Journal of Hydrology (N.Z.) Vol. 26, No. 2, 1987

SEDIMENT DEPOSITION BEHIND SHEEP CREEK BARRIER DAM, SOUTHERN UTAH

Bruce P. Van Haveren† William L. Jackson† Gregg C. Lusby*

†*Bureau of Land Management*
Building 50, Denver Federal Centre
P.O. Box 25047
Denver, Colorado 80225-0047

**U.S. Geological Survey, Retired*
Lakewood, Colorado

ABSTRACT

Reservoir and channel cross-sections were surveyed periodically over a 25-year period to determine sediment deposition and channel aggradation behind the Sheep Creek Barrier Dam in southern Utah. The reservoir below the spillway elevation was almost completely filled with sediment in 1961, one year following dam completion. Subsequent surveys indicated continuing deposition above the spillway elevation. Annual deposition for the period 1960-1984 averaged 18.2 x 10^3m^3 per year, while deposition for the most recent measurement period, 1969-1984, averaged 12.8 x 10^3m^3 per year. Channel deposition by April, 1984, extended 1424m upstream from the dam to an elevation of 18.0m above the spillway crest. An active channel has formed in the sediment deposit. Bankfull capacity of this channel is low compared to commonly experienced flows, but should increase as deposition proceeds. The ratio of the deposition channel slope to the original channel slope is presently 0.83.

INTRODUCTION

As a stream enters a reservoir, the flow depth increases and the velocity decreases, causing a loss in the stream's transporting capacity and deposition of a portion of the waterborne sediments. Deposition continues upstream in the channel above the reservoir to some upper limit which depends on several hydrologic and geomorphic factors.

In 1984 the sediment deposit behind the Sheep Creek Barrier Dam in southern Utah was resurveyed to determine the nature and extent of sediment deposition and channel evolution over the 25-year life of the structure. Five previous surveys of the sediment deposit were conducted between 1961 and 1964 (Lusby and Hadley, 1967). Additional surveys were conducted from 1967-1969. The storage pond behind the dam was completely filled with sediment by 1961, one year after its construction. Sediment deposition upstream above the emergency spillway elevation has continued ever since.

Site Description

Sheep Creek flows into the Paria River, one of the Colorado River's highest sediment-producing tributaries (Fig. 1). As part of a larger watershed rehabil-

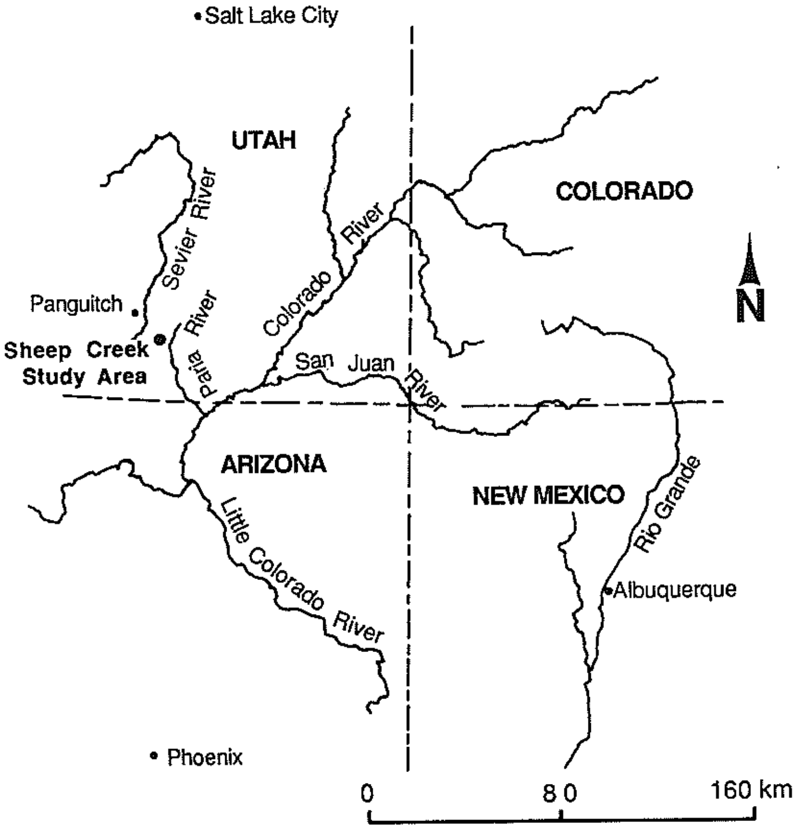

FIG. 1. Location of Sheep Creek study area.

