bottom) flooding.

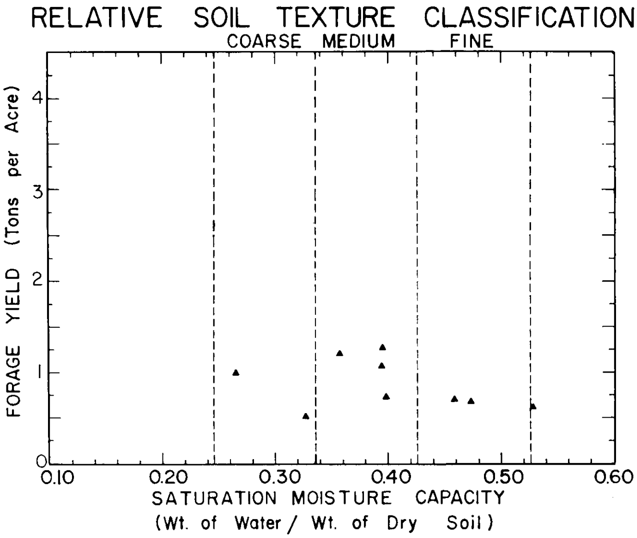


FIG. 13. Yields of foxtail barley obtained from soils having different saturation moisture capacities.

tured soil. These results indicate that an adequate supply of floodwater is usually available for sites having fine-textured soil. The results also indicate that an adequate supply of floodwater is less assured for sites having coarse soil than for sites having finer soils. Optimum flooding occurred on 45% of the 51 sites having coarse soils, on 50% of the 31 sites having medium soil, and on 46% of the 22 sites having fine soil. Thus, less than half of the spreader sites investigated received optimum flooding.

In each instance of excessive flooding, water was trapped in such a manner that it could not be dissipated by gravity flow along the surface of the soil. This was not expected on the 22% of the coarse sites where it was observed, because the permeability of the coarse soils was assumed to be great enough to eliminate this problem. Evidence of excessive flooding was also observed on 39% of the 31 sites having medium-textured soil, and on 54% of the 22 sites having fine-textured soil.

Excessive flooding induced by ponding can reduce forage production regardless of the texture of the flooded site. The yields of foxtail barley are shown in Fig. 13. The yields are smaller than those obtained from grasses which occur only on sites that receive optimum flooding (Fig. 11). Foxtail barley, water plants, and the weeds that grow on areas where ponding has occurred provide some forage, but there is little doubt that the water from which they were produced would have produced more forage if ponding had been eliminated.

### Total Moisture Retention Capacity in Soils

Forage production on range floodwater spreaders is influenced by the amount of moisture derived from flooding and retained in the soil.

The data obtained were analyzed to determine how the total moisture retention capacity of the A and $B_2$ horizons is related to the amount of forage that was produced on each sampling site. Results are shown in Fig. 14.

Computations were made beginning with the relation between saturation moisture capacity and moisture retention capacity illustrated in Fig. 8.

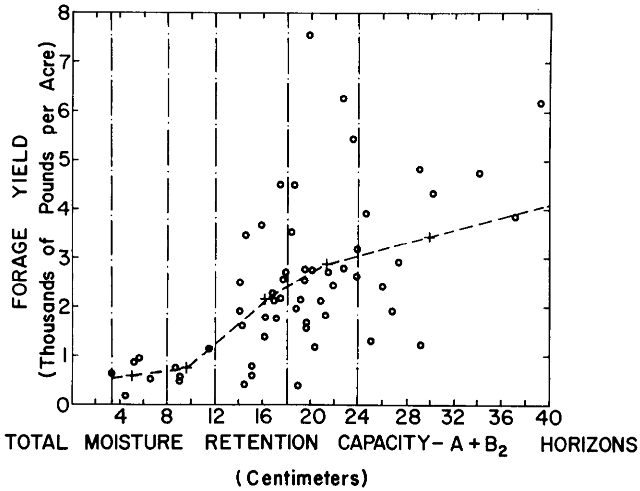


FIG. 14. Yields of forage obtained as compared to the centimeters of water that are retainable by the A and $B_2$ horizons of the soil profile at each sampling site.

For example, if the average saturation capacity of the A and $B_2$ horizons is 0.35, the moisture retention capacity is 0.30. For a depth to the base of the $B_2$ horizon of 100 cm, the total moisture retention capacity is 0.30 times 100 cm, or 30 cm.

