DEPOSITION BEHIND LOW DAMS AND BARRIERS IN THE SOUTH-WESTERN UNITED STATES

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ABSTRACT

Many flat-floored alluvial valleys in the western United States have been gullied to the extent that they have lost their usefulness for forage production and flood retardation. Numerous attempts have been made to stop further gully erosion and to refill existing gullies by construction of low dams and barriers. This report describes observations on particle-size distribution of material deposited, slope of deposit, volume and extent of deposit, and original channel gradient at: Sheep Creek (Utah), Polacca Wash and Zion Dam (Arizona) and Mexican Springs, Tinian and Cornfield Wash (New Mexico).

The observations indicate that the slope of deposition is dependent to some extent on the particle-size distribution of transported sediment. The rate of filling of steep-sided gullies is dependent on the availability for transport of material approaching the size of the original bed material.

Deposits behind low permeable barriers have steeper surface gradients than the original stream channels, and deposits behind low dams have surface gradients less steep than the original channels. The over-steepening behind permeable barriers may be the result of backwater causing enough reduction in velocity to deposit coarse sediment at a point up stream, while sufficient velocity is maintained near the barrier to carry the fine sediment through.

INTRODUCTION

Throughout the western United States many upland areas are being eroded rapidly by overland flow and, once the transported material reaches the main drainage channels, the state of these channels is such that little opportunity is afforded for redeposition of the sediment.

Historical records show that many of the valleys that are now cut by deep arroyos contained shallow, perennial streams at the time of settlement by white men. Much of the sediment delivered from uplands was deposited on the valley floors when run-off infiltrated the flood plains and valley floors.

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The reason for this change in stream regimen in many areas has not been fully determined, but the rapid erosion of many valley bottoms has been fairly well documented. According to Gregory (1917), for example, the cutting of Kanab Creek in southern Utah began with a large storm of July 29, 1883. Unusually large amounts of precipitation were received in 1884–85, and in this period the gully cut down 60 ft and widened 70 ft for a distance of about 15 miles. The gullies lowered water levels in the valley alluvium and caused the decline of desirable vegetation and subsequent dominance of undesirable vegetation. There are numerous similar examples throughout the south-western United States.

In recent years attempts have been made to reduce erosion and to promote the filling of gullies in problem areas. This would not only improve the economic basis for farmers and ranchers in the areas involved, but would also reduce down-stream sedimentation damage. In order to appraise the sedimentation problems correctly, it is necessary to have a reliable idea of the effect of raising the base level on the flow and transport conditions in a river (Sundborg, 1964). This paper describes the effects of several low dams and small barriers on stream profile, and the magnitude and extent of deposition attributable to an artificial base level.

The structures that will be considered in this paper are on Sheep Creek, a tributary of the Paria River in southern Utah; on Polacca Wash in north-eastern Arizona; Zion Dam near St Johns, Arizona; the Mexican Springs experimental area, near Gallup, New Mexico; and on Cornfield Wash and the Tinian barriers, near Cuba, New Mexico (see Fig. 1). The data from Mexican Springs and Zion Dam were not collected by the authors but are used here for comparison with other areas. The data from the Sheep Creek Basin are more detailed than those of the other areas because stream-flow records and suspended-sediment samples were collected. Data on the physical characteristics of the deposits from all of the study areas offer an opportunity to compare the effect of these factors on sedimentation.

SHEEP CREEK DAM

Sheep Creek originates in Bryce Canyon National Park at an elevation of about 8,000 ft and flows south-eastward for about 13 miles before joining Willis Creek, which is a tributary of the Paria River. In 1960 the Bureau of Reclamation constructed a low dam on Sheep Creek controlling an area of 31.1 square miles. The Geological Survey was asked, as part of a co-operative study project, to determine the effectiveness of this dam in inducing aggradation up stream.

