UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

INVESTIGATIONS BY THE U.S. GEOLOGICAL SURVEY OF SOIL AND MOISTURE CONSERVATION ON PUBLIC DOMAIN LANDS, 1941-1964

By H. V. Peterson and K. R. Melin

Open-File Report 79-987

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June 1979

PREFACE

by

R. F. Hadley and W. B. Langbein

This report presents a summary of investigations by the Geological Survey on soil and moisture conservation on public domain land in western United States during the period 1941 to 1964. This work began about 1940 when the Department of the Interior assigned to the Geological Survey the responsibility of furnishing hydrologic information and advice to several agencies of the Department that are responsible for the administration and management of public land. In the early years of the program, these agencies were the Grazing Service, the General Land Office, the Bureau of Indian Affairs, the Bureau of Reclamation, and the National Park Service. In the period, 1948 to 1964, most of the investigations were done in cooperation with the Bureau of Land Management. The information and advice on hydrologic problems centered chiefly on erosion control, sedimentation, water supplies, soil-moisture conservation, and land-treatment practices.

The Soil and Moisture Conservation Program had its origin in the Taylor Grazing Act of 1934 when the residual public domain land was to be brought under some form of management for the first time. H. V. Peterson undertook the leadership of the program activities in the Geological Survey in 1941, having acquired by then great familiarity with the geology and the soil and water problems of the arid to semiarid intermountain West. Mr. Peterson's training and background gave him a deep appreciation of aridity as the "overriding influence that shapes more things in the West than all else" as expressed by W. P. Webb (1931).

Mr. Peterson and his co-worker, K. R. Melin, present a review of the data, results of interpretive studies, and of the state of arid land hydrology over the period between the Taylor Grazing Act of 1934 and of the Classification and Multiple Use Act of 1964. Although it was a period when grazing by cattle and sheep continued as the dominant use of the public domain land, the authors were greatly impressed by the great changes in land conditions effected by the Taylor Act. A similar reaction probably will occur as land use changes from primarily grazing to a mix of diverse uses.

Mr. Peterson and his staff submitted hundreds of administrative reports to the land agencies on water prospects, erosion potentials, and on conservation measures. The gist of these reports and related reports published in the hydrologic literature are summarized here. Mr. Peterson completed a draft of this report prior to his retirement in 1964; Mr. Melin continued work on this draft until his retirement in 1970, and that date represents the close of the report. Mr. Peterson died in 1968 and Mr. Melin in 1973.

This report, as organized and abridged by us, is now released to the open file as part of the record of an important phase in the development of arid-land hydrology in the United States. At the time the Taylor Act was passed, hydrologic information was far short, even of the needs of the simpler grazing economy. Hydrologic information grew steadily in scope and accuracy during the period of the investigations reported here, but goals and objectives have changed faster. We are quite aware that the greater information needs created by new demands for broad environmental and resource assessment far outdistance the work begun by Mr. Peterson.

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ABSTRACT

The passage of the Taylor Grazing Act in 1934 marked the end of an era in the land policies in the United States in that disposal of the public lands by homesteading was terminated except under rigidly prescribed procedures, and the remaining public lands covering about 175 million acres in the western conterminous states were brought under regulatory authority for grazing use. In 1934 the lands were mostly in a severe state of deterioration as a result of overgrazing and drought. In addition to reducing numbers of livestock using the lands, successive programs of conservation practices were established of which the Soil and Moisture Conservation Program of the Department of the Interior is of particular interest here. The services of the Geological Survey, in an investigational and advisory capacity were enlisted in this program.

The work of the Geological Survey has consisted of the collection of hydrologic data, investigations of range-water supplies to facilitate management and provide information for design of structures and land-treatment measures. Appraisal of the effects of treatment practices has also been an important activity.

Conservation on the public domain involves mainly growing vegetation for forage and reducing erosion. The two elements are intimately related--accomplishment in one is usually reflected by an improvement in the other. Erosion is a serious problem on most of the public domain, but particularly in the Colorado River and Rio Grande basins where, despite low annual water yields, the public domain and similar lands on the Indian reservations contribute the major part of the sediment measured at the downstream gaging stations. In parts of the Missouri River basin also, erosion is obviously very active but the sediment yield contributed by the public domain cannot be as readily isolated. The reasons for the erosion are generally evident--the erodibility of the rock and soils and the sparsity of vegetation as a result of low precipitation, unfavorable soils, or past land use. How much is due to the land use is still controversial, resulting in many questions relative to planning corrective measures.

The problem facing the early administrators of the Taylor Grazing Act to bring about proper use and conservation of the public domain was a difficult one because of the lack of records on actual grazing use in animal-unit months of the qualified allottees and the lack of data on treatment practices in an arid area. Reduction of grazing was imperative in some localities, but generally, it could not be brought about as rapidly as it should have been. Numbers of animal units in the grazing districts were reduced from about 3.6 million in 1941 to about 3.2 million in 1964, whereas the areas included in districts was increased about 3 percent. Reductions are still being made in certain areas where deterioration is evident.

One of the earliest activities connected with management of the range was the development of water supplies to facilitate the distribution of grazing. The investigations needed for such development formed a large part of the early work in the Soil and Moisture program of the Geological Survey and has continued to be a major activity to the present time. Most of the work has involved investigations of sites for wells but has included also the investigation of proposed spring developments and collection of hydrologic data for use in reservoir design. Well-site investigations have been of two general types: (1) the investigation of a site selected by the land administration agency, and (2) an areal investigation covering entire grazing districts or units thereof. In each type of investigation, a study is made of the geology and the recharge conditions. Reports are prepared giving estimates of the depth of drilling required, the depth to water, the yield, and the quality of the water, together with other information on drilling conditions and developing.

Springs are a significant source of range water in many areas, and in general, all springs of substantial yield are known by the local stock operators. Additional use of springs thus does not involve discovery of unknown springs, but salvaging as much water as possible. For the most part, this consists of a system of water collection and controlling the growth of phreatophytes. The writers believe that many small springs could be efficiently used if proper salvage was carried out.

Surface reservoirs are widely used for range water; they are a primary supply when geologic conditions are unfavorable for well development and form supplementary supplies in other areas. Small reservoirs are relatively inexpensive to construct and require very little maintenance. The disadvantages of reservoirs in most parts of the public domain are the unreliability of the water supply and the losses of water by evaporation. Because of such losses, the use of reservoirs are contested by downstream water users, particularly in the Southwest. The most important elements in reservoir design are estimating the probable inflow and determining means to reduce losses. Since the Geological Survey Soil and Moisture Conservation program was started, records have been collected on reservoirs throughout a large part of the public domain.

In association with control of grazing, treatment of rangelands to improve forage growth and reduce erosion has been an important activity of the land administration agencies. The treatments are both structural and agronomical, in most cases a closely-knit combination of the two. The earliest treatments were started under the Civilian Conservation Corps using largely hand labor. For the most part, these were unsuccessful. The later work has utilized heavy power equipment of several kinds.

Waterspreading, one of the major practices, involves the diversion of floodwater from a stream to a relatively flat valley floor, but differs from the conventional irrigation system in that it functions unattended. In most spreaders, training dikes are installed to spread the inflowing water evenly. In most of the later waterspreaders that have been built, regulatory storage above the spreader is incorporated. Some waterspreaders have been drilled and seeded but most have been planned to increase the production of the native vegetation. Of the many waterspreaders that have been installed on the public domain, results have been highly variable. However, observations made on a large number of these have brought up some criteria that should be helpful in future planning and design. The important factors are: water supply, soil textures, soil-moisture retention, salinity, sedimentation, and the structural design for moving the water through the spreader.

Brush or tree control and seeding is one of the most successful methods of treatments for improvement of the rangelands. Although not all of the public domain is favorable to seeding, owing to deficient precipitation, unsuitable soils and excessive relief, several million acres offer good prospects. About 1,200,000 acres were seeded from 1955 to 1963, and about 234,000 acres were seeded in 1965. Data from a number of seeding experiments show that seeding can be successful in areas receiving an annual precipitation of 10 inches and moderately successful where the annual precipitation is 8 inches if soil conditions are favorable and temperatures not excessively high.

Mechanical land treatment as practiced at present involves the modification of the ground surface by motor-drawn implements, to increase the storage and infiltration of water and thereby promote growth of vegetation cover and reduce erosion.

Methods include ripping, pitting, lister plowing, or contour furrowing with modifications of each. The intensity of treatment ranges from breaking up less than 5 percent of the surface to closely spaced plowing in which the entire surface is converted to a series of furrows and ridges. Such treatments are confined mainly to soils of medium to fine texture because coarse pervious soil absorbs water readily without treatment. A study was made by the Geological Survey on 58 sites in which seven different types of treatment were evaluated with respect to increase or decrease of yields of perennial grass. The greatest increase in yield (1,520 pounds per acre) was found in broad-base furrows, but this finding cannot be considered as conclusive because of the few sites sampled. Increase in yield on the contour-furrowed areas (26 sites) averaged 512 pounds per acre. The furrows were spaced at 3- to 5-foot intervals and cut to a depth of 8 to 10 inches. This appears, in general, to be the most consistently successful treatment. Other treatments, including motor patrol trenches, eccentric disk pits, spike-tooth pits, and wing rips, showed smaller increases in yields. The auger-rip treatment showed a decrease in yield.

In an effort to monitor range-condition changes, surveys were made by the Bureau of Land Management during the period 1955-59, showing the acreage and percent of the public domain in several condition classes and the percent improving, static, and declining. This survey was compared to an earlier survey made by the U.S. Forest Service during the period 1930-35. The 1955-59 survey showed the following percentages in each of the condition classes: excellent, 2.0 percent; good, 15.0 percent; fair, 52 percent; poor, 26 percent; and bad, 5.0 percent. In trend this survey showed: improving, 24 percent; static, 57 percent; and declining, 19 percent. Although the stated categories of condition were not exactly the same in the 1930-35 survey and the 1955-59 survey, the change in each condition class as interpreted by the investigators indicated a very slight improvement between the two surveys. However, the change in trend was very significant; in the early survey, 1.0 percent was indicated as improving and 93 percent declining, whereas the later survey indicated 24 percent improving and 19 percent declining. This raises some questions about what change in trend means and whether it can be determined except by systematic recurrent surveys. Although the range surveys made in 1955-59 do not indicate a significant restoration of vegetation, several studies on the effects of grazing, including the Badger Wash study in the Colorado River basin, show that reductions in grazing pressure result in significant decreases in sediment yield.

Range-management and land-treatment practices similar to those applied in the Colorado basin are being carried out elsewhere on the public domain, and it is believed that a gradual improvement is taking place even if it isn't always apparent to the eye. Systematic evaluation is needed to determine the merit of management and treatment practices, particularly those applied to the most erodible lands.

INVESTIGATIONS BY THE U.S. GEOLOGICAL SURVEY OF SOIL AND MOISTURE CONSERVATION ON PUBLIC DOMAIN LANDS, 1941-1964

INTRODUCTION

The passage of the Taylor Grazing Act in 1934, with its subsequent amendments and executive orders, marked the end of an era in land policies in the United States. Through its enactment the indiscriminate disposal of public land was ended. Homesteading, which had been a cherished national policy for 72 years, was terminated except under rigidly prescribed procedures, the most important of which required classification of the land for determination of suitability for the use intended before entry would be allowed. The stock-raising homestead, which had been instituted nearly 20 years earlier in an effort to relieve unsatisfactory conditions on the Western range, was repealed, and the remaining unreserved land was set aside chiefly for grazing. To this end, the Act provided for establishment of grazing districts and set up procedures for administering lands not included in such districts. The administration within grazing districts was similar to that previously established for grazing in the national forests. It also provided for the disposal by sale of isolated tracts and spelled out the procedures for administering and enforcing the Act.

The Act applied to approximately 175 million acres of land, the great bulk of which was in the 12 conterminous western states. This acreage, representing the final remnant of the public domain, consisted mainly of low grade lands not adaptable to farming because of aridity, unfavorable soils or relief and valuable chiefly for grazing. The productivity of the land was low, but because of the great area involved it constituted an important national resource particularly to the livestock industry.

Because interest in homesteading on these lands had been slowly dying for years even under the stimulus of liberalized laws permitting enlarged entries and reduced requirements to obtain patent, its practical termination by the Taylor Grazing Act appeared to be of little concern to the general public. But passage of the Act was of utmost importance to the lands affected because for the first time they were placed under the regulatory authority of a Federal agency. Under the Act the lands ceased to be orphans open to grazing without restriction or regulation, and instead they were recognized as a valuable national resource to be conserved and protected. Furthermore, the Federal Government and informed members of the public came to recognize the seriousness of the problems that were developing in allowing further deterioration of the lands.

The passage of the Act and the withdrawal of the lands coincided with the severe drought then prevailing throughout much of the West and also with the marked increase of interest in the conservation of soil and water which developed in the depression years of the 1930's. As these Western ranges had long been cited as notorious examples of critical vegetation deterioration and destructive erosion resulting from years of continued overgrazing and abuse, it was natural that they should be accorded early attention. Organized efforts at erosion abatement and range improvement were made in the mid-1930's, first under the Soil Erosion Service in the Department of the Interior and later reorganized as the Soil Conservation Service in the Department of Agriculture.

In 1940, under Government Reorganization Plan IV, all soil and moisture conservation activities on lands under the jurisdiction of the Department of the Interior were transferred from the Soil Conservation Service in the Department of Agriculture to the Department of the Interior. The program was administered and coordinated in the newly created Office of Land Utilization in the Department of the Interior and the work was carried out by the land-administration agencies including the Grazing Service, the General Land Office--later combined to form the Bureau of Land Management--the Office of Indian Affairs, the National Park Service, the Fish and Wildlife Service, and the Bureau of Reclamation. As a part of the coordination effected by the Office of Land Utilization in the conservation program on Interior lands, the technical resources of the Geological Survey were enlisted. In the words of the Secretary of the Interior this was done for the purpose of ". . .making available the great storehouse of scientific information upon which wise use and development of natural resources could be based. In addition to supplying data already compiled on geologic and hydrologic conditions bearing on field problems, the Survey is requested from time to time to conduct field work necessary to collecting similar information on particular project areas" (Annual Report of the Secretary of Interior, 1941).

This report combines a general review of the activities of the Geological Survey in the soil and moisture conservation program of the Department of the Interior since 1941 with a broad picture of the condition and changes that have occurred during this period resulting mainly from the application of land treatment and management practices. Because of the size of the area, the variations in the character and climate of the lands, and the multiplicity of problems relating to their use and conservation, the descriptions and conclusions must be broadly generalized. Information on the conditions has been gleaned from many different sources but mainly from the observations and measurements made by Survey staff members working directly on the lands.

Acknowledgements

A preliminary draft of the report was prepared by H. V. Peterson prior to his retirement. This draft was passed on to K. R. Melin to revise and bring up to date. Mr. Peterson died in 1968. The Geological Survey thus lost the benefit of the advice that he could have given on the discussions of the later work. All members of the Geological Survey soil and moisture staff have contributed in some measure to the report, but special assistance was given by F. A. Branson and L. M. Shown, particularly on the discussions of vegetation conversions and mechanical treatments, and by R. F. Hadley on erosion and sedimentation. Acknowledgement is also due to many members of the Bureau of Land Management for their cooperation in the field and for the information that they supplied.

Scope of the investigation and purpose of the report

Although activities of the Survey under the Soil and Moisture program of the Department have been highly varied in detail, most fall into two general categories, (1) water development, (2) erosion and erosion abatement as influenced by range management and land treatment practices. A majority of the studies and investigations have been initiated and carried out at the direct request of the administrative land agencies for information on specific problems or areas where action programs were being planned. Other activities have been of a more generalized and long-range nature relating to the broad field of land and water conservation.

Range water development

Because the availability and distribution of water for livestock use is of such paramount importance to range administration and conservation, this has been an important phase of the Survey's program. Large numbers of requests have been received for assistance in developing range water. These have included requests for well-site examinations and for information and suggestions on spring development, stock reservoir locations and other types of water developments that might be used in serving the range. For each request, a field examination of the area in question was carried out. To avoid delay in furnishing the information to the requesting agencies, findings were prepared as brief memorandum reports delivered shortly after the individual studies were completed. Subsequently, some of these were combined and published as Geological Survey water-supply papers. A general summary of the water programs and an outline of some of the more important areal problems remaining to be investigated are contained in this report.

Most of the water development studies have been conducted on the public domain, but there has also been cooperation in this field with the Bureau of Indian Affairs on Indian reservation lands and to a lesser extent with the National Park Service on some of their arid areas. Because of the close similarity between many of the Indian lands and some of the park lands and the public domain the studies relating to erosion and conservation problems have also been involved with and are equally applicable to large areas of these lands.

Range improvement and erosion abatement

The serious state of erosion on the public domain and some of the adjacent Indian lands was evident both by the ravaged condition of large areas of the land and in the measured rate of sediment discharge from the land. The extent and seriousness of this condition was further verified by an early range survey conducted by personnel of the Grazing Service in which 50 percent of the land under its jurisdiction was classified as being in a state of severe to critical erosion, 32 percent as moderately eroded, and only 18 percent as slightly eroded or free of erosion (Anon. undated). That this condition was closely tied in with range use was indicated by the findings of the survey which showed that even in this critical state the lands were still being heavily overgrazed.

Since the beginning of the soil and moisture programs the seriousness of the erosion problem has been recognized, and intensive efforts have been directed by the land administration agencies toward its abatement. Many types of treatment have been applied, some successful, others of questionable value. In the field of grazing uses progress has been made in adjusting numbers of animals to the range carrying capacity, and regulating time of use; consequently, the spectre of gross overgrazing has to a large extent been removed. But in other phases of treatment, so complex, elusive and transitory are the effects that in many cases it is impossible to discriminate between success and failure. Thus a range examination conducted at present probably would show that although the vegetation in many localities shows evidence of distinct improvement, the areal extent of erosion has not changed materially since the original surveys were completed. Some treated areas show marked improvement, in others little change is discernible and in several localities erosion is still actively expanding. An important activity in the Survey's program has been aimed at developing standards and criteria for evaluating land conditions and in determining the reason for success or failure of specific types and intensities of treatment.

In this field one of the important activities has been the appraisal of the land treatment practices constructed during the Civilian Conservation Corps programs in the 1930's and in more recent periods. The fact that many of the treatments had been in operation more than 20 years had made possible an evaluation of long-term results based on visual field evidence. This has not entirely eliminated questions concerning the value of the treatment programs because recovery and changes on the land are also intimately affected by other factors not controlled by man including the vagaries of climate especially the occurrence of severe droughts as well as high intensity rains which generate extraordinary floods. However, the appraisals have served to point out the more desirable and promising types of treatment as well as those that have proven of questionable or negative value. This report contains generalized descriptions of these areas.

In developing designs for land treatment, questions relating to hydrology are invariably involved. These govern the overall approach and in large measure dictate the type and size of structure, if any, to be used in the programs. For this purpose, information is essential on such items as the frequency and magnitude of precipitation, the probable volume and maximum rate of runoff, the sediment yield, and the geology and soil characteristics of the area as they are related to runoff, erosion, and plant growth. Full use has been made of various publications of the Geological Survey, the U.S. Weather Bureau, and other agencies that have carried on investigations and research in hydrology as well as in land conservation. During the last decade or so, the literature has been greatly increased. However, because data of this type were not available for many localities on the public domain, efforts have been made specifically to install various types of gages or other kinds of measuring devices to obtain the information where needed. Many of these hydrologic data have been published either as Geological Survey reports or in technical journals. Highlights of these publications are reviewed in this report (Kennon and Peterson, 1960; Lusby et al., 1963; Peterson, 1962; Burkham, 1966; and others).

Other avenues of investigation reviewed in this report include the studies on the geologic and physiographic processes and on climatic conditions and changes as a background for determining the suitability of areas for such types of treatment as waterspreading, brush clearing, reseeding, and various mechanical land-treatment practices. Experience has shown the importance of carefully considering all such features if failures in the conservation programs are to be avoided and best results are to be achieved.

LOCATION AND GENERAL CHARACTERISTICS OF THE PUBLIC DOMAIN

More than 99 percent of the land affected by passage of the Taylor Grazing Act is located in 12 conterminous western states. Table 1 shows the areas, by states, in 1965 including the acreage both within and outside of grazing districts. The general location of the lands is shown in figure 1 (Federal Lands). About 80 percent of the land is contained in 58 organized grazing districts.

Table 1.--Area of public land in twelve western States under the exclusive jurisdiction of the Bureau of Land Management, 1965 1/

State	Vacant lands			Reserved lands and unperfected entries pending 2/
	Within grazing districts	Outside grazing districts	Total	
Arizona	10,512,346	1,929,731	12,442,077	543,852
California	2,235,575	11,993,118	14,228,693	1,020,261
Colorado	7,508,954	547,433	8,056,387	247,375
Idaho	11,275,789	480,275	11,756,064	478,961
Montana	4,938,378	1,207,139	6,145,517	2,077,572
Nevada	43,020,732	3,568,058	46,588,790	1,380,418
New Mexico	12,523,616	565,857	13,089,473	709,471
Oregon	12,422,762	835,901	13,258,663	2,354,836
South Dakota	------------	267,788	267,788	9,939
Utah	22,198,683	715,100	22,913,783	354,467
Washington	------------	274,743	274,743	474
Wyoming	13,363,831	3,114,036	16,477,867	969,239
Total	140,000,666	25,499,179	165,499,845	10,146,865

1/ From Public Land Statistics, Bureau of Land Management, 1965, Table 11, p. 36.

2/ Includes Land Utilization Project lands, the "O&C" and CBWR grant lands in Oregon and miscellaneous other reserved lands.

Uses of the public domain

Although grazing has been and will doubtless continue to be a principal use of the major part of the public domain within the forseeable future, a trend toward a multiple-use approach is clearly evident. As these lands represent the one remaining open space into which a rapidly increasing population can expand for a multiplicity of purposes they are certain to become more valuable and more in demand each year. This precludes their use being limited to one industry or one class of user.

The basis for this multiple use is assured by the passage by Congress in 1965 of:

P.L. 88-606 Public Land Law Review Commission Act, and

P.L. 88-607 Classification and Multiple Use Act.

The significance of these Acts is the enunciation of the policy contained in P.L. 88-606 which holds that the public lands of the United States shall be ". . .retained and managed or disposed of, all in a manner to provide the maximum benefit for the general public." As a means of defining proper use, P.L. 88-607 requires the Secretary of the Interior to "develop. . .criteria by which he shall determine which of the public lands. . .shall be disposed of. . .or retained. . .and managed." Thus a policy toward a future flexible use of the lands means that grazing need not always be the dominant activity, and in fact it has already been relegated to a minor position in some localities. Other uses and their importance in relation to conservation of the lands are described below.

Because of their sparse population and distance from intensive development, segments of the public domain will continue to have advantages for military and defense activities, and withdrawals for this purpose during emergencies can be expected. For these purposes the least productive lands have generally been selected, and in many cases their use for the military purposes has not seriously interfered with other activities, particularly grazing. Experience has shown also that many of the reservation withdrawals are restored to their original status once the emergency is over.

Commercial activities on the public domain involving such items as timber and wood harvest and rights-of-way for roads and public utilities are likely to continue at the present or at an accelerated rate. Formerly, these activities posed problems of conservation due to removal of cover and exposure of the ground to erosion but these problems although not entirely eliminated have in large part been resolved by recognition of the possible harm that might result and by early application of suitable land treatment practices to the rights-of-way and denuded areas.

Mining exploration and oil and gas leasing, often preceded by or accompanied by extensive geophysical investigations which involve a certain degree of land disturbance, will doutbless continue to expand. Clawson and Held (1957) have pointed out that oil and gas leases on the public domain rose from 5000 in 1942 to more than 100,000 in 1956. Although many leases are secured for speculation purposes and usually are not activated, others are prospected or are developed for production. Clawson (1967), in reviewing changes since publication of the earlier report, states that the number of leases increased until 1960, then dropped off to about the level of 1956, but actual development increased considerably. Where the development occurs, surveillance must be exercised to guard against land damage and assure proper conservation since the land is usually extensively disturbed. For example, activity in development of oil shale, much of which is located on public domain, is likely to accelerate within the next few decades and, if so, it could have a marked effect on public land use and conservation problems and practices in parts of Colorado, Utah, and Wyoming underlain by these deposits.

Undoubtedly, the most pressing new demands for the public lands will be for recreation purposes. This will involve not only increases in the usual activities of hiking, camping, mineral and gem collecting, photography, hunting, and fishing, but it will also doubtless include the establishment of additional new parks and monuments or other types of reservations to protect and preserve areas possessing special scenic, historical or recreational features.

To a considerable extent recreation activities can be carried out with minor interference or competition to other uses under the multiple-use concept. Areas of particular scenic value within the mountainous or plateau regions are often characteristically rugged and barren, and their withdrawal from grazing would be of minor concern to stockmen. On the other hand competition between the sportsman seeking better hunting and, to a lesser extent, fishing on the public domain and the use by livestock has become real and may grow in intensity. The two uses are not entirely compatible, particularly where brush clearing and seeding are being carried out as a means of increasing the range forage. Sportsmen claim that these practices reduce or destroy the natural habitat of wild fowl and big game and consequently are seeking to regulate and restrict them. Such restrictions will impose changes of range improvement programs as carried on in the past in areas amenable to this method of treatment unless some type of compromise can be developed.

Localities where special demands may accelerate the conversion of public lands to private ownership or transfer to local governmental agencies will probably be in the vicinity of established metropolitan areas. The sale of small tracts is proving to be especially active in the vicinity of Las Vegas, Phoenix, and other towns experiencing an explosive population growth. Many western towns are partly or completely surrounded by public domain lands, and thus by reason of both economics and necessity these lands become the chief areas of growth. Here the 2-5 acre tracts have proven especially attractive. Transfer of lands to metropolitan areas for parks and recreation use is also indicated and can become of greater importance. These new uses generally are superior to grazing when land values are considered but may also create some new problems of their own. However, these should be capable of solution if attention is given to them as the change in use takes place.

How soon and to what extent the above mentioned multiple uses will displace grazing on the public domain is difficult to predict. In the past the change was rather slow as can be deduced from table 2 which presents a comparison of grazing on the public domain, including both grazing districts and leased lands in 10 western states (representing more than 99 percent of total use), for the 10-year period 1955-1964. The decrease in animal-unit months of use during this period represents in part a forced adjustment to conform to the range-carrying capacity of grazing, but it also in considerable measure appears to reflect the change in attitude of stockmen who in an increasing proportion are coming to follow the principle that fewer numbers of livestock on the range result in better weights and higher returns.

Table 2.--Comparison of grazing use on grazing district and grazing lease lands between 1955 and 1964[1] in 10 western States.

State	1955 Animal unit months[2]	1964 Animal unit months[2]
Ariz.	887,796	890,997
Calif.	832,586	503,033
Colo.	1,009,758	742,104
Idaho	1,657,694	1,264,133
Mont.	1,233,399	1,491,875
Nev.	3,217,530	2,200,977
N. Mex.	2,153,841	1,867,976
Ore.	1,221,050	1,086,174
Utah	2,471,856	1,382,657
Wyo.	2,514,679	2,141,211
Totals	17,200,189	13,571,137
Change		-21%

1/ Extracted from Statistical Appendix to the Annual Report of the Director, Bureau of Land Management, 1956 and Public Land Statistics, 1965.

2/ An animal unit is defined as a standardized unit of measurement for range livestock which is equivalent to one cow or one horse or five sheep or five goats, all over six months of age. An animal-unit-month is the amount of forage estimated necessary for the sustenance of one animal unit for a period of one month.

The indirect use of the land as a watershed, which goes on in association with all other uses, is assuming greater importance. Although runoff from these lands generally is low and in many places so small that it seldom reaches the major streams, nonetheless the available streamflows have long since been appropriated, and in the Southwest particularly, these appropriations are jealously guarded against any withdrawals of water by upstream interests. This aspect becomes important in the consideration of any type of land treatment which might possibly influence the water yield reaching downstream appropriators.

However, the most significant aspect of the land as watershed is the sediment it yields in occasional runoff events even though the annual runoff is very low. This forms one of the main problems facing the land-administration agencies and is the primary reason for the money and effort being expended for conservation programs.

Laws designed for acquisition of the arid grazing lands

It is something of a paradox that at the time of passage of the Taylor Grazing Act more than 175 million acres of unreserved and unappropriated public land still remained unclaimed by a land-hungry public even though for more than a century the principal guiding policy of the government had been to get the lands into private ownership. To this end numerous laws had been formulated and enacted by Congress each designed to aid the citizenry in acquiring the lands. These laws are fairly well-known, and their effects have been described in detail by numerous writers. (See particularly Clawson and Held, 1957; Peffer, E. Louise, 1951; Webb, Walter P., 1931.) No attempt will be made to review them in detail here but a few of the provisions and proposals associated with their enactment will be mentioned inasmuch as they touch on problems relating to the use and conservation of the lands and the final adoption of the management phase for their administration.

The most important and most widely used of the acquisition laws was the Homestead Act of 1862. So successful was this Act in attracting settlers to the land that for a long period Congress considered it adequate for all classes of land. However, the limitation of 160 acres, embodied in this Act, proved to be a notable weakness when applied to the arid and semiarid grazing areas of the West. The act had been framed and was best adapted to serve the subhumid, humid, and largely homogeneous areas of the Midwest that were well suited to farming, and it had attained its greatest success there. It left much to be desired in its application to the range lands of the high plains and mountainous areas with their striking contrasts in soils, topography and climate compared with lands to the east.

Recognition of the conditions that made the Homestead Act unsuitable to the western area came a few years after passage of the Act. The Commissioner of the General Land Office, in his 1875 annual report, recognizing this aspect stated "...... Leaving out of view the mineral wealth of the region ...... and treating only that portion of it supposed to fall within the purview of the laws of disposal of the public lands not mineral, it may be safely affirmed that, except in the immediate valleys of the mountain streams where by dint of individual effort water may be diverted for irrigation purposes, title to the public lands cannot be honestly acquired under the homestead laws. That cultivation and improvement which are required and which are made to stand in the place of price are impossible; and if attempted are without result." (U.S. Dept. of the Int., G.L.O., Annual Report 1875)

In 1879 a Public Lands Commission, appointed by Congress to study the problem of the public lands, recommended classification of the lands as arable, irrigable, pastural, timber and mineral, and further recommended that disposal of each category should be made "only under laws specifically applicable thereto." The commission recognized the problem of the grazing lands when it reported "...... While these pasturage lands are already to so large an extent supporting thousands of people, yet the lands remain in the possession of the government, the laws for their disposal being such that no practical method is presented by which these pastoral people can obtain proper titles thereto. ...... If these lands are to be occupied by permanent settlers and the institutions of modern civilization founded, some new method of disposal is imperatively demanded." (Public Land Commission 1879) As a basis for a satisfactory solution, it was the judgment of the Commission that--"(I) The land must be disposed of in quantities sufficient to the establishment of a home; (II) The price of these lands must be fixed so low that men can afford to take them solely for pasturage purposes; that is, the farm unit must be large and the price of the farm must be reasonable."

