PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Evaluation of Land-Use and Land-Treatment Practices in Semi-Arid Western United States [and Discussion]

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Phil. Trans. R. Soc. Lond. B 1977 **278**, 543-554
doi: 10.1098/rstb.1977.0061

Phil. Trans. R. Soc. Lond. B. **278**, 543–554 (1977) [543]
Printed in Great Britain

Evaluation of land-use and land-treatment practices in semi-arid western United States

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There are about 81 000 000 hm² of arid to semi-arid rangeland in the 11 Western States of the United States. Much of this area was subjected to poor land-use practice in the early days of settlement resulting in deterioration of plant cover and severe erosion. Beginning in the 1930s land-treatment programmes were initiated to restore the range and control runoff and erosion. Results of investigations designed to evaluate the effects of land-use and land-treatment programmes are discussed. The types of practices considered are: (1) grazing control, (2) vegetation modification, (3) mechanical land treatments and (4) water spreaders. Grazing control alone reduced runoff by 30 % and sediment yield by 35 % in the Badger Wash basin of western Colorado. Vegetation conversion from shrubs to grass generally does not increase water yield, however, sediment yields are reduced as much as 14 times as shown by a controlled experiment at Boco Mountain in central Colorado. Of the many types of mechanical land treatments designed primarily to increase infiltration, the most effective is contour furrowing. Water spreading on valley floors by diverting flood flows increases forage production, reduces flood peaks and sediment loads to downstream areas.

All treatment practices designed to improve plant cover, induce infiltration, or control flood flows will use water. Therefore, these practices must be evaluated with regard to their effect on water yield, which is often critical in semi-arid regions.

Introduction

Much of the land area in the 11 Western States, outside the high mountain forests, is in a climatic environment that is arid or semi-arid. Although these lands generally can be classed as water deficient, they are of vital importance to the economy of the western United States. The total area of the 11 Western States is about 307 572 000 hm² (ha), of which over 81 000 000 hm² may be classified as arid or semi-arid rangeland. These rangelands, which are predominantly in federal ownership, are the subject of this paper. The dry climate combined with immature and commonly rocky soils and unfavourable topography precludes their use for agriculture. Most areas that are irrigable by reason of available water and favourable relief have already been developed for agriculture.

Most of these lands received 200–380 mm annual precipitation. Large areas in the arid regions of southern California, western Arizona, and southern Nevada, however, received less than 130 mm annually. The fact that much of the precipitation occurs as high-intensity summer thunderstorms coupled with high rates of evapotranspiration reduces further the available soil moisture for plant growth.

The same factors which in the aggregate make the land fit only for grazing also tend to make it vulnerable to erosion. The low annual precipitation supports a sparse plant cover that is not very effective as a protection against erosion. Periods of drought that take their toll of the fragile plant cover are often interrupted by high-intensity rains that produce destructive flooding. All of these factors make it imperative that management and use of land resources in arid and semi-arid environments be based on an understanding of hydrologic and geomorphic processes and soil–plant–water relationships.

History of land use

In addition to the physical, hydrological, and climatological characteristics that make the arid and semi-arid rangelands highly susceptible to erosion, there has been a long history of land abuse by overgrazing. From the middle part of the 19th century until 1934, all public domain lands in the West were open to use by anyone without restriction or regulation. The result was indiscriminate use by livestock and wildlife during all seasons of the year without consideration of grazing capacity or maintenance of the plant cover. By the 1870s, the livestock populations had reached, and passed, the safe grazing capacity of the range. This period was climaxed by a critical drought and the severe winters of 1885–6 and 1886–7 (U.S. Dept. of the Interior 1975). Livestock losses were so severe that some large ranching companies failed. In this same period, large areas of public land on the Great Plains, which at best were marginally suitable for agriculture, were being opened to homesteading. When farming proved unsuccessful, the virgin prairie now broken by the plough only added to the erosion and rangeland depletion problems initiated by overgrazing in the previous decades. The range condition continued to deteriorate and probably reached a low point in the 1920s (Clawson 1972).

