

SECTION 14

IMPACTS OF WATER WITHDRAWAL

	<i>Page</i>
GEOMORPHIC EFFECTS OF THE LAWN LAKE DAM FAILURE --	
Wayne J. Graham and Curtis J. Orvis.....	14-1
GREEN RIVER BELOW FLAMING GORGE DAM, 1952-1987 --	
Joseph K. Lyons.....	14-9
PREDICTING CHANNEL SHAPE OF THE PLATTE RIVER --	
Timothy J. Randle and Duane Woodward.....	14-17

GEOMORPHIC EFFECTS OF THE LAWN LAKE DAM FAILURE

By Curtis J. Orvis and Wayne J. Graham, Hydraulic Engineers, U.S. Bureau of Reclamation, Denver, Colorado

ABSTRACT

Lawn Lake Dam was located in a high, mountainous part of the Rocky Mountain National Park, Colorado. The 26-foot high dam failed on July 15, 1982 releasing 674 acre-feet of water in less than one hour. The incident has furnished the opportunity to observe and estimate the sediment transport and deposition associated with dam failures. The Roaring Fork River channel downstream from Lawn Lake Dam was severely incised from 5 feet to as much as 50 feet for a distance of about 4 miles. This scour combined with the resulting formation of the 42-acre Lawn Lake Alluvial Fan provides the greatest visual evidence of the geomorphic changes brought about by the dam-break flood. The eroded channel and alluvial fan can be seen from miles away. The Fall River, a meandering trout stream in Horseshoe Park, is evolving with the high sediment influx from the alluvial fan. The increased sediment load in the Fall River between Horseshoe Park and Lake Estes reduces channel capacity, poses additional problems at water supply intakes, and decreases storage capacity as sediment deposits in Lake Estes.

This paper evaluates the immediate and longer term geomorphic changes brought about by this unprecedented flood. The immediate event scour and deposition caused by the flood are discussed. The longer term influence on changes in sediment movement toward Reclamation's Lake Estes is also addressed.

INTRODUCTION

Description of the Study Site and Problem

Lawn Lake is located on the southeast side of the Mummy Mountain Range in the Rocky Mountain National Park. The natural lake was enlarged by a man-made structure in the early 1900's. Lawn Lake is situated at tree line at an elevation of about 11,000 feet MSL. The Roaring River descends from the dam to meet the Fall River at an elevation of about 8550 feet in Horseshoe Park. The Fall River flows through Cascade Lake at the east end of Horseshoe Park and becomes a tributary of the Big Thompson River which enters Lake Estes upstream from Olympus Dam. Figure 1 shows the locations of major features along the river channels from Lawn Lake to Lake Estes. The channel changes upstream from Lake Estes in the Big Thompson, Fall, and Roaring Rivers during and after the flood event are the major focus of this study.

The movement of 674 acre-feet of water in less than 1 hour down the Roaring River had a significant impact on the bed and banks of the river. Degradation, scour, and deposition along the stream channel that normally takes years to accomplish, happened in minutes. The effects are very visual. Being within a National Park, the channel morphology resulting from the flood from the failure of Lawn Lake and Cascade Lake Dams has remained relatively unchanged to date.

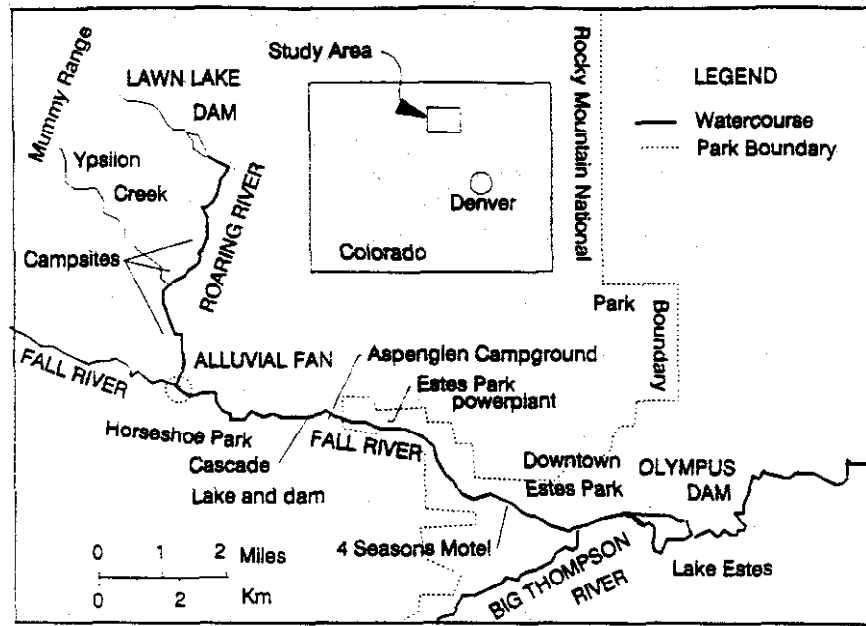


Figure 1. Location Map of the River Channel from Lawn Lake to Lake Estes

Purpose and Scope

Efforts undertaken to study the geomorphology of the Roaring Fork and Fall River systems from Lawn Lake to Lake Estes were separated into 4 areas:

1. review baseline data collected for analyzing the dam-break flood event and the existing post flood conditions;
2. summarize the hydraulic and sediment transport associated with the flood event qualitatively and quantitatively;
3. evaluate the channel hydraulic and sediment transport capacities at present; and,
4. outline possible trends for long term influence and sediment impacts on the channel and system.

GEOMORPHIC STUDY

Baseline Hydraulic Data

Written and oral statements from Park Service Employees, Park visitors, commercial radio broadcasters, local residents and law enforcement officials observing the flood were compiled by Graham and Brown(1983) with data from streamflow gauging, Lake Estes inflows, and stream mileage to compute the travel time for the flood. A graphical summary of the location of the flood peak with time is presented on figure 2. The failure of Lawn Lake Dam occurred at about 0530 MDT. The flood-wave peak reached Lake Estes, over 14 miles downstream, before 0900 MDT. Through the steeper Roaring River valley the leading edge of the flood traveled at about 9 miles per hour, slowed to 2 miles per hour through Horseshoe Park and increased speed to about 4 miles per hour for the remainder of the route from Cascade Dam to Lake Estes.