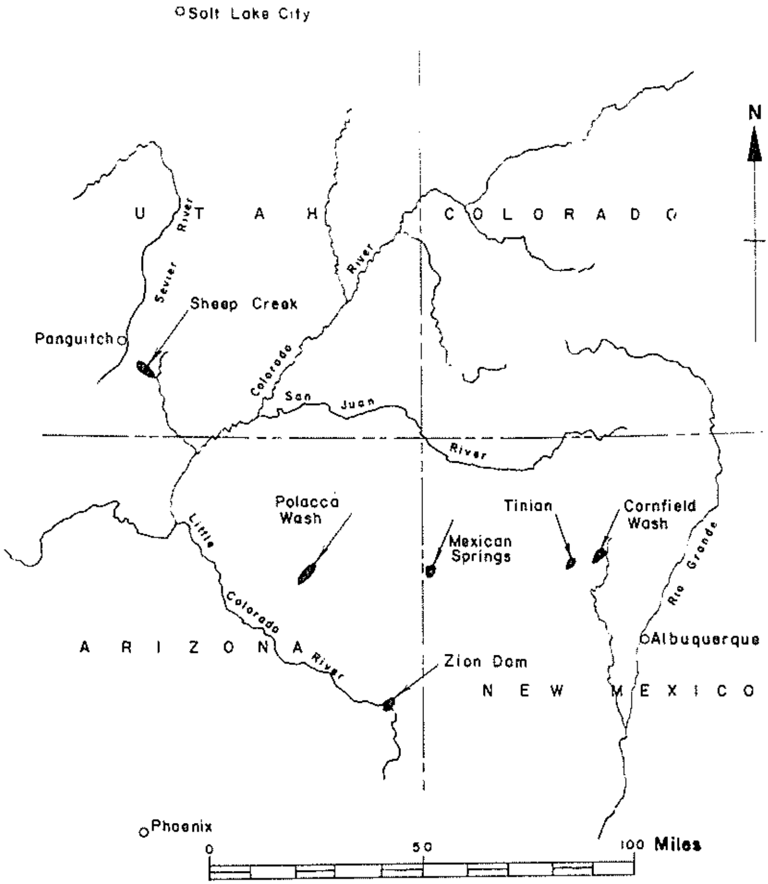

Fig. 1 — Location map.

The Sheep Creek Basin has been so extensively eroded that the terrain has become extremely rough. Viewed from a distance, the skyline has a blocky appearance with flat-lying tops and very steep sides dropping off to actively eroding channels in the valleys.

About 77 per cent (Gregory, 1951) of the drainage basin has developed on sandstone formations containing material ranging from fine-grained to coarse and conglomeratic. The remainder of the basin is underlain by shales and limestones.

The Sheep Creek channel drops 2,150 ft in a distance of about 12 miles. In its lower reaches the channel has a gradient of about 1.67 per cent or 88 ft/mile. In Sheep Creek and its tributaries, channels are deeply incised in alluvium that is generally separated into strata of sorted material ranging in size from clay to coarse gravel and boulders. Residual soils in the basin are decidedly non-cohesive and are consequently easily eroded. These porous, non-cohesive soils permit rapid infiltration, and large volumes and intensities of rainfall are necessary to induce run-off. Once these conditions are attained, however, the non-cohesive soil, the steep slopes, and the well-incised channels cause rapid run-off and severe erosion.

Concentration of suspended sediment in storm run-off is extremely high in this area. Run-off seldom occurs without concentrations of 200,000 parts per million or more in the initial movement of water. In the Paria River the average concentration in July, August, and September during 10 years of record was 250,000 p.p.m. (U.S. Dept. Interior, 1948–57).

Study Procedure

The dam was completed in May, 1960, and observation begun at that time. The original capacity of the reservoir was 87.9 acre-ft with a maximum depth of 15.5 ft below spillway level. The reservoir has an ogee-section concrete spillway 75 ft wide and is designed to accommodate all run-off from the drainage after the reservoir is completely filled with sediment.

To determine the depositional patterns in the reservoir, the original reservoir body was surveyed and periodic resurveys were made to determine the volume of sediment deposited. Channel cross sections were established up stream and down stream from the reservoir and were resurveyed periodically to determine channel changes. A continuous water-level recorder was installed in the reservoir to provide data for the computation of inflow and outflow. Samples of deposited material were obtained periodically and were analysed for grain-size distribution.

Results of Studies

(See Table 1.) As very little inflow to the reservoir was received during the summer of 1960, run-off and sediment yield were combined with amounts measured in 1961.

TABLE 1—Run-off and sediment deposition at Sheep Creek Barrier Dam

Period	*Sediment deposited (acre-ft)*	*Total run-off (acre-ft)*	*Peak flow (cusecs)*
May 19, 1960–Sept. 28, 1961	107.6	1,205	1,820
Sept. 28, 1961–Nov. 12, 1962	21.3	737	2,690
Nov. 12, 1962–Nov. 12, 1963	32.0	1,108	4,620
Nov. 12, 1963–Nov. 10, 1964	4.4	70	246
Total	165.3	3,120	—

Hydrographs of inflow and outflow for the reservoir, along with sediment-concentration curves, for a storm on August 31, 1963, are shown in Fig. 2. The inflow/outflow curves were computed from stage/capacity and spillway-discharge tables, and the concentration curves were drawn on the basis of sediment samples taken in the inflow and outflow. Computations of sediment discharge show that 106,000 tons of sediment came into the reservoir and 93,000 tons went out the spillway. By using a conversion factor of 90 pounds per cubic foot for deposited sediment (determined from density samples taken in the reservoir), a deposition of 6.6 acre-feet is indicated. This particular storm produced 43 per cent of the run-off in 1963. If the same run-off/concentration ratio were assumed to apply for the remainder of the year, a total of