The Taylor Grazing Act, passed by the U.S. Congress in 1934, provided the necessary legislation to regulate the use of public lands for grazing. The passage of the Taylor Act coincided with the severe drought then prevailing throughout much of the West that affected rangeland as well as farmland. In 1932, it was estimated that the western range had lost nearly 50% of its original productivity (U.S. Dept. of the Interior 1975). Because of the drought, attention was focused on erosion and soil conservation problems on the deteriorated semi-arid rangelands. In the period since about 1936, many programmes have been initiated to improve rangelands and control erosion and sedimentation. Many of these programmes were not successful because they were started without adequate hydrologic data or an understanding of hydrologic processes in the semi-arid environment (Peterson & Hadley 1960; King 1968). In recent years, however, controlled watershed experiments have made it possible to evaluate a variety of land-use and land-treatment practices representing a wide range of natural conditions of soil, vegetation, and topography.

Trends in range use and condition

If land-treatment practices are to be successful, the control of grazing is essential. With the establishment of grazing districts in 1936 and the assignment of individual grazing allotments to range users, itinerant herds were eliminated and major changes in grazing use began. Data on grazing before 1940 are almost non-existent but it is known that significant reductions in numbers of grazing animals occurred following passage of the Taylor Act 1934. For example, Peterson & Hadley (1960) state that between 1940 and 1955 in the upper Colorado River basin there was a 25% reduction in the animal-unit months of permitted grazing on public lands. These reductions were made on a voluntary basis, marking the beginning of a general awareness that the range had been overstocked and could not continue to be used so heavily. Reductions in numbers of animal-unit months permitted on grazing district lands has continued since 1955 as shown in table 1. Accompanying the more judicious use of the public lands for grazing has been an improvement in forage condition and soil erosion condition. Although much of the information on trends is qualitative, it probably reflects the effects of land management in a general way. Tables 2 and 3 summarize information published by Deming (1960) and the U.S. Dept. of the Interior (1975).

TABLE 1. PERMITTED USE OF GRAZING DISTRICT LANDS, 1960–1970†

State	1960	1964	1970
		Animal units‡	
Arizona	126568	105026	95050
California	97154	90704	78442
Colorado	296707	335466	332564
Idaho	393031	388525	399945
Montana	475116	440814	349807
Nevada	425057	451708	432224
New Mexico	347989	356682	285347
Oregon	264764	238778	201279
Utah	368501	344658	299394
Wyoming	416122	443711	437701
	3211009	3196072	2911753

† Adapted from Public Land Statistics.
‡ One cow or one horse or five sheep or five goats, all over 6 months of age.

TABLE 2. TRENDS IN RANGELAND CONDITION, PUBLIC DOMAIN IN WESTERN U.S.

forage condition	1930–35 ha	1930–35 per cent of total	1955–59† ha	1955–59† per cent of total	1975 ha	1975 per cent of total
improving	507898	1	14771550	24	12550961	19
unchanged	3182561	6	35047020	57	42873513	65
declining	48026963	93	11638363	19	10418597	16
total	51717422		61456933		65843071	

† Adapted from Deming (1960).

TABLE 3. SOIL EROSION CONDITION CLASSIFICATION FOR 58479150 ha OF PUBLIC LANDS IN WESTERN U.S., 1975†

	condition class				
	stable	slight	moderate	critical	severe
hectares	5263123	26900409	20467702	5263123	584791
per cent	9	46	35	9	1

† Bureau of Land Management (1975).

All conservation measures designed to control erosion or improve plant cover will use water by detention in reservoirs, mechanical improvement of infiltration, control of overland flow on upland slopes by mechanical treatments, or diversion of flood flows in channels for irrigation of bottomlands. Therefore, evaluation of these practices must include an assessment of on-site benefits as well as the effects on the water users downstream. Competition for water in semi-arid regions is constantly increasing for a variety of uses such as urban development, mineral development, recreation, and wildlife management. It is important to note, however that many of the areas with serious erosion problems generally have a meagre water yield when compared with the annual discharge of the entire river basin whereas sediment loads are often extremely high. If erosion can be effectively controlled in upland areas by a combination of grazing practices and mechanical or structural treatments, the rangelands may be measurably improved, resulting in reduced sediment loads. Results of studies considered here, however, indicate that this cannot be done without a consumptive use of water.