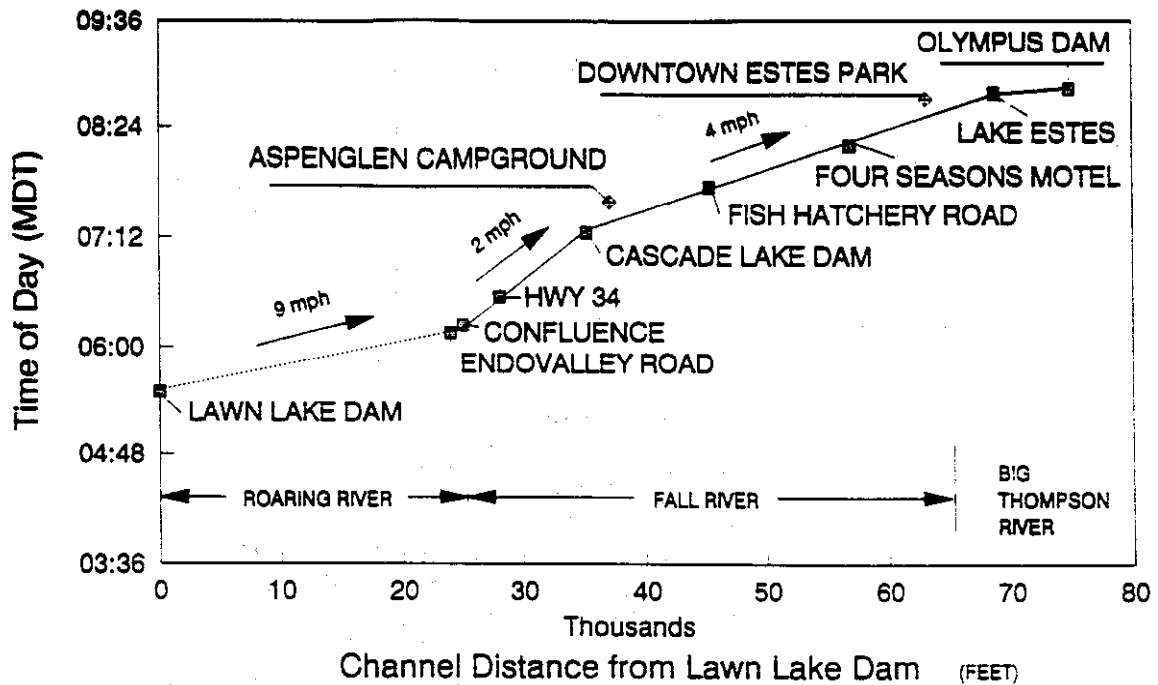


Figure 2. Travel times for flooding caused by the failures of Lawn Lake and Cascade Lake Dams on July 15, 1982

Description of Flood Event Morphology

A comprehensive report describing the hydrology, geomorphology, and dam-break modeling of the July 15, 1982 Lawn Lake Dam and Cascade Lake Dam failures was written by Jarrett and Costa(1984). Peak discharges resulting from the failure of Lawn Lake and Cascade Lake Dams ranged from 18,000 ft³/s at Lawn Lake to about 5,500 ft³/s at Lake Estes. The 1982 dam-break flood was computed to be 2.1 times the 500-year flood for the gaging station on the Big Thompson River. Table 1 was developed from hydraulic properties given for the flood in the report by Jarrett and Costa(1984). Based on channel hydraulics and computed tractive force, the equivalent spherical diameter rock which could be moved by the flood was computed and is included in table 1.

TABLE 1
Change in Hydraulic Properties with Channel Distance for the July 15, 1982
Flooding from the Failures of Lawn Lake and Cascade Lake Dams

Channel Distance (miles)	Peak Discharge (ft ³ /s)	Cross Sect. Area (sq. ft.)	Average Velocity (ft/s)	Top Width (ft)	Maximum Depth (ft)	Average Slope (ft/ft)	Tractive Force (lb/ft ²)	Transportable Size Shield's (ft)	Lane's (ft)
LAWN LAKE DAM - ROARING RIVER									
0.55	16560.0	2070.0	8.0	185.0	23.8	0.0782	116.1	18.9	23.2
1.50	15142.0	1340.0	11.3	97.0	18.5	0.0997	115.7	18.8	23.1
3.83	12573.0	1270.0	9.9	348.0	14.0	0.0862	75.3	12.2	15.1
HORSESHOE PARK - FALL RIVER									
5.36	10728.0	2980.0	3.6	927.0	9.0	0.0132	7.4	1.2	1.5
5.78	7425.0	2250.0	3.3	1112.0	7.9	0.0018	0.9	0.1	0.2
6.50	7176.0	1560.0	4.6	328.0	10.1	0.0047	3.0	0.5	0.6
CASCADE LAKE DAM - FALL RIVER									
7.68	13104.0	1170.0	11.2	148.0	10.8	0.0700	47.2	7.7	9.5
7.74	12852.0	1020.0	12.6	227.0	9.9	0.0410	25.3	4.1	5.1
8.78	11011.0	910.0	12.1	170.0	10.6	0.0331	21.9	3.6	4.4
10.28	8520.0	710.0	12.0	175.0	7.8	0.0206	10.0	1.6	2.0
11.45	6512.0	880.0	7.4	336.0	6.4	0.0186	7.4	1.2	1.5
BIG THOMPSON RIVER									
12.50	5508.0	810.0	6.8	99.0	10.5	0.0144	9.5	1.5	1.9
LAKE ESTES - OLYMPUS DAM									

Note: Transportable Size is Equivalent Spherical Rock Diameter

The following description of the dam-break flood event, sediment movement, and geomorphic response of the river is extracted from the report by Jarrett and Costa(1984). Prior to the flood event, the dimensions of the Roaring River were estimated to be 1 to 2 feet deep and up to 16 feet wide. The streambed material in the steeper portions of the channel was cobbles and boulders. Gravel, coarse sand and silt were noted in the channel through the less steep mountain meadows. Channel scour ranged in the vertical direction from 5 feet to as much as 50 feet resulting from the flood event. Flood widths from 70 feet to 500 feet were observed from high water marks. Although the average slope of the Roaring River is about 10 percent, scoured reaches of the channel as steep as 26 percent were followed by deposition in reaches as "flat" as 5 percent with a threshold slope separating the processes at about 7 to 9 percent. Sediments deposited in the meadow areas to depths generally no more than 2 to 8 feet thick with local deposits measured to a thickness of 10 feet. Most large boulders or rocks were reported to be moved less than 100 feet and no more than 1000 feet. Evidence showed that the single largest boulder moved during the flood in the reach of the Roaring River was 14x17.5x21 feet. It was estimated to weigh 452 tons. In the floodplain of the Roaring River within the surviving forest, sand deposits of 4 feet were reported.

The largest deposition area from the flood event occurred immediately upstream from the confluence of the Roaring and Fall Rivers. This site is now a major visitor attraction within the Rocky Mountain National Park. Using aerial photography, a contour map was developed and the Lawn Lake Alluvial Fan was estimated to have a surface area of 42.3 acres. Thicknesses of the alluvial fan were measured at 11 sites resulting in a maximum thickness of 44 feet and an average thickness of 5.3 feet. The calculated sediment volume for the fan was 226 acre-feet.

Prior to the flood event, the Fall River through Horseshoe Park had a defined meander pattern and a slope of about 0.7 percent. A maximum flood depth of 10 feet and maximum width of 1,300 feet were measured in Horseshoe Park. Water was reported to be out of banks for less than 4 hours. No immediate visible modification to the meander pattern of the Fall River was reported due to the dam-break flood. A thin veneer of fine-grained silt and sand was deposited in the floodplain with a maximum thickness of about 1 foot at the upstream end of Horseshoe Park.

The gradient of the Fall River steepens between Cascade Dam and the Estes Park Powerplant. Although the bed material was coarse gravel and boulders prior to the flood, boulders as large as 3.8x10.2x14.7 feet were reported to have been moved. The local scour depth immediately below Cascade Lake Dam was estimated to be 30 feet. Boulder berms, step-pool profiles, and debris torrents observed in the reach were discussed by Jarrett and Costa(1984).

In the reach of the Fall River between the Estes Park Powerplant and the Big Thompson River, water depths of 3 to 6 feet and an average width of about 200 feet were observed during the flood resulting in scour depths in the range from 0.5 to 2.0 feet. A measured maximum deposit of coarse sand and gravel was 2 feet. The majority of the flood waters left the channelized path of the Fall River at the west end of Estes Park and followed Elkhorn Avenue (the main street through town) before entering the Big Thompson at the east end. No significant amounts of scour or deposition were reported to have occurred during the flood event in the short reach of the Big Thompson River flowing

into Lake Estes. Deposits of sediment and debris left an expensive clean up in Estes Park. High water marks with fine sediment were observed 4 to 5 feet above Elkhorn Avenue. Total damages were estimated by the Colorado Division of Disaster Emergency Services to be about \$30.7 million. The Bureau of Reclamation spent \$80,000 for removal of debris in Lake Estes.