itation project in the Sheep Creek drainage, the Bureau of Reclamation constructed a large barrier dam in the main channel of Sheep Creek. The purpose of this structure was to control sediment from 80.5 km^2 of drainage area and to provide a stable base-level control for the Sheep Creek channel.

The dam was completed in May, 1960 and created a storage pond with an initial capacity of 108.4 x $10^3 m^3$ below the spillway sill elevation of 1,789 m. The principal spillway consisted of a 610-mm diameter perforated, corrugated metal standpipe, ground-water collector drain, and a 610-mm diameter, free-flow, reinforced-concrete pipe conduit through the dam. The emergency spillway consisted of an entrance channel, a 22.9 m-wide reinforced ogee-section concrete crest and chute section, and an outlet channel. Both outlet works were uncontrolled. The concrete spillway has a maximum design capacity of 193 $m^3 s^{-1}$ ($2.4 m^3 s^{-1} km^{-2}$).

Sheep Creek originates in Bryce Canyon National Park near the south boundary at about 2,500-m altitude. About 77 percent of the Sheep Creek watershed has developed on sandstones, both fine and coarse-grained. Undifferentiated shale and sandstone make up about 14 percent of the basin. The remaining 9 percent is composed of Wasatch Formation, a limestone, and the Curtis Formation, a gypsum and limestone complex. The Straight Cliffs and Wahweap Sandstones comprise 26 percent of the outcrop length along the main Sheep Creek channel and 27 percent of the drainage area. The Winsor Formation, a fine-grained sandstone, covers 48 percent of the channel length and 38 percent of the drainage area.

Most of the larger channels in the Sheep Creek watershed are graded to their valley floors and are still actively eroding. The lower channels are deep, narrow, and cut into bedrock. Very little opportunity is afforded for deposition of sediment once runoff enters the main channels.

Precipitation in the Sheep Creek watershed varies from 363 mm in the lower basin to 432 mm in the headwaters. August is the wettest month. Summer storms are usually short and intense. Storm totals may be high when convective events combine with Gulf of California moisture.

Vegetation in the Sheep Creek watershed is primarily pinyon-juniper type with open sagebrush flats in the middle altitudes. Riparian vegetation is scarce due to the lack of perennial streamflow in upper Sheep Creek.

Background

The Sheep Creek Barrier Dam was completed in May, 1960. The U.S. Geological Survey began monitoring sediment deposition and runoff at that time (Lusby and Hadley, 1967). The reservoir capacity below the spillway elevation was 108.4 x $10^3 m^3$. By November, 1961, 133.2 x $10^3 m^3$ of sediment were deposited in the reservoir. This increased to 203.8 x $10^3 m^3$ by late 1964 (Lusby and Hadley, 1967). At that time, the upstream end of the sediment deposit was 6.6 m above spillway elevation. The average slope of the deposit was 0.0112 $m.m^{-1}$ compared to 0.0167 $m.m^{-1}$ for the original stream bed, resulting in a deposition-slope to original-slope ratio of 0.67.

Hadley (1963) investigated channel structures in Arizona and concluded that a base level rise, such as that produced by a dam, reduced the channel slope and caused aggradation upstream to a higher elevation than that of the channel control. He inferred from field observations that the extent of deposition was determined by valley width, original channel slope, particle size of depositing material, and riparian vegetation. Leopold et al. (1964) theorized that deposition from a rising base level would proceed only up to the level at which the backwater transition curve intersects the original stream bed profile. However, they noted that gravel streams may behave differently, depositing sediment well above that level. Maddock (1966) concluded that the stream gradients above dams are usually less than the original gradient because the hydraulic roughness of an aggrading channel is less than that of the natural channel.