A part of the report of the Commission touching on this aspect of the problem was the unique proposal advanced by John Wesley Powell, one of the group of early scientific explorers of the West and second Director of the Geological Survey. Recognizing that the major part of the land was usable only for pasturage and that only a minor part could be irrigated, and noting also that "...... men engaged in stock raising need small areas of irrigable lands for gardens and fields where agricultural products can be raised for their own consumption and where a store of grain and hay may be raised for their herds when pressed by severe storms by which the country is sometimes visited", Powell proposed the organization of what he termed pasturage districts. Residents of the district were to be given a minimum of 2,560 acres for a pasturage farm plus a small tract of irrigable land. To secure this distribution of the land and to give the greatest number of water fronts, divisional land surveys were to conform to the topography rather than follow the established grid system oriented to meridians and parallels. For operation of the lands he stated "...... As pasturage lands should have water fronts and irrigable tracts, and as the residents should be grouped, and as the lands cannot be economically fenced and must be kept in common, local communal regulation or cooperation is necessary." (Powell, 1879)

The sharp break with tradition embodied in Powell's proposal in regard to the minimum size of individual holdings, the method of conducting the divisional land surveys and the communal type of operation, made it unacceptable to Congress. In the light of present day knowledge and experience it appears unlikely that it could have been successful if adopted because more adequate exploration and mapping of the arid areas has shown that in many parts of the West, particularly the Colorado Plateau and the Basin and Range Provinces, there are not enough streams and springs for even small irrigated tracts or watering places for stock. Nevertheless this was one of the first proposals for a solution of the grazing problem in the West, and it emphasized that 160 acres of arid range land was totally inadequate for a family livestock operation.

The requirements of large acreage for stock-raising purposes so clearly emphasized in the Public Lands Commission report was subsequently recognized by Congress. First was the passage of the Kinkaid Act of 1904, which applied only to the grazing lands in Nebraska, followed by the Enlarged Homestead Act in 1909, and finally the Stock Grazing Homestead Act in 1916, designed for the benefit of stock growers. The chief appeal of each of the acts was the provision allowing entry of as much as 640 acres.

The Stock Grazing Homestead Act applied most directly to the grazing lands. Its objectives were to stabilize the western stock-growing industry and to alleviate the deterioration occurring on the range. Although criticized by many stockmen, the Act did stimulate entries so that in the period between 1916 and repeal of the Act by passage of the Taylor Act in 1934, more than 68 million acres were entered. Of this, less than half, or 32.7 million acres, were taken to patent. At the time of repeal, much of the Act's appeal had been lost. Entries in the final 5 years were less than half what they had been during the first 5 years, and the acreage taken to patent was much lower than in former years. This could be attributed in part to the generally poorer quality of the remaining land but more importantly it reflected the increasing awareness by stockmen that even a 640-acre homestead did not supply the answer to the western range problem.

A major step in public land policy, which differed from that of disposal to private owners was the establishment of the forest reserves - later, the national forests - in 1891 although funds for their administration were not appropriated until 1897. Although the reservation of the forests met with a large amount of opposition from some private interests, the number of forests grew until about 1909 when the total area reached to near that of the present time. The forests were administered at first by the General Land Office until in 1905 when the Forest Service was established in the Department of Agriculture. Thus a large part and generally the best part of the federal lands came under management of a Federal agency, which formulated a system of fire control, and regulations covering timber sales and timber cutting, grazing, and other uses of the forests so as to prevent deterioration of the land and water resources.

However, even until 1930, more than 175 million acres in the western states remained in "unreserved public domain" status. Wide differences of opinion had developed concerning what to do with these lands. Some people advocated staying strictly within the original homestead law, their contention being that given enough time the area would be settled in 160-acre tracts. Others, were opposed to any homesteading of these lands and favored a system of leasing exclusively, and still others advocated transfer of the lands to the States in which they were located. These differences have not been completely eliminated with passage of the Taylor Grazing Act, and the establishment of the grazing districts together with the leasing provisions applicable to other lands as well as other provisions of the Act, represent a compromise. Whether the Act is best suited to the administration of the remaining approximately 175 million acres of land will be judged by the experience of time. To date most of the evidence indicates that, in general, it has proven satisfactory. At least, no other type of administration appears to offer definitely better prospects for optimum use and conservation of the land.

CONSERVATION PROBLEMS ON THE PUBLIC DOMAIN

Conservation problems on the public domain involve two critical features, erosion and vegetation. The two are intimately related, and measures which correct problems in one are usually beneficial to the other. Of the two erosion is the more critical since it represents a progressive destruction of land and forage plus the harmful effects in areas where the eroded sediments are deposited. It is likely to be the most difficult to correct. Vegetation is of more immediate concern to the stockmen, affecting as it does the profitability of his operations. As a conservation problem it differs from erosion in that the best quality and least eroded lands as a general rule have received priority treatment because they are most amenable to successful and rapid rehabilitation for forage production.

Erosion

It is widely recognized that erosion is the most significant problem on the public domain. Its effects are reduction in productivity of the land and sedimentation of the streams. A major part of the sediment being carried by the more important western streams originates from the public domain and Indian lands. As an example, in the Upper Colorado River basin the largest aggregation of public domain lands is located within the Colorado Plateau province occupying southeastern Utah, southwestern Colorado, northwestern New Mexico, and northeastern Arizona. As shown by available stream flow and sediment records, the area here constituting about half of the drainage basin above Lee Ferry contributes only 13 percent of the water but 60 percent of the sediment measured at the station. The computations of the relative areas occupied by the mountains and plateaus are based on the drainage areas and discharges above and below the principal gaging stations. Actually the discrepancy between water and sediment discharges of the strictly mountain and plateau areas may be even greater. In the San Juan River basin where the gaging stations are nearer the mountain boundaries the records show that the plateau area contributes about 6 percent of the water but 83 percent of the sediment measured at the station near Bluff, Utah. In the Rio Grande Basin, the Rio Puerco occupying 38 percent of the drainage area, which has a land pattern consisting mainly of public domain and Indian Reservation lands, contributes only about 10 percent of the water but 65 percent of the sediment carried by the Rio Grande as measured at the gaging station, Rio Grande at Bernardo.

Sufficient data are not available for a quantitative appraisal of the water and sediment contribution from other extensive tracts of the public domain among which are parts of the Milk River basin in Montana, the Bighorn, Powder, and North Platte River basins in Wyoming, and the San Simon and San Pedro River basins, tributary to the Gila River in Arizona. However, the records for the Bighorn and Powder Rivers show high sediment discharges, and the evidence of erosion is so striking in the public lands in these drainage basins that there can be no question of their importance as sources of sediments being carried by the streams.

The principal reasons for the high sediment yield from the public domain are evident. First is the sparse vegetational cover as a result of the arid climate and the erodibility of some of the soils; second is the abuse of the land that took place at a time when there was neither restriction nor regulation attached to use. Although both the natural factors and the land use undoubtedly have contributed to the development of the critical erosion of the land there is a considerable difference of opinion regarding the importance of each.

These conditions raise serious questions regarding the proper methods of treatment for erosion abatement. In short, it may be logical to question if the treatments as carried out in the past were incorrect or merely insufficient. Fundamental to securing the answers is a determination of the distribution and causes of the erosion. If present conditions are actually the result of land abuse--principally gross overgrazing--then given enough time at least partial recovery should be expected from elimination of the practice. But if other factors are involved, then obviously other corrective measures must be applied before improvement can be attained.

The studies and experience of the past years have failed to furnish clear-cut evidence on the best approach to solving the erosion problem. It is obvious that because of the general aridity prevailing over the range lands, the erosion is not self-healing in most localities. An optimum vegetation cover, which represents one of the best inhibitants to erosion, can be secured only where plants are given the maximum encouragement and protection. This means strict regulation of use or, where necessary, elimination of all use for a time or even permanently. This has been proposed for some of the so-called frail lands. If the vegetation has been destroyed the growth must be restored by whatever means are feasible. In short, the successful solution of the erosion problem will require continuing study and experimentation with the realization that no one practice or treatment is likely to prove successful in all localities. In general, each area must be judged on its own merits.

The public domain lands are subjected to all the common types of erosion including sheet and rill erosion, gully cutting, badland development and wind erosion. Of these, sheet erosion has the widest distribution but is usually the least noticeable, gullying is very spectacular and potentially highly destructive, and formation of badlands represent a complete deterioration of the land affected. The effect of wind action can range from the elimination of all plant life as in some areas of dunes, to the minor movement and deposition of sand which in certain respects may be beneficial. The treatment needed to secure abatement or control of each type of erosion presents an individual problem often unique to that type and the environment.

Sheet erosion

Sheet erosion, although often inconspicuous, is active on practically all range land. The rate at which it occurs is dependent on several factors including.slope, amount and intensity of precipitation, soil characteristics and vegetation cover, all of which influence the amount and rate of infiltration and thus control the runoff. It is seldom possible to isolate sheet erosion and measure it separately as most types of erosion occur together, but a close approach to this has been made at one small drainage basin in the Cheyenne River basin (Hadley and Schumm, 1961). This basin has a fair grass cover throughout, and there are few active rills. Volumetric measurements made in a stock reservoir gave an average annual sediment yield from the basin of 1.2 acre-feet per square mile of drainage area during a 15-year period.

This compares with a general annual average sediment yield of 1.4 acre-feet per square mile from 23 nearby drainage basins having a comparable vegetational cover but which contain gullies and rills of varying size and intensity.

These findings suggest that altheugh sheet erosion may go unnoticed except with careful measurements, it nonetheless forms an important part of the erosion process. In some localities, most particularly in the Southwest, sheet erosion becomes more conspicuous; there many areas show transitions from a well established plant cover through the stage of plant pedestaling to the death of all plants and the subsequent development of slicks totally devoid of any vestige of vegetation (fig. 2).

Figure 2.--Follows near here.

A. Early stages in formation of a slick showing plant pedestals and the removal of intervening soil by wind and sheet erosion, near Winslow, Arizona. Photo 1959

B. Erosion has removed pedestaled plants leaving a smooth "slick" surface; site near Correo, N. Mex. Photo 1960

Figure 2.--Transitions in the formation of a slick.

Thousands of acres have been affected in this manner particularly in the Rio Grande and Gila River basins, the San Simon Valley in southeastern Arizona being one of the more outstanding examples (fig. 3).

Figure 3 follows near here.

Here a belt ranging in width from a few hundred feet to more than a mile extends continuously along both sides of the main drainage channel for a distance of nearly 50 miles. The Bureau of Land Management estimates that a total of 23,000 acres is contained within this belt, most of it barren as a result of sheet erosion followed by deterioration to badlands (Note fig. 3-B). Other impressive tracts of this character occur along the Arroyo Colorado, tributary to the San Jose River near Correo, New Mexico; near Ladron Mountains along U.S.A. Highway 85 in New Mexico, and along tributaries of the Bighorn River in Bighorn Basin, Wyoming and Willow Creek, a tributary of Milk River near the Fort Peck reservoir in Montana to cite just a few examples. Smaller tracts can be found in practically every major drainage basin in the West.

A. Slick showing rate of sheet erosion. Fence installed 1938, erosion Approximately 6 inches. Photo Oct. 1959

B. Slick with newly formed channel beginning to form badlands. Photo Oct. 1959.

Figure 3.--Slicks resulting from sheet erosion on floor of San Simon Valley, Ariz.

Sheet erosion has effects other than the lowering of the ground surface and as a supplier of sediment. Removal of organic matter at the surface and the plants results in a change in the infiltration capacity of the soils to the extent that reestablishment of vegetation on these tracts becomes extremely difficult. Most soils on valley floors that are particularly subject to sheet erosion are fine-textured with inherently low infiltration rates. Plants and burrowing animals and insects which depend on plants for their livelihood, provide the major avenues for water to enter the soil. When the plants are eliminated these avenues cease to form. The reduction in infiltration is particularly noticeable during the short intense summer rains.

Gully erosion

Used in the sense of an erosion feature, a gully has been defined as a channel so deep that it cannot be crossed by a wheeled vehicle or eliminated by plowing (Peterson, 1950). This definition sets the minimum dimensions only; on the maximum side gullies can approach the dimensions of small canyons. In cross section a typical, newly formed gully has vertical sides and a flat bottom. It may range from 3 feet to 100 feet in depth and from a few feet to several hundred feet in width. The length can range from a few hundred feet to hundreds of miles. One of the distinguishing characteristics is the method of growth which is practically always headward, the channel generally being cut to its full depth at one time. Although it is difficult to determine how much of the gully cutting is due to abrasion by flowing water observations indicate that such cutting is quite minor as compared to slumping or sloughing of moistened walls. The slumping is enhanced by piping, a process in which water penetrates the valley floor and erodes a tunnel to the gully wall. Many piping holes have been observed 30 or 40 feet from the walls of deep gullies. The rate of the headcut advance may be only a few feet per year or it may range up to several hundred feet or even miles in a single storm or a series of storms. Views of typical gullies are shown in figure 4.

Figure 4.--Follows near here.

Many are too large to be effectively shown in a photograph.

A. Rio Puerco near San Luis, N. Mex. Lower part of channel is cut in shale. Photo Sept. 1965.

B. Polacca Wash below Polacca, Ariz.; shows the effect of diversion upstream and the gradual filling with wind deposits. Photo Oct. 1958.

Figure 4.--Views of typical gullies.

Gullies occur in most stream valleys located on the public domain in all the western states, and few areas have escaped being influenced in some manner by their presence. In New Mexico the gullied tributaries of the Rio Grande, including the Rio Puerco, Gallesteo, Jemez, and Salado, represent the more prominent examples of the myriads of gullied channels located within this area. In the Gila River basin most of the major tributaries, including Mangus Wash, Railroad Wash, San Simon, Santa Cruz and San Pedro Rivers, and a host of smaller tributaries, have gullied channels cutting almost the full length of their valleys.

Another display of gullied valleys is found in the Upper Colorado River basin. Bailey (1935) reports that an examination conducted by the Intermountain Forest and Range Experiment Station disclosed that of the 115 major tributaries of the Colorado and Green Rivers above Lees Ferry, 111 are gullied. Most of these traverse valleys containing large areas of public domain or Indian reservation lands. The combined length of these channels and their tributaries is on the order of thousands of miles, and the total volume of material removed in excavating the channel aggregates hundreds of thousands of acre-feet. This network of gullies and the associated other kinds of erosion provides the high sediment load carried by the Colorado River and particularly the exceptionally large contribution of streams draining the central plateau section of the basin.

Although somewhat less prevalent than in the Southwest, many gullied channels occur in the northern latitudes in the Missouri, Columbia River basins, and the Great Basin. The Wind River, Bighorn, and Powder River Basins of Wyoming contain numerous gullied channels, among the better known being the Fivemile, Muddy, E-K, and Badwater gullies in the Wind River basin; the Cottonwood and Fifteen Mile Creek gullies in the Bighorn Basin; and the South Fort Powder River and other channels in the Powder River basin. Their counterparts on a smaller scale are distributed through much of the remaining part of Wyoming. Willow Creek and other tributaries of Milk River as well as many direct tributaries of the Missouri River in northern Montana are also badly gullied.

Gullied channels also occur in the semiarid zones of eastern Oregon, in the dry Snake River plains of Idaho, and in the driest parts of the Great Basin in western Utah and eastern Nevada. For the most part, however, these are generally not so large as in the other basins and are mostly discontinuous. However, very little of the West is lacking in these features, and areas where most of the land is in public domain status possibly have the greatest number.

Although the amount of material that has been excavated from these gullies is tremendous, many gullies are no longer heavy contributors of sediment owing to the lowered rate of headward advancement and bank cutting. A considerable number of the channels are approaching the drainage divide, and as the drainage area above the headcut is decreased, the rate of advance is slowed and eventually must cease completely. Also, as the channels become wider they are less subject to bankcutting, and in many of the older channels aggradation is occurring in some of the wider sections, thus reducing the sediment delivery by the stream. Even in some channels that appear to be actively eroding, widening of the channel by sapping and undercutting of the banks actually is proceeding at a surprisingly low rate. Measurements made during a 6-year period at selected sections on raw vertical cutbanks in Lance Creek, Cheyenne basin, Wyoming, showed that the cutting rate averaged less than 0.5 foot per year (Hadley and Schumm, 1961). A detailed survey of the full length of Lance Creek during this same period revealed that about 29 percent of both banks were actively cutting. Applying a rate of 0.5 foot per year to the cutting reach, it was estimated that the annual contribution from bankcutting was 24 acre-feet out of a total sediment yield of 600 acre-feet from the Lance Creek basin.

Observations in gullied channels in the Southwest suggest that the findings in Lance Creek might also apply in these areas and, in fact, conditions over most of the West seem to warrant drawing the general conclusion that in years characterized by ordinary storms the actual enlargement of gullies through headward advance or bankcutting is not a major source of sediment. This is not meant to infer that gullies have not widened and lengthened over the years, as assuredly most have. However, the greater part of this enlargement occurs during years having extraordinary storms that produce copious runoff.

A critical feature of gullying is not just its contribution of sediment, but the fact that it sets the stage for the development of more serious deterioration of the land. A comparison between the condition of a valley, prior to and following its dissection by gullying, shows the reason for this. Prior to being cut, most western valleys had a flat alluvial floor unbroken except for a shallow main channel and tributary channels protected by trees, shrubs and other types of plant growth aligned along the banks. Floods of more than moderate size-usually the highest flows of each year or two-exceeded the capacity of the channel and spread out across the flood plains, thus furnishing an irrigation to the valley floor. In response to this increased water supply the flood plains became the heavy forage producers, and naturally they were sought out and utilized by the early stock grower, a condition which eventually helped destroy them. In some places water from the flood irrigation was sufficient to maintain the ground-water table near the surface, and many plants sent their roots to the water table or to the overlying capillary fringe.

As the gully developed, conditions in the valley changed drastically. Flows which had formerly caused overbank flooding were now confined in the new channel except during the largest floods and flood irrigation practically ceased. Furthermore, the new channel acted as a drain, and the high water table was soon lowered to a stage approaching the channel floor. The effect of such action can still be seen in places in the Southwest where the advance of a gully head-cut very soon is accompanied by the spectacle of dying plant life in a belt from one to several hundred feet wide on both sides of the channel (See fig. 3-B). Within a short period the lush vegetation that formerly grew on the valley floor is replaced by scattering of desert plants capable of surviving under the local rainfall conditions.

Another significant aspect of the gullying is the establishment of a new base level of erosion in the valley. Conforming to the rule of accordant junctions (von Engeln, 1942), the tributaries of a stream whose profile is lowered in this manner will eventually cut to the new level of the parent. This in turn sets the stage for erosion to attack the entire drainage basin. The weakening or removal of the protective vegetative cover that accompanies the headward advance of the gully initiates sheet erosion as previously described. As the gully network expands, the intervening areas are attacked and gradually destroyed, often deteriorating into badlands. Because of these processes, there appears to be ample reason for classifying gullying as the most destructive and far-reaching type of erosion.

Badland erosion

Badlands have a wide distribution throughout the public domain. A few of the more spectacular and picturesque examples have been designated as national monuments or parks, among the more important being the Badlands National Monument in South Dakota, the Painted Desert, a part of the Petrified Forest National Monument, in Arizona, and the Bryce Canyon National Park and Cedar Breaks National Monument of Utah. Aside from their aesthetic quality, however, the tracts are generally barren, with little or no capacity for production of vegetation and a very large potential for sediment yield.

The appearance and characteristics of badlands are well known. In them generally all types of erosion have operated and continue to operate. An essential requirement for their development is that the major part of the underlying rock or soil must be soft and nonresistant to erosion. However, the rock formations in many badland areas contain some lenses of fairly resistant rock enclosed in the erodible matrix. Through differential erosion the picturesque and weird forms occurring in some areas have been developed. The soils for the most part are fine-textured, vulnerable to rainfall impact, and readily moved by flowing water. In general, the materials have relatively low permeabilities but are not necessarily impermeable.

Although it is not known in quantitative terms how much of the erosion in badlands is due strictly to abrasion by surface runoff, observations have shown that part of the erosion comes about by mass movements such as creep and slumps of materials after thorough wetting by water which has infiltrated a short distance below the surface. Anyone who has walked or driven a vehicle through the badlands muds after a heavy rain will recognize that some of the moisture went into the ground. A necessary accompanyment for erosion to continue is sufficient flow in the main channels to remove the eroded materials.

Part of the badland tracts have developed as a result of erosion of unresistant rocks along uplifts. Here the slope of the land is probably the dominant factor in the intensity of the erosion. Other badlands have developed in belts along streams which have become deeply incised below the uplands. The proximity of a main stream provides the opportunity for the eroded material to be moved out from the lower part of the badland tract and thus allows the erosion to proceed.

In conformity with these criteria, badlands generally are found most prominently developed in areas underlain by formations composed largely of shale, clay, and siltstones, fine-textured alluvium and lakebeds. In some localities of eastern United States where the climate is much more humid than on the public domain of the West, badlands have developed also on thick residual soils derived from granite or other rocks. Large areas of badlands occur in the Cheyenne River basin of Wyoming along the outcrop of the Brule Formation of the White River group of Tertiary age, consisting essentially of slightly indurated soft shales and clays (Hadley and Schumm, 1961). Surveys show that about 15 percent of the outcrop area of the White River group within the Cheyenne River basin is badlands. Farther south where the same formation crops out in the North Platte Valley between Douglas and Orin, Wyo., badlands occupy an estimated 30 percent of the total outcrop area. Some 200 miles to the northeast the picturesque Badlands National Monument in South Dakota is carved in the same formation.

Another zone of badlands follows the outcrop areas of the Wasatch and associated formations of Tertiary age, extending across southwestern Wyoming into north-central Utah and south along the Wasatch Plateau into southern Utah. Bryce Canyon National Park and Cedar Breaks National Monument are the most striking examples.

Many areas of badlands occur in the Colorado Plateau. Some of the more conspicuous are carved in the Mancos Shale of Cretaceous age that crops out in a belt fronting the Book Cliffs extending from Debeque Canyon above Grand Valley Colorado around Price Valley and Castle Valley Utah to Emery, Utah. The steep slope of the Book Cliffs below the capping Mesaverde Sandstone might well be classed as a continuous line of badlands, and the adjacent secondary slope or pediment is cut forming badlands at intervals along the drainage courses for as for as 5 miles from the Book Cliffs.

Another series of badland areas follows the outcrop of the Chinle Formation of Triassic age where the best known example forms the Painted Desert in the Petrified Forest National Monument, east of Holbrook, Ariz. Prominent areas also occur in the Navajo Indian Reservation in northeastern Arizona along the side slopes of Beautiful Valley between Ganado and Nazlini and again farther north in the Chinle Creek basin north of the settlement of Chinle. Other areas occur in the Little Colorado River basin along the flanks of the Hopi Buttes and further west in the lower part of the Polacca Wash basin north of Leupp, Ariz.

Local badland areas occur in the Wind River Formation of Wind River Basin, Wyoming, and in the Willwood Formation and in Cretaceous Shales in Bighorn Basin, Wyoming. In Montana badlands underlain by the Bearpaw Shale and Judith River Formation occupy a long belt in the "Breaks" of the Missouri River. Other tracts of badlands occur on the outcrops of the Hell Creek and Fort Union Formations of eastern Montana.

Wherever measured, the sediment production from badland areas is high. A series of measurements by Hadley and Schumm (1961) and by Schumm (1956) made on small plots in badlands in the Cheyenne River basin, Wyoming, and the Badland National Monument, South Dakota showed degradation of the ground ranging from 0.6 to 1.8 inches per year, equivalent to 32 and 96 acre-feet per square mile, respectively. A measurement in a Bureau of Land Management reservoir located on Crescent Wash 20 miles east of Green River, Utah, gave an average sediment annual yield of 1.66 acre-feet per square mile of drainage area during a 4-year period, 1954-57, but the bulk of this occurred in two major storms which produced a total of 126 acre-feet of sediment from 19 square miles (Peterson, 1962). The drainage area consists largely of badlands carved on slopes of the Book Cliffs. The Paria River, which drains the badlands of Bryce Canyon National Park and other badland areas in southern Utah, carries a very heavy sediment load. Maximum daily concentrations for the period of record have reached 300,000 to 400,000 parts per million for storm flows in several years (Iorns et al., 1965).

Badlands of the type found in the national parks and monuments, in the Book Cliffs, as well as many other places, are old features, developed long before the period of white man's occupancy of the West, and his activities appear to have little effect on them. Possibly in some localities, prolonged overgrazing, trailing, or other type of land misuse may have aggravated the erosion, but in general, the steep slopes prevalent in these areas were unfavorable to grazing, and the soils are not of the type that produce a good vegetative cover. It is concluded that the development of badlands in these localities is primarily a natural rather than an induced condition.

On the other hand, large areas of badlands definitely have developed in the Southwest since arrival of the white settlers. Their formation is analagous to badlands that have developed locally on farm lands in many places in the eastern States, which have been studied and well-documented by the Department of Agriculture (Bennett, 1939). The previously mentioned transition of the alluvial floor of the San Simon Valley from slicks to badlands has occurred since the arrival of the American settlers in the late 1870's. The total area of the badlands is on the order of several hundred acres. Lacking any type of vegetative protection the rate at which the remaining slick lands can erode into badlands is limited only by the amount of runoff generated by rainfall and the competence of the main channels for transport of the sediment. The results of a capital storm on this type of terrain under present conditions could be catastrophic to the people and lands below.

Figure 5.--Follows near here.

Less extensive areas of badlands occur in other gullied valleys in the Southwest, particularly in Railroad Wash, Mangus Wash, and other tributaries of the upper Gila River, and in the San Pedro and Santa Cruz valleys in the lower Gila basin. Other tracts occur in the Rio Puerco basin tributary to the Rio Grande and in parts of the San Juan River basin in New Mexico. Significant areas also occur in the Little Colorado River basin in northern Arizona.

A. Extensive area of badlands near Bailey Well, San Simon Valley, Ariz.

B. Early stages of badland erosion near Tanque railroad siding.

Figure 5.--Badland erosion on the floor of the San Simon Valley, Ariz.

Continuing erosion of badlands results from the action of onsite runoff from rainfall or snowmelt together with transport of sediment in the main channels. Thus, badlands can expand indefinitely on either level or sloping land wherever the stream base level has been lowered and the soil conditions and the precipitation are favorable. The dissection of the large and expanding area in the San Simon Valley to the state shown in figure 5-A is an extreme example of what could happen in other localities where badlands are found.

Fortunately, badlands that have developed in some places are to a degree self-healing. Deposition of material eroded from the steeper slopes in the flatter areas tends to establish a new non-eroding level. Where conditions are favorable for establishment of vegetation on the newly deposited materials, parts of the badlands areas again become productive, and deposition is progressively increased. This is occurring in many of the badland areas in the Cheyenne River basin in Wyoming and to a lesser extent and at a slower rate, on some of the areas in the higher parts of the Little Colorado and San Juan basin in Arizona and New Mexico. Badlands in the humid eastern states have been greatly improved by changing land use accompanied by planting soil-binding vegetation. There, of course, vegetation will grow if given half a chance. However, there is little evidence of healing in the San Simon badlands or in other areas in the Gila River basin because it appears vegetation will not become established under the prevailing low rainfall and high temperatures and high evaporation, hence, there is nothing to induce deposition.

Wind erosion

Large expanses of public domain land are subject to wind erosion, but the extent and amount of actual damage caused by winds is often difficult to evaluate. Large moving dunes which overwhelm and destroy all types of vegetation are important locally, but compared to the total area of the public domains their effect is relatively small. In other areas affected the effect may range from severe or total destruction of the vegetation to a benefit from the deposition of sand.

Gregory (1917) has described the action of winds in the Navajo Indian Reservation and the dunes that floor the Tusayan Washes and other parts of the south slopes of the Black Mesa. Many of these dunes are stable and support a growth of vegetation; in fact, vegetation on the dunes often is superior to that on adjacent areas not covered by sand because of the high absorption rate and lack of runoff from the dune areas. Farther north in the middle and lower reaches of Chinle basin in Arizona and westward across the Kaibito Plateau toward Cameron, and beyond to the Coconino Plateau there are moderately large areas of active dunes. The great majority of these are low longitudinal dunes aligned with the prevailing southwesterly winds, and it is doubtful if they have any material ill effect on the forage resources of the area. Most of the wind movement occurs in the spring months, which is the period of low precipitation and little vegetative growth. During the summer rainfall season the dunes may exert considerable control on the runoff to the advantage of the vegetation and reduce fluvial erosion in the area.

In New Mexico a dune area in the Rio Grande basin extends northward from the Rio Salado just above San Acacia, to beyond the Ladron Mountains into the lower reaches of the Rio Puerco. Part of the area in the lower Salado basin contains large active barchan dunes, but the remainder is covered with low longitudinal dunes and deposits of loose sand. It is reported that this area once afforded good grazing, but as a result of serious overuse and protracted drought, the vegetative cover was badly depleted. It now appears that with a few years of normal or above normal rainfall the area has a good chance of recovery, because the sand deposits catch and hold the rain and make it available for plant use.

Another area of several square miles showing some beneficial effects of wind action is located on both sides of U.S. Highway 66 west of Coreo Junction, N. Mex. Following a period of severe overgrazing coupled with drought, the area had reverted to an almost barren plain. Vegetation consisted mainly of dead pedestaled clumps of grass and shrubs separated by wide stretches of barren slicks. Prospects for rehabilitation seemed poor. However, in 1951 a fortuitous sequence of high spring wind which caused sand to lodge behind the pedestaled plant stumps and other protected spots, followed by good summer rains, was sufficient to start a strong vegetation revival. The sand made a good moisture-retaining seed bed. The recovery since then has been impressive, and it now appears that with near normal rainfall and reasonable land, use vegetation approaching its original density will be re-established.

Some wind erosion damage on a local scale occurs in Utah. A number of the valleys that extend southward from Great Salt Lake contain dune areas along their western margins resulting from the deposition near the mountains of sand carried by the prevailing southwesterly winds. The greatest concentration of dunes occurs along the southern margin of the Great Salt Lake Desert, but as much of this land has been incorporated into a military reservation the effect of the dunes on forage yield is no longer of importance. One large dune area in the north end of the Tooele Valley has been stabilized by a combination of mechanical treatment and seeding and now produces good grass forage.

Barren areas attributable to wind erosion occur in the southeastern part of the State between Moab and Monticello, southwest of Blanding and, north of the San Juan River, where large tracts underlain by the Entrada, Navajo and Wingate Sandstone are swept clean by the wind, leaving no opportunity for the formation of soil. The tracts appear to have been in this state for a long period, suggesting that land misuse is in no way responsible. In other areas of the State affected by wind action, there has been no serious damage to the native vegetation, and wind erosion is not considered serious enough to warrant treatment for control of the sand.

Despite the generally windy character of Wyoming, actual damage to range lands by wind erosion is limited in extent, and so far as known there have been only very minor expenditures for wind erosion control. Most of the erosion on the public domain is confined to the southwestern and central parts of the State. Between Lyman and Green River south of Highway 30 there is a large denuded area of desert pavement displaying the typical mosaic of pebbles. This obviously is an old wind-swept tract, and it is doubtful if historically its cover of vegetation was any greater than at present.

A large area in the eastern part of the Wind River basin in the vicinity of Highland and extending south of Poison Creek contains accumulations of wind-blown sands which are now stabilized and are producing some of the best forage in the basin. These lands also show very little erosion by water although adjacent areas which have no sand deposits are extensively eroded.

A few additional areas displaying some wind erosion and which will probably require special treatment for abatement are in the Snake River Valley in the vicinity of Glenns Ferry and Mountain Home, Idaho. The erosion can be attributed in large part to the occurrence of grass fires and the most effective treatments appear to be the substitution of a grass cover that is less prone to fire than the highly flammable cheatgrass prevalent in this area.