Sediment Transport and Deposition Estimate for the Roaring River

The most dramatic impact from the release of clear water from the dam failure flood are still apparent in the Roaring River. An additional attempt was made to quantify the mass movement of sediment along the Roaring River as a part of this study using the post-flood cross section data and Geological Survey map prior to the flood. Profile plots of 30 cross sections surveyed in the reach of the Roaring River from Lawn Lake to Horseshoe Park were included in the report by Thorne and Bradley (1984) along with sketches plotting the dam-break flood area. Elevation control was not established at the ends of the surveyed cross sections due to the extremely steep slope of the channel and time and monetary constraints. Coordinating sketches from the survey with the quad sheet, a thalweg profile was developed for the Roaring River from Lawn Lake to the confluence with the Fall River and is presented as figure 3.

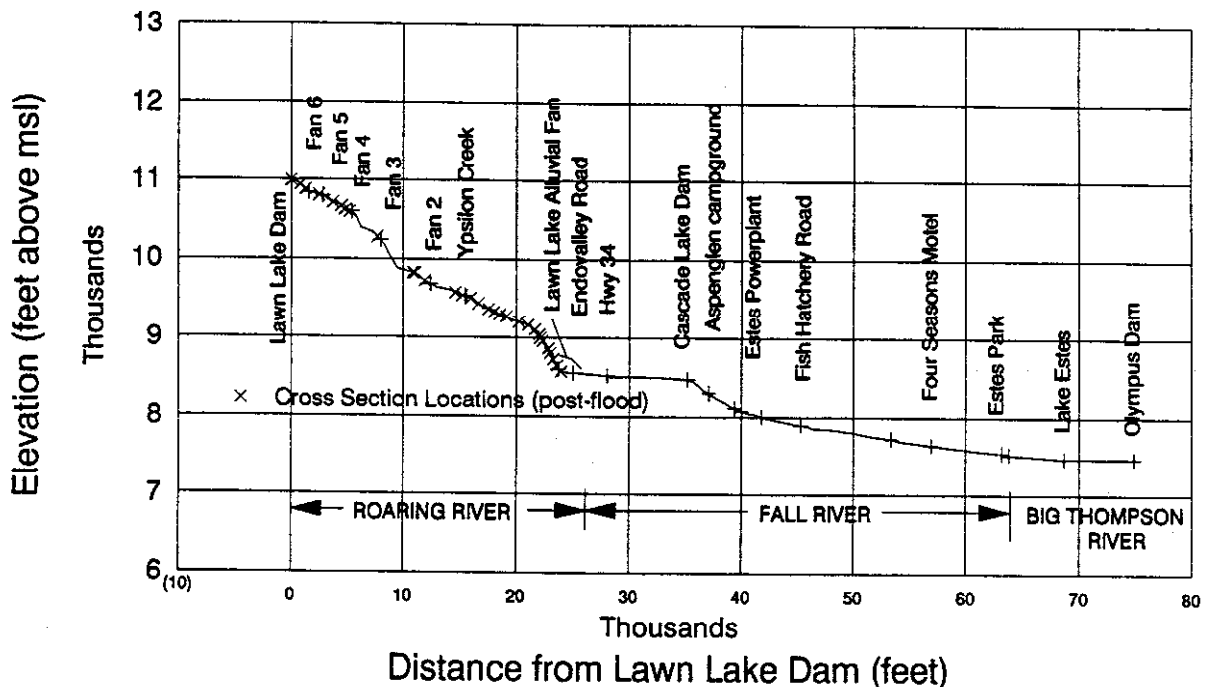


Figure 3. Longitudinal Channel Profile from Lawn Lake to Lake Estes

Since survey sketches included the approximate inundation area for the channel, widths at each of the 30 sections were estimated. Widths at the break points in the channel banks measured from cross section plots compared favorably to the inundation widths. It was assumed that the channel was undisturbed above the break point and the original thalweg would be about 2 feet lower. This was confirmed partially by locations of trees sketched on the cross section plots. The approximate thalweg of the post flood survey was computed. Average end areas were digitized to compute scour volumes removed

during the flood. The estimated original cross sectional area of 15 square feet (15 feet wide by 2 feet deep) was subtracted. The volume computation resulted in an estimate of 234 acre-feet of sediment available to deposit at the Lawn Lake Alluvial Fan. This compares favorably with the 226 acre-feet estimated by Jarrett and Costa to be deposited in the fan. Sediment removed from the channel and available to deposit at the upstream fans was estimated to be 122, 115, 57, 26, and 45 acre-feet for alluvial fans 2 through 6, respectively. Locations of the upstream alluvial fans are given on figure 3.

Lake Estes Sediment Deposition and Fall River Scour Estimates

Sedimentation ranges 4, 5, and 6 of Lake Estes were resurveyed in 1984 and cross section profile plots were included in the report by Thorne and Bradley(1984). A rough estimate of the sediment deposition volume since the 1962 survey was calculated using average end area techniques. A total of about 30 acre feet were computed to be deposited between 1962 and 1984 the majority of which has been attributed to the 1982 Lawn Lake and Cascade Lake Dam failure flood. An additional sediment volume was removed with the cleanup of debris from the flood but not measured.

Assuming the majority of the deposition in Lake Estes came from the river channel between Cascade Lake and Estes Park during the flood, comparison check on the channel scour can be made. From plots provided by Jarrett and Costa(1984) the main channel of the Fall River from Cascade Lake to Estes Park was estimated to have an average width of about 45 feet. For an average moveable bed width of 45 feet over the 5.3-mile reach, the depositional volume of 30 acre feet would represent an average scour depth of 1.0 foot. Observed scour in that reach of the Fall River ranged from 0.5 to 2.0 feet. Thus, the scour and depositional volumes are in reasonable agreement.

Post Dam-break Data Collection

In an effort to address the sedimentation problems in the Fall River following the Lawn Lake Dam failure, data were collected on streamflow, hydraulic and sediment transport rates, cross sectional geometry variation, and bed load sediment gradations during the period from May to August of 1984. A total of 6 sampling sites were chosen for the study in the reach between Lawn Lake and Lake Estes. A summary report was written by Thorne and Bradley(1984). Streamflow in the study reach ranged from 3.0 ft³/s to 130 ft³/s in the Roaring River, 12 to 288 ft³/s in the Fall River and 40 to 760 ft³/s in the Big Thompson River. Bed load transport ranged from 0 to 1105 tons per day in the Roaring River and 3 to 479 tons per day in the Fall River. Suspended sediment loads ranged from 0.06 to 662 tons per day at the three sites measured on the Fall River.

A detailed geomorphic study on the effects of a major sediment influx on the Fall River was authored by Pitlick(1985). Additional discharge, cross section, sediment transport, and mean bed variation data collected in 1983 and 1984 were presented.

A comparison of the pre-flood and 1983-84 channel sinuosities for the 5 study reaches within Horseshoe Park showed a decrease in Fall River sinuosity only at the upstream end along the alluvial fan. This decrease would be attributed to the readily available oversupply of sediment in the alluvial fan.

Changes in channel width and mean bed elevation were documented for 75 cross sections which were surveyed a minimum of 4 times during the two field seasons. All five study reaches experienced episodic fill and scour of the channel as sediment was moved through Horseshoe Park. Four of the five study reaches showed no significant morphological changes during the 2-year period.

Changes in bed material composition at selected sites were observed and reported. Finer fill deposited on coarser existing bed material as the alluvial fan material was transported through Horseshoe Park. In the middle reaches, a rapid return to pre-aggradation bed elevations and composition was noted.

The morphology of each of the 5 study reaches is discussed at length. The lack of morphologic changes was attributed to the stability of the channel. The dam-break flood has coarsened the bed material in the main channel of the Fall River and growth of vegetation along the banks has provided a semi-rigid boundary limiting the degree to which channel dimensions can adjust.