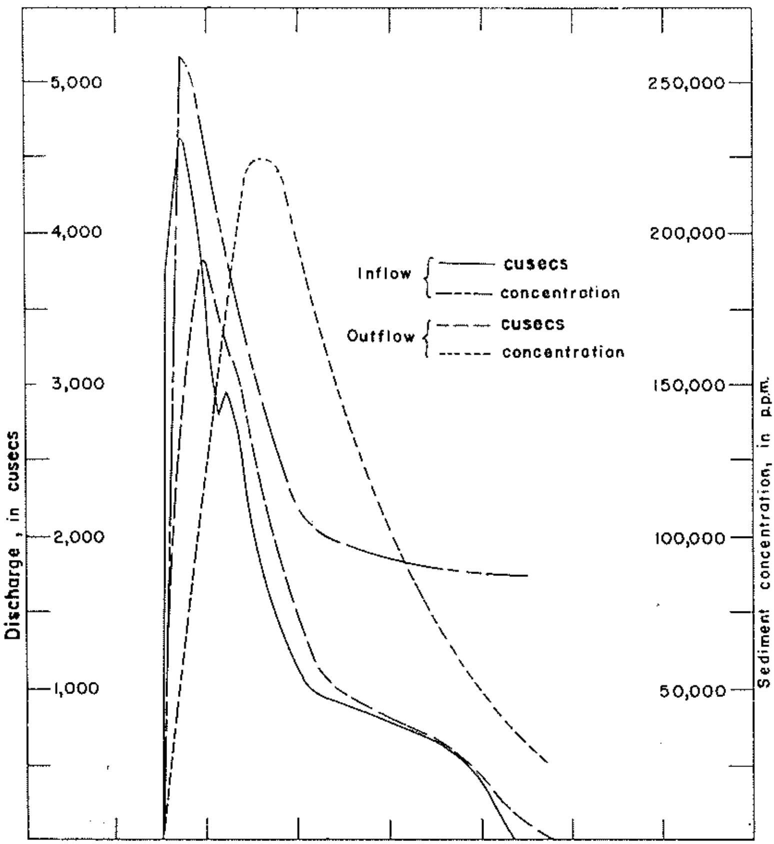

Fig. 2 — Hydrographs and sediment concentration of inflow/outflow at Sheep Creek Barrier Dam.

15.4 acre-feet of deposition would be indicated. In fact, 32.0 acre-feet were deposited. Although there are some limitations in the accuracy of these data, the difference is probably due in part to unmeasured bedload in the inflow.

Successive profiles of the stream bed from the dam to a point up stream beyond the point where any changes took place are shown in Fig. 3. During the first period, which extended through November 1961, the reservoir below spillway elevation was almost completely filled with sediment. In this period the reservoir received 1,205 acre-feet of inflow (sediment and water). About 108 acre-feet of sediment were deposited in the reservoir. Thus about nine per cent (by volume) of the inflow was deposited. During each of the next two years about three per cent of the inflow was deposited. In 1964, a year of very little run-off, about six per cent of the inflow was deposited.

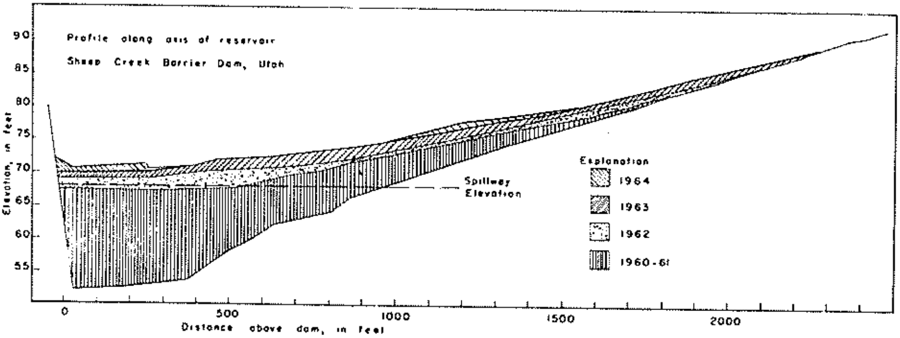

Fig. 3 — Successive stream bed profiles at Sheep Creek.