Relationships between the slope of sediment deposits above channel structures and that of the original channel thalweg (slope ratio) have been well-documented (Leopold et al., 1964; Heede, 1976). From field evaluations of gully control structures, Heede (1976) found that the ratio of deposition to original bed slope varied between 0.5 and 0.7. He applied a ratio of 0.7 to an extensive watershed rehabilitation project in western Colorado. Hadley (1963) presented data on slope ratios for diversion dams in Polacca Wash, Arizona. The ratios of deposition to original bed slope varied from 0.17 to 0.53. The average slope ratio calculated from data for small reservoirs near Gallup, New Mexico (Hadley,

1963) was 0.49. Ferrell and Barr (1963) used a slope ratio of 0.7 to design an extensive check dam system in southern California. Amidon (1947) found an average slope ratio of 0.66 above 67 check dams where original slopes were less than 14 percent. He also noted that slope ratio decreased as the original slope increased. Woolhiser et. al. (1965) investigated channel gradients above 44 gully-control structures and concluded that the original slope (Sp), width of channel at the structure (b) and height of the inlet above the original channel thalweg (H) were significantly related to the deposition slope (Sd) by the equation:

$$Sd=1.96\ Sp^{1.23}\ (0.591 + 0.00135b - 0.0527H)^{1.34} \quad (1)$$

Interestingly, b and H explained 40 percent of the variability in the slope ratio.

Vegetation growing on reservoir sediment deposits may influence the slope of the aggrading channel (Leopold et al., 1964). A dense and vigorous vegetation stand may trap large quantities of fine-grained sediment and result in an increase in the channel gradient (Maddock, 1966).

Drainage area may also have some bearing on the final slope of the sediment deposit. Data from Hadley (1963) suggest that slopes of aggrading channels above dams decrease with increasing drainage area and that the ratio of deposition slope to original bed slope also decreases with increasing drainage area.

Based on his Arizona data, Hadley (1963) also concluded that an increase in bed material size may be accompanied by an increase in channel slope. This relationship became more credible when the Sheep Creek data were included in the analysis (Lusby and Hadley, 1967).

Reservoir sediments have been found to accumulate several feet above the spillway elevation. At Polacca Wash, the height of deposition above the spillway ranged from 3.7 to 4.6m, with the volume of that being 5 to 10 percent of the total (Lusby and Hadley, 1967). The Polacca Wash surveys were taken approximately 10 years following dam construction. At the end of 1964, four years following completion of the Sheep Creek Barrier Dam, the amount of sediment deposited above the spillway was 47 percent of the total, and deposition had reached 6.6m above the spillway elevation (Lusby and Hadley, 1967). Although most data suggest that deposition slopes are generally less than original slopes, no studies have been conducted over a sufficiently long period to determine the final deposition characteristics behind a stream barrier. Leopold et al. (1964) concluded there was no evidence to suggest that a rising base level would affect deposition throughout a stream system.

Most deposition-slope prediction models are empirical. However, Mussetter (1983) used basic hydraulic and sediment transport theory to predict equilibrium deposition slopes. In that sudy it was assumed that the equilibrium slope would occur under a condition of equilibrium sediment transport; that is, upon completion of the deposition process, sediment transport into and out of the deposition reach would be equal and the same as before check dam construction. Thus, any difference between the deposition slope and the original slope would result from a need to compensate for differences in the other physical factors which influence sediment transport rates — specifically, differences in hydraulic geometry or bed material sizes between the deposition channel and the original channel. Therefore, the evolution of the deposition channel and deposition slope are totally interrelated processes.

Schumm (1971) developed a proportional relationship between hydraulic geometry variables and sediment load, Qs:

$$Qs \approx \frac{W,L,S}{D,P} \tag{2}$$

where S is channel slope, W is channel width, D is average channel depth, L is meander wavelength and P is sinuosity. Similarly, Lane (1955) developed a proportionality stating that sediment load is inversely proportional to the mean sediment size, d_{50}. If sediment transport rates are proportional to channel width and slope, and inversely proportional to channel depth and sediment size, application of Mussetter's (1983) model would result in a slope ratio less than unity for situations where the equilibrium channel has a larger width-to-depth ratio, lower bankfull capacity, or is composed of a finer mean sediment size than the original channel. Conversely, a narrower, deeper channel, a larger-capacity channel, or a channel with coarser bed sediments would theoretically correspond to a slope ratio greater than unity (a situation more likely to occur upon removal, rather than construction, of a check dam).