CONSERVATION PRACTICES ON THE PUBLIC DOMAIN

As set forth in the preamble, the objectives of the Taylor Grazing Act are "To stop injury to the public grazing lands by preventing overgrazing and soil deterioration, to provide for their orderly use, improvement, and development, to stabilize the livestock industry dependent upon the public range, and for other purposes." This statement embodies a broad directive for conservation on the public lands involving both the management of grazing and other use of the lands. In providing this broad framework, however, a whole field of unsolved questions and possible conflicts inherent in the problem of conservation on these lands becomes apparent.

Conservation and the design of conservation measures on any type of land is not simple, but on low-value arid lands it becomes increasingly difficult and complex. The word itself is subject to different definitions and interpretations, depending on the viewpoint and interests of the individual or group. Thus downstream water users are inclined to stress the need for the restrictive use of water on upstream range lands and the avoidance of any practice that might consume extra water. The major interest of range users, on the other hand, is growing forage, which possibly may be in conflict with downstream water yield. The conflict between sportsmen and stockmen over the kind and extent of range improvement has been mentioned.

The Committee on Soil and Water Conservation of the Agricultural Board has defined land conservation as an investment "(1) in maintaining productive potential, (2) in decreasing progressive deterioration, (3) enhancing the productive potential." (Nat. Acad. Science 1961) A definition possibly more nearly applicable to the management of the range lands is one enunciated by a former Secretary of the Interior: "The common denominator of most definitions is the concept that sound conservation demands wise and prudent use - without either waste or abuse of our natural resources"(Seaton 1957). Applied to the public domain either definition would appear to adequately describe the objectives of conservation, provided that rules and criteria for evaluating productive potentials and deterioration, waste and abuse can be devised and agreed upon.

Under whatever definition or objective was adopted, the task faced by the early administrator of the public domain to obtain optimum use of the range with maximum conservation was a formidable one. On lands where the vegetation had been badly depleted by grazing and drought, with 50 percent of the area in a state of critical erosion and another 25 percent showing moderate to severe erosion, and with limited financing and an inadequate staff for field examinations and essential range classification, his problems were multiplied many fold. In addition little was known concerning the procedures and methods that were best suited for use and treatment of the lands. What experience and knowledge on these subjects were available had been obtained in the subhumid and humid eastern parts of the country or in the national forests, which also were moister and had a better cover of vegetation. The majority of conservation methods used in these climates was not adaptable to the dry western range lands and as a consequence numerous mistakes were made in the early efforts at treating range lands.

One further circumstance complicating the program was the attitude of the stockmen many of whom were opposed to or suspicious of any form of Federal regulation of these lands. Although the Taylor Grazing Act was designed to benefit them through improvement of the range, great uncertainty existed as to how extensive this might be and how rapidly it could be achieved. Definition and recognition of the rights of individuals to use of the range was another critical question facing the stockmen. Because only minor parts of the land were in private ownership, and the door had been closed to further acquisitions, range rights had to be predicated on past use. This meant determining both the period and extent of the use and since there were no official records of either, dependence was placed on local users to furnish the information. The District Advisory Boards were organized for this purpose. Out of their deliberations grew the procedures for awarding rights to use of the range based in part on commensurability and in part on prior use by the individual during the 5 years immediately preceding the passage of the Act.

The right to use the range usually represented a compromise, often between antagonistic competitors. Rules governing the granting of the rights were slow in being enforced, and it was obvious that the favorable influence on the range resulting from changes in use would be slow in coming. The administrators were thus confronted with the need to develop other measures for improving the range as rapidly as possible within the framework of the early regulations suggested by the Advisory Boards and with a minimum of interference with the users. Two avenues to this end were open (1) immediate and continuing reduction of numbers permitted under the provisions of the Act relating to the itinerant herdsman who had been unable to establish a use right and (2) development of range water which would permit not only better distribution of livestock on the range but would also expand the range by bringing in use areas which previously had been inaccessible due to lack of water.

Reduction of livestock numbers

The obvious first step in seeking to improve the range following passage of the Taylor Grazing Act was reduction of livestock numbers to a figure approaching the proper carrying capacity. Correction of overuse was implicit in the Act, as indicated in one phrase of the preamble, which describes this as "An Act to stop injury to the public grazing by preventing overgrazing and soil deterioration. ....."

Under open range conditions, practically the only regulation on range use was imposed by a small percentage of resident stockmen who attempted to protect, in some cases by force, the area they were using against the itinerant herdsman who otherwise took forage wherever and whenever he could find it. To the credit of the majority of resident stockmen, they usually were more conservation-minded than their itinerant competitors, but in many localities in order to survive they also were forced to graze the range far beyond its proper capacity and thus ignore the effect this action might have on the future productivity of the land. It should be noted also that prior to the 1930's little effort had been made to control grazing numbers on private grazing lands or the public domain mainly because conservation as applied to range lands was little understood and had not yet acquired any popular appeal. Grazing numbers had been reduced on the national forests during the 1920's, but the reductions were protested by many of the stock operators. Actually the enforcement of regulations on the national forests tended to bring about an increase of grazing on the unreserved public domain. The widespread severe drought of the early 1930's with its injurious effect on the range was in great measure responsible for focusing attention on the deplorable condition of the range lands and in showing the necessity for conservation. The drought also had the effect of greatly reducing livestock numbers. The ranges had become so depleted that the stockmen had to get rid of livestock if they hadn't died of starvation.

The first step in securing regulation of grazing was elimination of the itinerant stockmen. This was made possible by Grazing Service regulations which made it mandatory that grazing rights were to be established on either a land base, adopted in the northern states, or a water base, adopted in Arizona, New Mexico, and southern Nevada. This automatically disqualified the itinerant user in the north who had failed to acquire land and establish a base and his counterpart in the south who had neglected to develop and perfect a range water right. Within a relatively short period after passage of the Act this type of use was eliminated.

The itinerant herds represented only a part of the overgrazing problem and additional reductions were imperative in many localities if this aspect of the range improvement was to be obtained. Owing to a number of circumstances, including the manner by which the carrying capacity of the range is determined, but also because of the economic, social and political elements involved, it was obviously impractical to insist on immediate broad-scale reductions and hence they have been made at a slow pace. Although the reductions to date have been substantial they are still going on and doubtless will continue for some years in localities where overgrazing remains a problem.

Some idea of the extent of the reductions in numbers of livestock on grazing district lands is shown in table 3 for the 24-year period 1941-64. The numbers are not entirely comparable because some changes in the amount of lands in the districts have taken place. Overall the acreage has been increased about 3 percent and associated with this were some livestock using the additional lands. The period is cited because the compilation for 1941 was one of the first that list by states the number of livestock using the range. It will be noted that the table shows a reduction in the total animal units from about 3.6 million to 3.2 million, despite the increase in acreage.

A more meaningful comparison between range-use conditions over a shorter period has been given in table 2 which shows the number of animal-unit months of grazing use on both grazing districts and leased lands in the ten States containing grazing districts for the 10-year period 1955-64. No reliable data on AUMs of use on leased lands are available prior to 1955. It is seen that reductions in AUMs were still being made during this period.

Table 3.--Permitted use in Bureau of Land Management grazing districts 1941[1/] and 1964[2/] (calendar years).

State	Area in acres		Number of animal units		Number of animal unit-months
	1941	1964	1941	1964	1964
Arizona	9,748,900	10,512,346	132,077	105,026	638,997
California	3,423,400	2,235,575	110,567	90,704	233,347
Colorado	7,494,100	7,508,954	304,460	335,466	668,455
Idaho	11,513,900	11,275,789	465,916	388,525	1,197,015
Montana	4,885,100	4,938,378	309,857	440,814	1,268,284
Nevada	34,955,500	43,020,732	490,107	451,528	2,158,977
New Mexico	15,106,400	12,523,616	424,145	356,682	1,828,194
Oregon	11,919,700	12,422,762	254,231	238,778	962,924
Utah	24,331,000	22,198,683	610,009	344,658	1,382,657
Wyoming	12,960,100	13,363,831	482,348	443,711	1,522,392
Total	136,338,100	140,000,666	3,593,718	3,196,072	11,861,242

1/ Compiled from Report of the Secretary of the Interior for fiscal year 1941, p. 256, table 2.

2/ Compiled from Bureau of Land Management Published Statistics 1965 pp. 148-9, tables 88 and 89.

Evaluating the effect of reduction of numbers and change in type of livestock use on range improvement and on the hydrologic characteristics on an area is very difficult due to the complexity of the several factors involved. Changes in vegetation withinthe arid zones occur at a slow pace and are difficult to inventory and evaluate except by carefully detailed measurements. Also, the magnitude, distribution, and time of occurrence of precipitation may be of greater importance to vegetative growth than grazing use and it is difficult to distinguish between these two effects. In studies made by Hutchings and Stewart,(1953), and Smoliak (1956), it was found that the responses in growth of range vegetation to annual precipitation were very significant.

One such study aimed at determining the effect of grazing exclusion on vegetative recovery and on runoff and sediment yield is being carried out cooperatively by the Geological Survey, the Bureau of Reclamation, the Bureau of Land Management and the Forest Service Rocky Mountain Forest and Range Experiment Station in the Badger Wash drainage basin near Mack, Colo. Details of the study and results obtained during the first five years of operation are reported by Lusby et al. (1963). The two outstanding features shown by the report are (1) the exceedingly slow rate of vegetational recovery in this area even under total grazing exclusion and (2) the smaller runoff and sediment yield from the ungrazed area as compared with the grazed areas.

The results shown seem in a way conflicting because it would be expected that the smaller runoff resulted from an increase in vegetation. Instead the improvement in growth and type of vegetation in the ungrazed compared with the grazed areas during the 5-year period was so minor that it could not be accorded any statistical significance. For the 5-year period the unit area runoff from the ungrazed areas was 80 percent of that from the grazed areas and the comparative unit-area sediment yield was 77 percent. As precipitation records indicate only minor differences in rainfall between the areas, the reduced runoff and sediment yield from the ungrazed areas are believed to be due to the absence of trampling by livestock in the excluded areas. However, additional intensive soil studies are now being conducted to obtain more conclusive information on this factor.

Reasons for the lack of response by vegetation to the increase in amount of moisture retained is not clear, but probably important contributing factors are the distribution and character of the precipitation. Nearly all the runoff occurs in response to relatively intense summer rains despite the fact that the summer rainfall represents only 50 to 60 percent of the total annual precipitation. Moisture retention thus is built up to a maximum at the end of the winter and presumably forms the main supply for the growth of vegetation during the following growing season. The runoff producing storms are of minor aid to the vegetation in either the grazed or excluded basins. The part of the precipitation from these storms that doesn't run off probably is lost very rapidly by evaporation. This seems to be confirmed by the shallow penetration of moisture observed in these storms.

Range-water development

The task of securing better distribution of livestock and making all parts of the range available for use depends in the main on the distribution of range-water facilities. Systematic range examinations conducted at an early date by land agencies, particularly during the Civilian Conservation Corps program in the 1930's, had shown an urgent need for range-water development. The pre-Taylor Act user of the range had expended a minimum on such development for the obvious reason that he had no way of protecting his investment, and the Federal Government had invested little or nothing. Thus it was shown by the early range examinations that although critical overgrazing characterized large parts of the public domain there still remained a substantial acreage that was unused or only partly used due to lack of range water. Providing stock-water facilities for these areas meant that overgrazing in other localities might in part be relieved without the necessity of reducing livestock numbers.

Although the construction of new wells and reservoirs and the development of springs has to date led to the improved use of the range and gradual reduction of the unused area, the optimum spacing of water facilities is still a far distant goal. Many thousands of acres of valuable grazing areas are still short of range water and in consequence remain only partly used; but of greater importance numerous tracts could be more efficiently used from a conservation standpoint with closer spaced, better distributed and more reliable rangewater facilities. The continuing improvement of the vegetation through land-treatment methods is also certain to result in a demand for additional range water since it has been amply demonstrated that better forage economically justifies closer spacing of range water. Thus it is evident that water development is certain to continue for a long period of time as a major activity in the range improvement and conservation. For these reasons the following discussion of methods for obtaining range water is presented in considerable detail.

Because the major part of the public domain contains no perennial streams, range-water supplies must come primarily from wells and springs or reservoirs located to catch and store flood flows on ephemeral streams. The use of supplies from these sources may be expanded by distribution through pipe lines or by hauling. Each method of development and distribution has its advantages and likewise its limitations. Selection of the proper method for servicing the range can be made only when the advantages and limitations are fully recognized and understood. These are discussed in the following pages.

Well-site locations

The program to assist in developing range water through location of favorable drilling sites for wells was begun almost immediately after the Geological Survey had been designated as a participant in the Soil and Moisture program of the Department of the Interior. The activity has grown almost every year since. Most requests have come from the Bureau of Land Management and its predecessors, the Grazing Service and the General Land Office, but a number of sites have also been examined for the Bureau of Indian Affairs and for National Park Service in parks and monuments where watering places are needed for wildlife use.

Wells have the advantages of providing a reliable and generally permanent supply of range water that is available immediately on the completion of drilling and one that seldom interferes with any established water rights. Offsetting these advantages are the risks of failure to find water inherent in drilling in most arid areas, and to the high cost of drilling, equipping and operating the wells, particularly where deep drilling is required to obtain the necessary yield.

The field examination for well sites made by Survey geologists are of two general types. One type involves what are termed "spot locations" where an examination is made to determine the prospect for obtaining water in a well at a particular site designated by the requesting agency. The second type is an areal investigation, involving areas ranging in size from a few square miles to an entire grazing district covering hundreds of square miles and may include consideration of other watering facilities in addition to wells.

The spot location in general is the most difficult to carry out within a reasonable amount of time. The request usually involves a single site in an isolated area, which may be far removed from other wells or geologic features that might furnish the examiner some clue as to the horizon where water might be expected. Ordinarily the investigation of a designated "spot site" should be as detailed as for a larger area but logically there must be a limitation on the time that can be spent in obtaining information on subsurface stratigraphy, possible aquifers, probable depth to water, recharge conditions or other features which influence selection of any site since the cost of the examination should not exceed more than a reasonable percentage of the cost of drilling. Thus the chances of developing successful wells at these sites is dependent on the experience and judgment, and also in some degree, on the luck of the examining geologist.

The second type of investigation is broader in scope and is applied to large areas of range lands, such as complete grazing districts to all grazing lands within a drainage basin which may include parts of one or more grazing districts. The objective in most instances is to develop a complete range-water development program. In such a study, an inventory is first prepared showing the location of all existing stockwater facilities: wells, springs, and reservoirs. These are appraised to determine reliability and chemical quality of their water where questionable.

As a means of determining where additional range water is needed, existing range water facilities are assigned a service area defined as the area surrounding the facility where stock can graze with a reasonable amount of travel from feed to water with the assurance that no harm to the range will result from heavy concentrations or excessive trampling around the watering place. Expanding from existing facilities, additional service areas are struck off until the entire area under study is covered. By this means the examining geologist working with the range managers determines where additional water is needed and delineates the areas where geologic or hydrologic studies should be intensified.

The service area is usually shown by striking a circle or segment of a circle using the existing facility as a center. The radius of the circle may range from less than one mile to three miles or more, depending on the nature of the terrain and other elements of the environment. Stock will walk greater distances for water and still thrive where the slopes are gentle and not rocky, where the temperature is not excessively high and where the forage is sufficient to keep the animal healthy and vigorous. As a general rule water facilities are most closely spaced on the better ranges that support the greatest number of animals. A service area with a radius of 2-1/2 miles is considered maximum in most areas, but stockmen as a rule would prefer to reduce the spacing to half this distance or less. Other items that must be considered in planning the water-development system are the ownership or allotment boundaries and the depth and cost of drilling to obtain water.

Because of the importance of water distribution in efficient management of the range, the recent trend has been for the land agencies to request range-water studies for a complete district or a division thereof constituting a physiographic or geologic unit having similar management and water-development problems.

One example of a broad inventory type of study made at the request of the Bureau of Land Management was completed for the Ely Grazing District in Nevada covering about 9 million acres located mainly south and southwest of Ely (Snyder 1963a). The study was initially undertaken to furnish information that would assist the Bureau of Land Management in a two-fold objective (1) setting up individual grazing allotments for the entire district; (2) formulate a water-development program for long-term management to insure optimum use for all parts of the district. Information on existing and potential sources of range water was essential to the achievement of both objectives.

A similar type of study has been completed for Western Utah covering lands extending westward from the Wasatch Mountains to the Nevada State line (Snyder 1963b). The area includes parts of four grazing districts and three small Indian reservations. As the entire area is within the Basin and Range physiographic province, and the valleys containing most of the grazing land are similar in many respects, it was logical to treat the area under a unit-study plan even through the lands were not administered as a single unit. Several other areal studies of smaller units also have been made.

The general procedures followed in conducting the well-site examinations are based on well-known principles of ground-water hydrology that have been developed over the years by geologists and need not be repeated here (Meinzer 1923, 1927, 1939); (Tolman 1937). It should be noted, however, that even though the principles are well established, the geologist in evaluating most sites on the public domain encounters the problem of very low recharge and commonly complex geology; consequently he will need to develop new techniques and standards for judging the prospects for successful drilling. Practically none of the public domain is watered or recharged by streams issuing from the humid mountain areas as is the case in the agricultural valleys of the western states. (See Snyder 1957, Peterson 1961).

Although a prospective well-site must be evaluated in relation to its role in the overall range management plant, it may be considered favorable when it is reasonably certain that an aquifer pervious enough to supply the needed yield for a stock well is present within an economic drilling depth. The low-yield requirements of a stock well make it practical to drill in locations and test aquifers that ordinarily would not be considered if larger yields were required. It is a generally accepted rule on most western ranges that no more than 100 animal units can be grazed within the service area of a single watering place for any extended period without exceeding the carrying capacity and causing damage to the surrounding range. A continuous yield of 0.7 gpm (gallons per minute) would meet the requirement of 10 gallons per cow per day, but owing to natural losses and to the fact that windmills, which ordinarily supply the energy for pumping, operate intermittently, a larger yield to compensate for both the losses and the non-operating time is required. Wells that yield from 5 to 10 gpm are considered satisfactory in most areas and in some cases yields of 2 to 3 gpm are acceptable, particularly if water storage facilities are utilized to meet the needs of peak demands.

Where wells are to be used as a source of supply for hauling water or for extended distribution by pipe line the yield must be greater in accordance with the enlarged demands. Most wells of this type use pump jacks or small deep well turbine pumps powered by gasoline or electric motors. Minimum yield requirements for these wells range upward from about 20 gpm. An increase in the added yield may be obtained by deeper drilling if the aquifer has sufficient thickness, but if this is not feasible it will be necessary to explore for another aquifer of higher yield. In some cases this may require moving to a site where geologic conditions are more favorable than those at the site first proposed.

For the low yield requirements, a variety of formations may qualify as aquifers provided they are in a position to be saturated. These range from alluvial materials which can vary widely in composition, texture and permeability, through the consolidated rocks, conglomerates, sandstone and some limestones, to hard, well indurated rocks made permeable in variable degree by fractures, joints, bedding planes, or other openings. Clay, shale, siltstone, and dense, massive rocks devoid of fractures or other openings will seldom yield sufficient water even for a stock well, and in general will not be considered as potential aquifers by the experienced geologist.

Of the several hundred well sites that have been examined, only a relatively small fraction have been drilled to date. This low rate of completion is not surprising for several reasons. At some sites prospects are so unfavorable that drilling is out of the question. Development at many of the sites examined is considered part of a long-range plan of management and improvements, and it is assumed that drilling of the favorable sites will be carried out in the future as funds become available. Developments have not yet reached the stage where these projected wells are scheduled. At other sites the estimated depth to water may be so great or the chances of bringing in a successful well so uncertain that the allottee or the land agency regard drilling as not justified at present. Some of these sites probably will be drilled in the future as the land and the grazing rights become more valuable or other needs increase following the country's growth pattern thus justifying the added expense and risk of drilling. Evidence of this is shown by a large increase in wells drilled since about 1960. Other reasons why drilling has not been done at some sites have been due to unexpected administrative or policy changes and changes in land-use patterns.

Springs

Springs are important sources of range water in some localities, but there is evidence that they have not been used to the full extent of their potential. Tolman (1937) states that only a small proportion of the springs of the world are developed to full capacity, and in the arid regions they are rarely fully developed. This condition is apparent in many parts of the western range lands.

Most of the public domain has now been fully explored and all springs of any substantial yield have been discovered. Chances of finding new springs, therefore, are somewhat remote, but many springs have not been developed to their maximum usefulness, and some are not used at all in the misconception that the flow is insufficient when actually it may be lost. Often such flow can be recovered and made available with a reasonable amount of work and expense. A spring which can be developed to deliver a continuous flow of even one-half gallen per minute can be valuable since, if the water is properly conserved, it is sufficient to serve 70 head of cattle.

In developing for maximum yield, each spring is an individual problem, and only general suggestions can be offered. One rule of general application is that it is seldom possible to increase the actual flow of a spring, and most effort, therefore, should be directed toward utilization of the flow by eliminating or reducing losses. Ordinarily the spring orifice is not the controlling feature in the discharge, and any attempt to increase the flow by blasting or otherwise modifying the orifice is likely to result in scattering the flow, thus increasing the difficulty of salvage. Any area of wet swampy land or one supporting rank vegetation near a spring is an indication of water that might be recovered. In some cases all of the flow may be lost in this manner, leaving nothing for stock use. Often in these circumstances a successful stock-water facility can be developed by reducing the loss and diverting the salvaged water to suitable storage tanks and troughs.

As previously noted, the requirements for a range water facility are such that springs producing flows as low as 0.7 gpm are potentially valuable for this purpose. On the basis of evaporation data compiled by the U.S. Weather Bureau (1959) this amount can be evaporated during the summer months from about .2 acre of open water in the northern latitudes and 0.15 acre in the southern latitudes. Investigations on plant losses reported by Blaney and Criddle (1949) and by Blaney (1957) indicate that evapotranspiration from such commonly found phreatophytes as willows, tamarisk (saltcedar), sedge grasses, and salt grass can equal and often exceed the evaporation from open water. Thus it is evident that any spring that supports 0.2 of an acre or more of swamp or phreatophyte growth has a potential yield sufficient for a stock-water development, even though there may be little if any visible flow. Salvage of the wasting water may be simple or complex, and there will be cases where the cost exceeds the value of the water. Most salvage methods employ a combination of full or partial removal of the vegetation combined with drains to lower the water table and reduce evaporation from the wetted ground surface. A collection system leading to suitable troughs and storage tanks is essential. Extensive observation indicates that many small and presently unused springs can be developed into valuable range-water sources by application of these salvage methods.

Extended distribution of spring flow by pipeline.--The value of springs, particularly those with yields of 5 gpm or more, can be greatly increased through the use of pipelines to obtain extended distribution of range water. The most favorable opportunity for such distribution occurs where the spring is located in a higher part of a grazing tract, making gravity flow possible, but even with springs at low elevation it is often feasible to pump water -- using either windmills or motor power -- to higher elevation storage tanks from where extended distribution can be obtained through gravity pipeline.

A number of installations using either steel or plastic pipe are currently being operated. Increased availability of plastic pipe in recent years has greatly expanded this type of installation because of decreased cost and ease of installation, and there is a prospect of further expansion in the future. Pipelines have a particular advantage where several water troughs can be located along their course at proper intervals to service the range. Such installations as a rule cost less and are more effective than an equivalent number of wells or reservoirs. Only a few of the larger springs have been subjected to a careful engineering analysis to determine if expanded distribution by pipeline is feasible; the remaining ones should be analyzed. (See Stock water facilities guide: Pacific Southwest Interagency Committee, 1962)

Stock reservoirs

Stock reservoirs commonly called stock ponds or stock tanks are used in most grazing areas. In some areas they supplement wells and springs and in others, where geologic conditions make it impractical or impossible to obtain water by wells, they constitute the only available source except for importation by pipeline or haulage. Reservoirs have certain advantages. Construction costs are often less than drilling and equipping a well, particularly where deep drilling is required, and in some cases the stockman can do his own construction during off-season periods using farm-power machinery. Once constructed the reservoirs require little maintenance as there are no engines, windmills, pumps, troughs or storage tanks to provide and keep in repair. Seldom is any attempt made to remove sediment from the reservoirs; instead, new ones are constructed. In some localities ranchers maintain a regular schedule of construction, one or two per year to replace those filled or breached.

The marked disadvantage of reservoirs is unreliability of water supply. Because a reservoir is filled only when surface runoff occurs, the usefulness of the reservoir is dependent on vagaries of the weather. This can become of critical importance on range lands commonly subject to periods of droughts and the infrequent occurrence of runoff producing storms. Another disadvantage of increasing importance in recent years is the mounting concern of downstream water users over the waste of water inherent in reservoir operation. Uses in the past as a rule were not challenged, but strong objections are developing to the recent practice of building more and larger reservoirs as means of assuring a permanent supply. As one example of this, Culler (1961) estimates that the large number of stock reservoirs in the Cheyenne River basin in Wyoming reduce runoff from the basin by amounts ranging from 20 to 40 percent with the largest proportional reductions occurring in the drier years.

Criteria for selecting reservoir sites.--Selection of good stock reservoir sites requires study and judgment. Site requirements are: (a) a location with favorable cross section for construction of dam and needed spillway at a reasonable cost; (2) a reservoir area of adequate size, shape, and tightness to insure sufficient storage with minimum losses; (3) a supply of suitable construction material; (4) an assured source of water. Require-able construction material; (4) an assured source of water. Requirements 1-3 can be evaluated to the needed preciseness by appropriate geologic and engineering studies. Estimating the probable water supply on the other hand is subject to many uncertainties because of the numerous factors that influence runoff, of which few can be accurately predicted and evaluated. Since the sole objective of any stock reservoir construction is to provide water, this requirement must be accorded first consideration.

Two methods of estimating the probable runoff at stock-reservoir sites are in general use. One is based on a precipitation-runoff relation, the other on direct measurement of runoff from drainage areas of the size and character likely to be selected for stock-reservoir locations. Because of the greater number and more extensive distribution of long-term precipitation records compared with the relatively few short-term runoff records, estimates based on a precipitation-runoff relationship have a wider application, but the success in estimating runoff by this method has been variable and in many instances only fair. Direct runoff records are more realistic and reliable but their use until recent years has been limited because of the few available records.

Observations over much of the public domain show that daily storms of less than 0.5 inch seldom produce runoff, and substantial runoff occurs only when the daily rains exceed this amount. Thus where precipitation records indicate that storms of this magnitude occur at yearly intervals or oftener there can be some assurance of runoff sufficient for the reservoir needs. Longer intervals between storms of this magnitude and particularly a succession of many months or years without such storms, would raise serious doubt concerning the adequacy of a supply for a reservoir.

The value of estimates based on direct runoff measurements depends on the number, distribution, and length of suitable runoff records available for comparison. Measurements of runoff from areas of the size considered suitable for stock reservoirs have been made at a number of localities on the public domain. A summary showing the period of measurement, the number of complete station years of record, and the number of station years when the runoff was less than 1.0 acre-foot per square mile of drainage is given in table 4. Listing the years with runoff of less than 1.0 acre-foot per square mile of drainage area is done on the assumption that since the drainage area of the majority of stock ponds is about one square mile or less, this figure represents the absolute minimum runoff that can be considered worthwhile for the reservoir supply.

The effect of the size of drainage area on the water supply from ephemeral streams is shown in table 5 where most of the station years of record given in table 6 have been grouped by size of drainage area into four classes.

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Table 4.--[illegible] runoff and station years of record when runoff [illegible] 1 acre-foot per square [illegible] in small watersheds.

Area	Number of observation watersheds	Period of record	Station years of record	Approximate annual precipitation on watershed (inches)	Mean annual runoff: Acre-ft per sq mi	Mean annual runoff: Inches	Station years of record in which runoff was less than 1 acre-foot per sq mi
Missouri River Basin							
Willow Creek basin, Montana	2	1954-67	24	12.1	88.0	1.65	0
Wind River basin, Wyoming	15	1954-60	116	8.8	19.2	.36	39
Fifteen Mile Creek basin, Wyoming	2	1954-59	12	8.2	22.8	.43	1
Cheyenne River basin, Wyoming	72	1951-54	226	12.7-16.0	23.8	.45	20
Colorado River Basin							
Badger Wash, area Colorado	17	1954-69	272	8.3	32.5	.61	34
Dry Creek basin, Colorado	1	1949-54	6	15.9	11.7	.22	1
Little Robber Creek basin, Wyoming	1	1954-58	5	12.9	30.7	.58	0
Crescent Wash basin, Utah	1	1954-57	4	8.6	17.4	.33	1
Oak Creek basin, New Mexico	1	1957-59	3	11.7	35.7	.67	0
Railroad Wash area, New Mexico	1	1953-59	7	9.9	47.2	.89	0
San Simon and Safford Valleys, Arizona	4	1941-60	58	7-11	17.8	.34	3

Table 4.--Mean annual runoff and station years of record when runoff was less than 1 acre-foot per square mile in small watersheds (cont'd).

Area	Number of observations watersheds	Period of record	Station years of record	Approximate annual precipitation on watershed (inches)	Mean annual runoff: Acre-ft per sq mi	Mean annual runoff: Inches	Station years of record in which runoff was less than 1 acre-foot per sq mi
Rio Grande Basin							
Zia Res. Jamez River basin, New Mexico	1	1954-59	6	8.5	8.7	.16	2
San Luis Wash area, New Mexico	3	1953-59	21	8.6	29.8	.56	1
Cornfield Wash area, New Mexico	19	1951-60	156	8.7	27.0	.51	27
Rio Colorado basin, New Mexico	1	1956-59	4	8.6	12.8	.24	1
Rio Salado basin, New Mexico	1	1953-58	5	8.6	12.8	.24	0
Rio Puerco basin, New Mexico	2	1941-60	31	7-6	19.4	.36	4
Rio Grande Valley, New Mexico	2	1941-48	16	11.5-13.8	24.0	.45	2
Totals	147		792				125

Table 5.--Runoff from drainage areas of different size groups

Size class of drainage area (sq mi)	Station years of record	Drainage basins in each class		Average size of drainage basins (sq mi)	Average annual runoff for class (Ac-ft per sq mi)	Station years with runoff less than 1.0 ac-ft per sq mi	
		Number	Percent			Number	Percent
< 0.5	370	75	51	.19	34.0	59	7
0.5-1.0	139	26	18	.71	15.9	18	2
1.0-2.0	120	18	12	1.26	23.6	14	2
> 2.0	163	28	19	9.9	19.9	34	4
Totals	792	147	100			125	15

The data given in table 5 represent 792 station years of record taken from 147 stations distributed through 18 drainage basins in 6 of the public domain States. Areas where the measurements were made can be considered as typical of the major parts of the public domain, and the measurements are believed to represent a fair approximation of the runoff that can be expected over other periods of comparable length.

The data given in tables 4 and 5 show that except for higher average unit runoff in the smallest drainage basins, there is not a consistent decrease in average unit runoff with increasing size of drainage basin. Furthermore the years of deficient runoff (less than 1 acre-foot per square mile) does not follow a consistent trend with size of drainage area. The controlling factor, if one can be isolated from these data is the average annual precipitation.

Precipitation during the periods of measurement appears to have been near normal; below-average precipitation occurred in some years at all localities, and some areas experienced unusually high rainfall resulting in heavy runoff. This same general sequence of events can be expected during most periods of comparable length in practically all parts of the public domain.