Effects of grazing

In order to verify the hypothesis that overgrazing or unregulated grazing on semi-arid rangelands has increased erosion, sediment yields, and destructive flooding, studies have been made on the hydrologic effects of grazing practices (Lusby, Turner, Thompson & Reid 1963; Lusby, Reid & Knipe 1971; Dunford 1949). Of the treatment practices that can be initiated to improve range condition and control runoff and sediment yield, grazing management is the simplest to apply to entire grazing units, but perhaps the most difficult to evaluate without strictly controlled experiments.

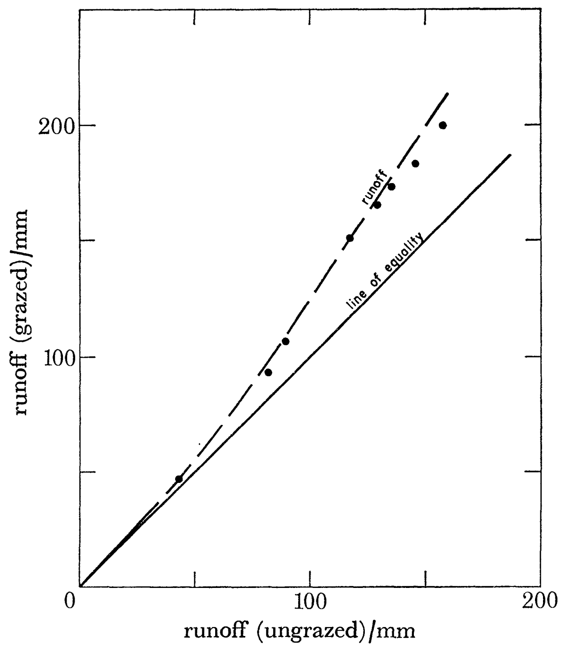

Figure 1

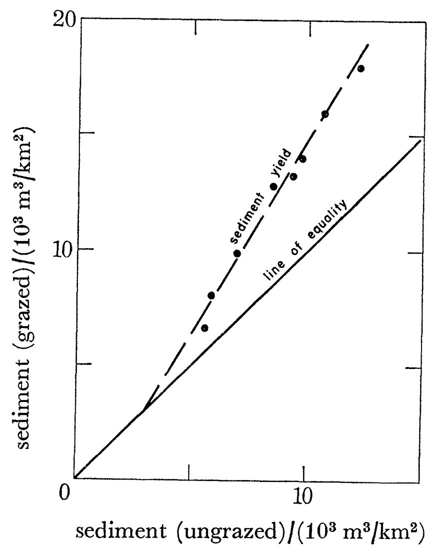

Figure 2

Figure 1. Mass diagram of runoff from four grazed and four ungrazed drainage basins in Western Colorado. The data represent 13 years of records. (Adapted from Lusby *et al.* 1971.)

Figure 2. Mass diagram of sediment yields from four grazed and four ungrazed drainage basins in Western Colorado. The data represent 13 years of records. (Adapted from Lusby *et al.* 1971.)

A long-term study of the effects of grazing on hydrology was conducted in Badger Wash basin in western Colorado from 1954 to 1973. Four pairs of small drainage basins were studied; one basin of each pair was grazed and one basin was fenced and excluded from grazing. The treatment was unchanged during the first 13 years of the study, 1954–66, and the results as described by Lusby *et al.* (1971) are summarized here.

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The climate of the Badger Wash basin is arid to semi-arid with an average annual precipitation of 220 mm. Vegetation is of the salt-desert shrub type and the cover is sparse on soils that are predominantly fine-grained. In the period 1954–66, runoff from three grazed basins averaged 131–140 % of that from three ungrazed basins (figure 1) and during the last 6 years of the period, runoff from grazed basins averaged 140–145 % of that from ungrazed basins. The greatest change occurred in the runoff relation after the third year of grazing exclusion. Similarly, the sediment yield from grazed basins was 50 % higher than from ungrazed basins (figure 2) (Lusby *et al.* 1971). The major factor influencing the marked differences in run-off and sediment yield appears to be the compaction of soils by grazing animals in the spring season when the surface materials are damp and loose from winter frost action. This causes increased runoff and erosion on grazed basins. This observation was verified in the period 1966–73 when the grazing season was changed, which had essentially the same effect on runoff as eliminating grazing completely (Lusby 1976, personal communication). A similar relation between grazing intensity and runoff was reported on plots in east-central Colorado by Dunford (1949). These studies indicate that grazing management alone can accomplish control of runoff and sediment yield.