The evolution of a channel in a barrier dam deposit can be descriptively deduced from the Schumm (1971) and Lane (1955) proportionalities. In general, channels early in the deposition process would be severely undersized and have large width-to-depth ratios compared to the original channel. In newly formed deltas, multiple channels and frequent realignments would be expected (Chang et al., 1967). Bed sediment sizes would be comparatively fine. As deposition progressed and deposition slopes increased, it would be expected that channel capacities would increase, width-to-depth ratios would decrease, and bed sediment sizes would increase. This description of channel evolution is generally supported by experimental data (Chang et al., 1967) and observations of sediment sizes in relation to deposition slope (Maddock 1966: Hadley, 1963; Lusby and Hadley, 1967). The fact remains, however, that hydraulic geometry is not a deterministic characteristic (Maddock, 1966).

METHODS

Sediment deposit volumes were calculated from standard rod and level surveys of 10 permanent cross-sections upstream from the barrier dam. All surveys were keyed to a permanent benchmark on the emergency spillway. Longitudinal profiles of the channel thalweg were also surveyed, as were selected channel cross-sections. Deposited materials were sampled and analyzed for particle-size distribution. The most recent surveys were conducted in April, 1984. Previous surveys were conducted in May, 1960; September, 1961; November, 1962; November, 1963; November, 1964; October, 1967; November, 1968; and November, 1969. In the early years of the study, inflow and outflow were derived from a continuous water-level recorder installed in the reservoir (Lusby and Hadley, 1967). No runoff data were obtained after 1964. Bankfull discharge, defined as the 2.0-year return period peak flow, was determined from regional relationships (Thomas and Lindskov, 1983). Channel capacities were computed by applying the Manning equation to measured channel cross-sections.

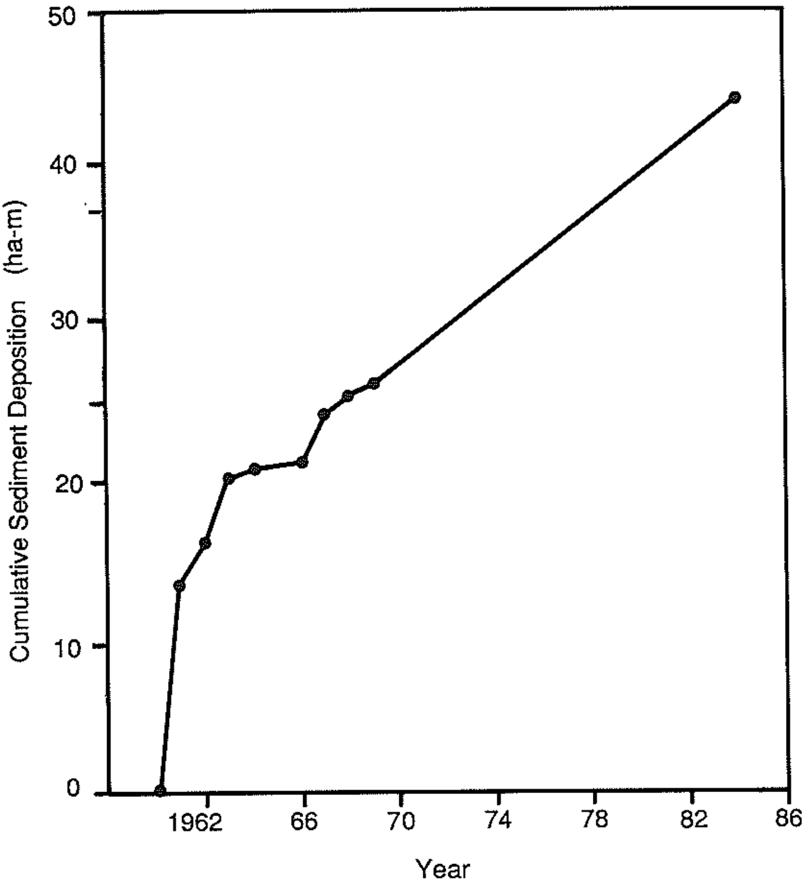

FIG. 2. Cumulative sediment deposition behind Sheep Creek Barrier Dam.