A qualitative assessment of the channel bed changes was made along with a quantitative mass balance computation for changes in sediment transport and storage. Results showed sediment entering the Fall River from the Roaring River and the alluvial fan was being deposited in a 1.2-mile storage zone at the downstream end of Horseshoe Park. Sediment initiated into motion at the Lawn Lake Alluvial Fan during a summer thunderstorm event was observed being stored along the channel in Horseshoe Park and released in later events.

SUMMARY AND CONCLUSIONS

The Lawn Lake and Cascade Lake Dam failure flood moved sediment volumes orders of magnitudes greater than the natural sediment transport capacity of the pre- and post-flood event Roaring and Fall River channels. The major features of the channel downstream from Lawn Lake Dam to Lake Estes are located on figure 1. From baseline hydraulic data (Brown and Graham, 1984), figure 2 was produced showing the travel times for the dam-break flood event. Flood event morphology was summarized from Jarrett and Costa (1984) and a table developed to compare hydraulics and calculated transportable rock size with observed data. Based on tractive force, the flood had the capability to move boulders as large or larger than those observed (14X17.5X21 feet). Using cross section data (Thorne and Bradley, 1984), a sediment transport and deposition estimate was completed for the flood event through the Roaring River. The volume computation resulted in an estimate of 234 acre-feet of sediment available to deposit at the Lawn Lake Alluvial Fan. This compares favorably with the 226 acre-feet estimated by Jarrett and Costa to be deposited in the Lawn Lake Alluvial Fan. Sediment removed from the channel and available to deposit in upstream fans was estimated to range from 26 to 122 acre-feet. Locations of the alluvial fans are given on figure 3 which is a longitudinal profile of the Roaring, Fall, and Big Thompson River channels.

A rough estimate of the sediment deposition in Lake Estes since the 1962 survey was calculated using average end area techniques. A total of about 30 acre feet were computed to be deposited between 1962 and 1984 the majority of which is attributed to the 1982 Lawn Lake and Cascade Lake Dam failure flood. For an average moveable bed width of 45 feet over the 5.3-mile reach from Cascade Dam to Lake Estes, the depositional volume of 30 acre feet represents

an average scour depth of 1.0 foot. Observed scour in that reach of the Fall River ranged from 0.5 to 2.0 feet. Thus, the scour and depositional volumes are in reasonable agreement. Hydraulic and sediment transport data collected in the 1983 and 1984 runoff seasons are orders of magnitude lower than those observed for the dam-break flood event. The oversupply of sediment available to the Fall River in Horseshoe Park at the Lawn Lake Alluvial Fan has not had an immediate effect on the channel morphology downstream. Channel sinuosity decreased only at the upstream end along the alluvial fan. The lack of morphologic changes was attributed to the stability of the channel. The dam-break flood has coarsened the bed material in the main channel of the Fall River and growth of vegetation along the banks has provided a semi-rigid boundary limiting the degree to which channel dimensions can adjust. Sediment initiated into motion at the Lawn Lake Alluvial Fan during a summer thunderstorm event was observed being stored along the channel in Horseshoe Park and released in later events.

REFERENCES

- Graham, W. J. and Brown, C. A., (1983) Dam Failure Warnings Evaluated, Natural Hazards Observer, Natural Hazards Research and Applications Information Newsletter, University of Colorado, Boulder, Colorado.
- Jarrett, Robert D. and Costa, John E., (1984) Hydrology, Geomorphology, and Dam-Break Modeling of the July 15, 1982, Lawn Lake and Cascade Lake Dam Failures, Larimer County, Colorado, U.S. Geological Survey, Open File Report 84-612, Denver, Colorado.
- Lane, E. W., (1952), Progress Report on Results of Studies on Design of Stable Channels, HYD-352, Bureau of Reclamation, Denver, Colorado.
- Pitlick, John, (1985) The Effect of A Major Sediment Influx on Fall River, Colorado, Master's Thesis, Colorado State University, Fort Collins.
- Shields, A., (1936) Anwendung der Aenlichkeitsmechanik und der Turbulenzforschung anf die Geschiebebewegung, Mitteil, PVWES, Berlin, No. 26.
- Thorne, C. R. and Bradley, J. B., (1984) Sedimentation Problems in the Fall River Following the Lawn Lake Dam Failure - Data Report, for U.S. Bureau of Reclamation, Denver, Colorado.

GREEN RIVER BELOW FLAMING GORGE DAM, 1952 - 1987

Joseph K. Lyons, Hydraulic Engineer, Bureau of Reclamation, Denver, Colorado.

ABSTRACT

The response of the Green River to hydrologic changes induced by Flaming Gorge Dam was studied using comparative analysis of the channel from historical aerial photography, published sediment and flow records, and sediment data collected during 1986-1988. Channel stability is of interest as future channel changes may impact the habitat required by endemic endangered fishes.

Since dam closure in 1963, the Green River apparently has reached a new equilibrium channel width and sediment transport condition. Presently, the Green River channel appears to be adjusted to the supply of sand-sized sediment. Future channel changes could occur if changes in discharge, sediment supply or transport occur in the basin.

INTRODUCTION

The Green River, tributary to the Colorado River, has a drainage area of 44,700 mi² (figure 1). The Green River is controlled by two reservoirs, Fontenelle and Flaming Gorge. Flaming Gorge Dam, completed in 1962, is located 410 river miles upstream of the confluence of the Green and Colorado Rivers. The portion of the Green River studied for this report extends from river mile (RM) 94 near Green River, Utah, to RM 310 near Jensen, Utah.

The impact of Flaming Gorge upon channel morphology and suspended sediment transport of the Green River was studied by Andrews (1986). He described changes in flow pattern and suspended sediment following dam closure as measured at gauges along the Green River and presented channel width reduction data for the 1964-1978 period. Andrews concluded that prior to 1962, quasi-equilibrium existed on the Green River with no net aggradation or degradation occurring. Following regulation, different flow and sediment patterns existed and channel adjustments followed. Andrews reported channel degradation for the Green River upstream of the Yampa River where sediment-free releases from Flaming Gorge occur and the majority of sediment load is obtained from the bed. Downstream of the Yampa River to the Duchesne River, Andrews noted quasi-equilibrium and below the Duchesne River he noted aggradation.

HISTORICAL TRENDS IN CHANNEL CHARACTERISTICS

Channel Width

Channel width was measured on aerial photography covering the Green River from RM 237 to RM 310 (upper study reach) for the following years: 1952, 1963-1964, 1974, 1978, and 1986; and from RM 94 to RM 121 (lower study reach) for 1952, 1974, 1981, and 1987. Channel area for each data set was tabulated and an average channel width computed using the measured channel length for each data set.