The material deposited in the reservoir ranges in size from fine, well-sorted sand in the down-stream part of the reservoir to coarse gravel mixed with large cobbles in the up-stream part. Most of the material deposited in the reservoir below the high-water line is sand size (0.0625 to 2.00 mm). Above the high-water line the deposited material becomes progressively more coarse until at the up-stream end of the deposit the size of deposited material approaches that in the channel before construction of the dam. Density samples indicate that material deposited in the upper end of the reservoir is about 139 pounds per cubic foot, while that up stream in the natural channel is about 124 pounds per cubic foot. Median grain-size diameter of material from the stream bed above the reservoir was about 6 mm. This sample excluded numerous large boulders incorporated in the stream bed. Analyses of suspended-sediment samples taken during storm run-off indicate the median diameter to be about 0.01 mm.

The ability of a stream to transport sediment depends on several factors, including velocity and depth of flow. Fig. 4 shows a reconstructed water profile for the peak flow during the storm of August 31, 1963, illustrating the effect on these factors as run-off enters the reservoir. The channel is of fairly uniform width up stream from section 1. Below section 1 the channel widens into the reservoir body until the maximum width is obtained at section 4. During the peak flow of 4,620 cusecs on August 31 the depth and velocity at section 1 were 2.7 ft and 15.0 ft/sec. respectively. At section 2 as the flow spread out over a greater width the depth and velocity were 1.8 ft and 10.6 ft/sec. At section 3 just above the backwater effect the depth was 1.7 ft and the velocity was 6.3 ft/sec. At section 4 near the dam the depth was 5 ft and the velocity was 1.3 ft/sec.

Although the figures given are averages and represent only one point in time, they indicate relative magnitudes. Also shown in Fig. 4 are the slopes and median grain-size diameter of sediment deposited during 1963. The reduction of velocity, brought about by change in slope and widening of the channel, has made it impossible for the stream to carry the coarser sediment to the lower end of reservoir.

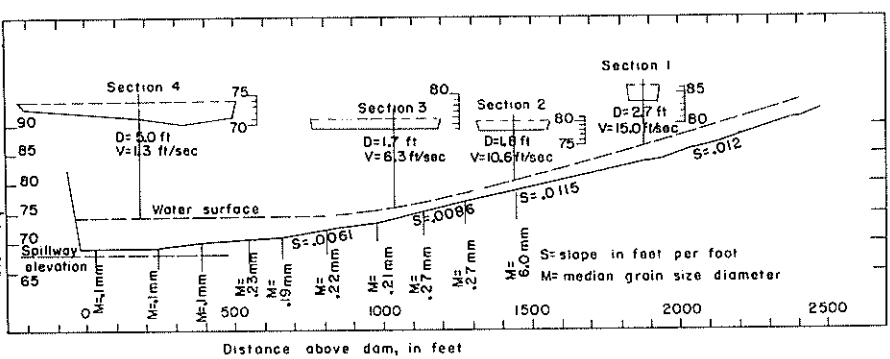

Fig. 4 — Reconstructed water profile and cross sections at Sheep Creek during storm of August 31, 1963.

For several miles above the dam the channel is entrenched in old valley alluvium which contains stratified layers of large cobbles and boulders (Fig. 5). The channel bottom is composed of coarse material and is fairly stable. The gradient of the channel is controlled by the size of material in the bed, and therefore — if enough material of this size were available — the channel would adjust to the raised base and attain approximately the same slope as before. Such gravel and boulder sizes are present in the valley alluvium up stream, but they are made available only by lateral

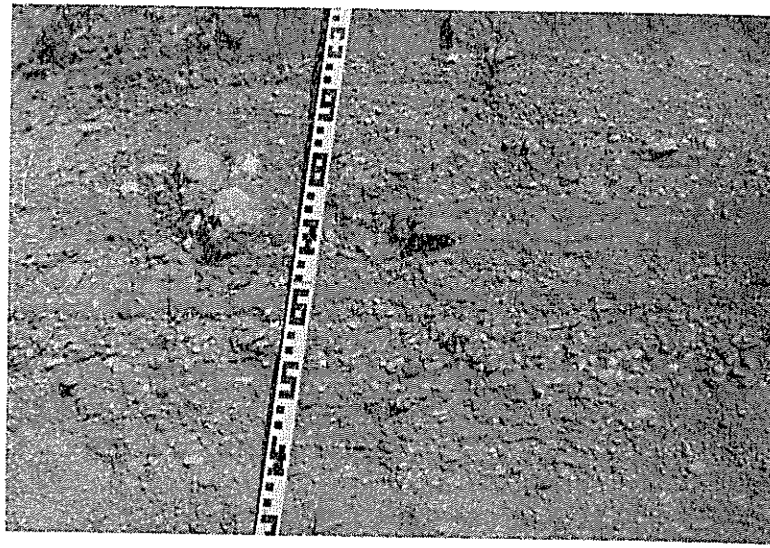

Fig. 5 — Alluvial material containing coarse material in channel walls of Sheep Creek.

cutting of the gully, after which the stream is capable of moving large material into the area of aggradation; in fact, boulders up to one foot in diameter have been deposited in the upper end of the reservoir. Thus, the rate of refilling in the gully appears to depend on the degree of lateral cutting up stream.