RESULTS AND DISCUSSION

Sediment Deposition

A summary of the sediment deposition characteristics is given in Table 1, and cumulative sediment deposition is shown as a function of time in Figure 2. Aside from annual variations in sediment accumulation, the rate of aggradation appears to be fairly constant with time. Annual deposition for the period 1960-84 averaged 18.2 x 10^3m^3. By 1961 the reservoir below the spillway elevation had nearly completely filled with sediment. Figure 3 shows the percent deposition above the spillway as a function of time. We believe the deposition above the spillway elevation will eventually exceed that stored in the reservoir below the spillway elevation. For this to happen, deposition must continue to occur in the channel above the reservoir. In April, 1984, the upper limit of deposition was 1424m (longitudinal channel distance) from and 18.0m (vertical) above

TABLE 1. Summary of Sediment Deposit Characteristics, Sheep Creek Barrier Dam.

Year	Volume of Sediment Deposited ($m^3 \times 10^3$)	Avg. Slope of Original Stream Bed	Avg. Slope of Deposit Surface	Avg. Height of Deposition above Spillway Elevation (m)	Percent of Deposit above Spillway Elevation	Ratio of Deposition Slope to Original Slope
1960	—0—	0.0167	—	—	—0—	—
1961	133.2	—	0.0044	3.66	18	0.26
1962	159.1	—	0.0086	5.03	32	0.51
1963	198.5	—	0.0095	6.56	45	0.57
1964	203.4	—	0.0112	6.56	47	0.67
1967	239.2	—	—	—	55	—
1968	250.3	—	0.0125	8.69	57	0.75
1969	258.9	—	0.0126	8.69	58	0.75
1984	438.9	—	0.0138	18.05	75	0.83

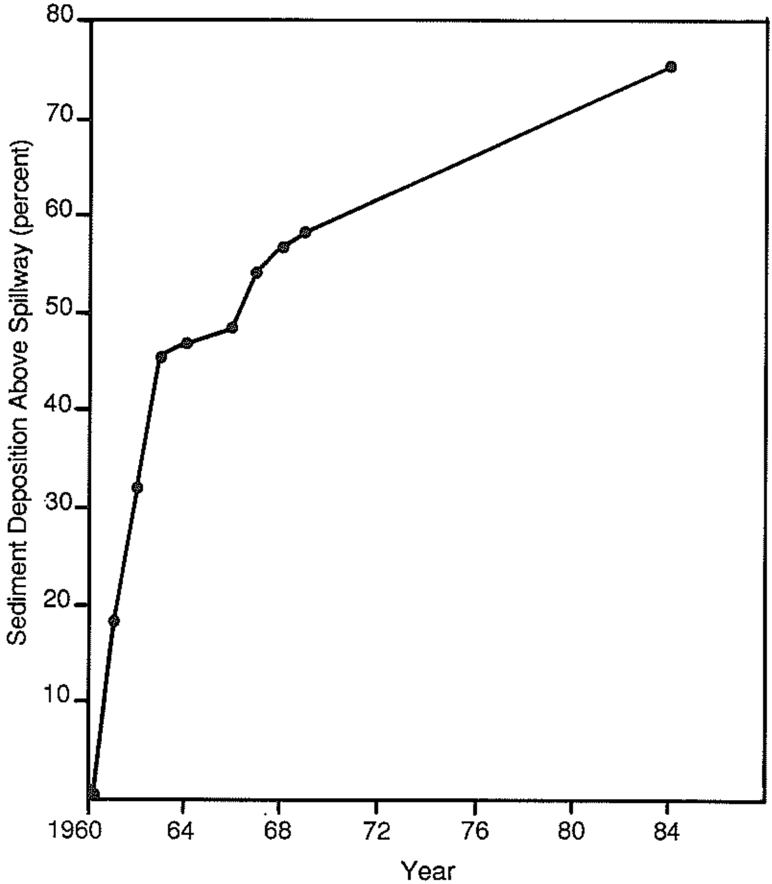

FIG. 3. Sediment deposited above the Sheep Creek Barrier Dam spillway elevation as a percentage of total deposition behind the dam.