The distribution of runoff-producing storms and the maximum period between storms is shown for six of the measured areas in table 6. It is seen that in the higher rainfall areas the maximum period each year between runoff events seldom exceeds seven months whereas in the low rainfall areas it is longer than eight months. At some times the period of no runoff may be longer than a year. The length of the no-runoff period is of particular significance in the design of the dam for maximum reservoir performance.

It is evident from table 6 that reservoir performance was quite deficient in the reservoirs measured in Wind River basin Wyoming and it is significant that a large increase in well drilling as compared to reservoir construction has occurred during the later years.

Table 6.--Annual occurrence of runoff producing storms in selected areas

Area	Year	Seasonal Runoff (ac-ft/ sq mi)	Runoff events: Number per season	Runoff events: First of season	Runoff events: Last of season	Period with no runoff (months)	Average annual evaporation in drainage area[3/] (inches)
Willow Creek basin, Montana[1/] (One station)	1954	80.8	10	May	Sept.	-	38
	1955	88.4	3	May	July	7	
	1956	45.0	7	March	Aug.	7	
	1957	80.2	10	March	Oct.	6	
	1958	11.6	2	July	Dec.	8	
	1959	7.6	7	April	Oct.	3	
Wind River basin, Wyoming[1/] (Average of 2 stations)	1947	5.5	5	May	Sept.	-	42
	1948	18.0	4	June	Sept.	8	
	1949	10.5	8	April	Oct.	6	
	1950	2.5	4	May	Oct.	6	
	1951	0	0	-	-	18	
	1952	0	0	-	-	30	
	1953	0	0	-	-	42	
Wind River basin, Wyoming[1/] (Average of 5 stations)	1954	6.6	5	May	Aug.	46	
	1955	8.0	3	May	Sept.	8	
	1956	4.9	3	May	July	8	
	1957	11.8	5	May	Oct.	9	
	1958	7.8	4	June	Aug.	7	
	1959	2.7	4	May	Sept.	8	
	1960	10.2	3	June	Sept.	8	

Table 6.--(Cont'd)

Fifteen Mile Creek basin, Wyoming1/ (Average of 2 stations)	1954	8.2	6	May	Sept.	-	38
	1955	21.5	7	May	Sept.	7	
	1956	0.6	2	July	Oct.	9	
	1957	45.0	9	May	Oct.	6	
	1958	26.8	7	Apr.	Sept.	5	
	1959	32.8	5	Apr.	Sept.	6	
Little Robber Creek basin, Wyoming1/ (One station)	1954	1.6	3	May	Oct.	-	37
	1955	28.8	7	Apr.	Sept.	5	
	1956	91.5	8	March	Oct.	5	
	1957	26.6	7	March	Sept.	4	
	1958	5.0	3	July	Sept.	9	
Badger Wash area, Colorado1/ (Average of 18 stations)	1954	43.6	4	Aug.	Oct.	-	37
	1955	45.6	3	July	Aug.	8	
	1956	11.8	1	July	Aug.	10	
	1957	62.2	9	May	Oct.	8	
	1958	1.5	1	-	Nov.	10	
	1959	26.8	5	Aug.	Nov.	8	
Cornfield Wash area, New Mexico2/ (Average of 14 stations)	1951	27.2	1	July	July	-	50
	1952	39.7	3	July	Aug.	11	
	1953	32.0	3	July	Aug.	10	
	1954	54.9	7	July	Sept.	10	
	1955	48.8	6	July	Aug.	9	
	1956	3.4	3	July	Aug.	10	
	1957	50.6	7	June	Oct.	9	
	1958	0	-	-	-	14	
	1959	8.7	5	June	Oct.	19	

Table 6.--(Cont'd)

Cornfield	1959	8.7	5	June	Oct.	19
Wash area, (Cont'd)	1960	3.5	-	Mar.	-	4

1/ Runoff data from U.S. Geol. Survey WSP 1475-I
2/ Runoff data from U.S. Geol. Survey WSP 1831
3/ From U.S. Weather Bureau, Technical Paper No. 37

Using periods with no runoff as a criterion, the depth, D, of a reservoir needed to furnish water for a given period of time can be estimated from the simple relation

$$D = n \times L + a$$

where n is the number of months with no runoff, L is the monthly loss in feet by seepage, evaporation, and stock use, and a is the minimum depth in the reservoir needed to prevent the water from becoming foul and unusable. Most ranchers set this last mentioned depth at from one to two feet.

On the basis of these criteria, reservoirs in the north where the monthly loss (evaporation plus seepage) is on the order of one foot or less require a depth of 7 to 9 feet to assure a supply during the summer grazing season. Whether knowingly or by chance, stockmen seem to follow this general rule as shown by surveys of 73 stock ponds located in the Twentymile Creek basin in the Cheyenne River basin in east-central Wyoming, reported by Hadley (1960). The average original depth of the reservoirs was 8.2 feet; the depth in 13 reservoirs was greater than 10 feet reaching a maximum of 15.2 feet, and the depth in 14 reservoirs was less than 6 feet with a minimum of 3.2 feet. Except for the shallow ones, most of the reservoirs contain water year-long.

Langbein (1951) used a somewhat different approach for determining depth in reservoir design. For assurance in obtaining sufficient water depth to carry over a reasonably long period of no runoff he suggested a rough estimate based on the formula $15 [2/(F+1)]$ where F is the average frequency of recharge per year. This leads to the conclusion that the minimum reservoir depth should be $15 [2/(F+1)] L$ where L is the average water loss in feet per month. The factor 15 applies to reservoirs located in areas where the period of no runoff seldom exceeds 15 months.

Reservoir losses.--In discussing the principles of stock reservoir design, Langbein (1951) points out that the efficient performance of a reservoir is dependent on depth of water rather than total capacity, since require-dependent on depth of water rather than total capacity, since requirements by stock are minor, ordinarily less than an acre-foot annually for the usual service area. A reservoir attains maximum value when it provides water at all times when grazing is carried on within the service area; its performance can be measured by comparing the frequency and magnitude of inflow with the major reservoir losses. Because the inflow in many places is erratic and unreliable it follows that improving the reservoir performance is attained either by increasing the depth to obtain longer carryover storage or by decreasing the losses. From a practical and legal standpoint the latter is the more desirable approach.

The high rate of loss from reservoirs located at low elevations in the Southwest, for example, makes it generally impractical to design for year-long use unless seepage can be reduced to a low figure. Annual reservoir evaporation in these localities will range from 6 to 8 feet. If it is assumed that seepage losses are approximately equal to the evaporation and that runoff seldom occurs except during the summer period, July-September, a reservoir depth of 12 to 20 feet will be required to assure year long supply. Reservoirs of this depth located on terrain with relief and slopes characteristic of most public lands in the Southwest will have capacities generally exceeding 10 acre-feet. This means that if the reservoir should fill each year, 10 percent or less of the stored water will be used by livestock, and the remainder will be lost by evaporation and seepage. For example, 1 acre-foot or 326,000 gallons is sufficient water for about 32,600 cow days or for about 89 head for a year. Because water is over appropriated in most localities and demands are continually on the increase, strong objections to losses of this magnitude can be expected. It is apparent, therefore, that successful use of stock reservoirs for periods approaching year-long operation is directly dependent on reducing the reservoir losses to a minimum.

Evaporation is relatively constant from year to year, but it can range widely between summer and winter. Chiefly because of temperature changes it increases markedly from northern to southern latitudes and from areas of high altitude to lower ones. The average annual evaporation in the six areas listed in table 7 ranges from slightly more than 36 inches annually in the northern latitudes to more than 48 inches in northern New Mexico reservoirs. In the southern low-altitude parts of Nevada and Arizona the annual evaporation from small reservoirs will range from 60 to 100 inches.

Evaporation losses can be influenced in some measure by proper design and location of the reservoir. Obviously, a reservoir design for minimal overall evaporation losses is one having a low ratio of surface area to volume. Not all reservoir sites permit much leeway in this regard, but in selecting sites, the possibilities should be recognized and taken advantage of where feasible. Selecting sites and designing the reservoir, with the objective of securing minimum wind movement across the reservoir surface, will also have a favorable effect in reducing evaporation since one of the chief factors influencing evaporation rates is air turbulence. Any provision which acts to lower the wind movement across the water surface will tend to reduce the evaporation.

Suppression of evaporation by the application of mono-molecular films has been the object of much research in recent years. Procedures for applying the film and an evaluation of the results obtained have been described (Cruse and Harbeck, 1960) (Koberg et al., 1963). The most widely used compounds are the cetyl alcohols, octadecanol and hexadecanol; both are nontoxic and tasteless. Each is a waxlike solid at ordinary temperatures insoluble in water but capable of forming a molecular film on the surface when dispensed in the water. Several other compounds have also been tested with varying results. A number of different methods for dispensing the materials to form the film have been tried, and new ones are currently being developed.

Although it has been conclusively demonstrated that the films suppress evaporation, great difficulty has been experienced in maintaining the film over large exposed bodies of water. Under laboratory conditions, where the film can be maintained continuously, reductions in evaporation up to 40 percent have been obtained but in larger bodies of water the results are far less. Experience at Lake Hefner, Oklahoma, showed a computed reduction of 9 percent over an 86-day period in 1958 (Harbeck, 1959, in Water-loss investigations Lake Hefner). Maximum savings of 14 percent were obtained during one weekly period. Intensive efforts to maintain the film during the test were only partly successful due to breakup caused by winds. The same difficulty has been encountered in other tests and appears to be responsible for the low rate of savings obtained under field conditions.

Koberg (1963) has reported on measurements of evaporation savings made on stock tanks located in southern Texas. Nine tests were conducted, using the three ceytal alcohols, hexadecanol, octadecanol and dodecanol. In some experiments, the compounds were applied in solution, using several different solvents, in others they were dispensed in the water using four different types of dispersing equipment. Intensive efforts were made to maintain a film on the water at all times during the experiment. Savings in evaporation were computed, using energy budget or mass transfer methods to determine what the evaporation would have been without the film. The maximum reduction in evaporation obtained was 27 percent during one two-week period. In other tests extending over several days the savings ranged from 7 to 12 percent, and in one text there were no discernible savings. The investigators conclude that at present efforts to suppress evaporation on stock reservoirs are not feasible due to the great difficulty of maintaining a film on the water surface and to the high cost of treatment.

The second major reservoir loss results from seepage. These losses fluctuate widely. In many cases high losses obviously are due to faulty dam construction, but losses vary greatly with the character of the material underlying the reservoir and for other reasons that cannot be readily explained. In general, reservoirs underlain by shale bedrock or fine-textured alluvium have the lowest seepage rates; higher rates can be expected where the reservoirs are located on such materials as coarse alluvium, granular sandstones and conglomerates and highly fractured igneous and volcanic rocks. The seepage losses in some places are so high that a reservoir built without a sealant is practically useless. The inadvisability of locating reservoirs in areas underlain by water soluble rock has been mentioned.

Table 7 gives the seepage rates measured during the summer period at reservoirs in 7 localities distributed over a broad area and underlain by several different materials. The total reservoir loss is the average of the recession rates taken either from the recorder chart at reservoirs so equipped or from measurements of changes in reservoir stage made during periods when there was no inflow. The mean evaporation is obtained from the U.S. Weather Bureau (1959) for the summer period (May through Oct.) adjusted for the period of observation and for differences in latitude. Measurements were not made during the winter period because most of the reservoirs are frozen over or become inaccessible at this time.

Table 7.--Seepage and evaporation losses in stock reservoirs during summer period

Location of reservoirs	Number measured	Seasons measured	Water losses in feet per month			Formation underlying reservoirs
			Total	Evaporation 1/	Seepage	
Bighorn Basin, Wyoming	1	4	0.73	0.50	0.23	Willwood Formation, predominantly shale and claystone
Wind River Basin, Wyoming	1	4	0.90	0.50	0.40	Wind River Formation, predominantly shale with some sandstone
Badger Wash area, Colorado	3	3	1.50	0.50	1.00	Mancos Shale, containing thin lenses of sandstone
Crescent Wash, Utah	1	2	1.80	0.50	1.30	Mancos Shale, with surface layer of sandy alluvium
Cornfield Wash area, New Mexico	4	5	3.40	0.55	2.85	Sandy alluvium 10-30 ft thick overlying shale and sandstone of Mesa Verde Formation
San Simon Valley, Arizona	3	3	3.10	0.65	2.45	Thick deposits of alluvium
Carrizo Creek basin, Arizona	2	1	3.00	0.50	2.50	Alluvium overlying the Supai Formation, jointed sandy shales and siltstone

1/ Evaporation obtained from U.S. Weather Bureau Tech. Paper No. 37, 1959

Age of the reservoirs and the extent of sedimentation are generally conceded to have an effect on the seepage rate, but in this case the trend is not well defined. As an example, reservoirs in the San Simon Valley andCarrizo Creek basin were 3 years old when the measurements were taken and they contained only minor deposits of sediment which might account in some measure for the high loss rate. In contrast, reservoirs in Cornfield Wash with an age of 5 years at the time of measurement contain thick deposits of sediment, yet this does not affect seepage to any extent as the rate of loss was about the same in the last year as in the first (Kennon and Peterson 1960). Langbein (1951) has reported on 15 reservoirs in Arizona with two years of measurements. The losses in eight of these exceeded 1.2 feet per month and in two exceeded 4 feet; whereas in the other seven reservoirs losses varied from 0.5 to 0.75 foot per month. Most of these reservoirs were older than those given in table 7. An analysis made of 58 reservoirs in Cheyenne River basin, (Culler 1961) showed that annual seepage loss from individual reservoirs ranged from one-tenth of the evaporation to 18 times the evaporation. Although these reservoirs were of differing ages and contained various amounts of sediment, those showing the smaller seepage losses generally were underlain by shale or fine-textured alluvium whereas those showing the greater loss were underlain by sandstone or coarse-textured alluvium.

Although conclusions based on loss data available at this time are not warranted, the implications appear to be that in small stock reservoirs located throughout the public domain a seepage rate ranging from 0.5 to 5.0 feet or more per month can be expected unless precautionary measures are taken to seal the reservoir.

Methods for reducing reservoir seepage have been used with varying degrees of success. Lining the reservoirs with bentonitic clays is one of the most effective, but unless cheap sources of bentonite are available within reasonable hauling distance the expense may prohibit its use. Application of bentonitic clay has a serious drawback where used in reservoirs that fluctuate widely or that go dry on occasions as the exposed clay dries out rapidly and is subject to heavy loss by wind. Frequent renewals of the treatment thus become necessary.

Treating the reservoir floor with rock salt to increase dispersion of the clay has been used effectively in some areas to reduce seepage. The treatment is beneficial only where the material in the reservoir contains considerable clay. The low cost and ease of application adds to the attractiveness of the treatment. Compaction of the reservoir floor, using accepted engineering procedures to mechanically create an impervious layer, is another method of reducing seepage losses. With proper types of soil and if carried out at the time of construction when the contractors' equipment is available, it can be both effective and economical. Instructions for this and other types of treatment are found in handbooks and the literature.

Several commercial compounds designed to reduce percolation losses in canals and reservoirs are now available. Most are mixable and can be applied by adding the compound to the water. Some reduce percolation by increasing the ionic attraction of the soil to water, thus reducing the pore space; with others an impermeable layer is precipitated in the top layers of the soil. Naturally, it is essential that the compounds be non-toxic and have no effect on the water's palatability. Field data on treatment of stock reservoirs using these compounds are not available, although reduction in seepage losses ranging from 60 to 90 percent in irrigation canals, and in one case 80 percent in a small irrigation supply reservoir has been reported. The cost of the treatment, ranging from 5 to 50 cents per square yard of area treated, may be prohibitive for most stock ponds.

Standards of stock reservoir dam design and construction.--The small size and relatively low cost of stock reservoir dams has been responsible for the general low standards employed in their design and construction. The result has been an inordinately high percentage of failures, in some instances as high as 70 percent. Except where height of the dam or volume of the reservoir were such as to require detailed plans to meet the requirements of state safety laws, few of the dams had any formal design or detailed planning. In general, there is no urgent need for detailed plans to insure permanence of these small structures, provided reasonable engineering design and construction standards are employed.

Design and construction standards applicable to earth fill dams of the type used for stock reservoirs are well developed and relatively simple to understand and perform. As they are widely disseminated in engineering texts and handbooks they will not be discussed other than by mention of some of the critical features of design and construction standards of greatest importance in preventing failures. (See National Resources Committee, 1938).

Examination of many breached stock dams shows that most of the failures can be attributed either to improper clearing and preparation of the base, or lack of proper compaction in the fill, which includes lack of moisture in the fill material. Some dams have failed because of overtopping due to inadequate spillways, and in rare cases foundation failures are evident. In a number of instances the failures can be traced to unsuitable fill materials such as rocky or very sandy soils which allow high rates of seepage. Thus the requirement previously mentioned for suitable construction material is a real one and imposes a limitation that excludes stock reservoirs from some areas that might otherwide use them to advantage.

Failures due to inadequate foundation clearing and preparation in general are easily avoided since proper standards relating to these items are inexpensive to carry out and require no highly technical knowledge. Data on the design and location of cutoff trenches, where needed, and instructions on methods for sloping the channel sides and the abutments to insure a good bond, are available from the handbook (National Resources Committee 1938). Cutoff walls or diaphragms are seldom used in constructing stock water dams, and outlet pipes are installed only where the reservoir is to be used for other purposes in addition to stock watering. These items, when used, merit special engineering attention both in design and installation. Installation of outlet pipes requires special care as experience has shown that this area is highly vulnerable and is responsible for many dam failures.

Supplying adequate moisture for optimum compaction of the fill presents a real problem particularly where water for this purpose must be hauled long distances. Because of the high cost the tendency in many instances has been to construct a dry fill or to use less than a minimum requirement of water. This nearly always results in high rate of failure. Construction at sites where water is not available at justifiable costs should either be postponed until the ground is made suitable by precipitation or the site should be abandoned. In places it may be permissible to lower the water requirements somewhat by increasing the cross sectional area of the dam, but this should be done only after an analysis by a competent engineer.

As with other phases of small dam construction, methods and standards for determining optimum moisture content and for placing and compacting the fill are readily available, and there is little excuse for not following them. The alternative is often a complete failure or a costly repair job.

Intensive geologic examination and test-drilling of the dam and reservoir sites are commonly not done at stock water reservoirs, and at most locations they are not essential. However, the geology can be critical in areas, for example, that are underlain by gypsum, cavernous limestone or other water soluble rocks. Such rocks often develop solution cavities sufficiently large to jeopardize the dam or to drain the reservoir contents within a few days or even a few hours after filling. Sites located on highly fractured rocks should also be regarded with suspicion. A brief geologic examination will indicate if these sites should be abandoned or if a suitable plan of treatment can be prescribed.

As most stock reservoirs have no outlet pipe, the spillway must have sufficient capacity to discharge runoff in excess of reservoir storage, otherwise overtopping of the dam will occur. If the reservoir is full or nearly so during any runoff period the spillway will then be required to pass the expected flood. Few data on peak flows from small drainage basins are available. Kennon (1954) had developed estimates of peak flows in western New Mexico and Arizona based on an analysis of streamflow records and flood frequencies from drainage basins ranging in size from 40 acres to several hundred square miles. The estimated peak flow from drainage areas of 1, 3, and 5 square miles with expected recurrence intervals of 5, 10, 15, and 25 years for the western New Mexico, eastern Arizona, and the western Arizona areas are shown in table 8.

Table 8.--Estimated probable peak floods for drainage basins of varying size and recurrence intervals

Drainage area Square miles	Peak discharge, cfs, for recurrence intervals of			
	5 years	10 years	15 years	25 years
	Eastern Arizona Western New Mexico			
1.0	147	195	228	276
3.0	264	348	408	492
5.0	341	451	528	639
	Western Arizona			
1.0	201	265	302	365
3.0	233	306	350	423
5.0	252	332	379	458

Very few data are available on probable peak flows for small drainage basins in the more northerly parts of the public domain. In the Willow Creek area near Fort Peck Reservoir, Montana estimates of peak flows for two watersheds made by D. G. Frickel (written communication) are as follows:

Watershed	Drainage area (sq mi)	Period of record (years)	Peak flow in cfs for indicated recurr nce interval		
			5 year	10 year	15 year
Burnett	5.0	14	430	590	680
Cactus Flat	6.4	10	580	1,240	1,520

Additional data on peak flow are being collected by the Geological Survey in connection with highway programs, but very few results for watersheds as small as those used for stock-water reservoirs have been released.

Other procedures for estimating flood peaks from small drainage areas use the rational method or the unit hydrograph. However, because of the difficulty of obtaining the information need for applying them and the time and expense involved the procedures are seldom used in the design of stock-reservoir spillways. Descriptions of these are contained in the literature (American Soc. Civil Eng. 1949; National Resources Committee, 1938).

Sedimentation in stock reservoirs.--Sedimentation limits the useful life of stock reservoirs and also by the progressive reduction of the storage capacity it shortens the period when water is available for livestock use. Associated harmful effects are the losses resulting from livestock becoming mired as they are forced to wade through the soft sediments surrounding the water pool. In some instances such losses have forced temporary or even permanent abandonment of the reservoir. Through observations on the rate of filling in older reservoirs, stockmen generally can approximate the life of any structures and most have an established schedule for constructing new ones. Experience shows that it is seldom practical to remove sediment from the old reservoirs.

Measurements of sediment yield from drainage basins of varying sizes and characteristics located in different sections of the country were given in table 5 and discussed in the section on erosion. The factors that are known to influence rates of sediment yield from a drainage basin including geology, slope, slope length, vegetation, cover, precipitation, drainage density and land use should be given careful consideration in selecting reservoir sites.

The high sediment yield experienced at many sites has stimulated efforts to protect stock reservoirs against sediment deposition. The offstream reservoir is designed with this in mind as it allows some opportunity to bypass the flow having a high sediment content and select for storage flows with a lower sediment load. The necessary features of such a structure include a dam or charco for storage and a diversion structure equipped with some type of regulatory device which permits rejection of flow carrying a heavy sediment load. In some cases the flow is clarified by providing dual storage, an upper reservoir for sediment deposition and a lower one for storage of the clear effluent. The advantage of the dual reservoir is that it works automatically whereas with a bypass system an operator must be present to select the clear flow for storage. This severely limits the usefulness of such systems.

Construction of sediment traps upstream from the stock reservoirs is commonly used to reduce the sediment load. The usual procedure is to enclose with a net-wire fence a tract, of an acre or more, located just upstream from the high-water line of the reservoir. The fence acts as a trap for sediment which in turn provides a good environment for plant growth. When protected against grazing vegetation develops at a surprisingly fast rate, and commonly within 2 to 5 years the enclosed tract becomes something of a jungle. Such areas are highly effective in trapping sediment, and the effluent flow is relatively clear. Offsetting this is the problem of deposition in the trap, which may range from a few inches to a foot or more annually, thus requiring refencing or extension of the trap at periodic intervals. An additional disadvantage results from the high rate of water loss by the vegetation which leaves less for inflow to the reservoir. This loss may become enough to seriously affect the performance of the reservoir.

Distribution of range water by pipeline and hauling

Two additional methods of providing range water, distribution by pipeline and hauling, are being used with greater frequency on the public domain, particularly in areas where the depth to water is relatively great and where the range productivity is approaching maximum potential through land treatment practices. Both methods have the advantage of great flexibility, but owing to the high cost their use generally is restricted to the better range lands. Hauling water is dependent also upon the availability of reasonably good roads.

Pipeline distribution systems.--The use of pipelines in expanding the service area of springs has been mentioned, but the lines are also used where wells are the source of supply. The general practice is to pump from the supply source to a tank or reservoir located at an elevation high enough to permit distribution by gravity to the service area. The distribution system may consist of a single pipeline or a network distributed over the service area. Watering troughs equipped with float valves are distributed along the lines usually at intervals of about one mile. This close spacing results in even grazing of the intervening area, an important feature on seeded range lands of high forage yield. Because of the cost of piping water from the supply source to the high point for distribution by gravity pipeline, the service area for such a system will range upward from a minimum of about 5,000 acres. A minimum yield of 30 gpm from the supply source is considered essential for such installations. For this amount the wells are equipped with deep well pumps.

The low cost of plastic pipe as compared to metallic pipe and development of low-cost methods for its installation using trenching and laying machines account for the increased use of pipelines where the terrain is favorable. The cost of the pipeline will vary with local conditions but generally the total cost will be affected more by the cost of the well furnishing the water than by the cost of the pipeline. The total cost of a system installed in a reseeded area in the Vale Oregon Grazing District in 1962, which included a well, control storage tank, troughs, and valves is reported to have been about $4.00 per acre. This compares with a cost of about $10 per acre for clearing the land and reseeding. Figure 6 shows a view of the well-and-storage tank and the plastic pipe used in the installation.

Figure 6.--Follows near here.

For a more recent Bureau of Land Management installation (1970) in New Mexico the cost of about 4.4 miles of 1- to 1 1/2-inch pipe line, 3 water facilities, equipped with float valves and 2 storage tanks, was reported as $8,600. This system is set up to service 14 1/2 sections of range. The cost of installation thus is about $490 per section or nearly $1 per acre. The pipe line takes off from a well that has been in operation for some time.

A. Well with pipe line to storage tank on hill; distribution line to service area at right.

B. Five hundred foot rolls of plastic pipe used for distributing water to troughs.

Figure 6.--Well with storage tank at highest elevation and plastic pipe used in water distribution at Rome seeding, Vale District, Ore.

Where wells are used as a source of water for distribution by pipe line they become highly important to the administration of grazing lands. For example, there are now several localities where improved and highly productive range lands ranging up to 15,000 acres or larger in extent are serviced by water distributed from a single well. To provide full use of the range, wells of this type must not only yield sufficient water but they must be completely reliable. Such wells merit high standards of construction, careful testing and well designed pumps and power sources. Specifications for these wells must be carefully prepared and the drilling operations must be adequately inspected to see that all phases of the specifications are adhered to. Gravel packing, for example, a practice unthought of a few years ago when applied to stock wells, is currently being recommended in many localities. Although the expense of construction of such wells may appear to be excessive, the added reliability of performance and the longer life more than compensate for the high initial cost.

Hauling stock water.--The extension and gradual improvement of roads on the public domain together with the improvement in equipment has been responsible for an increase in the practice of hauling range water for stock. The practice has a number of strong advantages: (1) it permits better use of the range through frequent moving of the livestock; (2) travel from feed to water is reduced to a minimum, thus maximizing livestock gains; (3) all parts of the range can be grazed except where limited by lack of suitable roads; (4) the frequent observation of the livestock, which comes about automatically by this practice furnishes the opportunity for inspection and treatment of accidents or disease.

Opposed to these advantages is the cost of hauling. This varies according to the length of hauls, the condition and gradient of the road, the type and size of the tank trucks used and in some degree to local pricing policies. Published costs (U.S. Dept. Agr. 1957) ranged from $1.00 or $1.25 per animal per month for an 8 to 15 mile round trip haul over moderately level terrain in Oregon, to $1.39 per animal-unit per month in the Fish Lake National Forest in Utah where the round trip averaged 57 miles over rough terrain with average grades of 5 percent and short grades of 12 percent. One livestock association at Bend, Oregon contracted for a 5 month seasonal haul for $5.25 or $1.05 per animal month. Average length of the haul was 8-9 miles.

At these costs the expense of supplying range water was several times greater than the grazing fees per animal-unit month charged on the public domain. Although this emphasizes the value of range water, such charges obviously cannot be justified except in those localities where the forage is ample and other sources of water are even more costly. However, as range values increase, water hauling is likely to be expanded, and with it new facilities will be required to provide for furnishing the additional quantities needed for hauling operations.

Catchment areas

In recent years increasing attention has been accorded to supplying range water by construction of the so-called catchment areas also known in places as water harvesters, rain catchments or guzzlers. These are adaptations of the old cistern principle in which a ground area of a given size is waterproofed in some manner and thus can be substituted for a roof of a building. The water is collected in a storage tank which is a substitute for the cistern. For livestock grazing use the catchment area may range up to any size but currently the maximum is about 10,000 square feet. Most are built nearly square, 100 feet on a side. The storage tanks range in size from 20,000 to 50,000 gallons, some covered, but most uncovered.

Waterproofing materials for the catchment areas include sterilized and compacted soils, hot or cold rolled asphaltic covers, specially designed blankets including those made of butyl rubber, and metal sheets of aluminum or galvanized steel and fiber glass. The runoff from paved highways has been used in some localities. Figure 7 shows two installations designed for livestock water in grazing areas. Smaller installations have been used for supplying game animals and birds.

Figure 7.--near here.

A. Asphaltic paving on prepared sub grade. San Carlos Indian Reservation Ariz. Photo by Bureau of Indian Affairs.

B. Aluminum sheeting on light asphaltic base, plastic lined trough leading to storage tank. Granite Reef Ariz. Photo by Charles Sloan, USGS.

Figure 7.--Types of catchment areas being used for obtaining range water.

As the catchments are expensive to install and maintain, they are used only in localities where water cannot be obtained by wells or very deep drilling is required, where reservoirs are impractical because of low, infrequent and unreliable runoff or high seepage losses or where distances from existing supplies are so great as to preclude feasible importation of range water by pipe line or hauling. Costs vary greatly depending on the size and type of installation, location, availability and price of materials and labor, site preparation and other related factors. Reported costs for completed installations range upward from about $4,000. The contract cost for a fiber-glass membrane catchment, 10,200 square feet in area, being built (1970) in the Arizona Strip District is $6,800. Another catchment built of butyl rubber membrane, 10,300 square feet in area, recently completed (1970) in the Albuquerque District is reported to have cost $12,957.

The yield of the catchment is highly variable depending on the precipitation and the size and effectiveness of the catchment area. Assuming a recovery of 90 percent which is about the maximum that can be expected, a catchment of 10,000 square feet yields about 5,600 gallons per inch of precipitation; thus, from 12 inches of precipitation annually the yield will be about 67,300 gallons. Providing that none of this water is lost, this quantity is equal to the water requirements for 6,730 animal-unit-days of grazing. This will maintain a herd of 75 cows for approximately 3 months. In snow areas efforts are often directed toward increasing the catch by selecting locations subject to natural drifting. Snow fences in strategic places are often constructed for the same purpose. Recovering the additional snowmelt usually requires a large and covered storage tank because the melt occurs well before the grazing season opens.

The effectiveness of the catchment area varies. It attains a maximum using well constructed sheet metal coverings where it can approach 100 percent except for light rains during hot weather when the evaporation from metal surface is proportionately very high. Lowest effectiveness is likely with compacted earth catchments which naturally are the cheapest to install. Asphaltic pavement and blankets are somewhat less effective than metal coverings even where properly maintained, but they are subject to continuing damage by plant growth. Sterilizing the soil prior to construction is helpful but is not completely effective in preventing this. To avoid similar damage metal catchments are usually placed on timber supports a few inches above the ground. The combination of complete shade and lack of water under these conditions tends to reduce plant growth to a minimum.

Because of the expense and the uncertainties of water supply, construction of catchments should be undertaken only after careful engineering studies. If practical several years of records of precipitation to determine amounts and time of occurrence in the immediate vicinity of the catchment should be obtained in addition to the usual engineering design and cost analysis for comparison with costs of providing water by other methods at the particular site.

Unwatered areas

Two major areas critically in need of range water at present are the Arizona Strip and an area of several hundred square miles located in north-central Nevada, southeast Oregon and southwest Idaho, commonly termed the Owyhee desert. Smaller local areas of bedrock mountains and hills, particularly in Nevada but scattered elsewhere in other states also are not fully used because of lack of watering places.