Calculations of reservoir capacity indicate that, during the three-year period 1962–64, about 15 acre-feet of material large enough to sustain a channel slope comparable to the original were deposited in the upper part of the reservoir above spillway level. About 170 acre-feet of this coarse sediment would be needed to re-establish the original channel gradient across the wide section of the reservoir. At the present rate of deposition, about 34 years would be required for this to be accomplished. To attain this gradient across the reservoir, the gully up stream must also be filled for a considerable distance, lengthening the time needed to refill the channel and reservoir.

Perhaps the deposit in the reservoir will become cut by channels and armoured with coarse material; if so, the entire reservoir need not be filled to establish the old slope, and this would shorten the time necessary to re-establish the channel at the original slope. It is not known whether the run-off experienced during the first five years of observation represents an average for a long period. Precipitation records at a Weather Bureau station about eight miles from the study area indicate that during the five years of study the long-term yearly average was exceeded twice. During the remaining three years, precipitation was considerably less than the average.

DAMS IN POLACCA WASH BASIN

There are several erosion-control dams on Polacca Wash and its tributaries in the Hopi Indian Reservation in north-eastern Arizona. These structures are comparable in size with the Sheep Creek Dam. The detailed data on run-off and annual increments of sediment deposition that have been obtained at Sheep Creek are not available for the Polacca Wash structures. Surveys have been made, however, to determine the extent and characteristics of deposition behind these dams, and the results can be compared with the data from Sheep Creek. The dams in Polacca Wash Basin were built in the 1940s and 1950s as conservation measures intended to promote aggradation in the gullied valleys and to restore the usefulness of the valley floor for grazing and flood-water farming.

Polacca Wash and its principal tributary, Wepo Wash, are typical of the many streams that drain Black Mesa in the Navajo and Hopi Indian Reservations. In the upper part of the basin the channels are narrow and are confined in deeply incised canyons. In the lower part of the basin the channels become wider and are in broad, relatively flat valleys. In the central and lower parts of the basin the tributaries are generally aggraded, forming alluvial fans which obliterate the confluence with main channels. The channel of Polacca Wash is, however, deeply entrenched in the valley alluvium for most of its length.

Between about 1900 and 1945 the channel of Polacca Wash eroded to a depth of 40 feet or more in the reach near the village of Polacca. In the period 1944 to 1953 three dams were constructed on Polacca Wash and one near the mouth of Wepo Wash. In 1957 less than one per cent of the original storage capacity remained. The deposits above these dams were examined to determine their character and extent.

Study Procedures

The sediment deposits in Polacca Wash Basin were surveyed in 1957 to determine their areal extent and samples were taken to determine particle-size distribution. The amount of sediment which is deposited in the channels and on the valley floors of Polacca and Wepo Washes, and which is attributable to the construction of the dams, was calculated from surveys of longitudinal profiles and valley cross sections and by mapping on aerial photographs. The accuracy of the results of these calculations is reduced by the lack of precise data on the original profile of the stream bed and shape of the channel, though measurements of the channel and valley down stream from the dams probably provide a reasonable representation of the original reservoir contours above the dam. Moreover, by extending the longitudinal profile from some point down stream from the dam to a point where the extension intersects the channel floor above the reservoir deposits, the original profile can be closely approximated. Using these data on valley shape and slope, the volume of sediment was calculated.

Results of Studies

Polacca Dam 1 was constructed on the main channel of Polacca Wash in 1952 about 14 miles up stream from the village of Polacca and 22 miles up stream from the mouth of Wepo Wash. The arroyo has been filled to the level of the original valley floor for a distance of 2,300 ft up stream from the structure, and sediment deposits extend up stream for 7,300 ft (see Fig. 6). The volume of sediment in the reservoir and on the valley floor is 1,980 acre-ft, and the annual rate of deposition has been 1.4 acre-ft per square mile. The drainage basin above Polacca Dam 1 has few if any diversion or storage structures. Other pertinent data regarding the structure are summarized in Table 2.

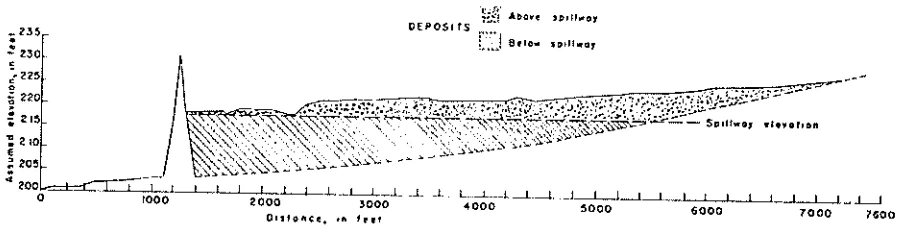

Fig. 6 — Distribution of sediment deposits up stream from Polacca Dam 1.