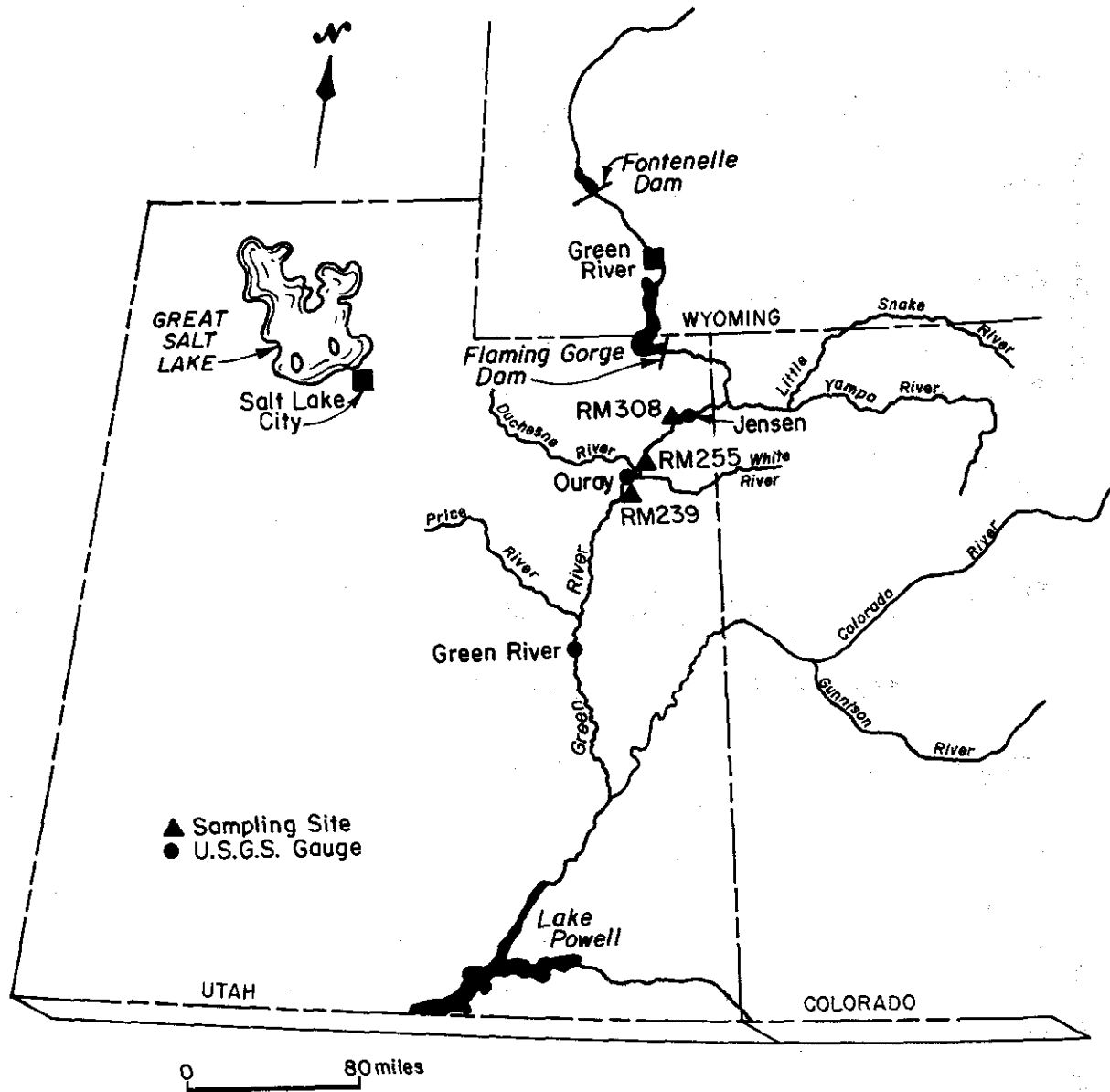


Figure 1. Location Map, Green River Channel Study.

These average channel widths are compared to average channel widths reported by Andrews in figure 2. Using large-scale aerial photographs, Andrews measured channel width near Jensen at 15 transects in relatively straight reaches of channel without midchannel bars and at 14 transects in the lower study reach downstream of Green River, Utah. The discrepancy between Andrews' average channel widths and those reported here are likely due to the different methods of analysis used. The delineation of channel area for a long reach of channel provides an integrated estimate of the entire range of channel width conditions.

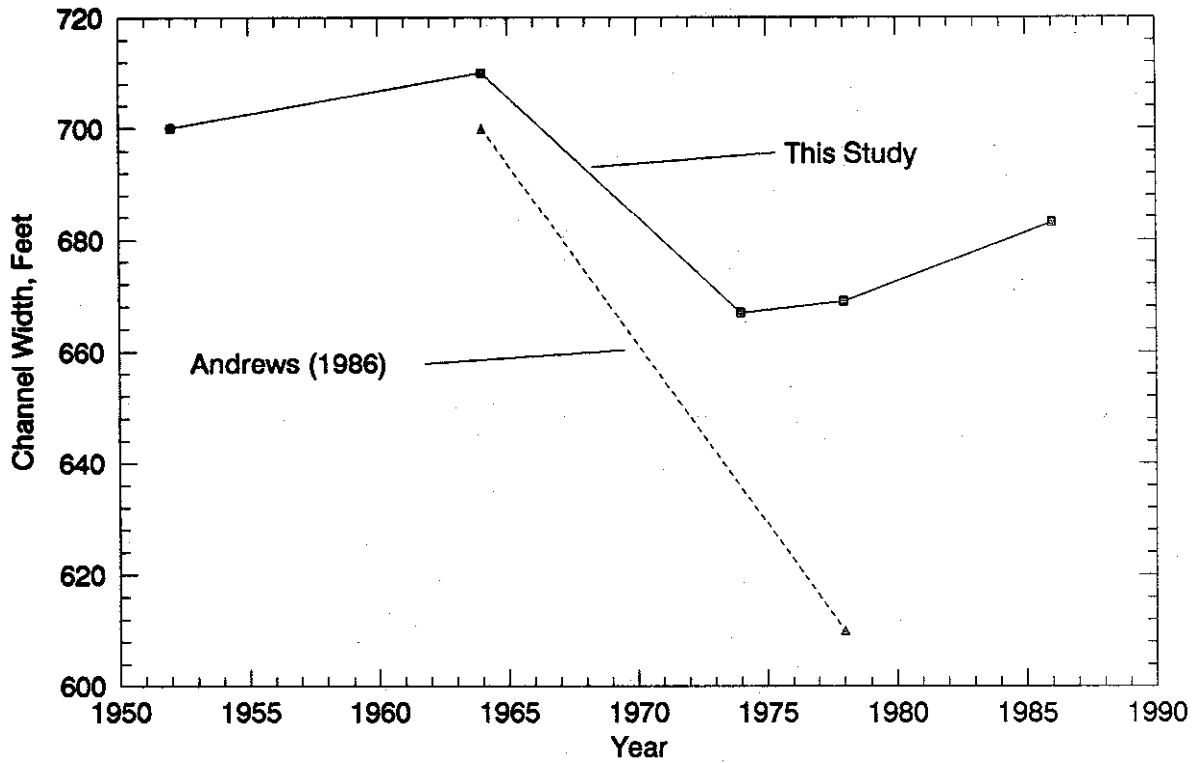


Figure 2a. Channel Width of the Green River, river mile 237 to 310.