The Arizona Strip is the name commonly given to that part of northwestern Arizona lying north of the Colorado River, and west of Kanab Creek. It forms a part of the Colorado Plateau physiographic province and most of it has an elevation several hundred feet higher than the Colorado River on the south or the Virgin River on the northwest. Drainage is about equally divided between these streams through a series of steep washes and canyons. Because of its favorable orographic position the Strip has relatively high precipitation providing fairly good range forage, that is not used to its full capabilities because of inadequate water distribution.

Prospects for obtaining water by wells in the area are poor because of unfavorable topographic and geologic conditions. This is evident both from geologic studies and from the drilling of a number of dry wells, most of them for stock water but two as deep tests for oil. The few sandstone formations that might be considered as possible aquifers present within the series of sedimentary beds underlying the "Strip," crop out in the precipitous walled canyons of the Colorado River and its tributaries and each apparently has been drained. Extensive faulting in the area may have also contributed to the draining of the possible aquifers. Because of the unfavorable prospects it is doubtful if additional drilling for water will or should be attempted. A few allottees urgently in need of water, and ignoring the advice of geologists, have resorted to the services of "water witchers" with negative results.

In recent years the Bureau of Land Management has constructed a number of stock reservoirs in the area. A few sites are still available in the northern and western parts of the area, but conditions are less favorable in the southern and eastern parts because of the steep gradient of the stream channels and in many places because of a dearth of suitable materials for dam construction. The erratic character of the runoff imposes another handicap on the use of reservoirs. At present, few data are available on the runoff from either small or large drainage basins, but beginning in 1960 one reservoir was equipped with a recording gage to measure runoff. Precipitation data within the interior of the Strip are also sparse but a number of storage gages were installed in 1961-62.

Since reservoirs obviously must be depended on to provide new sources of water in the future, the program for obtaining runoff and precipitation data needs to be expanded. Exploration and research should be initiated to locate reservoir sites having drainage areas of greatest potential runoff. Research on methods of increasing runoff in favorable localities should be included.

The Owyhee Desert extending over a part of north-central Nevada, southwestern Idaho and southeastern Oregon, is one of the largest areas of unbroken sagebrush lands in the West. More than 60 townships or nearly 1.5 million acres, are included, most of which is public domain. Because of the low forage value of the sagebrush, the grazing pressure on these lands has to date been low, and the inadequacy of the range water facilities has not been critical. However, with the demonstrated success of clearing sagebrush and seeding of these lands resulting in greatly increased forage resources, the demand for grazing is certain to increase, bringing with it a need and a demand for increased range water.

Several features make it difficult to obtain range water in this area. The area is dissected by the canyons of the Owyhee River and its larger tributaries which are cut to a depth ranging from 300 to 600 feet below the general level of the area. The canyons act as drains; thus ground water is found only at the approximate level of the streams. Drilling to this depth is both expensive and hazardous. Most wells located east of the river in Idaho have been successful, but a number of holes that have been drilled west of the river are dry even though drilling was carried to river level. The condition is apparently due to unfavorable geology which at present is not completely understood.

A general reconnaissance indicates that the area is a part of an ancient lake basin which has been filled with lake beds derived from surrounding highlands interbedded with volcanic sediments and flows of rhyolite and basalt. This series of beds overlies a body of dense impervious rhyolite of unknown thickness and areal extent. The rhyolite is exposed in the walls of the Owyhee Canyon and its tributaries in some reaches, and also to a limited areal extent in some of the surrounding mountains.

Some of the lake beds, the volcanic sediments and the basaltic lavas are pervious, and successful wells can be developed where these formations occur at a level slightly above to somewhat lower than the Owyhee River. In contrast the rhyolite in general appears to be impervious as it contains neither interstitial openings or joints which might transmit water. On the basis of the reported logs, each of the dry wells drilled to date penetrated the rhyolite at or below the level of the river. Obviously, therefore, successful drilling in the future must depend on a more accurate delineation of the position and areal extent of the rhyolite so as to avoid drilling in unfavorable localities. The recent deepening of the Button Lake well in northern Nevada, which resulted in finding water is a hopeful indication that other successful wells can be developed. Detailed geologic studies necessary for this purpose are being augmented as resources permit.

The use of stock reservoirs in this area has definite limitations. Because a large part of the area contains rocky soils with lava flows at or near the surface, the construction of dams and the excavation of reservoirs to the depth required to maintain season long water is both difficult and expensive. Added to this is the uncertainty regarding runoff. The area contains neither long-term precipitation nor stream-gaging stations so practically nothing is known concerning runoff. In 1962 six precipitation storage gages and five crest-stage gages to obtain some indication of annual maximum discharges were installed in the Nevada section of the area. More and better types of gages are needed both in Nevada and in the Idaho and Oregon sections if the basic hydrologic data essential to the proper location and design of reservoirs are to be obtained.

Because of the great potential for range improvement through clearing and seeding and other practices in this area, the need for expanded hydrologic and geologic studies to provide the stock water for proper use of the range are clearly evident.

Range treatment methods

The gradual elimination of harmful overgrazing through reduction of livestock numbers and the introduction of improved grazing practices, combined with the improvement of range utilization through development of additional range water facilities represents but one aspect of conservation being carried on at present. Of equal or greater importance in securing range improvement has been the direct treatment of the range lands. This has been a natural approach since it was recognized by range men at an early date that despite aridity, poor soils, and other features that unfavorably affect the growth of range plants on much of the public domain, the productivity of large segments of the area was well below maximum capability. Restoration of these areas to something approaching their former condition of productivity is an all important step in conservation since it has the dual function of providing increased forage and protection against erosion.

Land treatment methods currently being used represent an evolution based in part on experience and in part on the acquisition of scientific data and of development methods and equipment. Through research, knowledge has been increased in relation to such features as soil, and soil-plant-moisture environments, introduction of new plant species, and best methods of seeding and protection of the new seedlings.

The earliest program of treatment practices was the Civilian Conservation Corps program, active during 1935-41. The practices were limited almost exclusively to building small structures by hand from local materials with only minor use of machines and construction materials from outside sources. As is well known, emphasis in this program was to furnish as many jobs as possible. Later, the requirements for large quotas of hand labor, the heavy cost of maintenance of the structure and the generally poor results obtained forced abandonment of this approach in favor of practices which promised better results and could be carried out in large measure by machine operation.

Included in these practices is a continuation of structural treatment patterned in some respects after those started in the C.C.C. program but using larger and better designed retarding structures primarily for control of flood flows and sediment movement in the large channels. Similar structures have been used as a control for water-spreading operations, and their use has often marked the difference between success and failure in this practice. But probably more important than structures is the direct treatment of lands, which seeks to modify the existing plant cover by removal of worthless and undesirable plants by mechanical or chemical methods and the substitution of more valuable and productive species either by stimulating and protecting the native seed plants or by seeding, following so far as practicable well founded agronomic principles. Details of these practices are discussed in the following sections.

Water spreading

Water spreading has generally been regarded as an effective method of increasing range forage. Rapid and, in some cases, spectacular increases in vegetation have resulted from the practice in some localities; in other places success has been moderate and in still others the treatment has been a failure. Reasons for this variation are not always apparent but, in general, differences may be traced to either lack of maintenance of the system, inadequate water supply or poor soil characteristics.

As the name implies water spreading is a form of irrigation using water from an outside source applied to a spread area. Spreading is used mainly to increase forage but it is also used as an erosion abatement measure by regulating and decreasing flood discharge through increased infiltration. The basic requirements are a supply of water flow which can be diverted onto an area of relatively flat level land. The practice is used in areas of relatively high precipitation just as often or more so than in drier areas. As a general rule, however, the high cost of construction and maintenance of spreaders limits their use to areas that receive precipitation of 10 inches or more annually. Areas with unusually low precipitation - 7 inches or under - are seldom considered as spreader sites unless the water can be supplied from an area of higher altitude receiving greater precipitation.

In a recent study developing criteria for a range water spreading conducted by the Geological Survey((Miller et al., 1969) a number of features affecting the success of spreading are discussed. These include the effect of soil texture, soil moisture retention, salinity, sedimentation, drainage, system maintenance, and water supply on the efficiency of the treatment. These and other features are reviewed in the following discussion.

Several methods of spreading are used. In the simplest one, flow is diverted from a channel onto an adjacent relatively flat flood plain area with no ditches, training dikes or other structures to route the flow. With more elaborate methods the flow is guided across the spread area by a system of training dikes and channels designed to spread the water evenly and slowly to all parts. The system may be operated with or without regulation of the inflow by a storage reservoir, but experience has shown that in most localities the cost of maintaining the structures without regulation is very high and may be excessive enough to completely defeat the operation.

The system that has most commonly been used by the Bureau of Land Management consists of a series of contour dikes from 3 to 5 feet in height and ranging in length from 100-2000 feet aligned normal to the direction of land slope and spaced so that the toe of one is a few inches lower than the top of the next lower one. For this type of treatment a relatively flat area of adequate size having a slope of about 40 feet per mile or less is required. The dike may be constructed with the borrow pit on either side but usually it is on the downstream side and the flow is so directed that it moves in one direction on the upstream side of the dike and returns in a reverse direction through the borrow pit on the downstream side. Because the downstream lip of the borrow pit is on contour, it in theory acts as a control to spread the water in a more or less even sheet across the intervening area to the next dike. Here the direction of flow around the dike is usually reversed from that of the preceding one. This operation is repeated for all dikes in the system. The size of a spreader installation can vary from one with only a few dikes on an area of a hundred acres or less, to areas of several hundred acres with as many as twenty or thirty dikes aligned one below the other. The arrangement of a typical spreader system is sketched in figure 8.

Figure 8.--Follows near here.

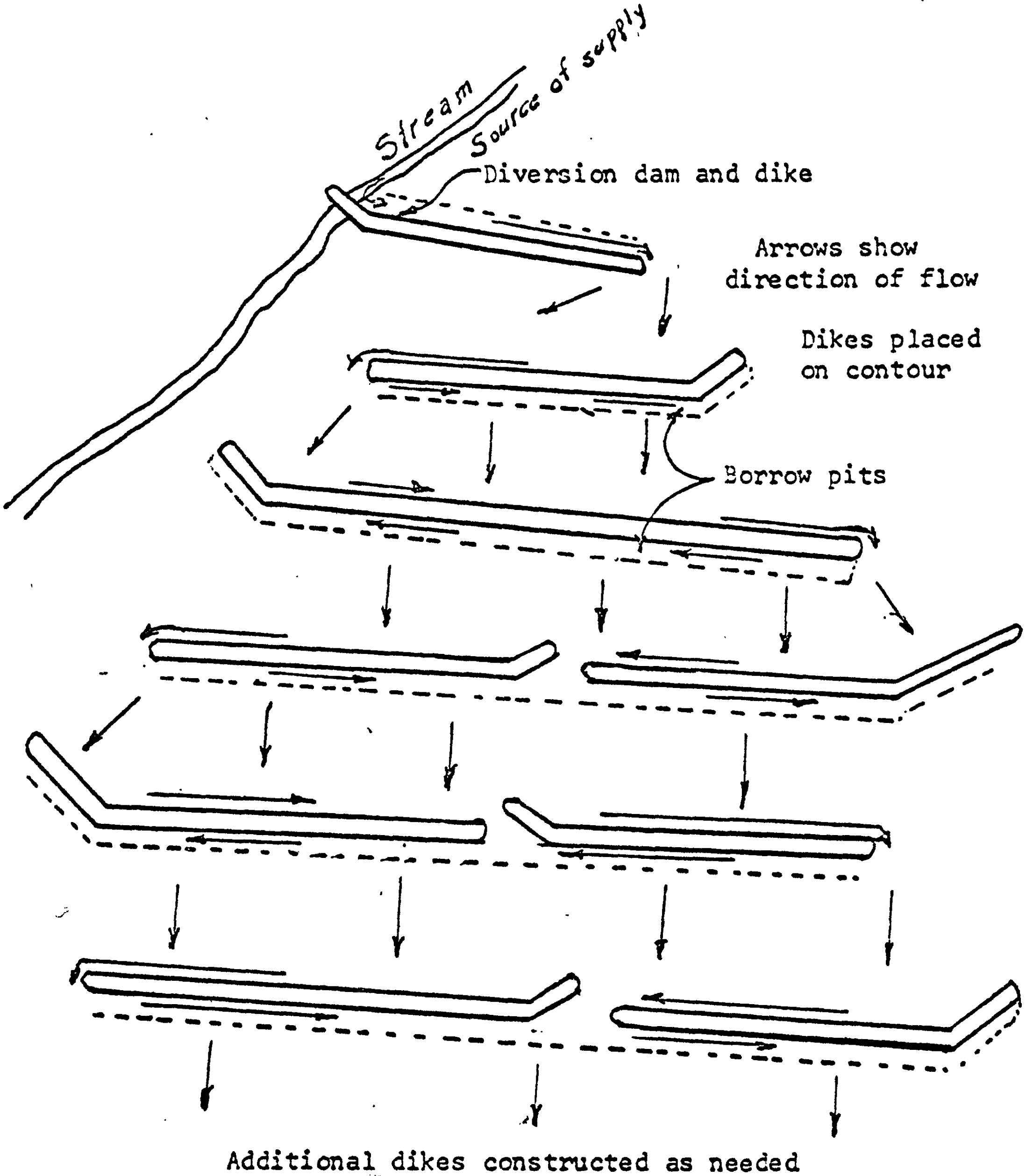

Figure 8.

Sketch showing layout of typical Bureau of Land Management spreader system

In most installations the dikes contain no weeps and the flow moves along the contour by building up a head. This results in a considerable amount of ponding on both the upstream and downstream sides particularly where the dikes are of inordinate length. Miller et al. (1969) have called attention to the effect of this ponding in destroying vegetation where the water stands for as long as 48 hours or more or in downgrading it to a growth of weeds and foxtail barley (Hordeum jubatum) even though the dominant growth in the naturally watered swales may consist of the highly desirable western wheat grass (Agropyron smithii) or other desirable species. Figure 9-A shows excessive ponding behind a dike in the Burnett

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Figure 9.--Follows near here.

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spreading system in the Willow Creek area of Montana. The ponding here is aggravated by an excessively long dike extending more than 2000 feet, and from appearances much of it could be relieved by breaking the dike into two or more segments, as illustrated in the lower dikes of figure 8.

A. Ponding above one of the spreader dikes in the Burnett spreader area, Willow Creek basin, Mont. Excessive ponding has killed vegetation in the ponded area and downgraded it around the fringes.

B. Excellent vegetation below a dike in the Coal Creek spreader, eastern Mont. Note absence of borrow pit and ponding.

Figure 9.--Spreader dikes in the Burnett and Coal Creek spreader systems, Mont. Photos Aug. 1965.

The spreader system on the Coal Creek Resources Conservation Area near Terry, Mont. is designed to avoid ponding. The spread area of about 400 acres has 23,270 lineal feet of dikes containing 68,000 cubic yards of fill. The dikes were constructed using end haul from borrow pits located some distance from the spread area so there was no excavation along the dike. Water passes through the system in a series of 18-inch corrugated steel-pipe weeps installed in each dike at intervals close enough to prevent excess ponding above the dike. Figure 9-B shows the vegetation below one of the dikes. The vegetation is preponderantly western wheatgrass and forms some of the best forage observed in the State in 1965.

Construction costs for this type of installation are high. The per acre expense including cost of the dikes and the appurtenant regulatory storage dam, drop structure and a diversion dam was nearly $19. The high cost is justified on the basis that the installation has corrected a serious erosion condition by controlling runoff and it has increased the forage production by significant amounts. As the installations have been in operation only since 1963 their permanent effect cannot yet be determined.

The results here cannot necessarily be considered as justifying similar installations in all locations as this is an unusually favorable area for spreading because of the relatively high precipitation--about 12 inches annually. However, this spreader demonstrates very clearly the advantages secured by the elimination of ponding on both the increase and upgrading of the vegetation.

Basic data requirements for a successful water-spreading installation include (1) information on frequency and probable magnitude of flood flow for use in the design of the spreading works and the appurtenant regulating reservoir, if used, and on the amount and frequency of precipitation on the spreading site, (2) knowledge of the infiltration rate on spread area which will govern the areal extent of the spreader system, and (3) information on soils by which suitability of the site for flood irrigation can be judged.

Efforts to obtain the above types of data were started soon after construction of some of the earlier spreaders when operational problems clearly indicated the necessity for such information. Early estimates of frequency and magnitude of flow were of necessity based on scanty information secured from local residents or from rainfall-runoff relationships, as measurements of runoff from small tracts were seldom available. Such estimates were often in error by large amounts. As gaging installations were installed and runoff data became available, reports covering a region were prepared, one example being the previously cited report by Kennon (1954). This report contains a compilation and analysis of all streamflow data for small basins in Arizona and western New Mexico, and provides the land agencies with reasonably well-founded estimates of the amount and frequency of runoff to be expected in the areas described. Additional runoff data are now available for other parts of the country and are being expanded continuously. (See Culler 1961, King 1959, Peterson 1962, and Burkham 1966).

The importance of an adequate water supply in spreading operations is clearly shown in the two photographs of figure 10, one taken in the

Figure 10.--Follows near here.

Dads spreader area, the other in the Little Robber Creek spreader, both located in the basin of Muddy Creek, tributary to the little Snake River in southern Wyoming. The increase in vegetation at the Little Robber area as a result of spreading has been on the order of several hundred percent, whereas in the Dads area scarcely any improvement is discernible. Over a 5-year period, 1954-58, the Little Robber spreader received a total of 1,306 acre-feet of runoff, or an average of 261 acre-feet annually. During the same period the Dads area has had but one complete spread, which occurred in late September after the growing season, and only a few partial spreads. The soils in both areas being derived from the Tertiary Wasatch formation consisting of clays and siltstone, should be and appear to be similar.

A. Excellent forage in the Little Robber spreader area; growth is chiefly native western wheatgrass; dikes constructed 1954. Photo Aug. 1964.

B. Nuttall saltbush above spreader dike in Dads area; minor increase in vegetation and forage since installation; dikes constructed 1956-57. Photo Aug. 1964.

Figure 10.--Little Robber and Dads spreader areas. Muddy Creek basin, Wyoming.

The added water supply at Little Robber appears to be due to a larger ratio of the contributing drainage area to the spread area. The Little Robber spreader covering about 300 acres has a contributing drainage area of 8.5 square miles, giving a ratio of drainage area to spread area of 18 to 1. The flow of Little Robber Creek is regulated by a retarding dam, and during the first three years of operation the early spring snowmelt runoff was stored and released for spreading in May and June. Because of apparent weakening of the dam, storage of water for long periods was discontinued and flow through the reservoir regulated by the outlet pipes was spread mostly in April and May. At the Dads area where the ratio of drainage area to spread area is only about 1 to 1 there is no regulation as the flow originates in a number of small drainage basins that enter the spread area independently. The only discernible improvement in vegetation occurs at the first or second dike directly below the contributing basins, indicating that these are the only places receiving any appreciable amount of spread water.

A detailed study showing the advantage of an adequate water-supply has been completed for a spreader located 5 miles west of the settlement of Alzada in southeast Montana. The spread area covers 275 acres and the contributing drainage area is 1,060 acres, a ratio of about 4 to 1 between the contributing area and the spread area. The runoff is not regulated. For the 4-year period, 1951-54, the total inflow to the area averaged 259 acre-feet annually, or 0.9 acre-feet per acre of spread area. Branson (1956) reports that this addition of water increased vegetation in the spread area by 2.6 times compared to a nontreated control area.

A spreader showing the effect of inadequate water supply, poor soil conditions and other unfavorable features is illustrated in the Crescent Wash spreader area located 20 miles east of Green River, Utah. This spreader was constructed in 1953 with a total of 20 dikes spaced over a length of about 2 miles covering 1,250 acres. The contributing drainage area is 30 square miles, 19 of which was controlled by the retarding reservoir. During the first 4 years of operation flow from the retarding reservoir was measured but no measurements were obtained of the uncontrolled flow. A storm on August 30, 1957 almost filled the reservoir with sediment so that thereafter measurements were impractical, and the studies had to be discontinued.

During the 4-year period, 1954-57, the average measured flow at the retarding reservoir was 331 acre-feet annually; the maximum annual flow in 1957 was 1094 acre-feet, in 1955 there was no flow and in 1956 the flow was 34 acre-feet. The combined discharge from the reservoir and the uncontrolled area of 11 square miles was sufficient to breach the first two dikes on at least three occasions, yet the water never reached beyond the fourth spreader. Field infiltration tests in the spread area gave an indication of the reason for this. The soil in the upper part of the spread area is a uniform fine sand with an infiltration rate of 8 to 12 inches per hour as measured by the use of the double cylinder method. As the spread area directly below the first three dikes is approximately 200 acres, it is capable of absorbing water at a rate of about 165 acre-feet per hour which means that the total flow for the maximum year, 1957, could have been absorbed in slightly more than 6 hours. In that year there were four major-runoff events, each lasting several hours. Thus the evidence is fairly conclusive as to why the water did not move beyond the third dike.

Because of the lack of water the lower 15 dikes in the system have been practically inoperative, and the only discernible evidence of any improvement in vegetation is an occasional narrow strip distributed along the upstream side of a dike which received and held some water from local runoff.

Impervious soil conditions can also be a serious handicap in spreading operations. Unless regulated in some manner, the runoff generated by the usual summer thunder shower seldom lasts more than one or two hours. Soils with low infiltration capacities, measured in fractions of an inch per hour, take in very little moisture from this type of storm unless the spreaders are designed to slow down the flow rate. However, in storms of longer duration, or when flow is retarded ponding occurs in surface depressions which results in a lack of vegetation or growth of undesirable species such as foxtail barley. Under the best of circumstances very tight soils are a distinct handicap in spreading operations, because on the one hand it is difficult to put enough moisture in the soil for any benefit, and on the other, water logging of the shallow horizons can kill the sparse original vegetation or give rise to inferior vegetation. A study has been started in a spreader of tight soils in the Willow Creek area in northeastern Montana to determine the amount of water needed and the duration of ponding that can be tolerated by desirable vegetation.

The Little Robber and Coal Creek spreaders and the Dads, Crescent Wash and parts of the Burnett spreader system represent extremes in spreader performance. The first two are highly satisfactory, and the expense of construction and maintenance seem to be well justified. In contrast the Dads and the Crescent Wash spreaders are almost complete failures owing mainly to inadequate water supply at Dad's and to the sandy soil at Crescent Wash. Performance of the Burnett Creek system could be materially improved by changing the spreaders so as to eliminate excessive ponding.

Range men or hydrologists should not be censured for failure to recognize the unfavorable features that have contributed to the poor performance of the unsuccessful spreaders at the time of their construction. Data simply were not available to permit making a reasonably accurate estimate as to what might be expected. With these installations as examples, however, opportunity has been gained to make better evaluation of the various factors that adversely affect the site potential. Consequently, these areas should be studied with the same thoroughness and detail as the successful spreaders.

Spreader installations are among the more expensive land treatment practices. Construction of the spreader dikes ranges from 5 to 10 per acre of spread area. This does not include the cost of appurtenant features such as regulating reservoirs, diversion structures, weeps through the dikes or fencing. The cost of nearly $19 per acre for the Coal Creek system is for the highest type of design and construction thus far undertaken, but at this cost it probably has the most favorable benefit-cost ratio of any installation observed. Such high costs however do emphasize the need for careful selection of the spreader site and assurance of adequate water supply.

Equally important in considering cost is that of maintenance. Most spreader dikes are pushed up by bulldozer and have low standards of construction. They are thus highly vulnerable to damage and breaching from the attack by rodents, by water seeping through or eroding along the dikes and by over-topping. The usual result is a heavy annual maintenance cost and often repairs are needed after each large storm. The maintenance charges increase appreciably where there is no regulation of flows from the contributing area. All of these factors should be carefully considered and analyzed in developing the final design of the spreader. Attempts to economize on the initial cost may result in a less effective and more expensive installation over a long period of operation.

Fencing for control of grazing is essential to successful spreader operations. Most spreader areas are seeded in the borrow pits where the original vegetation cover has been removed. As with any other well designed seeding the young seedlings must be protected from grazing until they are well established. Often the seeded plants are eventually replaced by native vegetation but this does not decrease the importance of protection until this occurs (See figure 10-A). It is recognized as a good policy also to keep livestock off the spreader area when it is wet.

The fencing and strict control of grazing in the Little Robber and Coal Creek spreader areas have doubtless contributed to their success. However, there is little indication that fencing would have improved conditions in the Dads area since the water supply was not sufficient to give any impetus to growth of either the native vegetation or the seeded varieties. The Crescent Wash area was fenced some time after the dikes were constructed, but the protection appears to have had no effect on the performance of the spreader system. The extra forage produced on the spreader area is scarcely enough to attract livestock although admittedly the fenced area both within and outside the spreader system is showing improvement due to grazing exclusion.

Because of the high cost involved, most of the land agencies now require that spreader sites be located on relatively high quality lands. This means that the soils should not contain more than limited amounts of sodium salts and should combine other characteristics of good soils with regard to infiltration, drainage, and fertility. Water-supply must also be adequate. To assure compliance with these criteria, the Bureau of Land Management and the Geological Survey are now cooperating in making detailed studies to determine the suitability of any proposed spreading area.

Another phase of water spreading receiving added attention in recent years has to do with water rights and the possible infringement of spreading on established higher priority downstream rights. Downstream users in many sections of the West are objecting with increasing vigor to spreading, their contention being that use of water for this purpose reduces the streamflow and thus infringes on established rights. Resolving this problem can be extremely difficult since determination of stream depletion resulting from the spreading of ephemeral runoff is a complex and difficult task. Nonetheless the problem must be solved if the water is to be used at highest efficiency and existing rights are to be respected. This problem is discussed further in a later section.

Range seeding

Seeding as currently practiced is in general one of the most successful methods of treatment for range rehabilitation. Although not all of the public domain is amenable to seeding owing to inadequate precipitation, unsuitable soils, excessive relief or other causes, surveys indicate that several million acres are suitable for treatment. Held and Clawson (1965) state that the BLM long range resource improvement program needs to include brush control on 15 million acres and seeding on 12 million acres. On the basis of results achieved on large areas treated to date, criteria for judging the chances of success in a given locality are fairly well established.

The primary purpose of seeding is the modification of existing vegetation to provide additional forage for livestock and game, to abate or cont erosion and to eliminate or control noxious or toxic plant species. In some cases secondary benefits in increased water supplies have been claimed.

As seeding is essentially an agronomic practice, its success is dependent on following, so far as circumstances will permit, successful well-developed agronomic principles and practices. This means that consideration must be given to such critical items as soils, moisture conditions, and methods of preparing the seed beds and distributing and covering the seed, and protection against grazing long enough to permit the plants to become firmly established. Finally, the established seeded areas must be properly used if their continued growth of the plants is to be assured under the hazards of an uncertain moisture supply.

Seeding has for the most part been confined to two general types of range, one on which the existing vegetation is predominantly sagebrush, mainly big sage (*Artemisia tridenta*), the other pinyon-juniper. Soil characteristics and moisture requirements for these two types of vegetation are in general equivalent to the requirements for successful seeding. For success in seeding, competition from the existing vegetation must be eliminated by burning or by mechanical or chemical methods, in order to release moisture for use by the seeded plants.

Table 9 shows the annual acreage of seeding that was done on the public domain during the 9-year period 1955-63, inclusive. As shown, the increase in the practice has been significant. A part of the increase has been due to extra funds provided by Congress to combat the invasion of the poisonous plant halogeton in the Snake River Valley of Idaho and in northern Nevada and Utah. However, because of its success, seeding is now the major method of increasing forage production in all areas favorable for its use. The total area reseeded in 1965 as reported in Public Land Statistics for 1965 was 233,644 acres. Of this, about 98,000 acres was in Nevada.

Table 9 .--Seeded acreage within and outside of grazing districts.[1/]

(Includes seeding on the public domain done under the range improvement, soil and moisture, and weed control programs, and also seeding by allottees)

State	1955	1956	1957	1958	1959	1960	1961	1962	1963	Total
Ariz.	2,170	2,788	3,700	11,055	21,738	8,770	26,382	3,680	5,960	86,243
Calif.	11,389	10,850	8,414	7,436	5,846	5,140	9,385	18,511	4,705	81,676
Colo.	3,117	2,943	3,014	6,388	8,131	5,610	4,631	11,000	17,991	62,825
Idaho	16,096	14,402	22,796	34,826	74,503	33,474	111,498	46,884	17,956	372,435
Montana	5,893	200	1,904	2,060	2,353	3,270	4,211	0	1,740	21,631
Nevada	17,706	11,831	10,309	32,730	31,418	49,643	31,855	29,740	22,010	237,242
N. Mex.	7,466	4,991	2,980	12,856	21,071	6,653	5,919	4,658	16,448	83,042
Oregon	12,856	8,845	7,860	7,957	9,441	8,159	72,204	2,723	27,629	157,674
Utah	2,420	7,509	10,025	9,858	12,288	18,512	16,272	23,396	11,329	111,609
Wyoming	4,235	3,265	0	3,634	0	250	4,660	188	882	17,114
Wash.	280	600	120	480	900	310	300	0	0	
	83,628	68,224	71,122	129,280	187,689	139,791	287,317	140,780	126,650	1,231,481

1/ Data from Statistical Appendixes to the annual reports of the Director, Bureau of Land Management, 1955-1963

Moisture requirements for seeding.--Equally and perhaps more important than proper clearing and preparation of the seedbed for successful seeding is the availability of moisture at timely intervals to insure both germination of the seed and continued growth of the plants. It is something of a paradox that important as this feature is, few precipitation gages have actually been installed in the immediate vicinity of seeded areas, even the very large ones. Records from precipitation stations, some located as much as 20-50 miles distant have been used as criteria. Variations in precipitation over these distances can be great. This lack of accurate information imposes a severe handicap in judging the success of the seedings, particularly those of low production since it is impossible to ascertain to what extent the failure was due to deficient moisture or to other causes such as improper planting methods, unfavorable soils, high salinity, cheatgrass or other annual weed competition, or other factors. The expense of operating a gage compared to the cost of the seeding is insignificant. Even measurements made at two to four-week intervals during the growing season and of the accumulation during the winter would be of inestimable value in judging the progress and success of the seeding.

As a measure of moisture requirements, Stoddard (1946) stated that areas with average annual precipitation of less than 15 inches would likely be difficult to seed with surety and that those with less than 10 inches were almost certain to be unsuccessful. This statement has proven to be unduly pessimistic and to follow his 15-inch rule would severely restrict the areas where seeding could be practiced and would prohibit seeding on much of the public domain.

Additional experience has shown that successful seeding can be obtained with an average annual precipitation of 10 inches, and moderately successful ones with 8 inches provided the soil conditions are favorable and the growing season temperatures are not excessive (Shown et al., 1969). For Idaho, Hull and Holmgren (1964) state that with good seedbed preparation reasonable success can be expected in areas with average annual precipitation of 9 to 11 inches, and several seedings have been successful in the 7- to 9-inch precipitation area. For the lower precipitation areas the distribution and time of occurrence of the rains is especially significant. Criteria for this can best be obtained from rain gages located in the immediate vicinity of existing or proposed seedings.

The most critical period in seeding follows germination of the seed. To survive, the young plant must have sufficient moisture to develop a root system and a surface growth of ample size and stability to withstand successive dry periods. Hot, dry weather occurring before the seedling becomes firmly established results in high plant mortality. Because of this, the selection of the time for seeding that will take advantage of likely recurring favorable moisture conditions is of great importance. Naturally, it is impossible to predict when precipitation will occur but a study of past records gives some indication of periods when the occurrence and distribution of rainfall is likely to be most favorable for seeding operations. Such studies cannot guarantee the success of seeding in a given locality but they can reduce the chance of failure.