Vegetation modification

As already stated, the plant cover was seriously deteriorated on much of the semi-arid rangeland of the western United States in the 1930s by a combination of factors attributable to overgrazing and drought. Much of the mixed sagebrush–perennial grass rangeland soon became dominated by sagebrush with very little grass understory as the competition for soil moisture was accentuated by the drought. Many conservationists felt that vegetation modification by conversion from shrubs or trees to grassland would not only improve the forage production on the range but would reduce erosion and sediment yields and possibly increase water yield. Many of the early predictions of what could be beneficially accomplished by vegetation conversion were intuitive rather than being based on controlled experiments. In recent years, several studies have been made that quantitatively evaluate the environmental effects of vegetation conversions from woody to herbaceous species. A discussion of the advantages of shrubs in terms of palatability for livestock and wildlife and an analysis of the indictment that shrubs are worthless invaders is beyond the scope of this paper. For an excellent treatment of this subject the reader is referred to a paper by McKell (1975) regarding the usefulness of shrubs as a resource. Some of the effects of vegetation conversions on runoff and sediment yield are considered here.

Several million hectares of sagebrush have been converted to grassland in the Western United States in the past 25 years. The most common methods of removing the shrubs are ploughing or spraying with chemical herbicides. Following the elimination or control of the sagebrush, the rangeland is seeded to perennial grasses with the objective of increasing forage production and controlling erosion. Results of a study of sagebrush conversion to grassland by Shown, Miller & Branson (1969) show that the most successful conversions usually occur where the annual precipitation exceeds 254 mm and on soils having medium moisture-holding capacities such as sandy loams, loams, or silt loams.

In a controlled watershed experiment conducted by the Geological Survey, the effects of conversion from big sagebrush cover to wheatgrass cover on runoff and sediment yield were investigated during a 9-year period, 1965–73. Four small basins, 2.02 to 4.04 ha, located about 4.8 km north of Wolcott in western Colorado were used for the study. The study area is named Boco Mountain.

Annual precipitation at the study area is about 343 mm; about 229 mm occur as rain during April through October, and about 114 mm occur as snow that accumulates as a snow-pack during November through March (Shown 1971). Runoff and sediment yield from four study basins were measured in reservoirs to evaluate the effects of the treatment. After a calibration period of 3 years, the sagebrush was removed from two of the basins by disk-ploughing and those basins were seeded to wheatgrass (Shown 1971).

During the calibration period, 1965–7, the average annual runoff from the four study basins was 33.8 mm and the average annual sediment yield was 962 m^3/km^2. For the 6-year period, 1968–73, after two basins had been converted from sagebrush to wheatgrass the average annual runoff for the two sagebrush basins was 29 mm and for the two grassed basins it was 32 mm. Therefore, the results indicate that the vegetation conversion did not affect the total runoff from rainfall and snowmelt appreciably (G. C. Lusby 1976, personal communication). However, there was a considerable reduction in sediment yield. The two basins left in sagebrush cover had an average annual sediment yield of 266 m^3/km^2 during the 6-year post-treatment period while the two grassed basins yielded only 38.1 m^3/km^2 which represents a large decrease in sediment yield on the treated basins over that measured during the calibration period.

There have been few studies of the hydrologic effects of conversion of shrubs to grass such as the Boco Mountain study. However, observations in semi-arid regions indicate that such vegetation manipulation will not result in large increases in water yield. Also, more study is needed regarding the long-term effects of vegetation conversion on runoff, sediment yield, and forage production.

Mechanical land treatments

Various mechanical treatments have been used on rangelands in semi-arid regions of the Western United States. The most common of these practices is contour furrowing with the principal objective of increasing infiltration to enhance soil-moisture storage and consequent forage production on upland slopes. In an evaluation study of mechanical land treatments in the Western United States by Branson, Miller & McQueen (1966), they conclude that contour furrowing on medium- to fine-textured soils is the most effective type of treatment for conserving soil moisture. According to Caird & McCorkle (1946), 404 700 hm^2 of pasture and rangeland were contour furrowed between 1936 and 1940. The practice has been continued since 1940, and the area treated has perhaps doubled. As with structural treatments in stream channels and on valley floors, mechanical treatments on upland areas tend to impede overland flow and reduce flood peaks, thereby increasing on-site consumptive water use.