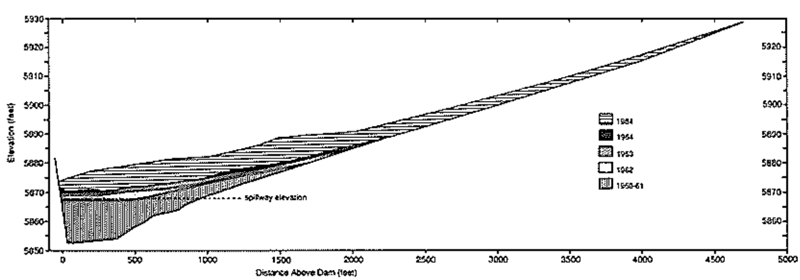

FIG. 4. Successive profiles of sediment deposition behind Sheep Creek Barrier Dam.

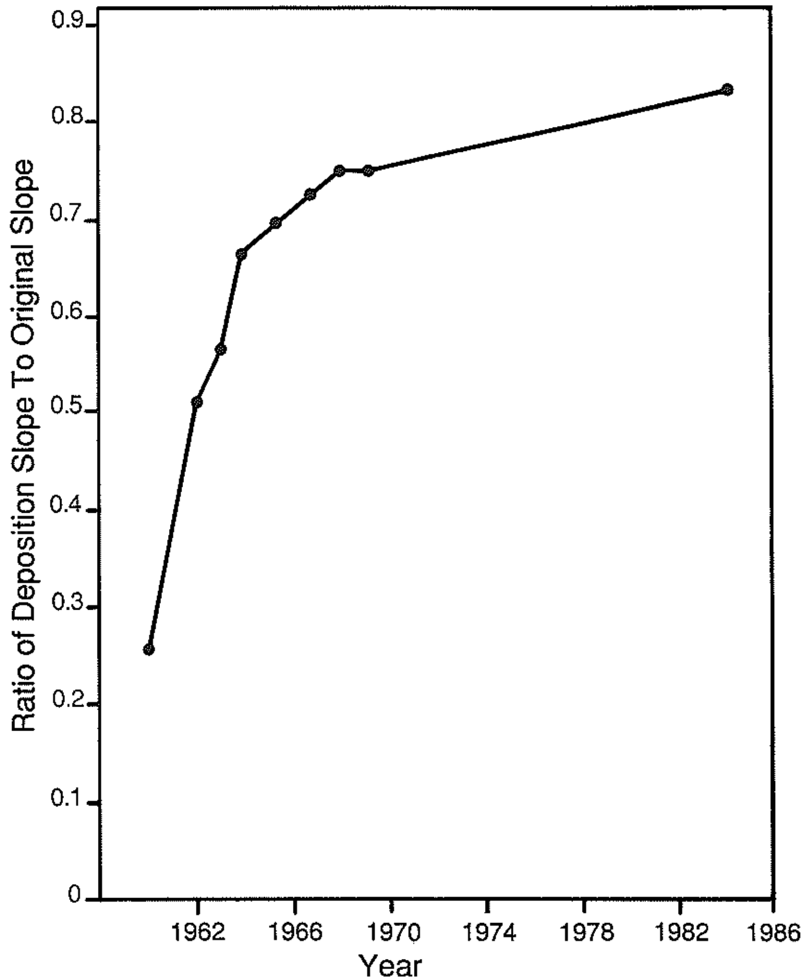

FIG. 5. Ratio of deposition slope to original channel slope for Sheep Creek Barrier Dam.

the spillway. This sediment wedge will continue to build and steepen until an equilibrium slope is reached or until the upstream sediment supply runs out.