Low annual precipitation coupled with unfavorable distribution of monthly amounts indicates that seeding will be hazardous and most likely unsuccessful over much of southern Nevada, in Arizona except for the northern and southeastern parts, and over parts of New Mexico and Wyoming, Utah, Colorado, and Oregon. Generally, the unfavorable prospects in these localities are well recognized and seeding is no longer attempted except in association with waterspreading. However, even within these more arid parts there are local places where, owing to higher elevations or favorable orographic conditions, the precipitation is enough to assure reasonably successful seedings. Such localities may represent only a small part of the total area but they can be of significant importance in relieving the grazing pressure on other parts of the range and in furnishing forage during critical non-productive drought periods.

Seeding sagebrush areas.--The major part of rangeland seeding is currently being carried out on sagebrush lands in the northern states and the higher cooler parts of Arizona, Nevada, and New Mexico. Eliminating the sagebrush and seeding on these lands has for the most part been quite successful, largely, it appears, because conditions favorable to the growth of sagebrush are also favorable to the growth of selected range grasses. Many observers believe that sagebrush has spread appreciably or has increased in density as a result of over-grazing of the associated original grass. The extent of spread of sagebrush is controversial, but it is generally agreed that the amount of interspersed grass has been reduced in many places on the public domain.

Sagebrush presently occupies about 96 million acres of the western rangeland (Pechanec, Plummer, Robertson, Hull, 1965). Its habitat extends through each of the principal public domain states from northern Arizona and New Mexico to beyond the Canadian border at an altitude ranging from 3000 feet to that of timberline. It grows most abundantly on well-drained low-salt soils and is particularly well adapted to the volcanic soils of the Snake River Valley in Idaho and eastern Oregon, the alluvial valley and foothill soils in the Basin and Range Province and most of the foothill slopes and mesas in the Colorado Plateau. Although it has some value for livestock forage (U.S. Dept. Ag. 1937) and for forage for big game this is minor compared to the productivity of the substitute grass cover. Because of this there are strong indications that eventually a large part of the sage-brush area will be cleared and converted to grass lands. At present sagebrush clearing and seeding is the principal range improvement program in those states having large sagebrush areas.

Studies carried out under the Soil and Moisture Program of the Geological Survey (Shown, et al., 1969) describes in detail the results of seeding on 51 Bureau of Land Management crested wheatgrass sites located on sagebrush areas in Idaho, Wyoming, Nevada, Utah, and Colorado. Although the studies cover only a small segment of the total seeded sagebrush area, the study tracts are in general representative of the areas in which new seedings may be undertaken. The studies give detailed information on soils, soil-moisture holding capacity, methods of brush eradication, methods of seeding and the results obtained. The following discussion is aimed at a broad generalized coverage of these same subjects.

For successful seeding, elimination of the sagebrush cover is essential to remove the competition for moisture and to provide a better growing environment for the seeded plant. For this purpose burning has been used with some success. The practice is not widely used, however, for several reasons, some of which are: timber production, recreational and watershed value of the land may be endangered or destroyed; it is often difficult to control a fire when burning conditions are optimum, desirable forage or browse species may be damaged; undesirable species such as rabbitbrush or cheatgrass may be increased, the soil is completely exposed to erosion until plant cover is restored, and occassionally, fairly dense stands of sagebrush seedlings become established despite all precautions.

Although the clearing and seeding of most sagebrush areas can be justified on the basis of increased forage yield, the extent of such increase can vary widely depending on the fertility and moisture-holding capacity of the soil, erosion conditions within the cleared tract, the type of grass used, method of clearing and planting but probably most important on the amount and distribution of precipitation. Because of the last mentioned item, the forage production can vary greatly from year to year. Seedings that in a good year may produce a luxuriant growth, may in subsequent years of low precipitation produce very little. For this reason the value of a seeding cannot be judged conclusively on its performance during any short time period.

In support of the general justification for seeding, Stoddart (1946) reporting on Utah conditions states that "modern knowledge of seeding makes possible vast increases in production from dry ranges in the inter-mountain west." Barnes et al. (1952) in a similar vein state that "The benefits of reseeding have now been so well publicized that reseeding is widely recognized as a profitable practice leading directly to range improvement."

Using various methods of measurements it has been determined by numerous investigators that the increase in forage resulting from clearing and seeding may be tenfold or greater under favorable conditions. Gray and Springfield (1962) report increases up to 400 percent from cleared and seeded mixed juniper-sagebrush areas compared with native yields in north-central New Mexico. In an earlier study Pingrey and Dortignac (1957) report that the lowest yield on big sage areas in northern New Mexico seeded with crested wheatgrass was on the order of 10 times natural production of grasses.

In a Utah study covering 54,000 acres, Cook and Lloyd (1960) state that prior to seeding from 10 to 14 acres was required to produce one AUM of grazing. Following seeding this requirement dropped to 3 to 5 acres. Annual rainfall on the ranges varied from 8 to 13 inches and averaged about 12 inches. The annual monetary return based on the increased gains of the livestock on seeded areas ranged from $2.00 to nearly $5.00 per acre after paying costs of the treatment plus cost of the deferred grazing while the seedings were established.

In the 39 sagebrush seeded sites studied by Shown et al., (1969) 30 sites showed yields ranging from a trace to 2,290 pounds of crested wheatgrass per acre, with the highest as a rule in the areas of highest precipitation. The estimated annual precipitation at each of the sites ranged from 8 to 14 inches and averaged about 11 inches. Nine of the sites were failures, but this was not due entirely to low precipitation as unfavorable soil factors were also involved.

The success of the 50,000-acre Berger seeding in the Burley District, Idaho is outstanding. Forage production in 1963 had been increased to an estimated amount 15 times greater than what it had been in 1954 when treatment was started. The total cost including fencing, the construction of roads, and the development of range water facilities is said to have been amply justified.

Almost equally impressive but with a somewhat lesser yield are the seedings in the Vale District of Oregon where, by 1965, 174,400 acres had been treated for brush control and 106,400 acres had been seeded. The lower yield in the Vale District compared with the Idaho seedings is apparently due to the lower average annual precipitation, which ranges from 8 to 12 inches. Views of the Berger seeding in Idaho and the Mud Flat seeding in Oregon are shown in figure 11. Other typical views

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Figure 11.--Follows near here.

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of the increased forage resulting from the clearing and seeding of sagebrush land are shown in figures 12 and 13. Figures 13-A and 13-B

Figures 12 and 13.--Follow near here.

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show a similar contrast in the Cedar City, Utah Grazing District at a location near State Highway 20 about 15 miles southeast of Beaver, Utah.

A. Berger seeding (Burley District, Idaho. Crested wheatgrass planted 1959. Yield estimated at more than 2,000 pounds per acre. Lightly grazed 1965.

B. Mud flat seeding Vail District, Oregon. Moderately heavy grazing. Planted 1958. Mixed seeding of 4 wheatgrass species. Photo Sept. 1965.

Figure 11.--Crested wheatgrass seedings in big sagebrush areas, Idaho and Oregon. Photos Aug. 1965.

A. Uncleared unseeded area.

B. Area cleared and seeded.

Figure 12.--Contrast between seeded and unseeded areas, near Arco, Idaho.

A. Crested wheatgrass planting 4 years old. Light grazing after 2 years. Aug. 1962.

B. Uncleared area, about 1/2 mile north of A. Note almost complete absence of grass. Aug. 1962.

Figure 13.--Range conditions before and after clearing and seeding sagebrush lands. Cedar City District, Utah.

Other successful seedings on sagebrush lands have been established in northern Arizona in the vicinity of Fredonia (Univ. of Ariz. Experiment Station, 1964) and in northern Nevada in the Elko and Winnemucca Districts. Typical views of the seedings are shown in figure 14. The

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Figure 14.--Follows near here.

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average annual precipitation at the Arizona seeding is about 12 inches; in the Nevada area it is about 10 inches.

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A. Crested wheatgrass seeding about 15 miles southeast of Fredonia, Arizona. Area has not been grazed this season. Photo Sept. 1965. Annual precipitation probably about 12 inches.

B. Heavily grazed seeding south of Elko, Nevada. Excellent kill of sagebrush but crested wheatgrass shows some effect of overuse. Sandy soil. Photo Sept. 1962.

Figure 14.--Seeded areas in northern Arizona and northern Nevada.

It should not be concluded from the above that all seeding on sagebrush lands has been successful. There have been some notable failures, and unfortunately the reason for the failures in many localities is not always evident. One striking contrast has occurred in the foothill area a short distance west and southwest of Malta, Idaho. The two contrasting areas were cleared and seeded as a step in the control of the poisonous weed, halogeton. Soil conditions, slope and exposure in both localities are about the same. The soil is a gravelly loam on a broad alluvial slope. Figure 15-A shows the area 2 miles

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Figure 15.--Follows near here.

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west of Malta with an almost complete kill of sagebrush and halogeton and a moderately good stand of crested wheatgrass. Figure 15-B shows the area located about 3 miles south of A and treated in the same year, 1954. A good kill of the sagebrush was obtained but there has been no recovery of grass and the halogeton has increased. Figure 16 shows the

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Figure 16.--Follows near here.

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two same areas 3 years later. From B it can be seen that the grass cover has increased and halogeton has decreased probably as a result of an increase in precipitation.

A. Moderately successful sagebrush clearing and seeding 2 miles west of Malta, Raft River Valley, Idaho. Seeding 2 years old.

B. Unsuccessful seeding in an area located 3 miles south of A. Note Absence of plants in drill rows; low spreading plant is halogeton. Seeding 2 years old.

Figure 15.--Range seeding near Malta, Burley Grazing District, Idaho. Photographs taken Aug. 1962.

A. Approximately same area as shown in Fig. 15-A. Crested wheatgrass still shows a good growth, but note strong invasion of sagebrush.

B. Same area as 15-B. Moderate improvement. Halogeton growth reduced. Light colored grass is cheatgrass; darker colored is crested wheatgrass.

Figure 16.--Seedings near Malta, Idaho showing changes that occurred during a 3-year period. Compare with figure 15. Photos Aug. 1965.

Another seeding showing an excellent kill of sagebrush but an almost total lack of grass recovery is located a few miles east of Paradise Valley in the Winnemucca District, Nevada. The western part of the total seeded area covering several hundred acres shows a good growth of crested wheatgrass. A mile to the east the seeding is a complete failure. The contrast is shown in figure 17. The reasons for the

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Figure 17.--Follows near here.

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difference in results have not been conclusively explained, but possibly the following elements had an effect. Siberian wheatgrass, which generally is used less and is considered slightly inferior to crested wheatgrass was used in the eastern segment; and although the soils appear to be similar, those in the eastern part are derived in the main from rhyolite and dacite and are somewhat finer textured and a little more saline. Also, the area that failed is underlain by a genetic hardpan that may have had an adverse effect on grass establishment. This aspect is being investigated.

Of the 51 seeded sites studied by Shown et al., (1969) 15 were were failures in that there was little or no growth of the crested wheatgrass. Reasons for the failure are not clear but it is stated that it could be due to low rainfall, soils that were too fine textured, and possibly a high salt content of the soils in some areas. Possibly in some places poor results were due to using broadcast seeding. There were some indications that failure might have been expected as the vigor index of the big sagebrush was low on many of the sites.

A. Moderately successful crested wheatgrass seeding. Area has been grazed for the past 3 years.

B. Total failure of Siberian wheatgrass seeding. Photo taken about 1,000 feet east of A. Plants growing in the drill furrows are annual weeds.

Figure 17.--Contrasts in seeded areas located east of Paradise Valley, Winnemucca Grazing District, Nevada. Areas planted 1960. Photos Sept. 1965.

These and other examples of unsuccessful seedings on sagebrush lands emphasize the need for additional research on land clearing and seeding problems. More intensive studies are essential for determining the effects of salts, and the possible lack or over-abundance of minor constituents in the soils. Fertility and the possible need and justification of the use of commercial fertilizers should be investigated. Possibly the greatest need of all is for more complete and precise data on precipitation. No rain gages are located within the areas where failures have occurred and consequently no information on the magnitude or time of occurrence of precipitation in the treated area before or since planting is available. Because of the importance of timely precipitation to the success of the seeding practice, information on it is essential.

Seeding pinyon-juniper areas.--Pinyon-juniper areas ranging from closed stands with a meagre understory of grass and shrubs to scattered trees interspersed with open tracts of grass and brush occupy some 60 million acres in Western United States. About 14 million acres are in Arizona, about 15 million in New Mexico, and the remainder in Utah, Nevada, Colorado, and west Texas (Arnold, Jameson, Reid, 1964). Much of the pinyon-juniper area now supports very little forage and otherwise produces little of value. Excellent descriptions of the areal extent and distribution of the trees, their growing environment, soil and moisture requirements, methods of treatment for conversion to grassland and other details concerning the plant and its effect on range productivity are given by the above mentioned authors. A report by Aro (1971), based on studies by the Geological Survey of 65 treated sites located in Arizona, Colorado, Nevada, New Mexico, and Utah summarizes the effects of treatments conducted by the Bureau of Land Management.

Part of pinyon-juniper land was formerly moderately productive range, and it is generally conceded that in many places the spread of the trees represents an invasion of grass land resulting from grazing and possibly fire suppression (Pearson, 1931). Thus, the growth and expansion of these woodlands constitute a direct reduction in range-forage production. It likewise represents an added expense in livestock operation because of the difficulty and inconvenience of controlling the movement of stock in this environment.

Most of the pinyon-juniper growth lies at altitudes between 5,000 and 8,000 feet and in a precipitation belt ranging from 10 to 14 inches. At the higher altitudes where precipitation is greater, the trees generally merge into a Ponderosa pine forest and at the lower altitudes into sagebrush, desert grassland, and shrub zones. The trees grow on a variety of soils but are most common on the coarser textured types derived from sandstone, limestone, and volcanic and granitic rocks. They are less common on clay soils associated with shales and siltstones.

Precipitation in the pinyon-juniper habitat is generally adequate for production of grass, but other factors bring up some questions and differing opinions as to how much of the pinyon-juniper area can be feasibily converted to a grassland. Slope imposes one limitation as it has generally proved impractical to treat lands by mechanical methods with slopes greater than 15 to 20 percent. Soil conditions offer another important restriction because a relatively large proportion of the pinyon-juniper growth occupies coarse-textured, rocky soils that are not favorable to the production of herbaceous range forage. These factors will probably limit the area of treatment to about 10 or 12 percent of the total. Development of new methods of treatment including controlled burning or use of chemicals could increase this percentage, but on the other hand, demands of sportsmen for increased acreage of the woodland for wild fowl and big-game propagation and by other interests for recreation, residential or commercial ventures could limit the treated area to something less than the suggested 10 percent.

Methods and practices used in converting pinyon-juniper woodlands to grass differ materially from those used in the treatment of sagebrush lands. A high percentage of the tree kill is essential for success in grass recovery. The methods for killing include burning, single or double chaining or cabling, bulldozing and chopping or sawing. Elimination of the trees by use of chemicals has not proven feasible to date, but research is continuing with some promise that a successful cheap chemical control will eventually be developed. Each of the above methods have been described in detail in the previously cited report by Arnold et al. (1964) and studies by Aro (1971).

Considerable difference of opinion has developed among investigators on the value of the various methods of treatment. Aro considers burning one of the most successful and points to the excellent results obtained both from accidental burns and from planned burning in the Haulapai Indian Reservation of northern Arizona and in several other locations. Arnold et al. (1964) on the other hand lists the many difficulties encountered in burning both in propagating the fire and in obtaining a good grass cover following the burn. It is obvious that considerable more research and experimental work is needed before a final judgment can be made on the value of burning as a conversion method.

A number of evaluations have been completed on the effects and benefits of pinyon-juniper clearing. Table 10 gives a summary of the data obtained from examination by the U.S. Geological Survey of 48 Bureau of Land Management conversion projects located in Arizona, Colorado, New Mexico, and Utah (Aro, 1971). The studies show that in general best results were obtained where the clearing was done by burning or by double chaining followed by windrowing, burning, and seeding in areas where the average annual precipitation was 12 inches or higher. In these areas the forage production was increased from 2 to 20 times. Less successful treatments, ranging downward to almost complete failures were attributed to a poor kill of trees resulting mainly from single cabling, low precipitation and rocky soils not adapted to grasses. The number of questionable results and near failures reported suggest that not enough care was used in selecting some of the sites or carrying out the treatment procedures. The report notes that at several sites the potentials justified more intensive treatment. This condition has been observed at other localities and leads to the conclusion that using half-way measures in pinyon-juniper treatments represents false economy. Only those sites with potentials sufficient to justify full-scale treatment including clearing, burning, and seeding should be selected.

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Table 10.—Summary of data on pinon-juniper clearing projects in Arizona, Colorado, New Mexico and Utah. After Aro 1965

State, grazing dist., project name	Year treated	Method of treat.1/	Alt. of treat. area (feet)	Est. ann. precip. (inches)	Changes in vegetation: Pinon and juniper trees per acre	Percent killed by treatment	Dry wt. untreated lbs/acre	Dry wt. after treatment lbs/acre	Remarks
Arizona									
Arizona Strip Little Wolf juniper eradication and reseeding	'58-'59	C	5200	14	215	-25	60	50	Treatment increased trees, decreased forage Not a true woodland type area
Phoenix Lawrence-Steegal-Cook reseeding and juniper control	'56-'59	C	5000	13	-	25	50	50	Subject to excessive overgrazing. -
Colorado									
Craig Farcus Tree chaining	'62	C	6600	14	340	95	100	500	Outstanding success but many young trees were left standing
Craig Hunter Creek	'59	C	7000	15	-	-	-	-	Many young trees missed but grass recovery good
Craig El Paso Burn	'62	F	7200	15	-	100	-	600	Successful, excellent example of results of burning of mixed tree shrub type.
Durango Grade Seeding	'63	C	6400	13	225	53	120	-	Heavy chaining trash, probably helps erosion but makes grazing difficult
Durango Grand Seeding	'62	C	6800	13	-	25	-	50	Burning could have been effective Trash cover presently very heavy
Durango -	'56-'59	C	6800	12	-	-	-	-	Most of sparse stand survived chaining No discernible increase in forage
Montrose Robideau juniper eradication	'61-'62	C	7200	12	115	41	20	200	-
Montrose Garrison pinon-juniper chaining	'62-'63	C	7400	12	685	31	10	100	Dense young stand, mostly pinon, offered little chance for chaining success
Montrose Paxton pinon chaining	'61-'63	C	7600	12	710	41	10	100	High density of trees with high proportion of young pinon made this a good burning site, poor results from chaining
Canyon City Penrose pinon removal	'57-'58	C	6000	13	345	48	-	100	heavy trash should be burned but objected to by Forest Service. Tree recovery a problem
Canyon City Huerfano chaining and seeding	'63	C	8200	18	150	50	80	200	-
Canyon City Mt. Blanca pinon-juniper seeding	'63	C	8400	10	285	9	20	100	-
Canyon City Clayton chaining	'61	C	8400	9	200	25	40	100	Forage recovery poor but could be improved as slash is removed by woodcutters
Grand Junction Gittler Canyon	'63	CC	7600	12	270	-	50	400	Site justified more intensive treatment
New Mexico									
Las Cruces Chaupadera Mesa pinon-juniper control	'58	CB	6500	15	85	-18	320	-	Rocky soil, double chaining failed to kill small juniper trees and did not increase forage
Albuquerque - Santa Cruz seeding	'63	M	7000	10	335	67	240	1300	Foliage volume of trees reduced by treatment but kill of trees only moderate. Outstanding grass recovery
Albuquerque Shrover pinon-juniper seeding	'63	C	7300	15	385	47	140	-	No appreciable increase in forage production
Albuquerque Gene Johnson pinon-juniper chaining	'63	C	7000	12	200	75	140	300	-
Farmington Brown Juniper eradication	'58	C	6300	10	-	25-50	-	-	No appreciable increase in forage
Farmington Sowers juniper eradication	'58	C	5900	10	160	64	600	-	Treatment has had little lasting effect on grass production
Farmington Ramon Ulibarri juniper chaining	'64	C	6400	11	285	49	120	-	No appreciable increase in forage production
Utah									
Vernal Pine Springs reseeding	'62	CC	7100	15	595	51	100	500	Tree regrowth a problem, was good burning site prior to chaining
Vernal Monument Ridge Burn seeding	'53-'58	F	7000	13	670	100	50	500	Successful forage recovery. Abundant fuel factor in burning. Recovery is from native grasses
Vernal McCook Ridge Fire	'53	F	7400	14	-	100	80	1300	Highly successful. Forage recovery from native grasses exclusively
Vernal Lower McCook Ridge pinon-juniper chaining	'62	C	7000	13	540	40	100	300	Many young trees not killed. Site offered good burning conditions
Vernal Boulevard Ridge aerial seeding	'62	CC	7300	14	-	50	100	-	Grass production only in areas where trash accidentally burned. Good site for burning
Price Pinnacle Bench reseeding	'62	CC	6400	12	260	46	20	400	Parts of project would have been good burning site, with excellent chance of good grass recovery
Price West Huntington reseeding	'61	CC	6500	13	375	63	20	300	Seeding of valuable browse species may assure success for treatment as a game habitat
Murray Ekker seeding	'62	CC	5800	13	295	78	50	800	Trash windrowed and burned on part of project, tree kill good; forage production satisfactory
Fillmore Indian Creek	'55-'59	W	6400	12	-	95+	50	500	Successful, area heavily grazed in the year preceding examination
Fillmore Porcupine	'57-'58	W	6400	12	315	95+	50	600	Successful, high potential realized
Fillmore Snag Hollow	'61	W	6600	12	-	95+	50	700	Do.
Fillmore Jackeys	'57	W	6600	12	-	95+	50	600	Do.
Fillmore Sheep Creek	'60	W	7200	16	-	95+	60	1000	Outstanding success with a high potential site
Richfield Tarantula Mesa	'62	C	6400	12	-	-	-	-	Ecological and forage improvement questionable
Cedar City Little Cr. Mtn. tree removal and seeding	'61-'65	W	5600	12	280	95+	40	50	Low precip. during first year probable cause of grass failure. Reseeding planned
Monticello Table Top reseeding	'58	C	6000	12	200	32	30	50	High potential justified more intensive treatment. heavy trash reduces value of project
Monticello Alkali Point reseeding	'61	CC	6200	12	405	56	20	300	Do.
Monticello Brush Basin seeding	'62	CC	7000	14	-	50	20	500	Survival of small trees and covering of trash offsets value of grass production
Monticello Cyclone Flats reseeding	'61	CC	6800	13	300	42	10	500	High potential site justified more intensive treatment. Survival of trees offsets grass production
Monticello Little Baullias reseeding	'60	C	6000	13	455	35	20	100	Low tree kill and high percentage of young vigorous trees prevented growth of grass
Monticello Reid Ranches reseeding	'60-'62	CC	6600	13	350	67	60	50	Lack of timely rainfall hurt project
Monticello Peters Point reseeding	'60	C	7200	14	270	46	30	500	High potential site justified more intensive treatment. Good but temporary grass recovery
Kanab Haris Brown reseeding No. 1	'63	CC,F	5700	13	130	95	30	500	Successful. Burning over part of area contributed to success. Grass shows potential for higher production
Kanab Mackelprand Brush control and reseeding	'61,'63	CC	5500	12	-	-	20	-	Poor kill on trees. Forage production could improve with time

1/ C = single chaining; CC = double chaining; CB = cabling; F = burning; M = Marden Brush Cutter; W = windrowing

2/ Based on B.L.M. estimate of pretreatment carrying capacity and authors estimate of forage production at time of examination

A significant study of the value of pinyon-juniper clearing in an experimental area just south of Eureka, Utah has been reported by Valentine et al. (1963). Annual precipitation here is about 13 inches. As observed in Sept. 1965 the increase in forage resulting from removal of pinyon-juniper followed by seeding to crested wheatgrass has been outstanding. Figure 18 shows views of an uncleared area adjacent to a

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Figure 18.--Follows near here.

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cleared windrowed and seeded tract. The cost of this treatment was about $13 per acre, which is thought to be well justified by the increase in forage. Some parts of the experimental tract not shown in figure 18-B are less successful owing in some cases to different methods of treatment, in others to differences in soil types. The impression gained is that the intensive treatment represented by figure 18-B will give the best return on the investment.

A. Pinyon-juniper area has practically no understory of grass or other forage and is valueless for grazing.

B. Area adjacent to A cleared, windrowed, and seeded to crested wheatgrass. Increase in forage more than 20 times. A further increase could be obtained by burning the windrow.

Figure 18.--Cleared and uncleared pinyon-juniper areas near Eureka, Utah. Photos taken Sept. 1965.

An outstanding example of an intensive juniper clearing and very successful seeding treatment is shown in Figure 19-A. Here it will be

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Figure 19.--Follows near here.

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noted that all vestiges of pinyon-juniper have disappeared and no new growth has developed in the 6 years since treatment. The exceptional grass growth shown may be due in part to unusually high precipitation during the 1965 summer. A gage nearby showed 6.25 inches between May 6 and Sept. 3. However, the local stock operators state that the production each year has been nearly as great. The carrying capacity on this tract has been materially increased since the seeding matured but it is obvious that additional increases might well be considered.

Figure 19-B shows a clearing located east of Mt. Turnbull in the Arizona Strip. This pattern of clearing was designed to increase browse for use of deer. The one way cabling used here resulted in good kill of pinyon and juniper trees and possibly some increase in browse, but without a more intensive treatment including seeding, the benefit for livestock and game use is practically nil. Although less favorable than the site shown in 20-A, the potential here for a high grass yield should be good because the average annual precipitation here is expected to be nearly as much as that measured at Mt. Turnbull, which is about 13 inches.

A. Outstanding pinyon-juniper 6 year old seeding with slender wheatgrass. South end Wah Wah Valley, Utah. Forage yield about 2,000 pounds per acre. Annual precipitation about 15 inches. Note absence of trees. Area double cabled, windrowed, burned, plowed, and seeded.

B. Cabled area on private lands, Arizona Strip. Minor benefits if any but area has good potential if properly cleared and seeded. Annual rainfall estimated at 10 to 12 inches. Treated 1962.

Figure 19.--Examples of highly successful and less successful pinyon-juniper conversion treatment. Photo taken Sept. 1965.

Figure 20 shows two views of a treatment that combines forage

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Figure 20.--Follows near here.

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increase for livestock with conditions favorable for game animals. The area shown in A was cabled, cleared, and seeded. The islands of trees were purposely left as a shelter and feeding area for game animals. About 3,500 acres in this vicinity were treated between 1959 and 1964. The results look promising, but the 1964 seedings are too young to permit making a valid judgment on their value. Observations during the inspection show that deer readily graze the crested wheatgrass.

In an analysis of the cost of grazing livestock on pinyon-juniper rangelands in northern Arizona, Cotner and Kelso (1963) show little optimism for the benefits of clearing. Based on a survey of 189 northern Arizona beef producers located in the pinyon-juniper areas, they state that the allowable costs for reducing the number of trees on rangelands vary from $1.19 to $3.89 per acre. It is not clear if the ranchers surveyed were ultraconservative, but obviously, costs of this low magnitude would preclude conversions such as those conducted by the Government agencies in the last few years.

A. Area cleared and windrowed but not burned. Broadcast seeding; islands of trees are left to provide shelter and browse for game animals.

B. Area chained but not cleared; broadcast seeding.

Figure 20.--Cleared pinyon-juniper areas on Segmiller Mtn. Arizona Strip. Pattern and method of clearing designed for both livestock and big game use.

These figures are in strong contrast with an analysis of Lloyd and Cook (1960) who demonstrate that a return of 6 to 10 percent on the investment and cost of operating cleared and seeded sagebrush lands can be obtained where a third to half the cost of treatment is subsidized. Treatment cost in the analysis used ranged from $13.50 to $14.35 per acre and included, in addition to clearing and seeding, fencing, range water development, and interest for the 24-month non-use periods. These treatment costs are somewhat higher than costs of treating pinyon-juniper by chaining or cabling with seed broadcast ahead of the cabling as reported by Valentine et al. (1963). Because the increased forage production is usually higher than on sagebrush lands due to the generally greater average precipitation, the treatment shows a favorable benefit-cost ratio. Results such as those shown by figures 23-B and 24-A would justify an even higher treatment cost.

Aside from unfavorable appearance, especially of uprooted trees left where they fell, the greatest deterrent to the expansion of pinyon-juniper clearing is likely to be from State or Federal fish and game departments and from sportsmen. Research with the objective of developing grounds for compromise is needed as the benefits of clearing and seeding pinyon-juniper areas are certain to apply to both livestock and big game.

Effect of vegetation conversions on water yield.--Effects of the clearing and seeding practices on water yield and on erosion and sediment yield are being investigated at a number of localities, but few quantitative data are available now. The effect of sagebrush eradication is one of the most difficult to evaluate, chiefly because the plant is generally found on well-drained soils which naturally produce a minimum of runoff. On the basis of observations at several locations in Idaho, Utah, and New Mexico, the clearing and seeding of sagebrush lands appears to have little effect on runoff or sediment yield; at most of these locations there was no significant yield of either prior to clearing and little change since. As the observations extend over a period of a few years only, many of which had below average annual precipitation, and as it is not certain that the cleared tracts are representative of sagebrush areas in general, the observation cannot be considered as either reliable or conclusive.

A study was started by the Geological Survey in cooperation with the Bureau of Land Management in 1964 in the Boco Mountain area near Wolcott, Colorado. Four small watersheds having a total area of 30 acres are being used to determine the effects on runoff and sediment yield when sagebrush land is converted to grassland. Two of the watersheds were plowed, and then seeded to blue-bunch wheatgrass in the fall of 1967. Plant cover and soil conditions appear to be approaching stability in 1970 on the grassed watersheds, so fairly conclusive results of the treatment effect should be available in 3 or 4 years.

A study of the effects of pinyon-juniper eradication and reseeding to grass on water yield was started in the Fort Apache Indian Reservation, Arizona in 1957 (Collings and Myrick, 1966). Two adjacent drainage basins, Carrizo and Corduroy Creeks with drainage areas of 237 and 213 square miles, respectively, were used to measure the effect of clearing on water yield. Both are tributary to the Salt River and drain a part of the Mogollon Rim area above Roosevelt Dam. In the Corduroy basin, 38 percent was treated, whereas the Carrizo basin was undisturbed. Precipitation and runoff records were collected for 7 years prior to treatment and for 5 years after treatment. The clearing was limited to areas having slopes less than 20 percent. The interpretations made by the authors are as follows: "From the results of this study it cannot be demonstrated that the partial clearing of Corduroy Creek basin resulted in either an increase or a decrease in water yield."

Additional detailed studies on the effect of pinyon-juniper removal and seeding to grass were started in 1958 on two watersheds called the Cibeque 1 and 2, near the boundary of the Carrizo Creek basin. The areas of the watersheds are 36 and 56 acres. Measurements are being made of precipitation, runoff, soil moisture, and vegetation. The precalibration measurements were continued for 9 years prior to removal of the trees and seeding of grass in the one watershed. Unpublished records (R. M. Myrick, personal communication) showed that after the first full year of treatment the runoff (for 1967) from the treated basin was about twice that of the untreated basin, but this was before the planted grass became fully established; much of the treated ground was bare. The runoff for 1968, after a very good stand of grass had become established in the treated basins, was very nearly the same for the two basins but was considerably below average.