Benefits derived from contour furrowing are documented by the studies of Branson *et al.* (1966). They state that forage yields were increased by 118 % in treated areas in Montana and by 136 % in treated areas in Wyoming. When newly constructed, the water storage capacity of furrows generally exceeds 51 mm of precipitation. Assuming infiltration rates of at least 13 mm/h, the storage capacity should not be exceeded in semi-arid regions where a 2-h rainfall of 51 mm has an expected recurrence interval of 50 years.

As emphasized by Branson *et al.* (1966) the storage capacity of contour furrows decreases with time. Figure 3 shows that the decrease in storage capacity tends to be rapid during the first 5 years and becomes relatively stable after about 9 years. However, when the plant cover becomes well established, the effectiveness of the treatment as an erosion and runoff control measure apparently lasts for more than 20 years.

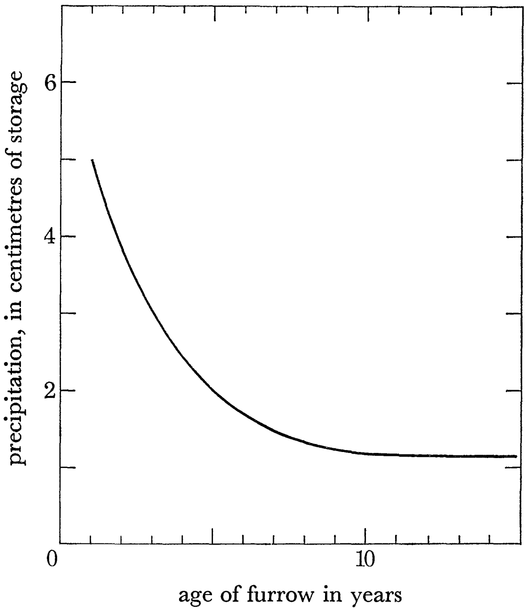

Figure 3. Decrease in water storage of contour furrows with age. Storage capacities were computed from measurements of depth, width, and spacing of furrows. (Adapted from Branson *et al.* 1966.)

Water spreaders

Water spreading on alluvial valley floors adjacent to ephemeral stream channels is a common practice in semi-arid regions to increase forage production, reduce flood peaks, and induce aggradation in trenched valleys. In a study by Miller *et al.* (1969) of water spreaders in the western United States it was found that the practice was most successful in areas receiving 280 mm or more of precipitation annually and was not successful in areas receiving less than 203 mm of precipitation annually.

The primary objective of a floodwater spreader is to divert flood flows from a trenched ephemeral-stream channel onto adjacent flood plains and low terraces. Many of these valley floors were flooded naturally in the past before the alluvium was trenched by erosion. Depletion of the vegetation by overgrazing caused the alluvial deposits to become more susceptible to erosion. Deepening and headward cutting of the gully trench not only lessened the frequency of overbank flooding but also decreased the soil moisture available for plant growth because the gullies served as drainage ditches. In order to restore the irrigation of the bottomlands, which are the most productive lands in the semi-arid regions, ranches soon began devising ways to utilize the flood flows by diverting water onto the valley floors.

There are two common methods of water spreading: (1) direct diversion of flood flow from the channel by constructing earthfill dams across the trench and allowing natural flooding of the valley floor, and (2) construction of a detention dam and reservoir with a series of training dykes that distribute the water back and forth evenly across the valley floor. In both designs the important consideration is to get the water on and off the spreading area without ponding for long periods. Ponding will cause deposition of very fine sediment and prolonged inundation that will kill the existing plant cover.

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The operation of a water spreader was evaluated in a study by Hadley & McQueen (1961) in the Box Creek basin of east-central Wyoming in an area that receives about 356 mm annual precipitation. The Box Creek water spreader is operated by direct diversion of ephemeral flows from the main channel by a series of 27 earthfill dams. Natural flooding of an area of about 146 ha on the valley floor occurs along a reach of the stream channel about 6.4 km long. The drainage area upstream from the water spreader is about 363 km².