Successive stream bed profiles of Sheep Creek upstream from the dam are plotted in Figure 4. The rate of steepening of the channel is a function of sediment supply, especially those particle sizes which are required to maintain the new channel slope. Figure 5 shows the ratio of the deposition slope to the original channel slope increasing with time. A value of 0.83 was determined from the 1984 survey. This value is in agreement with others measured in western U.S. locations. Steeper deposition slopes, and thus larger ratios, are usually

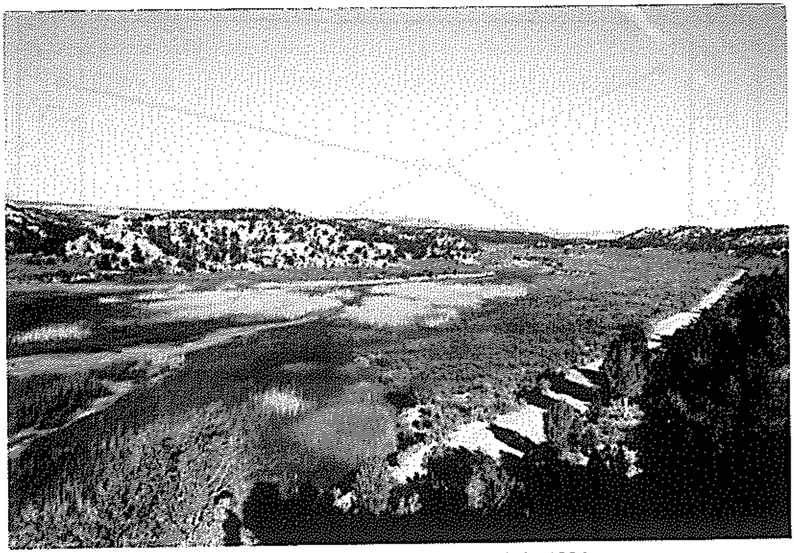

FIG. 6. The Sheep Creek Barrier Dam sediment deposit in 1984.

found in channels carrying coarse sediment. Channels with finer sediment sizes are associated with flatter deposition slopes and smaller ratios (Heede, 1976).

Channel Formation

A rectangular channel with an average bankfull capacity of $2.63m^3s^{-1}$ ($s=1.33m^3s^{-1}$) has formed in the sediment wedge between the emergency spillway and the natural channel above the reservoirs. There is no significant (α=.05) trend in bankfull capacity with distance above the spillway. The two-year return period flow at the barrier dam was estimated using regional relationships in Thomas and Lindskov (1983) and is approximately $9.63m^3\ s^{-1}$. Generally, the two-year return period flow approximates bankfull capacity in alluvial channels (Dunne and Leopold, 1978). Therefore we can conclude that the present channel is still undersized in relation to commonly experienced flows. Observations of channel behaviour over the past several years indicate that the channel undergoes frequent realignments within the barrier dam sediment deposit.

Bankfull channel widths average 8.6 m (s=1.3 m) and increase slightly with distance above the spillway (Table 2). Channel widths are not correlated with local channel slope.

In 1964, most of the material deposited in the reservoir below the high water line was sand-sized. Above the high water line, deposited materials became progressively coarser, and began to approach channel material sizes before dam construction (Lusby and Hadley, 1967). In 1984, deposited sediments averaged 88 percent sand, 8 percent silts, and 4 percent clays by weight. Channel bed sediments were considerably coarser, with an average of 15% by weight of bed sediments being greater than 6 mm in diameter. The median bed sediment size (d_{50}) was 3 mm. There were no trends in sediment size with distance above the dam.

TABLE 2. Sheep Creek Channel Characteristics.

Cross-Section	Bankfull Width (m)	Slope	Bankfull Discharge (m^3s^{-1})	Distance Above Dam (m)
1	7.3	0.013	1.6	144
2	7.3	0.008	4.0	245
3	8.8	0.006	1.0	324
4	10.4	0.010	3.9	437
5	9.1	0.011	2.5	543

CONCLUSION

Lusby and Hadley (1967) concluded that the sediment deposit and new stream channel above the Sheep Creek Barrier Dam would continue to aggrade until the pre-dam channel gradient was attained, provided that coarse sediment would continue to be supplied from lateral bank cutting upstream. This prediction is being realized. In 1984 the gradient of the sediment had reached 83 percent of the original channel gradient. The deposition process is continuing. A total of 438.9 x 10^3m^3 of sediment, 75 percent of which was above the spillway elevation, was deposited by April, 1984.