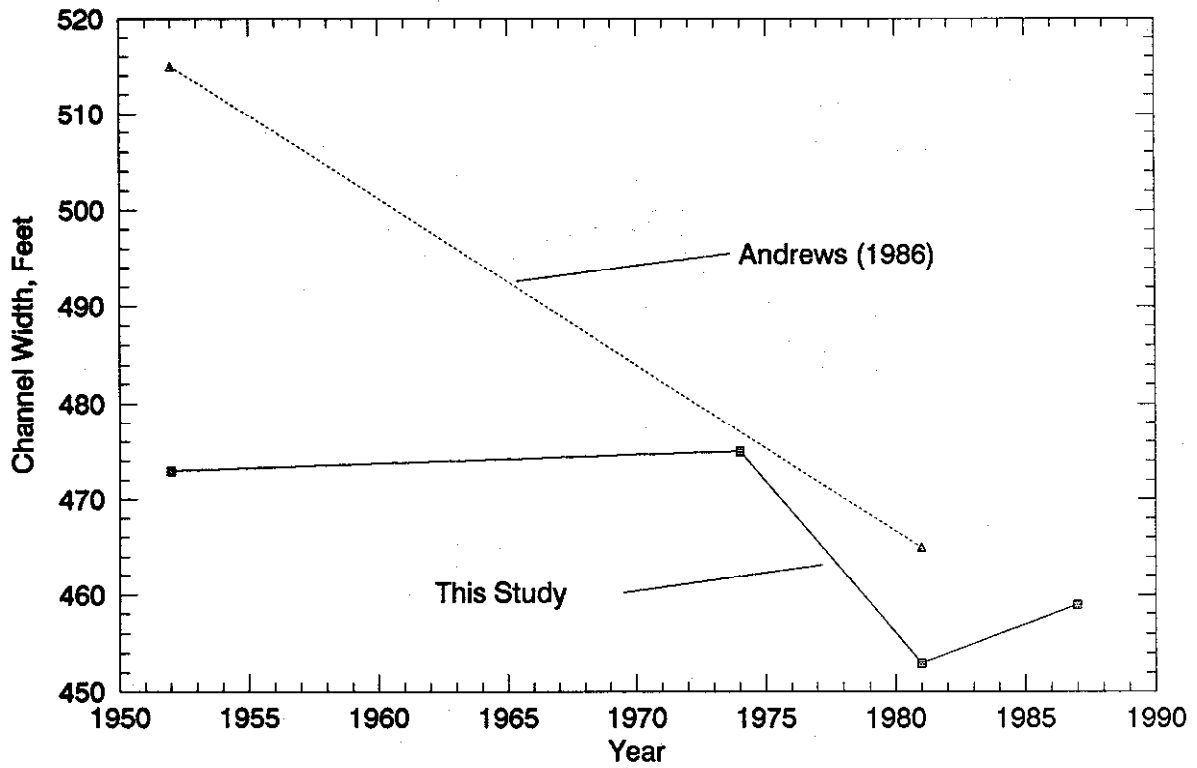


Figure 2b. Channel Width of the Green River, river mile 94 to 121.

For the upper study reach, the similarity of the average channel width estimates for 1952 and 1964 supports Andrews' conclusion that quasi-equilibrium conditions existed prior to regulation by Flaming Gorge. Also, the close agreement of the average channel width estimates for the 1974 and 1978 photography suggests that the channel had reached a new equilibrium width by 1974. Between 1978 and 1986, average channel width increased by 2 percent.

For the lower study reach, the similarity of the average channel width for 1952 and 1974 indicates that the adjustment in channel width occurred later in this reach than in the upstream reach. The decrease in channel width between 1974 and 1981 may represent a width adjustment to regulation by Flaming Gorge. Channel width increased slightly in this reach between 1981 and 1987.

Discharge Patterns

Annual peak flows for the Geological Survey gauge near Jensen were separated into three time periods, 1953-1964, 1965-1978, and 1979-1986, the photography intervals for the upper reach. An analysis of covariance detected no statistical difference ($\alpha = 0.05$) in the means of the annual peak flows for these intervals. A similar analysis for the annual peak flow data for the Green River gauge detected no significant difference in the means of the data for 1953-1974, 1975-1981, and 1982-1987.

Flow-duration analyses of the gauge data were done for the photographic intervals. The flow conditions of the most recent time period at each gauge (1979-1986 and 1982-1987) are more similar to pre-reservoir conditions than the earlier post-reservoir period. The increase in channel width between 1978 and 1986 in the upper study reach parallels an increased occurrence of flows greater than 11,000 ft³/s relative to the earlier post-reservoir period recorded at the Jensen gauge. A similar pattern exists in the lower study reach with an increase in channel width occurring between 1981 and 1987 along with an increased occurrence of flows greater than 19,000 ft³/s.

SEDIMENT TRANSPORT ANALYSIS

Sediment Data Collection

Data collection began in 1986 at three locations. At RM 308, 15 samples were obtained at discharges ranging from 1,081 ft³/s to 10,328 ft³/s. At RM 255, 18 samples were collected over a range of 1,107 ft³/s to 10,787 ft³/s. A third location at RM 239 was sampled 16 times from 2,649 ft³/s to 13,892 ft³/s. The median diameter of the bed material at these sites is about 0.3 mm. About 1 percent of the bed was composed of material finer than sand and about 1 percent of the bed was composed of material coarser than sand. The bed-material load carried by the Green River is essentially equal to its sand load.

Sediment Rating Curves

Using the Modified Einstein procedure (Bureau of Reclamation, 1955), sand-load discharge was computed for each sample. The computed sand loads for RM 308 and 255 are best described by a suspended sand-load rating curve developed for the Jensen gauge data from 1951-1986. The computed sand loads for RM 239 are best described by a suspended sand-load rating curve developed for the Ouray

gauge data from 1951 to 1966. For the Green River gauge, a suspended sand-load rating curve was developed from 1951-1982 data.

Suspended sediment rating curves were developed for Geological Survey gauges on the White and Duchesne Rivers. Suspended sediment data were collected for the Duchesne River from 1976 to 1987 near Randlett, Utah, and since 1974 on the White River near its confluence with the Green River.

Effective Discharge

Effective discharge, an index of the range of flows that influence the shape of a channel, is defined as the midpoint of the flow range in which total sand load is maximized. The gauged mean daily flows for the Green River for 1965-1987 were separated into 35 flow ranges of equal size for this analysis. Total sand load, which is the sum of the computed sand loads for all discharges in a given flow range, was computed for each site using the sand-load rating curves described above.

Gauged flows for the Jensen gauge were used for the sites at RM 308 and 255. The flows recorded at the Green River gauge were adjusted for the site at RM 239. The effective discharge at RM 308 and 255 is approximately 11,900 ft³/s and about 19,200 ft³/s at RM 239. The range of flows that influence channel characteristics is quite broad for the Green River with approximately 80 percent of the sand load and is transported over the following discharge ranges:

RM 308 & RM 255	1,700 ft ³ /s to 19,800 ft ³ /s
RM 239	2,150 ft ³ /s to 29,200 ft ³ /s

These ranges cover about 90 percent of gauged flows of the Green River from 1963 to 1987, see figure 3.

Effective flow did not approximate bankfull flow as defined by the cross section data collected in 1986. The bankfull flows predicted by step-backwater computations exceeded the calculated effective flows. These computations used a calibrated roughness value from data measured in 1986 and 1987. This application of a calibrated roughness value to larger discharges assumes that no roughness changes occur over the range of flows of interest. Also, the channel measurements used in this analysis describe the Green River channel following high flows in 1983, 1984, and 1986. These conditions may not represent average channel conditions for the period used in computing effective flow.

Mean Annual Sand Load

The sand-load discharge rating curves were used with flow duration data from the gauges near Jensen and at Green River for 1965-1987. The mean annual flow for the 1965-1987 period was 3,320,000 acre-feet/yr at Jensen and 4,640,000 acre-feet/yr at Green River. The mean annual sand load at RM 308 and 255 for this period is 1,480,000 tons/year (t/yr). At RM 239, the mean annual sand load is 2,910,000 t/yr. The suspended sand-load rating curve for the Ouray gauge was used in conjunction with adjusted discharges from the Green River gauge for this estimate. At Green River, the mean annual sand load is 3,090,000 t/yr. This estimate is based upon the mean daily flow