Gauging stations were established upstream and downstream from the water spreader and suspended-sediment samples were taken at both gauging stations during the 1956 and 1957 seasons (April through September) for which inflow and outflow through the water-spreading system could be determined. The total inflow for six runoff events was 2.50 hm³ and the outflow was 1.64 hm³, which represents a loss of 34 % of surface flow entering the water spreader.

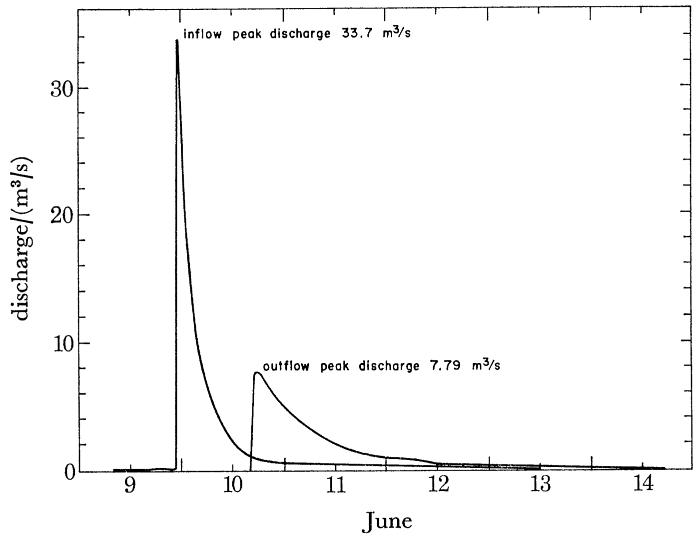

FIGURE 4. Flood hydrographs for gauging stations at Box Creek water spreader for the period 9–14 June 1957.

There were two storms during the study period that centred in the headwater reaches of Box Creek, and all flow in the channel originated above the water-spreading system. These runoff events occurred 9–14 June and 30 June–4 July 1957. Data collected on streamflow and suspended-sediment discharge during these two periods provide a good example of the operation of the water spreader. Inflow to the water spreader during the 9–14 June period was 0.626 hm³ and the instantaneous peak discharge was 33.7 m³/s. Outflow from the water spreader was 0.434 hm³ and the instantaneous peak discharge was only 7.8 m³/s. The inflow and outflow hydrographs for the 9–14 June runoff event are shown in figure 4. During the runoff event of 30 June–4 July 1957, the inflow to the water spreader was 0.59 hm³ and outflow was 0.44 hm³. The instantaneous peak discharge at the upper gauging station was 23.8 m³/s and the outflow instantaneous peak discharge was only 7.0 m³/s.

During the 9–14 June period, the suspended-sediment load entering the water spreader was 2460 t and at the outflow station the load was only 752 t. In the period 30 June–4 July, the suspended-sediment load at the inflow station was 1633 t and at the outflow station was only 263 t. Therefore, during the two runoff events there was a depletion of suspended-sediment load through the water spreader of 3078 t, or 75 %, by deposition in the channel and on the valley floor. The histograms of suspended-sediment load shown in figure 5 illustrate graphically the effect of the water spreader on suspended-sediment discharge.

As has been shown in other studies in semi-arid regions (Culler 1961; Hadley & Schumm 1961), generally there is a natural depletion of stream flow and sediment during runoff periods in ephemeral streams. Operation of water-spreading systems, such as the Box Creek water spreader, will reduce peak discharges and increase the expected flow losses and sediment

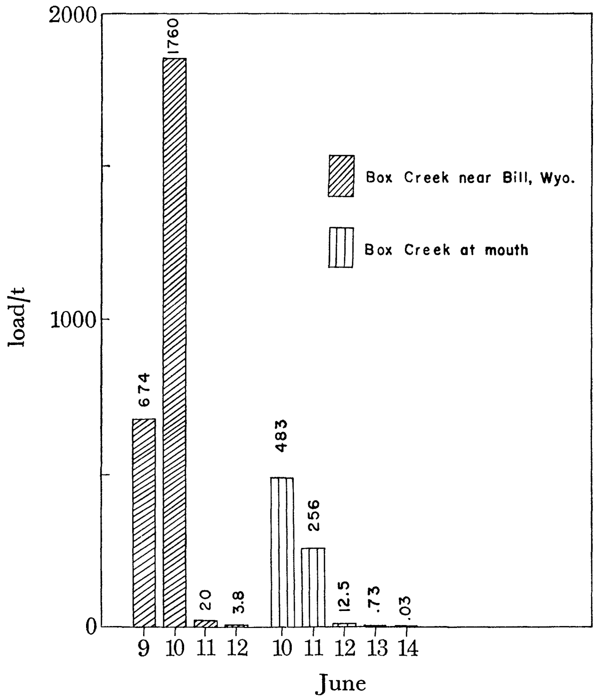

FIGURE 5. Histograms of suspended-sediment load at gauging stations on Box Creek for period 9–14 June 1957.