Polacca Dam 2 was constructed on Polacca Wash in 1945 and is about four miles up stream from the mouth of Wepo Wash. The crest of the dam is 47 ft above the bed of the arroyo, which is about 40 ft deep in this reach. The arroyo has been almost completely filled with sediment for a distance of 4,000 ft up stream from the dam. Since 1952, storage in Polacca Dam 1 has undoubtedly reduced the amount of sediment delivered to the reservoir and on the valley floor above Dam 2.

Polacca Dam 3 was constructed in 1946 about a quarter of a mile below the mouth of Wepo Wash. The crest of the dam is 48 ft above the floor of the arroyo. Deposition has completely filled the arroyo for a distance of about 9,000 ft up stream from the dam.

TABLE 2 — Summary of characteristics of deposits above dams

Name of dam[a]	*Drainage area (sq. miles)*	*Maximum thickness of deposit (feet)*	*Volume of sediment deposited (acre-ft)*	*Time period since construction (years)*	*Average slope of original stream bed (ft/ft)*	*Average slope on surface of deposit (ft/ft)*	*Height of deposition above spillway elevation (feet)*	*Per cent of deposit above spillway*
Polacca Dam 1	338	15	1,980[b]	5	0.0040	0.0017	12.5	5
Polacca Dam 2	511	38	3,290[b]	12	0.0041	0.0016	13	9
Polacca Dam 3	757	38	1,300[b]	11	0.0058	0.0010	15	10
Wepo Dam	197	15	880[b]	13	0.0030	[c]	[c]	—
Sheep Creek Barrier Dam	31	18	165	5	0.0167	0.0112[d]	21.5	47

[a] See Fig. 1 for location.
[b] Includes sediment deposits on valley floor caused by water-spreading.
[c] Cannot be determined because of recent construction within the original reservoir area.
[d] Average for last survey. Slope is still changing.

Reservoir and valley-floor deposits amount to 1,300 acre-ft. The valley floor has been raised three feet by over-bank deposition, and deposits extend 15 ft above the elevation of the spillway. Establishment of riparian vegetation on the deposits up stream from the dam has undoubtedly influenced deposition by desilting the flow through the reservoir.

The Wepo Dam was constructed in 1944 on Wepo Wash about $1\frac{1}{4}$ miles above the mouth. The crest of the dam is 25 ft above the arroyo floor, and the dam has caused sediment deposition for a distance of about 5,500 ft up stream. The total volume of sediment deposited in the channel and on the valley floor above Wepo Dam is about 880 acre-ft, and the average annual rate has been 0.1 acre-ft per square mile for the period 1944–57.

EFFECT OF DAMS ON CHANNEL SLOPE

Longitudinal profiles were surveyed above each dam on Polacca Wash and on Sheep Creek. Results of these profile surveys and comparisons with original channel profiles are shown in Table 2. In each case the profile of the original channel was much steeper than the profile of the present channel on the deposited material. Above Polacca Dam 1 the average slope (feet per foot) of the original stream bed was 0.0040 and the average slope of deposition is 0.0017, or 42 per cent of the original slope. Similarly, for Dams 2 and 3 the average slopes of deposition are 39 per cent and 17 per cent of the original slopes. On Sheep Creek the average original slope was 0.0167 and the average slope of deposition after the survey in 1964 was 0.0112, or 67 per cent of the original slope. These results are comparable with the findings of Kaetz and Rich (1939), who surveyed profiles behind several barriers and dams in Arizona, New Mexico, and Utah. They conclude that the slope of deposition ranges from 30 to 60 per cent of the average original stream-bed gradient. Moreover, they state that the steeper depositional slopes occur on coarse material. The longitudinal profile on the Sheep Creek deposits is the steepest of the four examples cited here, and the stream bed is composed of coarse material. The stream-bed material in the Polacca Wash area is chiefly fine sand and silt.

In studies of reservoir deposits elsewhere, similar relationships were found. In the Mexican Springs experimental area near Gallup, New Mexico, several small dams were constructed in 1936 to evaluate the effects of water-spreading. Topography of the arroyos and valley floor was mapped in detail at that time by the Soil Conservation Service. The slope of the arroyo bed ranged from 0.0071 to 0.0105 and averaged 0.0075. In 1949, when the arroyos above the dams had been completely aggraded, the Geological

Survey measured the slopes of the sediment deposits (H. V. Peterson and C. T. Snyder, pers. comm. 1949); they ranged from 0.0025 to 0.0044 and averaged 0.0037, or 49 per cent of the original slope.