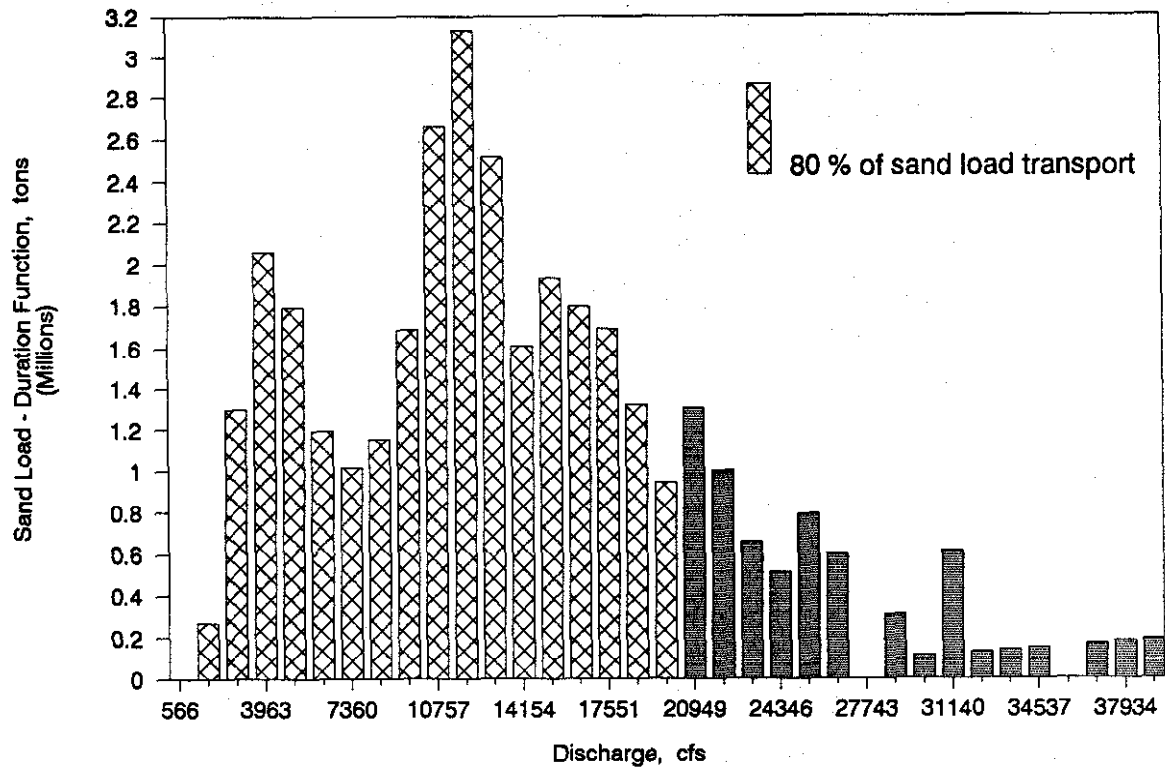


Figure 3a. Effective Discharge, RM 255 and RM 308, Green River.

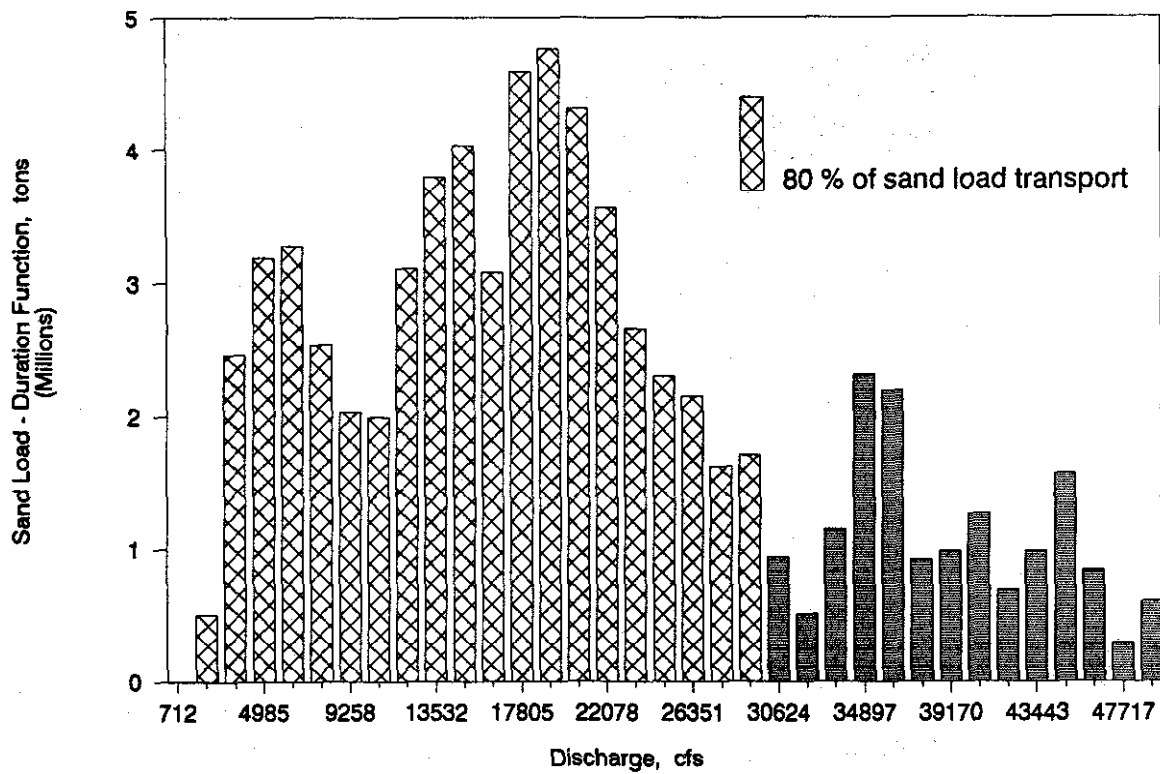


Figure 3b. Effective Discharge, RM 239, Green River.

record from the gauge and the suspended sand-load rating curve developed for this site. For the Duchesne River, the suspended sediment rating curve was used along with the mean daily flow record from this gauge 1965-1987 (mean annual flow of 462,000 acre-feet/yr). Assuming 27 percent of suspended load is sand, the annual sand-load estimate for the Duchesne is 46,000 t/yr. For the White River, the flow-duration data for 1974 to 1986 was used to derive an estimate for suspended sand-load discharge of 1,020,000 t/yr and a mean annual flow of 610,000 acre-feet/yr.

Sand-Load Mass Balance

A mass balance of the suspended sand load for locations along the Green River and its tributaries describes the present transport status of the channel. An imbalance of sand load between two locations may indicate aggradation or degradation of the channel while an imbalance of total suspended sediment load is not as reliable an indicator of channel conditions.

The data collected from 1986 to 1988 for this study confirmed that bed-material transport of the Green River in the upper study reach could be described using the long-term gauging records of suspended sand-load collected near Jensen and Ouray. Sand-load estimates from the White River and Duchesne River gauges and the suspended sand-load record for the Green River gauge were also used.

The mass balance for the Green River indicates that between RM 255 and RM 239 an additional 1,430,000 t/yr of sand load is gained. The White River and Duchesne River computed sand-loads total 1,066,000 t/yr. The difference, 364,000 t/yr, represents about 12 percent of the mean annual suspended sand load of the Green River at RM 239. Bedload can range from 10 to 35 percent of the total suspended sediment load for rivers similar to the White River (Strand and Pemberton, 1982). The difference in suspended sand load is satisfied if a bedload correction factor of about 10 percent is assumed for the mean annual suspended load for the White River (3,630,000 t/yr for 1975-1986). The suspended sand-load estimates for the White and Duchesne Rivers are sufficient to assume a quasi-equilibrium exists for the Green River between RM 255 and RM 239.

At Green River, the mean annual suspended sand load is about 6 percent greater than the load computed for RM 239. The Price River, the main tributary in this reach, is gauged 22 miles above its confluence with the Green River but insufficient gauge records prohibit calculation of its mean annual sand load. The mean annual discharge of the Price River is 114,500 acre-feet/yr, only 2 percent of the flow of the Green River and its sand-load contribution is not likely a major component of the total sand load of the Green River. The similarity of the mean annual sand load at RM 239 and at Green River suggests that quasi-equilibrium exists in this reach.