deposition. Also, it should be noted that the Box Creek water spreader was 30 years old at the time of the study by Hadley & McQueen (1961). The trenched channel had been nearly filled with sediment and the plant cover on the valley floor was well recovered. New systems in valleys with deep trenches, reduced soil moisture, and poor plant cover may be expected to deplete flood flows even more than the observed measurements in Box Creek.

LAND USE AND HYDROLOGY

Many of the land-use and land-treatment practices that have been described are successful in the control of runoff, abatement of erosion, and increase of plant cover but generally on relatively small and widely scattered upland areas. When compared with the millions of hectares that are in need of improved land-use practices, it seems improbable that the impact of these conservation measures would be detectable in the hydrologic response of the major streams. However, there are many examples in the literature (Hadley & Schumm 1961; King 1968; Emmett 1974; Hadley 1974) of recent changes in channel morphology and sediment discharge of streams in semi-arid regions of the western United States. Although our information on land-treatment practices and changes in range condition since 1930 are far from adequate, the evidence suggests that reductions in sediment yields are a reflection, at least in part, of improved land use.

In a study by Hadley & Schumm (1961) in the Cheyenne River basin, eastern Wyoming, there are numerous examples of channel and flood plain aggradation. On Twentymile Creek, near Lusk, Wyoming, the extent of overbank deposition was determined by measurement of buried fence posts along a line that crosses the valley floor. The flood plain had been aggraded to a depth of about 1 m throughout a reach that is 3.2 km in length and approximately 460 m wide in a period of 31 years, 1920–51. In the same period about 100 small reservoirs were built in upland tributaries of Twentymile Creek for the purposes of providing livestock water and erosion control. These structures undoubtedly have reduced flood peaks and flood volumes and induced deposition of sediment on the valley floor.

TABLE 4. AVERAGE ANNUAL DISCHARGE AND SUSPENDED-SEDIMENT LOAD AT GAUGING STATIONS IN THE UPPER COLORADO RIVER BASIN FOR TWO PERIODS OF RECORD (after Hadley 1974)

gauging station	period† 1	discharge hm³	suspended sediment load 10³ t	period† 2	discharge hm³	suspended sediment load 10³ t	ratio period 2/period 1: discharge	ratio period 2/period 1: sediment
Colorado River at Grand Canyon, Arizona	1926–41	15460	177300	1942–60	14500	86400	0.944	0.486
Colorado River near Cisco, Utah	1930–42	6340	17300	1943–62	6170	8700	0.973	0.501
Green River at Green River, Utah	1930–42	4490	22100	1943–62	5200	15100	1.156	0.683
San Juan River near Bluff, Utah	1930–42	2430	41700	1943–62	1880	15900	0.775	0.381

† Water year (1 October–30 September).

In the Wind River basin of Central Wyoming, King (1968) reports a similar example of induced aggradation by control of runoff in two adjacent drainage basins, Logan Draw and Conant Creek. Logan Draw has a drainage area of 157 km² and Conant Creek has a drainage area of 153 km² upstream from the junction with Logan Draw. In 1953, the Bureau of Land Management completed a flood control programme on Logan Draw consisting of diversion dams and water spreaders that completely utilized all flood flow from the basin.

Since 1953 no flow has passed the mouth of Logan Draw into Conant Creek. The result has been that the channel of Conant Creek, which was adjusted to floods from both basins, began to aggrade. Surveys of channel cross sections by King during the period 1955–66 show that the channel filled to a depth of 1.2 m and total deposition was about 10200 m³ in a reach of Conant Creek 1 km in length.

These examples of channel aggradation are not unique. Emmett (1974) and Hadley (1974) report on observations at several locations in the Missouri, Rio Grande, and Colorado River Basins of aggrading channel reaches in the past 20–30 years.