Studies of a similar nature and having the same general objectives are being conducted by the Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service in the Wet and Dry Beaver drainage basins tributary to the Verde River in central Arizona. Effects on water yields by clearing both pinyon-juniper and pine forests are being determined.

The need for studies on the effect of various types of brush and tree control as they affect forage production, erosion and water yield on rangelands is obvious because of the rapid expansion of these practices. There is a particular need to determine which areas have the greatest potential of success. The great increase in pinyon-juniper clearing has taken place mainly since 1950. Thousands of acres are presently being cleared annually and plans for future treatment involve greater areas. Private landowners in many localities regard clearing as a good investment and are clearing large acreages at their own expense. At several locations allottees are sharing the cost of clearing public domain lands with the Bureau of Land Management and indicate their willingness to continue on an expanding scale. If it can be demonstrated that in addition to increasing forage the clearing may also result in increased water yield and reduced erosion and sediment yield, the cost-benefit ratio should justifiably reflect these advantages. The possibility that clearing and seeding could result in lower water yield must also be recognized.

Mechanical land treatment

Mechanical land treatment of land as practiced at present involves the modification of the ground surface by motor-drawn implements. Its objectives are the same as in other types of treatment, (1) increase of the vegetation cover, and (2) abatement of erosion. Essentially, the treatments are designed to increase infiltration by creating additional avenues for water to enter the ground and by slowing down the runoff thus prolonging the time opportunity for infiltration. Effectiveness of any type of treatment depends in large measure on the method of treatment and the physical characteristics of the area treated. Final success of the treatment is judged primarily by the increase in plant growth.

The common method of treatment on range lands has been to puncture or otherwise disturb the ground surface by such practices as chiseling, ripping, pitting, lister plowing or contour furrowing. The intensity of treatment ranges from widely spaced contour furrows or the small punctures left by rotary pitters which disturb less than 5 percent of the surface, to closely spaced lister plowing in which the entire surface is converted into a series of ridges and furrows. In depth the treatment may vary from a few inches to as much as 30 inches or more in some methods of ripping. Seeding and brush clearance may or may not be used in conjunction with the treatment depending on the type and intensity of the treatment and on the potential of the native plants to provide the seed needed for restoration of the vegetation cover.

Since the purpose of mechanical treatment is to increase infiltration, it should logically be restricted to areas which show evidence of runoff or lack of infiltration. Fine-textured soils bearing meagre vegetation and slicks should be most benefited. Areas with coarse soils which readily absorb water are not improved by treatment. Because, as a rule, no water from outside sources is added, the treatment is further restricted to areas that have sufficient precipitation for reasonable forage production.

In a recent study by the Geological Survey, Branson et al. (1966) have described the effects of mechanical land treatment on 58 sites in which seven different types of treatment were used. The reader is referred to this report for a more detailed discussion of mechanical treatment methods than can be presented here. The treatments include contour furrows, broadbase furrows, motor patrol trenches, eccentric disc pits, spike tooth pits, and two types of ripping, one using an auger tip, the other an auger tip provided with wings or furrow openings. The implements used in the treatments and the method of operation on range lands are relatively well known and are adequately described by the authors and in the literature.

On the basis of this study, contour furrowing is shown to be most commonly used and the most effective treatment. The practice has changed drastically since its early use during the Civilian Conservation Corps program of 1934-40, when it is reported that more than 1 million acres were contoured (Caird and McCorkle, 1946). The early furrows, excavated mainly by moldboard plows and some by hand, were spaced at intervals of 15 to 40 feet. Observation shows that their effect on dry range lands has been practically of no consequence, mainly it appears because they affected only a very small part of the land and provided only minute increments of surface storage as an aid to infiltration and control of surface flows.

Contour furrowing.--In modern range practice, furrows are spaced at 3 to 5 foot intervals using specially designed contour plows. This breaks up a major part of the soil and creates surface storage for a maximum of about 2 inches of precipitation. As storms exceeding this magnitude are infrequent, practically all the annual precipitation is stored in the soil and made available for vegetation. The surface storage naturally becomes less with age as the furrows are filled and if the treatment is to remain successful the increase in vegetation must serve to maintain infiltration and reduce or prevent runoff. Because much of the soil is disturbed, seeding is commonly carried out in conjunction with the furrowing operations.

The most popular furrowing device at present is the Arcadia Model B which is provided with a device that can be set to make cross dams in the furrow at selected intervals and with a seeder arrangement at the rear. The cross dams prevent flow along the furrows where the locations deviate from the contour. Figure 21-A shows a typical

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Figure 21.--Follows near here.

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furrowed area located in the Fifteenmile Creek basin, Worland Grazing District, Wyo. As can be seen, the vegetation growth is completely dependent on the local precipitation.

A. Contour furrows made with Arcadia Model B plow. Fifteenmile Creek basin, Worland District, Wyoming. Vegetation is crested wheatgrass. Average annual rainfall is less than 10 inches.

B. Ripping near Cuba, Albuquerque District, New Mexico. Poorest vegetation occurs directly over the rips. Area was not seeded. Average annual precipitation about 13 inches. View taken 2 years after treatment.

Figure 21.--Mechanical land treatment, Wyoming and New Mexico.

Pitting and ripping.--Pitting and ripping have been popular treatments in the past, but both practices have proven to be of rather questionable value. Pitting, using both eccentric discs and rotary spike tooth pitters, has been used on several thousand acres in New Mexico and Arizona and in some of the northern states. The treatment has been largely ineffective for what now seem to be understandable reasons. The pitting disturbs only 10 percent or less of the surface soil, and the total surface storage provided is equal to only a fraction of an inch of precipitation. Within a year or two wind action and rain splash partly or completely fill the pits. Unless the pitting operation is accompanied by seeding there is little stimulation of plants even in the pit depression because the native plants are largely destroyed in these localities. Furthermore, the pit makes a poor growing environment for any type of plant seed that might accidentally fall into it because it can be covered only by fine-textured windblown material. Examination of pitted areas in New Mexico and Arizona three years after treatment failed to show any plant growth in the pits, and in fact little evidence of the pitting operation was discernible. Because of the disappointing performance pitting to a large extent has been discontinued.

Ripping likewise has shown disappointing results. Practically the only success observed has been attained with the auger ripper to which wings or furrow openers have been attached. This leaves a furrow, 2 feet in width and from 4 to 6 inches in depth. With the furrows moderately good results in range recovery have been obtained. Use of the ripper without the furrowing device showed only a very slight increase or an actual decrease in range productivity. Figure 28-B shows the unfavorable effect on vegetation in ripped furrow made two years after treatment. The area is located about 4 miles south of Cuba, New Mexico at an altitude of about 7000 feet. Other types of treatment almost certainly would have resulted in better forage recovery.

The spacing interval for most ripped furrows ranges from 4 to 8 feet. Usually an effort is made to keep the furrows on contour, but this has not always been carried out because of the expense involved in surveying and staking. A recent invention called the gyroscopic inclinometer attached to the tractor gives the operator a guide for keeping on contour and largely eliminates the need for surveying and setting stakes.

Reasons for the poor results in range recovery by auger ripping are not always clear but some features are evident. Auger ripping, without the use of the wings or furrow openers, when spaced at 6-foot intervals disturbs less than 10 percent of the soil; in many cases less than the pitting treatment. As pointed out by Branson et al. (1966) treatments that do not modify the soil surface to form catchment areas have been shown to have little influence on vegetation because the surface soil, not the subsoil, must take in the precipitation for plant growth. This appears to rule out the high-cost treatment by auger ripping in favor of the more moderately priced contour furrows. The choice between the two types of treatment might logically be made on the basis of forage production and cost with the probability that contour furrowing would have the advantage on both counts.

Ripped furrows as a flood-control measure is being tried on a newly burned-over area on Bureau of Land Management lands above the city of Elko, Nev. Figure 22-A is a broad view of the ripped area and figure 22-B is a close-up view of the ripping. Although called ripping,

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Figure 22.--Follows near here.

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the treatment used here is very much akin to contour furrowing done by other implements inasmuch as a furrow is excavated to provide surface storage of water. The furrows were aligned on contour using the gyroscopic inclinometer. Both the contour alignment and the contour spacing appear to be satisfactory.

A. Panoramic view of furrowing on area burned during summer of 1965.

B. Close view of ripped furrows. Estimated average width of furrows 12 inches, depth [illegible] inches. Spacing about 6 feet.

Figure 22.--Ripped furrows being used as a flood control measure on a recently burned area near Elko, Nevada. Photos taken Aug. 26, 1965.

The main feature of the treatment is the extra size of the ripped furrow, estimated to average about 12 inches wide and 7 inches deep. With a 6 to 8 foot spacing the furrows provide storage for about 1 inch of precipitation, but this probably will be increased during the storm period by added infiltration into the loose material in the bottom of the furrow and in the furrow ridges. The success of the treatment as a flood-control measure will depend on the rapidity with which the vegetation is reestablished and on the magnitude and intensity of the early rains. A high intensity storm of more than an inch occurring before the grass is restored probably will cause considerable runoff even with the furrows. The effect of this method of ripping on the vegetation recovery has yet to be demonstrated before this type of treatment may logically be considered as a range improvement measure.

Vegetation measurements on treated areas.--Efforts to evaluate the effect of land treatment on forage production, erosion, and sediment and water yield have been carried out in a few localities, but the coverage is not complete for all soil types or climatic conditions. The study of Branson et al. (1966) shows the effects of mechanical land treatments on forage yields at 58 sites located in Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona. The study covered 20 different vegetation types, a variety of soil conditions, and the 7 different mechanical treatments previously mentioned. The dominant vegetation on the sample sites prior to treatment included grasses, forbs, and some brush types. Two of the sites were barren. The results based on sampling on vegetation increase during one year only are summarized in table 11.

The authors state that the most beneficial and consistent responses occurred on medium-to fine-textured soils. The most effective mechanical treatment was contour furrowing where the furrows were spaced at 3 to 5 foot intervals and cut to a depth of 8-10 inches. The broad-base furrows that were examined were moderately successful, although their effectiveness as a practice may be questioned because of the small number of sites sampled. The one treatment which resulted in a decrease in forage yield was the auger ripper. Of the 10 sites samples of this treatment all but two showed a decrease in vegetation.

No data were obtained at any of the sites on the effects of treatment on runoff or sediment yield.

Table 11.--Average increase or decrease in yield of perennial grass resulting from mechanical treatment of range lands[1].

Type of treatment	Yield lbs/acre	Number of sites sampled
Contour furrows[2]	+ 512	26
Broad base furrows	+1520	2
Motor patrol trenches	+ 160	12
Eccentric disc pits	+ 50	3
Spike tooth pits[3]	+ 117	2
Auger rips	-220	10
Wing rips	+100	3

1/ Extracted from Branson et al. (1966)

2/ Furrows 8-10 inches deep spaced at 3 to 5 foot intervals

3/ Based on yield measurements of two pitted and two untreated basins

A study designed to obtain the effect of pitting and runoff, sediment yield and vegetation recovery was conducted in the Cornfield Wash area, New Mexico between 1956 and 1960. The study area on which the water and sediment yields were measured contains 4.56 square miles, part of which was treated and part untreated. The pitting was carried out by crossing the area with a heavy drum provided with 16-inch spikes on 3-foot centers. The spikes penetrated to a depth of 8 to 10 inches, leaving a pit of loosened soil 6 to 10 inches across constituting about 5 percent of the surface. Soil in the area is a thin to moderately thick residual sandy-clay loam overlying marine shales of late Cretaceous age. The area was not seeded.

Sediment yield and runoff were measured volumetrically in stock reservoirs. Measurements of vegetation were made during 1958-60 in a treated area of 1350 acres and an adjacent untreated area of 680 acres. The measurements were obtained by clipping and weighing the annual growth from a number of portable exclosures located at random within both the treated and untreated areas. The results are shown in table 12.

Table 12.--Follows near here.

Table 12.--Annual vegetation yields in pounds per acre for pitted and unpitted watersheds in the Cornfield Wash basin, Albuquerque Grazing District, N. Mex. 1958-1960[1/]

Type of vegetation	Pitted watersheds (1,350 acres)	Unpitted watersheds (680 acres)
Grass	282	165
Forbs	214	337
Total vegetation	502	510

1/ Data from U.S. Geol. Survey Water-Supply Paper 1831, p. 70, 1966

Although measurements of runoff and sediment yields from the treated area and untreated areas were made, results were erratic and inconclusive, presumably because of the many other factors that had an effect. Precipitation varied greatly during the period of record, and the difference in size of the drainage basins also brought up an uncertainty. Unfortunately too, there was not an opportunity to obtain a reliable pretreatment comparison of the watersheds. A surprising feature is the lack of vegetation recovery in the treated area. The increase in grass is offset by a decrease in forbs resulting in an insignificant net change. Soil sampling showed that except in the sandiest soils the soil moisture penetration in the pits was slightly greater than in the unpitted tracts.

In another study Branson et al. (1962) has reported on the increase in vegetation resulting from furrowing and seeding with crested wheatgrass in the Willow Creek basin north of the Fort Peck Reservoir near Glasgow, Mont. Soil in the area is a montmorillonitic, non-calcareous, silty-clay alluvium derived mainly from marine shales of Cretaceous age. The area has been heavily grazed, and parts have deteriorated to barren slicks. The long-term average precipitation in the area is about 13 inches of which about 70 percent falls in the 5-month summer period, May through September. A converted disc plow which made furrows a few inches deep and 3 feet apart was used in the treatment.

Before treatment the area supported a sparse growth of Nuttal saltbush and prickly-pear cactus. Following treatment by furrowing and seeding and protection from grazing for a period of 10 years the better soils produced a stand of crested wheatgrass ranging from 500 to 700 pounds per acre, an increase of about 115 percent. Poorer parts of the area, particularly the slicks, yielded less. Production of the desirable native vegetation, chiefly Nuttall saltbush, did not increase as a result of the treatment. No measurements were made of the effect of the treatment on water yield or erosion.

Treatment for vegetation recovery involves hydrologic study on two counts, (1) the amount of moisture penetration needed for growth and (2) the increased infiltration and reduction in runoff caused by the increased vegetation. In the drylands here considered essentially no water penetrates to the water table, and there is no ground-water outflow. The need for recognition of the hydrologic factors involved in successful land treatment has come about from fining time after time that success in vegetation restoration can be achieved only where climatic and soil-moisture conditions are favorable. Selection of the proper place and time for treatment involves careful consideration of the area's hydrology.

PROGRESS IN CONSERVATION

After some 30 years of conservation effort during which the treatments and practices previously described have been applied to the public domain in varying extent and degree of intensity, it is logical to inquire as to what progress has been made in the permanent rehabilitation and improvement of the land. Specific answers to such an inquiry are difficult to furnish owing in part to the tremendous area involved and in part to the lack of standards for defining conservation and its attendant improvement. In an area of nearly 200 million acres distributed through twelve states and encompassing large variations in climate, soils, topography and land use, a rigorous concept of conservation is difficult or almost impossible to define. Lacking such a concept, conservation is not the same to all people in all localities; consequently, a judgment of its value becomes largely one of personal opinion, which in turn is dependent on the background and interest of the one expressing the opinion.

In some respects the accomplishments in conservation during the past 30 to 35 years have been encouraging, in others they have been disappointing. Observations and measurements taken at intervals during this period show that many of the attempts to abate erosion on the public domain have met with negative or only limited success, and compared to the total area of eroded terrain the part showing definite evidence of improvement is relatively minor. Some areas are known to have improved, others have deteriorated, but erosion conditions over the major part of the area appear to have remained essentially static. The greater part of the area originally classed as being in a state of severe to critical erosion would most probably still be so classed; however, as will be explained further, the improvement may be greater than meets the eye.

The apparent limited extent of improvement raises questions of whether feasible programs for the treatment of critically eroding lands can be devised. The 10 million or more acres now designated as frail lands constitute a prime example of the doubt concerning land treatment. These areas of generally low but erratic rainfall, highly erodible soils, sparse or negligible vegetation, and advanced erosion to a large extent have been left untouched. Three reasons for this seeming neglect are thought to be: (1) the high cost of treatment, (2) lack of agreement on the best method of treatment and (3) lack of assurance that substantial improvement will result from the use of even more elaborate and expensive types of treatments than have been developed to date.

As another example of the uncertainties regarding land treatment methods, the great number of gullied valleys throughout the West can be cited. There is as yet no unanimous agreement between experienced conservationists and engineers on feasible methods for restoring these valleys, particularly those in the Southwest. Some favor a piece-meal attack using upland types of treatment of relatively proven merit, others believe that only major structures on the main channels can be expected to produce the desired rehabilitation. It is recognized that although upland treatments may show favorable results in a relatively short time, their effect is so limited and local in extent that a large part of the basin must be covered before any strong effect on the principal valley gully system will occur.

Moreover, some conservationists assert that if erosion and sediment yield from the uplands is significantly reduced, there will be no material to fill up the gullies in the valleys. The writers take the view that this stage has not been reached on the public lands. The sediment yield from the uplands is enough to cause some aggradation of the valley gullies, provided floods can be reduced. The importance of flood peaks has been cited earlier in this report. A very significant factor in floods is the increased velocity and carrying capacity of the flow. Throughout the literature on hydraulics and sedimentation this point has been stressed, and the formulas used in design are well known to the persons now engaged in the construction of conservation structures.

Although the design of many of the structures installed in the past for erosion abatement on the public domain may not have been subjected to a rigorous hydraulic analysis, nonetheless, practically all the structures conform in some measure to such an approach. Reduction of both velocity of flow and peak discharge of streams have been inherent objectives in most programs of land treatment. Waterspreading of any kind, contour furrowing, and other methods of mechanical treatment all act with varying degrees of effectiveness to reduce runoff and the velocity of flow. The opportunity for erosion is thereby reduced, and infiltration increased to the benefit of growing protective vegetation. Dams and barriers placed in gullied channels act specifically to induce aggradation by reducing the gradient and velocity and hence the sediment carrying capacity of the stream. Reduction of peak flow by use of storage dams has the effect of reducing the eroding capacity of the stream below the dam, but in many instances this is offset by the increased capacity of the relatively clear discharge water with the result that new channel cutting commonly occurs.

Structural treatment for abatement of erosion

The failure in so many of the treated areas, particularly the early ones, to produce favorable results in relation to both erosion and forage improvement even though the practices apparently did conform in a reasonable way to hydrologic theories, presents serious questions. It is pertinent to question if the failures were due to lack of adequate precipitation and runoff data for design purposes, to errors of judgment in both the design and construction standards or to neglect in maintaining the structures. Doubtless each of these factors and perhaps other unrecognized ones were in a measure responsible. Certainly with the myriad of structures involved in these early conservation attempts it was almost impossible to provide more than cursory designs or to enforce rigid or even reasonable construction standards.

All of these deficiencies are well displayed in the early Civilian Conservation Corps treatment areas that almost universally have shown disappointing results. In this program, which was carried on from 1934 to 1941, treatments covered thousands of acres of range lands distributed throughout the West, much of it on highly eroded areas, much of it now designated as frail lands. The treatments included many different structures, all intended to intercept, impede and spread surface runoff and thus furnish greater opportunities for infiltration and with it more favorable conditions for vegetation growth. Principal structures in the programs included contour furrows, terraces, spreaders of all types, pits, gully plugs, diversion dams with training dikes leading to spread areas and a considerable number of retarding-type reservoirs placed in the larger stream channels to cut down flood peaks and cause aggradation in the stream channel.

An evaluation study conducted by Valentine (1947) on treatments in the Jornada Experimental Range, Rio Grande Valley, New Mexico, concludes with the statement that "None of the types of structures used have been found to be effective in bringing about an improvement in vegetative cover on the sites where they were installed." Structures mentioned include contour terraces, brush and rock terraces, and rock spreaders combined with contour furrows about 6 inches in depth and 30 to 40 feet apart. Soil characteristics were reported to be chiefly responsible for the failure. At most sites the soil was too light to retain moisture long enough for vegetation to become established. At other locations heavy impervious soils proved to be equally unsuitable because even with longer exposure they failed to take in enough water to supply any vegetation of consequence. This would indicate an error in judgment by those responsible for the program in this locality and emphasizes the need for an intensive examination of any area where treatment is planned.

Observations in other parts of New Mexico and in treated areas in Arizona, Utah, Colorado, and Wyoming show similar unsatisfactory results (Peterson, 1950 and Peterson and Branson, 1962). Principal reason for the poor results can be traced to the low construction standards employed and to the lack of hydrologic data needed for design purposes. The structures as built were simply inadequate to control the runoff generated by the high-intensity cloudburst type storms commonly experienced during the summer season in most of the treated areas. Terraces were breached at any early age, most of the brush and rock spreaders failed at the low points and ceased to function following the first major storm, and many of the contour furrows filled or breached at strategic points and lost their effectiveness soon after construction. Most of the retarding dams failed resulting in no regulation of discharge in the larger stream channels and very little diversion of water onto adjacent lands. Furthermore, recurrent long dry spells made it difficult to establish vegetation even where other growing conditions were favorable. Ranchers and allottees who controlled these areas took the attitude that even minor repairs to the structures could not be justified on the basis of the negligible benefits obtained, and in consequence there was little if any serious effort ever directed at maintenance.

It seems possible that had adequate data on precipitation, runoff, infiltration capacity, and sediment movement been available during the period of the CCC activities, had higher standards of construction been employed, and had the areas been protected against overgrazing until the new vegetation became established, the results might have been somewhat more favorable. It seems clear also that had regulation of flow in the larger channels been provided by larger and better constructed retarding reservoirs the effectiveness of the program might have been improved. These changes naturally would have added materially to the cost of the treatment and would have required the use of heavy equipment, whereas emphasis in the CCC program was on hand labor. However, observation on the performance of the structures coupled with an increased understanding and appreciation of the hydrologic problems involved has been useful in demonstrating the inadequacy of the early CCC type of small structure approach as a means of abating erosion or increasing vegetation without some added safeguards or controls.

Later work has been more successful, but much additional research is needed before reliable methods of treatment for the poorer lands, particularly the frail lands, can be developed. Costs will be high so it is necessary that increased forage productivity be obtained to justify treatment. Likewise any increase in water consumption that fails to produce a compensating benefit in better vegetation is certain to be looked on with disfavor throughout the West by both the water users and the stockmen. Logically therefore, the types of treatment applied during the CCC program to these lands should be used sparingly or discontinued until data are available making it possible to predict with reasonable accuracy the benefits or detriments of the method.

In practically all of these severely eroded and gullied areas some method of inducing aggradation in the eroded channels is essential for providing an environment suitable for plant growth. How this can be done presents a most difficult engineering and conservation problem. The need for restoration becomes imperative on most badlands and in belts riddled by piping. Preventative treatment is also in order in many areas displaying less serious erosion such as rills and an overdevelopment of shallow drainage channels. In many of the numerous valleys in the Colorado River and Rio Grande basins and in other parts of the public domain the chances of halting the deterioration or permanently improving the land are practically nil until aggradation in the channels can be induced. Figure 23 shows typical example of these conditions.

Figure 23.--Follows near here.

A. Network of finger gullies along floor of Saleratus Wash near Green River, Utah.

B. Gully and badland erosion cutting into a valley north of Shiprock, New Mexico.

Figure 23.--Areas typical of many gullied valleys where it is obvious filling of erosion channels is a requisite to establishing favorable growing conditions for range plants.

In a few localities aggradation is occurring naturally, but in most it must be induced by construction of dams or other types of barriers forcing streams to drop their sediment load. Sites where natural aggradation is occurring are generally confined to the depositional areas of discontinuous gullies or to valley reaches where notable changes in gradient occur. In many localities the heavy sediment load carried by the steeper side tributaries will deposit at the valley edge due to the sharp change in stream gradient. The alert conservationist will search out all areas of natural aggradation to assess and take advantage of any possibilities of expanding the aggrading area for improvement of other eroded lands, and also, where necessary, to take steps to prevent erosion from developing on the newly laid deposits.

Use of dams or other types of barriers to induce aggradation is a common practice in many areas on the public domain, but the full potential of the structures on land rehabilitation and their effect on streamflow have not yet been completely evaluated. Some of the structures have not been in operation long enough to permit a full appraisal of their performance, and in others mechanical failures have destroyed or interrupted the functioning, thus making it impossible to draw any valid conclusions relative to correctness of the design as far as aggradation is concerned.

Measured effects of barriers

Measurements have been made on deposits above barriers by Kaetz and Rich (1939), Myrick and Leopold (published in Leopold et al., 1964). and Lusby and Hadley (1967). Kaetz and Rich found that the slope of the sediment deposits on the units they measured in 1939 ranged generally from 30 to 60 percent of the original streambed. Repeat surveys in 1961 by Myrick on some of the deposits measured by Kaetz and Rich did not show consistent changes. The gradient on some deposits were essentially unchanged whereas on others the gradients were considerably greater. Lusby and Hadley found that the gradient on deposits of fine-grained materials in the Navajo and Hopi Indian Reservations ranged from 17 to 49 percent of that of the original streambeds. At a barrier on Sheep Creek east of Zion Park in Utah, the average gradient for the entire length of the deposit was found to be 67 percent of that of the original streambed; on the upstream gravelly part of the deposit the gradient was about 72 percent.

On all the barriers studied by Lusby and Hadley the deposits extended upstream to elevations well above the spillway level of the barriers, but as yet the probable upstream limits of the deposits cannot be inferred. Presumably the limit will depend on the gradient of the original channel, and on the roughness and grain size of the material transported. If vegetation of some kind becomes established on the deposits the aggradation should be increased and continue progressively upstream.

Measurements on barriers have shown that the spillway levels should be at least as high as the valley floor so that backwater will cover the valley floor. Aggradation is thus induced because the velocity over the valley floor is generally less than in a confined channel.

A serious disadvantage of sediment control associated with the use of structures is the effect on streamflow. Available data show that even temporary storage in a reservoir results in some water loss. It is obvious also that where overbank flooding is supporting additional vegetation still further stream depletion can be expected. Although the amount of water so used in most areas of the public domain is very small with respect to irrigation of cultivated lands, downstream users object to such depletions on the grounds that they infringe directly on established water rights. The objections in the Southwest are most emphatic because there the newly deposited sediments are very well adapted to the growth of the aggressive phreatophytes, particularly saltcedar, which is a heavy consumer of water. Although this plant helps promote aggradation, it has no value for forage, and water consumed in its support is considered wasteful. In such areas efforts should be made to grow a grass as an incentive to aggradation and also provide forage.

A 2-year study, 1956-57, to evaluate the action of induced aggradation in the restoration of eroded valley lands and to show its effect on steam-flow and sediment movement was conducted on privately-owned lands along Box Creek, a tributary of Twentymile Creek and the Cheyenne River in east-central Wyoming (Hadley and McQueen, 1961). Before 1930 the lower 4½ miles of Box Creek was dissected by a continuous gully which contained practically all flows. Installation of some 27 dams and dikes during a period of 30 years induced aggradation in the gully to the extent that overbank flooding again occurred, and the area was converted from a state of low productivity to its present condition where the entire valley floor is being used as a hay meadow. Measurements show that a net volume of 17.8 acre-feet of sediment was deposited on the valley floor during the 2-year study period. Depletion in streamflow entering the reach from both upstream and side tributary sources due to retention on the flooded area ranged from 18 to 66 percent during individual storms. Of a total flow of 1,594 acre-feet entering the reach during the 2-year period, 696 acre-feet or about 43 percent was retained.

Objections to use of structures on Box Creek have not developed, largely, it is believed, because the owner has acquired a right to spread and also because the small area of spreading affects only a minor part of the Cheyenne basin. It appears certain, however, that any move to greatly expand this type of treatment would meet with strong opposition from downstream water users.

Another area in which studies have been conducted to determine the probable effect of induced aggradation and one which clearly illustrates the necessity of such treatment for the restoration of critically eroding areas is the San Simon Valley of Arizona. Limited studies directed mainly to measurement of stream flow were conducted over a period of 3 years, 1956-58 (Peterson, DeJulio, and Rupkey, 1960). The results have not been published mainly because the data on water losses were somewhat inconclusive and subject to various interpretations that served to intensify the controversy over water yield and water rights.

The public lands in the San Simon Valley differ somewhat from most public lands in that they include lands adjacent to or near a stream that carries appreciable flow. A substantial part of the flow is derived from the national forests on the boundaries of the basin. Although the stream is ephemeral along much of its length, it has some flow every year. An appreciable amount of flow seeps into the channel alluvium to recharge ground water. Discussion of the probable changes in seepage, the recovery of water and related items under a system of barriers for inducing channel aggradation is given in the following pages.

Conditions in the San Simon Valley resulting from severe erosion have previously been described. Examinations conducted in recent years by the Bureau of Land Management show that at present the valley floor contains an estimated 23,000 acres of nearly barren land, much of it in the condition shown in figures 3 and 5. The annual forage production from this eroded area is estimated by BLM range technicians to be sufficient for an insignificant 300 AUMs, whereas previous to erosion it supported several thousand cattle year long.

Large numbers of structures, together with other types of treatment applied to the lands during the CCC program 1933-42, failed to produce any notable erosion abatement or improvement in vegetation during the intervening years. This has led the Bureau of Land Management range technicians to conclude that treatment of the land is valueless unless the major channels can be filled and the adjacent badlands are restored to a condition favorable for reestablishment of vegetation. With this object in view, three dams were constructed in the upper part of the valley between 1953 and 1955, one on the main stem of San Simon River, and two on a major tributary, Gold Gulch. All were of earth-fill type with an ungated outlet set at about the valley floor level. Reservoir data are shown in the following tabulation:

Dam	Stream	Drainage area (sq mi)	Capacity (acre-ft)	Diameter outlet pipe (inches)
Fandrop	San Simon River	1,400	2,900	36
Creighton	Gold Gulch	106	2,800	48
H-X[1/]	Gold Gulch	147	1,700	60

1/ Located 6 miles below Creighton. Drainage area includes area above Creighton.

The principal functions of the structures are (1) to control and regulate flood flows originating from upstream sources and thus reduce the erosion potential of the stream below, (2) induce sedimentation in the reservoirs and in the stream channel above thereby creating a favorable land surface on which a protective forage cover might be established. Aggradation in the reservoirs became evident shortly after the dams were constructed as shown by figure 24, but degradation below the dams also began when the reservoirs started discharging clear water.

Figure 24.--Follows near here.

In the 3-year period, 1956-58, a total of 250 acre-feet of sediment was deposited in the Creighton and H-X reservoirs. Deposition above the Fandrop reservoir was not measured for the reason that the sediments were distributed over the reservoir floor and within the channel for more than 6 miles above the dam, and it was not possible to identify the material laid down during any specific period or to determine if the deposition in the channel was entirely attributable to the influence of the dam.

A. Aggradation in San Simon channel about 6 miles above Fandrop dam 5 years after construction. Fill in channel shown by drilling to be about 10 feet deep.

B. Deposits above Creighton dam 3 years after construction. Channel was formerly about 12 feet deep.

Figure 24.--Changes in the San Simon River and Gold Gulch channels following construction of the Creighton and Fandrop dams.

On the basis of the performance of the three dams, the Bureau of Land Management in 1955 proposed a fourth structure to be located on the main stem of San Simon River, 4 miles above the mouth, drainage area, 2,150 square miles. As with the others the intended function of the dam was to regulate flood flow and induce aggradation and vegetative recovery on the eroded valley floor above. On the basis of estimates of the average annual sediment load carried by San Simon River and the amount of aggradation that could be expected above the proposed dam, developed as part of the study, BLM technicians concluded that 13,800 acres located along the valley floor might be restored to productivity within a 40 to 60 year period. The resulting substantial benefits from grazing and wild life and recreation use are reported to give a very favorable cost-benefit ratio.