Moisture retention ranges are defined by vertical lines in Fig. 14. The average yield of forage for the average of the total moisture retention capacity within each range is designated by a cross. Each of these crosses was connected with a dashed line to illustrate the approximate shape of the curve representing the relation between forage yield and the total moisture retention capacity of the A and $B_2$ horizons.

At the time each site was sampled there was no way of determining if its moisture retention capacity had been underfilled, filled once, overfilled, or refilled more than once. The scatter of the data about the lines drawn between the averages may result from variability in filling the available moisture retention capacity.

Low yields were consistently obtained from flooded sites that had a total moisture retention capacity of 12 cm or less. Yields increased sharply as the total moisture retention capacity approached 14 cm. This indicates that at least 12 cm or approximately 4 inches of total moisture retention capacity is required to produce 1,000 lb/acre of forage. Yields greater than 1,000 lb were obtained from all soil profiles capable of retaining between 14 and 40 cm of water. Thus, construction of range floodwater spreaders should be restricted to sites that have soils deep enough to store at least 12 cm or approximately 4 inches of water.

## LITERATURE CITED

ASTM. 1958. Procedures for testing soils. American Soc. for Testing Materials, Philadelphia, Pa. 544 p.

BENNETT, H. H. 1939. Soil conservation. McGraw-Hill Co., New York. 993 p.

BOUYOUCOS, G. J. 1928. A new, simple, and rapid method for determining the moisture equivalent of soils, and the role of soil colloids on this moisture equivalent. Soil Sci. 27: 233–241.

BRANSON, F. A. 1956. Range forage production changes on a waterspreader in southeastern Montana. J. Range Manage. 9: 187–191.

HOUSTON, W. R. 1960. Effects of waterspreading on range vegetation in eastern Montana. J. Range Manage. 13: 289–293.

HUBBARD, W. A., AND S. SMOLIAK. 1953. Effects of contour dykes and furrows on short-grass prairie. J. Range Manage. 6: 55–62.

HUBBELL, D. S., AND J. L. GARDNER. 1950. Effects of diverting sediment laden runoff from arroyos to range and crop lands. U.S. Dep. Agr. Tech. Bull. 1012. 83 p.

MCQUEEN, I. S. 1963. Cooler and humidifier for subsoil centrifuge. U. S. Patent No. 3, 109, 872. 5 p.

MCQUEEN, I. S., AND R. F. MILLER. 1963. Temperature and humidity control in the centrifuge moisture equivalent test. Agron. Abstr. p. 64.

MILES, W. H. 1944. Water spreading. Soil Conservation 10: 73–76.

MONSON, O. W. AND J. R. QUESENBERRY. 1968. Putting flood waters to work on rangelands. Montana Agr. Exp. Sta. Bull. 543. 39 p.

PETERSON, H. V., AND F. A. BRANSON. 1962. Effects of land treatment on erosion and vegetation on range lands in parts of Arizona and New Mexico. J. Range Manage. 15: 220–226.

PRILL, R. C., AND A. I. JOHNSON. 1959. Effect of temperature on moisture contents as determined by centrifuge and tension techniques. Amer. Soc. Testing Materials, Spec. Tech. Pub. 254. p. 340–349.

RICHARDS, L. A., AND OTHERS. 1954. Saline and alkali soils. U.S. Dep. Agr. Handbook 60. 160 p.

SHOWN, L. M., et al. 1964. Comparability of soil saturation percentage with soil moisture equivalent measured in a cooled, humidified centrifuge. Agron. Abstr. p. 50.

SNEDECOR, G. W. 1953. Statistical methods. The Iowa State College Press, Ames, Iowa. 485 p.

STIVEN, G. A., AND M. A. KHAN. 1966. Saturation percentage as a measure of soil texture in the lower Indus Basin. Soil Sci. 17: 255–263.

STOKES, C. M., F. D. LARSON, AND C. K. PEARSE. 1954. Range improvement through waterspreading. U.S. Government Printing Office, Washington, D. C. 36 p.

USDA. 1941. Climate and man. The Year Book of Agriculture. 1240 p.

USDA. 1951. Soil Survey Manual. U.S. Dep. Agr. Handbook 18, 503 p.

USDA. 1962. Supplement to U.S. Dep. Agr. Handbook 18. p. 173–188.

VALENTINE, K. A. 1947. Effect of water-retaining and water-spreading structures in revegetating semidesert range land. New Mexico Agr. Exp. Sta. Bull. 341. 22 p.