The observations of improved plant cover and sediment deposition in smaller tributaries of the western United States river basins is also manifested regionally. For example, comparison of the suspended-sediment discharge records at the Grand Canyon gauging station on the

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Colorado River for two periods, 1926–41 and 1942–60, show that the suspended-sediment loads for the latter period are only about 50 % of the earlier period (Hadley 1974). A similar relationship is found in the records of two major tributaries of the Colorado River, Green River and San Juan River. Although the periods of record are not exactly the same there is sufficient overlap for comparison. The records are summarized in table 4 (Hadley 1974).

The reduction in sediment yield in the Upper Colorado River basin between 1942 and 1962 coincides with the period when land-use and land-treatment practices were initiated and grazing regulations began on public lands. Admittedly, it is difficult to determine the effects of individual treatment practices, whether they consist of structural control, mechanical treatment, or grazing plans. Nevertheless, it is evident that progress has been made in the management of the limited land and water resources of semi-arid rangelands in the western United States.

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Discussion

B. Dasgupta (*Institute of Development Studies, University of Sussex*). As the speaker is surely aware, while many of the measures suggested by him are technologically sound, these may not be feasible in financial or economic terms. Would the speaker be kind enough to indicate, approximately, the total cost incidence of various schemes and how the money was raised?

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N. E. Reynolds (*The Ford Foundation*, 55 *Lodi Estate*, *New Delhi* 110 003, *India*). Dr Gupta's statement that 'third world countries like India cannot afford conservation works' is largely unexplained and cannot be accepted. In India large sums are spent on relief and this money can pay for works whose calculated rates of return may be low and otherwise unacceptable. The proper question is the administration of relief and, to go further, of general local administration. Nor should conservation be treated in isolation. In India the large areas of forest and grazing land destroyed over the last 50–60 years testify to the importance of legal and institutional factors, factors that remain central when considering conservation and land-use issues in populated areas. Another set of factors is: employment as a basic right (Maharashtra's Guarantee Employment Scheme); as an economic development strategy; and as a means to the husbandry and development of scarce resources.

Conservation work is surrounded by difficulties in poor countries. Contour lines do not fit existing field and farm boundaries so that, without land consolidation, work on the contour is not easy. The power structure within watersheds tends to reside at the bottom, amidst the better soils, more level lands, stream and communication lines. Erosion of upland in the early stages is not seen as a threat to the powerful. Siltation, indebtedness and greater instability can be to the advantage of lower level farms if those farmers can secure the services of the conservation department to build siltation works, and those farmers may be able to command a more docile labour supply by creating greater dependency through money-lending, etc. Good conservation is often a good distributive measure. To do it in that manner requires a strong political leadership supported by confident and determined disciplinary groups and departments.

S. Sandford (*Overseas Development Institute*, 10–11 *Percy Street*, *London W*1). In evaluating the success of land-treatment practices, Dr Hadley had quoted figures for reductions in runoff and in sediment-load as his criteria. Do figures also exist to show the effect on economic output, possibly measured in terms of quantity of meat?

R. F. Hadley. Beneficial effects of contour furrowing, rangeland pitting, and other mechanical land treatments that conserve soil moisture are all generally similar. In addition to reducing runoff and sediment yields they increase forage production and livestock growth. It has been reported in a study in southeastern Wyoming that effects of rangeland pitting increased sheep carrying capacity by about 32 % and lamb gains by about 11 kg/ha per year.

E. B. Worthington (*I.B.P.*, *c/o The Linnean Society*, *Burlington House*, *Piccadilly*, *London W*1*V* 0*LQ*). What is the effect of 'water spreading' to encourage the growth of fodder plants on the quality of the runoff water downstream, or, in cases where all the spread water is transpired locally, on the soils? Would not the salt or alkaline content accumulate with time in a way comparable to older irrigation schemes in arid and semi-arid areas?

R. F. Hadley. Water quality is generally improved downstream from a water spreader. Sediment discharge is decreased by reduced velocities and deposition in the spreader system. Because of annual deposition of fresh sediment and leaching of salts in the medium-textured soils of successful water spreaders salinity problems are minimal. In poorly-designed water spreaders where water is ponded for long periods and soils are very fine grained, however, salinity problems do exist.