The Bureau of Reclamation measured the amount and location of sediment behind Zion Dam on the Little Colorado River near St Johns, Arizona, in 1952 and 1953. The slope of the original channel from the dam up stream to the elevation of the spillway, as determined by borings, averaged 0.0012. The gradient of the depositional surface averaged 0.0006, or 50 per cent of that in the original channel.

RELATION BETWEEN CHANNEL SLOPE AND SIZE OF BED MATERIAL

Kaetz and Rich (1939) conclude that no significant correlation exists between the type of material deposited and the grade of deposition; the streams depositing gravelly material do, however, have steeper gradients. The relation between channel slope and size of bed material for areas investigated in this report is presented in Fig. 7. The parameter d_{80}, or the size of sieve opening through which 80 per cent of the material would pass, was used for comparison with slope. This was used under the assumption that the coarser particles probably affect the slope more than the finer particles that are generally carried in suspension. The use of d_{80} is entirely arbitrary and is meant to give emphasis to the coarse fraction of the transported load. There is some suggestion that slope is a function of d_{80}, but the range of sizes of material is too small to be conclusive.

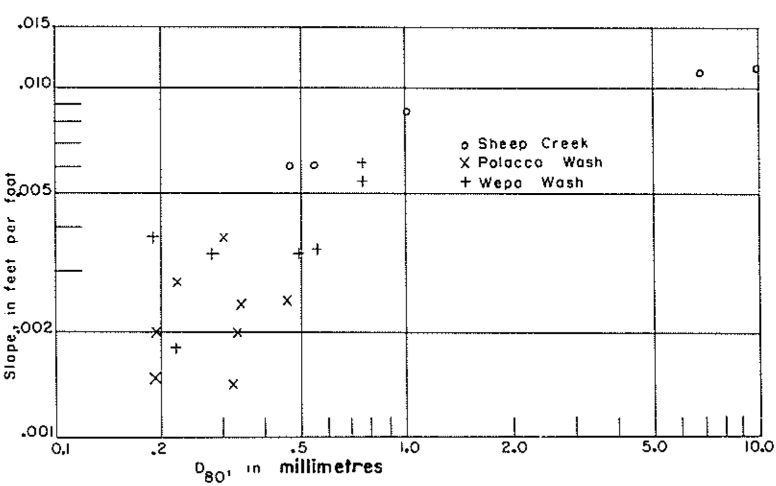

Fig. 7 — Relation of size of deposited material to slope of deposition up stream from low dams.

DEPOSITION BEHIND LOW, PERMEABLE BARRIERS

In some areas a different type of structure has been constructed for the purpose of inducing aggradation up stream. These are barriers consisting of wooden fence posts and woven-wire fencing material, and are set in the ground so that they stand about one foot above the original land surface (see Fig. 8). They were placed up stream from small reservoirs used for stock water, and were intended to start sediment deposition and prolong the useful life of the reservoir. Data on sediment deposits and channel slopes at two such structures were gathered for comparison with impermeable dams.

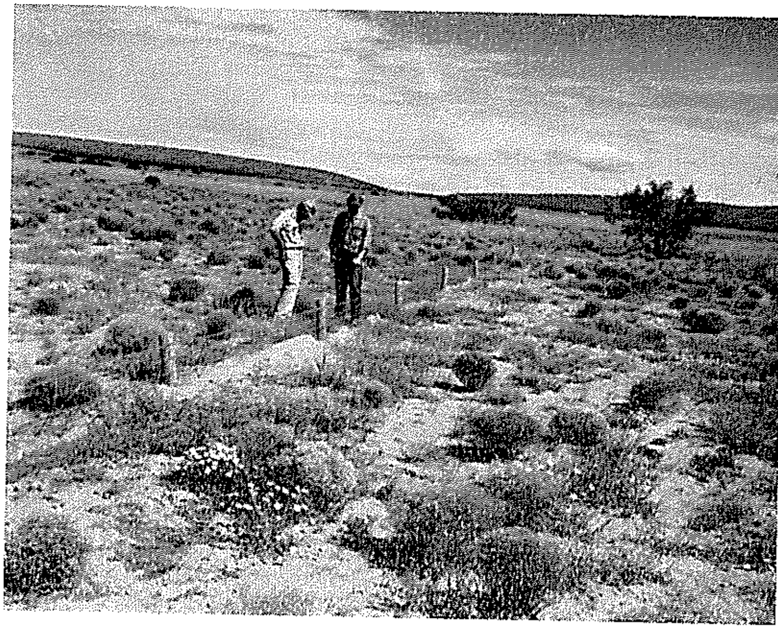

Fig. 8 — View of typical permeable barrier in New Mexico constructed from woven wire.