Construction of this proposed lower dam was vigorously opposed by downstream water users on the grounds that runoff from the drainage area would be depleted and existing water rights thereby jeopardized. Because of the controversy it was agreed that construction would be deferred pending completion of a study to determine the effect of not only the proposed structure but also of the three existing reservoirs in the basin. The studies were carried out by the Geological Survey with funds supplied by the Bureau of Land Management and are described in the previously mentioned report (Peterson et al., 1960).

Losses chargeable to the existing reservoirs included the evaporation and seepage occurring during periods of storage plus any increased channel losses resulting from regulation of the flow. Probable losses in the proposed reservoir were estimated by routing historical flows through the reservoir and applying evaporation and seepage loss obtained in studies of the upstream reservoirs. Increased channel losses below the dam due to regulation by the reservoir were considered to be small because of the location near the mouth of the stream.

A summary of the reservoir losses and the increased channel losses resulting from regulation by the three existing reservoirs are given in tables 13 and 14. For comparison, figures are given for the yearly flow entering the reservoirs and for the regulated flow in the channels. The combined reservoir and increased channel losses equalled about 12 percent of the total flow measured at the reservoirs in each of the 3 years. The estimated losses that would have resulted from routing the flow of San Simon River through the proposed reservoir for the same 3-year period are also given. No estimate is given of the additional losses that would occur as the channel was aggraded and the flow spread across the valley floor lands. Such losses would range from a minimum during the period immediately following construction of the dam to a maximum some years hence when the projected 13,800 acres had been restored and the area was subject to periodic flooding by the stream in high stages. The evidence is strong that at present the major part of the indicated reservoir and channel seepage losses recharges the ground water and will eventually be recovered.

Table 13.--Estimated annual water losses, by water year, to Bureau of Land Management reservoirs, San Simon basin, Arizona

Reservoir	1955-56		1956-57		1957-58	
	Inflow (ac-ft)	Loss (ac-ft)	Inflow (ac-ft)	Loss (ac-ft)	Inflow (ac-ft)	Loss (ac-ft)
Fandrop	811	105	13,167	307	14,331	740
Creighton	371	18	3,157	143	3,095	70
H-X	557	85	1,987	176	1,329	300
Total	1,739	208	18,311	626	18,755	1,110

Table 14.--Increase in channel losses, by water year, resulting from regulation by the reservoirs

Stream reach	1966-56		1956-57		1957-58	
	Regulated flow (ac-ft)	Loss (ac-ft)	Regulated flow (ac-ft)	Loss (ac-ft)	Regulated flow (ac-ft)	Loss (ac-ft)
San Simon River from Fandrop to mouth 30.5 miles	706	102	13,675	963	13,619	683
Gold Gulch from Creighton Reservoir to H-X Reservoir 6.0 miles	353	13	3,012	683	3,026	306
Gold Gulch from H-X Reservoir to mouth 7.0 miles	472	-38 1/	1,812	41	1,033	78
Total	1,531	77	18,491	1,687	16,678	1,067

1/ Regulation would have resulted in a saving this year.

The combined losses in the three reservoirs and the channel reaches for each year were as follows:

1955-56	285 acre-feet
1956-57	2,313 acre-feet
1957-58	2,177 acre-feet

Estimated losses had flow been routed through the proposed reservoir were as follows:

1955-56	1,291 acre-feet[1/]
1956-57	2,427 acre-feet
1957-58	4,172 acre-feet

Since completion of the study in 1958 a highly disconcerting feature associated with the reservoirs' performance has been the invasion of the storage area by phreatophytes as shown in figure 25.

Figure 25.--Follows near here.

The waste of water by this type of growth is so obvious that any further construction of reservoirs for the purpose of inducing aggradation is certain to be delayed until some feasible method of dealing with the phreatophyte problem has been developed.

The examples described above show the complex and conflicting nature of the sediment-control phase of the conservation problem. There is the urgent need for structures and other treatments designed to induce aggradation on large areas of presently useless range land in order to decrease the rate of erosion and restore the land to productivity, but even at this date we have not found a positive approach.

[1/]Potential losses in 1955-56 greatly exceed the inflow and there would have been no flow through the reservoir this year.

A. Baccharis above Creighton dam. Compare with figure 25-B. Level of outlet pipe has been raised since 1959. Baccharis is being replaced by saltcedar in upper area of growth.

B. Growth of baccharis in the H-X reservoir. Level of the outlet pipe has been raised 5 feet since 1960.

Figure 25.--Phreatophyte growth above the Creighton and H-X dams, San Simon Valley, Ariz., Sept. 1965.

Although the building of major structures on the main channel of San Simon River gives some assurance that with sufficient time the gully can be filled, such structures are highly expensive, and as yet there is no clear-cut evidence as to how soon the benefits will be realized or how extensive they will be. Moreover, problems relating to the effect of the structures on water yields and water rights have to be resolved. Invasion of the filled areas behind the structures by phreatophytes is a most vexing problem that must be solved in connection with the use of major structures as there would be little benefit in filling the channel if the newly filled material is to be occupied by the worthless water-wasting phreatophyte growth. Thus, there is a logical reason why the conservation program has to date been applied mainly to the better grade lands. It will probably continue so until better and more feasible methods for treating the poorer lands have been developed.

Range vegetation

While the overall evidence of erosion abatement is in general not impressive there are some indications of favorable changes in range vegetation. First is the large acreage of successful seeding and range rehabilitation that has been carried out to date. General improvement in range forage in some unseeded parts of the range is also believed to be shown by greater density, improved vigor, and reproductive ability of the desirable perennial range plants. However, there is not much reliable quantitative information to prove this.

In an effort to monitor range-condition changes and evaluating their importance, Deming (1960) utilized a dual system for appraising both the condition of the range forage and the condition and trend of the soil mantle on range lands. For judging the range-forage condition, four elements relating to range plants were considered: quality, quantity, vigor, and reproductive ability. The composite effect is used to classify the range as being in excellent, good, fair, poor or bad condition. Elements used in judging the condition and trend of the soil mantle include soil stability, erosion resistance, natural vulnerability to erosion, and protective cover. Again using the composite effect of all the elements the range is judged to be improving, static or unchanging, or declining. Based upon this system, Deming's appraisal of range forage and soil condition trends on more than 150 million acres of the public domain range is shown in table 15 for the period 1955-59. The classes are shown by percentage of the total usable range in each state. The acreage of declining lands is also shown.

Table 15.--Range condition and trends, public domain range lands 1955-59 1/

State	Usable range (acres)	Percent in each range class					Trends 1955 to 1959			Acreage declining
		Excel-lent	Good	Fair	Poor	Bad	Per-cent impro-ving	Percent static or inde-finite	Per-cent decli-ning	
Ariz.	12,493,000	0.3	6.7	36.0	50.3	6.7	37.1	54.1	8.8	1,099,000
Calif.	3,697,000	1.0	11.0	75.0	12.0	1.0	1.0	72.0	27.0	998,000
Colo.	7,462,000	0	14.0	60.0	23.0	3.0	34.0	55.0	11.0	821,000
Idaho	11,856,000	3.4	19.5	48.9	25.3	2.9	35.3	44.7	20.0	2,371,000
Mont.	7,831,000	1.1	55.0	39.9	3.9	.1	19.7	69.6	10.7	838,000
Nev.	45,113,000	2.3	11.0	53.4	27.4	5.9	17.2	65.5	17.3	7,805,000
N. Mex.	13,561,000	.8	22.2	62.9	11.6	2.5	29.0	58.0	13.0	1,763,[illegible]0
Ore.	12,586,000	.6	15.5	48.3	28.2	7.4	24.7	50.5	24.8	3,121,000
Utah	23,073,000	.3	4.2	54.0	36.3	5.2	23.8	47.0	30.2	6,922,000
Wyo.	14,258,000	4.0	23.0	60.0	11.0	2.0	26.0	54.0	20.0	2,852,000
Total weighted Average	151,930,000	2.0	15.0	52.0	26.0	5.0	24.0	57.0	19.0	28,758,000

1/ Adapted from Deming (1960)

Using the data obtained in this 1955-59 analysis, Deming has compared range conditions at that time with those described 25 years earlier in a range survey of 128 million acres of the public domain made in the period 1930-35 by personnel of the Forest Service and reported in Senate document 199, 74th Congress (1936). Although the terms used in classifying the range condition and trends differ somewhat in the two surveys, the meanings are similar. The comparisons are shown in table 16. All lands described in the 1930-35 appraisal are contained within the larger area classified in Deming's 1955-59 survey. Except for the additional acreage included by Deming, the areas described in the two reports are identical. Table 17 compares the trend in range condition in the two surveys.

Table 18 shows the year-by-year trends in the condition of the range during the 6-year period 1955-60 taken from the report of the Secretary of the Interior for 1961.

Table 16.--Change in range forage condition 1930-35 and 1955-59[1/]

1930-35		Percent of total area	1955-59		Percent of total area
Forage condition	Acres		Forage condition	Acres	
Moderately depleted	1,868,000	1.5	Excellent condition	2,453,000	2.0
Materially depleted	18,320,000	14.3	Good condition	23,042,000	15.0
Severely depleted	61,168,000	47.9	Fair condition	80,377,000	52.0
Extremely depleted	46,000,000	36.6	Poor condition	39,231,000	26.0
			Bad condition	6,826,000	5.0
Totals	127,356,000			151,926,000	

1/ Adapted from Deming (1960).

Table 17.--Trend in range condition 1930-35 and 1955-59[1/]

1930-35			1955-59		
Forage Condition	Acres	Percent of total		Acres	Percent of total
Appreciable improvement	1,255,000	1.0	Improving	36,500,000	24
More or less unchanged	7,864,000	6.0	Indefinite or static	86,600,000	57
Appreciable decline	118,673,000	93.0	Declining	28,758,000	19
Totals	127,792,000			151,858,000	

1/ Adapted from Deming (1960).

Table 18.--Trends in condition, in percent of useable area 1955-60[1/]

Year	Improving	Static or indefinite	Declining
1955	22.0	57.0	21.0
1956	19.7	54.1	26.2
1957	22.0	55.0	23.0
1958	25.0	56.0	19.0
1959	24.0	57.0	19.0
1960	20.0	62.0	18.0

1/ From annual report of the Secretary of the Interior (1961).

Because of the tremendous area involved in the field examination, the classifications developed in each study were doubtless much less detailed than desired, and broad extrapolations must have been employed in estimating the percentage area in each class. Because of the limited extent of the field work it might be questioned if the differences in classifications are reliable indications of changes in the range or do they reflect in some measure differences in the opinion, background and training of the examining personnel. It is believed that the data obtained in the 1955-59 surveys were more accurate than those obtained earlier owing to more extensive field work and possibly to the development of better methods for evaluating the range. It will be noted also that the descriptive terms used in identifying the classes are broad and general rather than specific thus permitting considerable leeway in the assignment of areas to a given class. Clawson et al. (1960) also point out that authors of the early Forest Service report may have been unduly influenced by and failed to recognize in proper perspective the deterrent effect on range productivity of the severe drought years of the early 1930's. Held and Clawson (1965) express the opinion also that this report was highly exaggerated even though carried out with sincere conviction. In this event, the improvement between the two surveys would have been somewhat less than the table indicates.

In comparing forage conditions, the 1930-35 survey shows that the percentage of the moderately depleted and materially depleted differs very little from percentage of the excellent and good condition of 1955-59, 14.3 percent being classed as materially depleted as against 15 percent in good condition in 1955-59. Likewise the severely depleted area of the earlier survey is within about 4 percentage points of the fair-condition area of the later survey. In the poorest classes, the extremely depleted--36.6 percent of the early survey--is about 5 percent higher than the combined poor condition and bad condition classes of the later survey.

The notable favorable change is seen in the trend in range condition with an increase of from 1 to 24 percent in the area showing trend improvement between the two periods and a decrease of 74 percent in the area showing declining trend. This is a change of striking magnitude, but in light of other data on condition it brings up some significant questions. If the two surveys were realistically comparable this implies that the improving trend did not take hold until shortly before the later survey. This would mean that it requires 20 or more years of management for even the trend to change.

Renner (1954) has recognized improvements in western ranges although his statements are not specific in regard to the public domain. For the most part the ranges he considered are more productive than the public domain. He states that between 1928 and 1953 the livestock population of the 17 western states increased, but there was still a marked improvement in range conditions throughout most of the area. He attributes this to the perfection of new machinery and chemicals for eradication of useless brush, to additional research in the development and planting of new forage grasses, but possibly most important to the change in attitude of the stock men and the public from one of indifference concerning the range to a recognition that conservation and improvement of the range is not only possible but feasible. These generalized statements relating to changes on the range although not specifically aimed at the public domain support the change in trend as shown in table 18.

Effects of vegetation on sediment yield

That a reduction in grazing pressure could result in less erosion and lower sediment yield has been amply demonstrated by repeated studies. The effect of vegetation on sediment yield reported by Forsling (1932), Hadley and Schumm (1961), and by Rich (1961) have already been mentioned (p. 87). In a somewhat similar study Packer (1953) in a series of controlled experiments has shown the effect of trampling by sheep on sediment and water yield. Using small (2 feet by 6 feet) plots on wheatgrass and cheatgrass cover of 70 to 90 percent density, a steel foot to simulate sheep trampling, and artificial precipitation applied at a rate of 3.8 inches per hour for 30 minute intervals, he found that trampling on 40 to 60 percent of the area, equivalent to moderately heavy to heavy grazing, doubled the runoff and tripled the sediment yield on cheatgrass plots of 70 percent density. At higher vegetative density the changes resulting from trampling were less extreme.

Although Packer's studies were restricted to relatively small plots in which the density of cover, and the magnitude and intensity of rainfall and the method of appraising grazing use differed considerably from that ordinarily occurring in the upper Colorado River basin, the results obtained should, nevertheless, be somewhat representative of what might be expected in the basin as grazing was lightened. A reduction of 17.5 percent of the total animal-unit months of grazing should result in an improved vegetation cover and less erosion and sediment although no measurements are available for making a quantitative evaluation of the item.

In the study made in the Badger Wash area, Colorado, which is typical of the Colorado plateau, Lusby et al. (1970) found that for the 13 years of record 1954-66, the average sediment yield in four excluded (ungrazed) watersheds was 34 percent less than averages of four counterpart grazed watersheds. The range among the individual pairs was from 26 to 49 percent. The difference in sediment yields from the grazed and ungrazed watersheds was least in the first 2 years of exclusion; after the second year the average sediment yields in the ungrazed watersheds has been nearly constantly about 45 percent less than that of the grazed watersheds. Runoff from the ungrazed watersheds has averaged 24 to 29 percent less than that of the grazed watersheds.

The authors state "The causative factors for changes in the runoff and sediment-yield relations are not entirely clear. At the end of 13 years, a significant change had occurred in the amount of bare soil and rock, ground cover index, and litter and moss on the grazed watersheds. These items remained essentially unchanged on ungrazed watersheds. The changes in ground cover factors were not of large magnitude and did not occur at the same rate as the changes in runoff and sediment yield. It appears that a large part of the difference was caused by a change in the structure of surface soil brought about by the elimination of trampling by livestock."

The results obtained in the Badger Wash area study give an indication of what effects the reduction of grazing could have had in the Colorado River basin during the period we have been considering. They also point out that the reasons for changes in sediment yield are not always apparent. Although changes in vegetation in the Badger Wash watersheds were not great and may not have been noted except by intensive measurements such as those made in that study, the sediment yields declined a fairly large amount. Similarily, although the range-condition changes that were observed in the Colorado River basin during the surveys made from 1955-59 were very small, it seems possible that their full affect in actual erosion and sediment yield was not recognized. Admittedly, this reasoning is speculative, but it seems to provide the only explanation for what has happened.

The trend in vegetation and erosion conditions is very difficult to appraise by visual inspection, particularly in areas of sparse vegetation and severe erosion because even though there may be evidences of recent erosion the rate may be less than it was during a preceding period. If the erosion rate is decreased, the sediment yield is likewise decreased. This well may have been the case in the observations made in the Colorado River basin. We still find areas where erosion is very active, and sediment yields for the plateau portion of the basin are still very high though not as high as they were years ago when very few observations of the conditions on the ground were made.

To properly evaluate changes in vegetation with respect to erosion and sediment yield, systematic recurrent measurements must be made on a much more intensive scale than has been done in the past. Admittedly, this is an expensive undertaking, but justified, when considered in light of the costs of management and treatment practices for land conservation. In general, the uses and values of the public land are increasing. Care must be used in protecting the vegetation and preventing erosion as much under multiple use as under grazing, the primary or only use in the past. Systematic measurements are needed to determine what use can be permitted and what treatment practices are likely to be successful.

Although considerable information is available on the affects of vegetation in general and on the effects of grazing, assigning separate quantitative values to the effects of the several types of land treatment and range management practices on the conservation, improvement and rehabilitation of the public domain is extremely difficult even with the data we now have. Some of the values that have been developed may be challenged on the grounds that they are representative of local conditions only, and therefore, they are not applicable to large areas having dissimilar characteristics. Nevertheless, the evidence strongly suggests that many of the individual treatments and practices are acting in a common direction and their combined effect justifies the belief that over a part of the public domain an improvement in range conditions has been achieved in the past three decades. The significant reduction in sediment yield in the Upper Colorado Basin may be cited as an example of such improvement. Other examples are the large increases in forage production on extensive cleared and seeded areas in many places.

The land treatment and range management practices similar to those applied in the Colorado Basin are being carried out also on the public domain in the other regions. It is believed, therefore, that a gradual improvement overall in range conditions in these regions is taking place. Unfortunately, sediment records available in those regions are not as long as those for the Colorado River basin and in general, are not as well segregated with respect to the contribution from the public lands. The records are useful as an inventory of the erosion conditions but to date do not reflect the changes that might have resulted from management and treatment practices for the long term.

Despite the improvement that is thought to have occurred, there are scattered but extensive areas where erosion is very active--the so-called frail lands. In the aggregate, these represent from 15 to 25 percent of the total area of the public domain. They are truly the problem areas, not only because of the technical and financial features involved in their successful treatment, but also because in most localities their treatment impinges on the sensitive field of water yield and water rights. Although the yield of water from most of the public land is so small that runoff may never reach a downstream irrigation project or would be almost meaningless in amount, the attitude of the downstream users in the Southwest, particularly, is against the onsite use of water upstream. The required treatment on the public lands will be delayed until an acceptable compromise can be developed. But this and the many other problems in the broad field of land use and conservation on the public domain must be solved before maximum productivity of all the area can be realized.

LITERATURE CITED

Arizona Agricultural Experiment Station, Department of Watershed Management, 1964, The evaluation of seedbeds, methods of seeding and species for seeding arid rangelands of Arizona: A Progress Report for the calendar year 1964 submitted to the Bureau of Land Management.

Arnold, J. F., Jameson, D. A., and Reid, Elbert, 1964, The pinyon-juniper type of Arizona, *in* Effects of grazing, fire and tree control: U.S. Department of Agricultural Production Research Report, no. 84, Forest Service.

Aro, R. S., 1971, Evaluation of pinyon-juniper conversion to grassland: Journal of Range Management 24:188-197.

Bailey, R. W., 1935, Epicycles of erosion in the valleys of the Colorado Plateau Province: Journal of Geology, v. 43, p. 337-355.

Barnes, O. K., Lang, R. L., and Beetle, A. A., 1952, Grass establishment on Wyoming dry lands: Wyoming University Agricultural Experiment Station Bulletin 314.

Blaney, H. F., 1957, Monthly consumptive use of water by irrigated crops and natural vegetation: Eleventh General Assembly Transcript, International Union of Geodesy and Geophysics, Toronto, Canada.

Blaney, H. F., and Criddle, W. D., 1949, Consumptive use of water in the irrigated areas of the Upper Colorado River Basin: Ms. Report, U.S. Department of Agriculture, Soil Conservation Service Research.

Branson, F. A., 1956, Forage production changes on a water spreader in southeastern Montana: Journal of Range Management, v. 9, no. 4.

Branson, F. A., Miller, R. F., and McQueen, I. S., 1962, Effects of contour furrowing, grazing intensities, and soils on infiltration rates, soil moisture and vegetation near Fort Peck, Montana: Journal of Range Management, v. 15, No. 3, p. 151-158.

Branson, F. A., Miller, R. F., and McQueen, I. S., 1966, Contour furrowing, pitting, and ripping on rangelands of the western United States: Journal of Range Management, v. 19, no. 4, p. 182-190.

Burkham, D. E., 1966, Hydrology of Cornfield Wash area and effect of land-treatment practices, Sandoval Co., New Mexico, 1951-1960: U.S. Geological Survey Water-Supply Paper 1831, 87 p.

Caird, R. W., and McCorkle, J. S., 1946, Contour-furrow studies near Amarillo, Texas: Journal of Forestry, no. 44, p. 587-592.

Clawson, Marion, 1967, The Federal lands since 1956--Recent trends in use and management: The Johns Hopkins Press, Baltimore, Maryland.

Clawson, Marion, and Held, Burnell, 1957, The Federal lands: John Hopkins Press, 501 p.

Collings, M. R., and Myrick, R. M., 1966, Effects of juniper and pinyon eradication on streamflow from Corduroy Creek basin, Arizona: U.S. Geological Survey Professional Paper 491b.

Cook, C. W., and Lloyd, R. D., 1960, Does range seeding pay?: Utah Agricultural Experiment Station Farm and Home Service 21, 78-79, 85-86, Utah State University, Logan, Utah.

Cotner, M. L., and Kelso, M. M., 1963, Northern Arizona beef is affected by pinyon-juniper: Progressive Arizona Agriculture, v. 15, no. 2, March 1963.

Cruse, R. R., and Harbeck, G. E., Jr., 1960, Evaporation control research 1955-58: U.S. Geological Survey Water-Supply Paper 1480.

Culler, R. C., 1961, Hydrology of the upper Cheyenne River Basin: U.S. Geological Survey Water-Supply Paper 1531-A.

Deming, M. H., 1960, Conditions and trends surveys: Our Public Lands, Bureau of Land Management, Oct. 1962.

Forsling, C. L., 1932, A study of the influence of herbaceous plant cover on surface runoff and soil erosion in relation to grazing on the Wasatch Plateau in Utah: U.S. Department of Agriculture Technical Bulletin 220.

Gray, J. R., and Springfield, H. W., 1962, Economics of lambing on crested wheatgrass in north central New Mexico: New Mexico University, Agricultural Experiment Station Bulletin 461.

Gregory, H. E., 1917, Geology of the Navajo Country: U.S. Geological Survey Professional Paper 93, p. 131-132.

Hadley, R. F., McQueen, I. S., and others, 1961, Hydrologic effects of waterspreading in Box Creek basin, Wyoming: U.S. Geological Survey Water-Supply Paper 1532-A.

Hadley, R. F., and Schumm, S. A., 1961, Sediment sources and drainage-basin characteristics in upper Cheyenne River basin, *in* Hydrology of the upper Cheyenne River basin: U.S. Geological Survey Water-Supply Paper 1531-B.

Harbeck, G. E., Jr., 1959, Evaluation of cooperation suppression at Lake Hefner, *in* Water-Loss Investigations: Lake Hefner 1958 Evaporation Reduction Investigations, Report by Collaborators, Bureau of Reclamation, p. 11-17.

Held, R. B., and Clawson, Marion, 1965, Soil conservation in perspective: Johns Hopkins Press, Baltimore, Md.

Hull, A. C., Jr., and Holmgren, R. C., 1964, Seeding southern Idaho rangelands: U.S. Forest Service Research Paper INT-10, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Hutchings, S. S., and Stewart, George, 1953, Increasing forage yields and sheep production on intermountain winter ranges: U.S. Department of Agriculture Circular 925.

Iorns, W. V., Hembree, C. H., and Oakland, G. L., 1965, Water resources of the upper Colorado basin technical report: U.S. Geological Survey Professional Paper 444.

Kaetz, A. G., and Rich, L. R., 1939, Report of surveys made to determine grade of deposition above silt and gravel barriers: Unpublished memorandum, December 5, 1939, U.S. Soil Conservation Service, Albuquerque, N. Mex., on file in SCS Library, Albuquerque.

Kennon, F. W., 1954, Magnitude of summer floods in western New Mexico and eastern Arizona: U.S. Geological Survey Open-File Report.

Kennon, F. W., and Peterson, H. V., 1960, Hydrology of Cornfield Wash, Sandoval County, New Mexico, 1951-55: U.S. Geological Survey Water-Supply Paper 1475-B.

King, N. J., 1959, Hydrologic data Wind River and Fifteen Mile Creek basins, Wyoming, 1947-54: U.S. Geological Survey Water-Supply Paper 1475-A.

Koberg, G. E., Cruse, R. R., and Shrewsbury, C. L., 1963, Evaporation control research, 1959-60: U.S. Geological Survey Water-Supply Paper 1692.

Langbein, W. B., Hains, C. H., and Culler, R. C., 1951, Hydrology of stock-water reservoirs in Arizona: U.S. Geological Survey Circular 110.

Leopold, L. B., Wolman, M. G., and Miller, J. P., 1964, Fluvial processes in geomorphology: San Francisco and London, W. H. Freeman and Co., 522 p.

Lloyd, R. D., and Cook, C. W., 1960, Seeding Utah's ranges, an economic guide: Agricultural Experiment Station Bulletin 423, Utah State University, Logan, Utah.

Lusby, G. C., and others, 1963, Hydrologic and biotic characteristics of grazed and ungrazed watersheds of the Badger Wash basin in western Colorado, 1953-58: U.S. Geological Survey Water-Supply Paper 1432-B, 73 p.

Lusby, G. C., and Hadley, R. F., 1967, Deposition behind low dams and barriers in the southwestern United States: Journal of Hydrology, v. 6, no. 2, New Zealand Hydrological Society, p. 89-105.

Lusby, G. C., Reid, V. C., and Knipe, O. D., 1970, Effects of grazing on the hydrology and biology of the Badger Wash basin in western Colorado, 1953-66, U.S. Geological Survey Open-File Report, 152 p.

Meinzer, O. E., 1923, The occurrence of ground water in the United States: U.S. Geological Survey Water-Supply Paper 489.

__________, 1927, Plants as indicators of ground water: U.S. Geological Survey Water-Supply Paper 577.

Meinzer, O. E., 1939, Ground water in the United States, a summary of ground-water conditions and resources, utilization of water from wells and springs, methods of scientific investigation and literature, relating to the subject: U.S. Geological Survey Water-Supply Paper 836-D, p. 157-232.

Miller, R. F., Branson, F. A., and others, 1969, An evaluation of range floodwater spreaders: Journal of Range Management, v. 22, no. 4, p. 246-257.

National Academy of Science, 1961, National Research Council Publication 885, p. 4.

National Resources Committee, 1938, Low dams: Publ. of Natl. Resources Committee: U.S. Government Printing Office, Washington, D. C.

Pacific Southwest Inter-Agency Committee, 1962, Stock water facilities guide: Hydrol. Subcommittee, Stock Pond Task Force, Mimeograph Report.

Packer, P. E., 1953, Effects of trampling disturbance on watershed condition, runoff and erosion: Journal of Forestry, v. 51, no. 1, p. 28-31.

Pearson, G. A., 1931, Forest types in the southwest as determined by climate and soil: U.S. Department of Agriculture Technical Bulletin 68, 222 p.

Pechanec, J. F., Plummer, A. P., and others, 1965, Sagebrush control on rangelands: Agricultural Handbook No. 227, U.S. Department of Agriculture.

Peffer, E. L., 1951, The closing of the public domain: Stanford University Press.

Peterson, H. V., 1950, The problem of gullying in western valleys, *in* Trask, Parker D., ed, Applied Sedimentation: John Wiley and Sons, p. 407, 434.

__________, 1962, Hydrology of small watersheds in Western States: U.S. Geological Survey Water-Supply Paper 1475I.

Peterson, H. V., and Branson, F. A., 1962, Effects of land treatment on erosion and vegetation on range lands in parts of Arizona and New Mexico: Journal of Range Management, v. 15, no. 4, p. 220-226.

Peterson, H. V., De Julio, O. P., and Rupkey, R. H., 1960, Effect of Bureau of Land Management structures on discharge of San Simon Creek: Pacific Southwest Field Committee, Department of Interior, Mimeograph Report.

Pingrey, H. B., and Dortignac, E. J., 1957, Economic evaluation of seeding crested wheatgrass on northern N. Mex. range land: New Mexico Agricultural Experiment Station Bulletin 433, February 1959.

Powell, J. W., 1879, Report on the lands of the arid region of the United States (2d ed.): U.S. Government Printing Office, Washington, D. C.

Public Lands Commission Report, 1897, p. 29.

Renner, F. G., 1954, The future of our range resource: Journal of Range Management 7:55-56.

Rich, L. R., 1961, Surface runoff and erosion in the lower chaparral zone, Ariz.: Rocky Mountain Forest and Range Experiment Station Paper 66.

Schumm, S. A., 1956, The role of creep and rainwash in the retreat of badland slopes: American Journal of Science, v. 254, p. 693-706.

Seaton, F. A., 1957, Conservation: U.S. Department of Interior Bulletin 39.

Secretary of the Interior, Annual Report 1941.

Shown, L. M., Miller, R. F., and Branson, F. A., 1969, Sagebrush conversion to grassland as affected by precipitation, soil, and cultural practices: Journal of Range Management, v. 22, no. 5, p. 303-311.

Smoliak, S., 1956, Influence of climatic conditions on forage production of shortgrass rangeland: Journal of Range Management, v. 9, no. 2.

Snyder, C. T., 1957, The geologist's role in stock-water development on range lands in Western United States: International Geology Congress, 1956, XX Session, Mexico City, Mexico.

__________, 1963a, Hydrology of stock-water development in the Ely Grazing District, Nevada: U.S. Geological Survey Water-Supply Paper 1475-L.

__________, 1963b, Hydrology of stock-water development on the public domain of western Utah: U.S. Geological Survey Water-Supply Paper 1475-N.

Stoddart, L. A., 1946, Seeding arid ranges to grass: Agricultural Experiment Station, Utah State University, Circular 122.

Tolman, C. F., 1937, Ground water: McGraw-Hill Book Co., New York.

U.S. Department of Agriculture, 1937, Range plant handbook: Forest Service, U.S. Government Printing Office, Washington, D. C.

__________, 1957, Hauling water for cattle: Leaflet No. 419, U.S. Government Printing Office, Washington, D. C.

U.S. Department of Commerce, Weather Bureau, 1959, Evaporation maps for the United States: U.S. Government Printing Office, Washington, D. C.

U.S. Department of the Interior, 1875, Annual Report of General Land Office.

__________, 1965, Public Land Statistics, 1965, 197 p.

U.S. Senate, Senate Document 199, 74th Congress, 1936.

Valentine, J. F., Cook, C. W., and Stoddart, L. A., 1963, Range seeding in Utah: Utah State University Extension Circular, Logan, Utah.

Valentine, K. A., 1947, Effect of water retaining and water spreading structures in revegetating semi-desert range lands: Agricultural Experiment Station, New Mexico A&M College Bulletin 341.

von Engeln, O. P., 1942, Geomorphology: Macmillan Co., New York, p. 175-177.

Webb, W. P., 1931, The Great Plains: Ginn and Co., Boston.