A new channel has formed in the reservoir sediment deposit, but its capacity is small compared to commonly experienced (i.e., 2.0-year return period) peak flows. Thus flooding occurs on the sediment deposit for all significant runoff events. Flooding serves to reduce runoff peaks and stream energy, allowing sediments to deposit in the channel and on the floodplain. Deposition has been aided by a dense stand of vegetation which has invaded the sediment deposit (Figure 6). While ongoing sediment deposition now probably represents an insignificant proportion of the total sediment load delivered to the structure from up-stream, we believe deposition will continue. As a result, deposition slopes will increase further, channel capacities will increase, and bankfull width-to-depth ratios will decrease. We cannot predict the final slope ratio or channel characteristics, but the availability of coarse bed sediments may result in final slope ratios near the upper end of those reported in the literature, possibly greater than 85 percent.

ACKNOWLEDGEMENT

We wish to acknowledge the assistance and co-operation of Mr Ron Hooper, Hydrologist, U.S. Bureau of Land Management, Cedar City, Utah.

LITERATURE CITED

Amidon, R. E. 1947. Discussion of "Model Study of Brown Canyon Debris Barriers" by K. J. Bermel and R. L. Sunks. *Transactions, American Society of Civil Engineers 112*:1015.

Chang, H., D. B. Simons, and R. H. Brooks. 1967. The Effect of Water Detention

Structures on River and Delta Morphology. *Symposium on River Morphology,* General Assembly of Bern, Switzerland, Sept.-Oct. 1967, International Union of Geology and Geophysics: 438-448.

Dunne, T., and L. B. Leopold. 1978. *Water in Environmental Planning.* W. H. Freeman and Co., San Francisco, Calif. 818p.

Ferrell, W. R. and W. R. Barr. 1963. Criteria and methods for use of check dams in stabilizing channel banks and beds. *Proceedings,* 1963 Federal Interagency Sedimentation Conference. U.S. Department of Agriculture Miscellaneous Publication 970.

Hadley, R. F. 1963. Characteristics of sediment deposits above channel structures in Polacca Wash, Arizona. *Proceedings,* 1963 Federal Interagency Sedimentation Conference. U.S. Department of Agriculture, Miscellaneous Publication 970:806-810.

Heede, B. H. 1976. Gully development and control: The status of our knowledge. *Research Paper RM-169,* USDA Forest Service 40p.

Lane, E. W. 1955. The importance of fluvial morphology in hydraulic engineering. *American Society of Civil Engineers, Proceedings Hydraulics Division 81:*745-1 to 745-17.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. *Fluvial Processes in Geomorphology.* W. H. Freeman and Co. 522p.

Lusby, G. C. and R. F. Hadley. 1967. Deposition behind low dams and barriers in the southwestern United States. *Journal of Hydrology (N.Z.) 6(2):*89-105.

Mussetter, R. A. 1983. Equilibrium slopes above channel control structures. *In: Proceedings D.B. Simons Symposium on Erosion and Sedimentation.* R. M. Li and P. F. Lagasse, eds., Simons and Li Associates. Fort Collins, Colo.: 2.30-2.52.

Maddock, T., Jr. 1966. Behaviour of channels upstream from reservoirs. *International Association of Scientific Hydrology, Publication 71:* 812-823.

Schumm, S. A. 1971. Fluvial geomorphology: channel adjustment and river metamorphosis, *In: River Mechanics.* H. W. Shen, ed., Fort Collins, Colo. 1:5-1 to 5-22.

Thomas, R. E. and K. L. Lindskov. 1983. Methods for estimating peak discharge and flood boundaries of streams in Utah. *Water Resources Investigation Report 83-4129,* U.S. Geological Survey 77p.

Woolhiser, D. A. and A. T. Lenz. 1965. Channel gradients above gully-control structures. *American Society Civil Engineers Journal of the Hydraulics Division 4333 (HY3):* 165-187.