The two areas that were examined are in the upper Rio Puerco Basin of north-western New Mexico. One area is in the Cornfield Wash Basin in north-western Sandoval County and the other is near Tinian Trading Post in eastern McKinley County (see Fig. 1). The sediment transported by the streams in both areas is mostly very fine sand and silt. The characteristics of the original land surface and the slope of deposition are summarized in Table 3. In all cases except Barrier 1 in the Tinian area, the average slope of deposition behind these permeable barriers is steeper than the original slope of the land surface (see Fig. 9). This is contrary to the kind of deposition that has been observed above non-permeable earthfill dams, and may be attributed — at least in part — to the lack of ponding behind the barriers. The deposition below Cornfield Wash Barrier 1 is due partly to backwater caused by the presence of a reservoir immediately down stream. Ponding behind these barriers during run-off probably does not last long enough for fine materials to settle out near the structure, but enough backwater is created to deposit coarser materials at a point up stream. These barriers have been effective in inducing aggradation where they have been constructed strongly enough to withstand high flows and the weight of accumulating debris carried by floodwaters. They have not, however, been observed for sufficiently long to permit a forecast of what will happen to the deposits if the slope of deposition becomes greatly steepened.

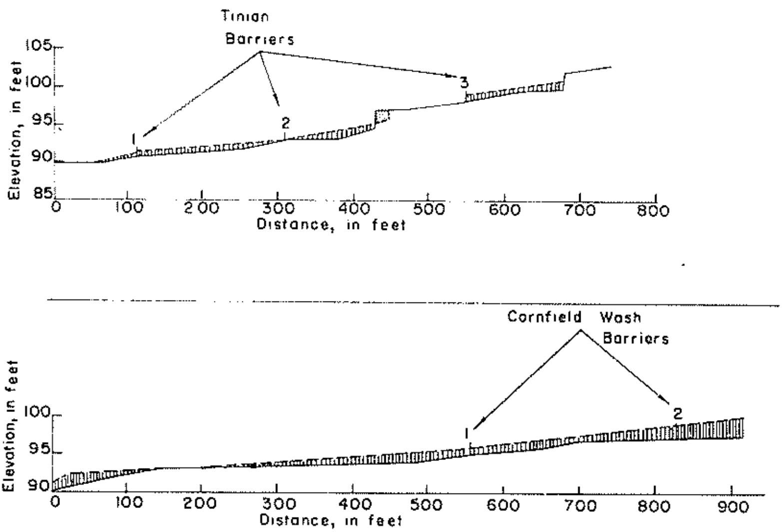

Fig. 9 — Depositional patterns up stream from low, permeable barriers in New Mexico.

TABLE 3 — Summary of depositional characteristics above low, permeable barriers

Name	*Drainage area (sq. miles)*	*Height of barrier (feet)*	*Average slope of original land surface (ft/ft)*	*Time since construction (years)*	*Average slope of deposition (ft/ft)*
Cornfield Wash					
Barrier 1	1.2	1.5	0.0086	8	0.0124
Barrier 2	1.2	2.0	0.0022	8	0.0079
Tinian area					
Barrier 1	0.5	1.0	0.0089	7	0.0066
Barrier 2	0.4	1.2	0.0158	7	0.0185
Barrier 3	0.4	1.5	0.0100	7	0.0195

CONCLUSIONS

It is well known that the introduction of an artificial base level into a stream channel alters the flow characteristics sufficiently to allow deposition of a certain part of sediment load. A large change in base level causes immediate deposition of most of the transported sediment. Continued filling of the channel up stream, however, appears to depend to a large extent on the amount of coarse material being moved as bedload. Observations of gullied channels over a large part of the south-western United States indicate that under existing conditions these channels are generally able to transport successfully most of the detrital material introduced into the streams at up-stream points. Run-off from upland areas usually carries sediment of a smaller average size than the bed material of the gully. In some streams — such as Sheep Creek — coarse material is made available by lateral cutting of the channel banks, but the rate of removal of such material is relatively slow. In Polacca Wash the sediment available for transport is generally fine and the slope of deposition is much flatter. At present 47 per cent of the deposit above Sheep Creek Dam lies above spillway elevation, and the depositional process is continuing. In Polacca Wash from five to ten per cent of the deposited material is above spillway level, with the largest percentage at Polacca Dam 3. Although the deposits behind all the dams in Polacca Wash are equally fine-grained, riparian vegetation behind Dam 3 has undoubtedly aided in the deposition of sediment above spillway level.

Permeable barriers induce deposition by altering base level and reducing velocity, but the depositional patterns above them are not the same as those above dams. Permeable barriers may not respond to sediment-laden water in the same way as earth dams because of the lack of ponding or the presence of a reservoir during run-off periods. The slope of the deposits above barriers is steeper than the original slope in all but one case.

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