CONCLUSIONS

The average suspended sand load for 1965-1987 of the Green River at RM 308 is nearly 50 percent of the river's sand load at Green River, Utah. About 70 percent of this difference is accounted for by the sand-load discharges of the White and Duchesne Rivers. The sand-load mass balance based on long-term gauge histories of the Green River indicates that sand-load transport is

approximately equal to supply in the reach from Jensen, Utah, to Green River, Utah. Aerial photography interpretation done for this study indicates that channel width in the Jensen, Utah, area apparently reached an equilibrium prior to 1974 and channel width near Green River, Utah, decreased between 1974 and 1981, presumably in response to Flaming Gorge. These changes are consistent with those proposed by Schumm (1977) as possible responses to changes in bed material discharge. Similar channel changes are possible if further changes in discharge, sediment supply or sediment transport conditions occur in the basin.

REFERENCES

- Andrews, E. D., 1986, Downstream Effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. Geol. Soc. Am. Bull. 97, 1012-1023.
- Schumm, S. A., 1971, Fluvial Geomorpholgy: Channel Adjustment and River Metamorphosis, in River Mechanics, ed. H.W. Shen, Fort Collins, CO, p. 5-1 - 5-21.
- Strand, R. I. and Pemberton, E. L., 1982, Reservoir Sedimentation, Technical Guideline, Bureau of Reclamation, Denver, CO, pp 48.
- Bureau of Reclamation, 1955, Step Method for Computing Total Sediment Load by the Modified Einstein Procedure, Bureau of Reclamation, Denver, CO.

PREDICTING CHANNEL SHAPE OF THE PLATTE RIVER

Timothy J. Randle and Duane Woodward U.S. Bureau of Reclamation Engineers

INTRODUCTION

Background

The Platte River in Central Nebraska has been characterized as a braided or ana-branched stream with a wide shallow sand bed. Channel narrowing over time has been documented with aerial photography and cross section measurements. Reductions in flow, sediment transport, and the encroachment of woody vegetation are reasons suggested for this channel narrowing. Investigations into quantitative relationships that describe channel geometry and equilibrium flow have resulted in a wide range of flow estimates. Formative discharges, regime equations, macroform geometry, and sediment transport models are some of the quantitative relationships used in the investigations. These estimates could help define the flow regime needs for channel maintenance. A reliable relationship between channel shape and river discharge has yet to be determined.

Purpose

This paper presents relationships between water discharge and channel width for two separate times (1938 and 1983) for the Platte River, near Overton, NE. The concept for this paper is based upon two relationships presented by Simons and Senturk (1977):

- (1) Channel width is directly proportional to both water discharge and sediment load.
- (2) Channel shape, expressed as width to depth ratio, is directly related to sediment discharge.

Given enough time and a moveable bed, river shape will be adjusted so that the incoming sediment load is transported through a reach. This paper demonstrates that channel narrowing of the Platte River can be described primarily by changes in water discharge and sediment load even when the effects of vegetation, streambank protection, or bridges are ignored.

METHOD OF ANALYSIS

Relationships between water discharge and channel width were determined for the Platte River near Overton for conditions during 1938 and 1983. Various parameters were then adjusted to determine their sensitivity to the results.

The unknown values in deriving the width-discharge relationships were bed material load (Q_b), cross sectional area of flow (A), channel width (W), and Manning's roughness coefficient (n). The values considered to be known were water discharge (Q_w), channel slope (S), and the bed material size gradation (D_s).

The basic equations used to solve these unknowns are shown below:

$Q_s = a Q_w^b$	Bed material load rating curve where "a" and "b" are constants
$Q_s = f(Q_w, A, W, S, D_s)$	Bed material load transport equation
$Q_w = \frac{1.486}{n} \frac{A^{5/3}}{W^{2/3}} S^{1/2}$	Manning's equation for normal depth

A measurement of channel width (W'), and an estimate of the corresponding discharge (Q_w') were also known. With these data, three additional equations can be written (nearly identical to the first three equations) with two more unknowns: Q_s' and A' , which are the bed material load and cross sectional area of flow corresponding to the known values of W' and Q_w' . An iterative procedure was used to solve these equations and develop a relationship between water discharge and channel width (and other channel characteristics).

The discharge associated with the measurement of channel width was considered to be the effective discharge. The effective discharge is defined as the single discharge which transports the greatest amount of sediment over time. Larger discharges may transport more sediment, but occur with far less frequency, and lower discharges, which occur more frequently, do not have as much capacity to transport sediment.

Assumptions

The basic assumption in this analysis is that the Platte River is free to adjust itself to any channel width necessary to transport the incoming sediment load. The additional assumptions used in the analysis are listed below:

The bed material load-discharge ratings curves, presented by Lyons and Randle (1988), can be used to compute the quantity of sand transported by the Platte River near Overton for a specific time period.

A bed material load equation such as the Velocity-Xi Adjusted Einstein Equation (Pemberton, 1972) or the Yang Equation (Yang, 1973) is applicable to the sand-bed channel of the Platte River.

Assuming normal depth, Manning's Equation can be used to define the relationship between water discharge, cross sectional area, channel width, and hydraulic slope. The roughness coefficient was assumed to be constant over the range of discharge studied.

The river cross section is relatively wide and shallow such that the wetted perimeter and top width are essentially equal.

Analysis results were not sensitive to changes in water temperature and a constant temperature of 55 °F was used.

Basic Data

The basic data used in this analysis are from the report presented by Lyons and Randle (1988). Average channel width of the Platte River near Overton has been determined for 1865, 1938, 1957, and 1983 (table 1).

Year	Channel Width (ft)	Effective Discharge Years (ft ³ /s)	Channel Slope	Average Bed Material Size D ₃₅ (mm)	D ₅₀ (mm)	D ₆₅ (mm)	D ₉₀ (mm)
1865	4,795						
1890			0.00116				
1938	2,313	1926-39 3,900		0.295	0.406	0.565	1.297
1957	1,139	1940-57 1,650					
1983	1,050	1958-86 1,600	0.00121	0.540	0.802	1.283	4.468

Table 1. - Characteristics of the Platte River near Overton.

The effective discharges associated with these average channel widths were computed by Lyons and Randle (1988) using mean daily flow values and the bed material load-discharge rating curves. The rating curves for the Platte River near Overton are shown below for two time periods.

$$1931 \text{ to } 1941: Q_s = 0.104063 Q_w^{1.38334} \quad R^2 = 0.843$$

$$1965 \text{ to } 1980: Q_s = 0.000325263 Q_w^{1.96362} \quad R^2 = 0.931$$

where: R^2 is the coefficient of determination
 Q_s is the bed material load (tons/day)
 Q_w is the water discharge (ft³/s)

The rating curve for the 1965 to 1980 period is based upon bed material loads computed from the Modified Einstein Equation. The Yang equation was used to develop the rating curve for the 1931 to 1941 period since suspended sediment load measurements were not available. The rating curve for the earlier period has been adjusted by a factor equal to the ratio of regression equations using the Modified Einstein and Yang Equations for the latter period ($0.000214 Q_w^{1.002}$).

The average channel widths measured from aerial photographs are related to the computed effective discharges and sediment rating curves. This analysis attempts to represent conditions of the Platte River in 1938 and 1983; years when the average channel width was measured. Both the effective discharge computation and sediment rating curve equations are based on data collected from time periods preceding measurements of channel width.

The effective discharge of 3,900 ft³/s (1926 to 1939 period) is rather distinct (figure 1). However, the effective discharge of 1,600 ft³/s (1958 to 1986 period) may be better expressed as a range of flows. The centroids of the curves representing the 1926 to 1939 period and 1958 to 1986 period are 5,580 and 9,380 ft³/s, respectively.

During the time that the Platte River narrowed, the bed material became coarser but there was little change in channel slope. The bed material size

gradations shown in table 1 are the average of bed material samples collected on the Platte River. The channel slope was measured from topographic maps, stream gauges, and channel surveys.

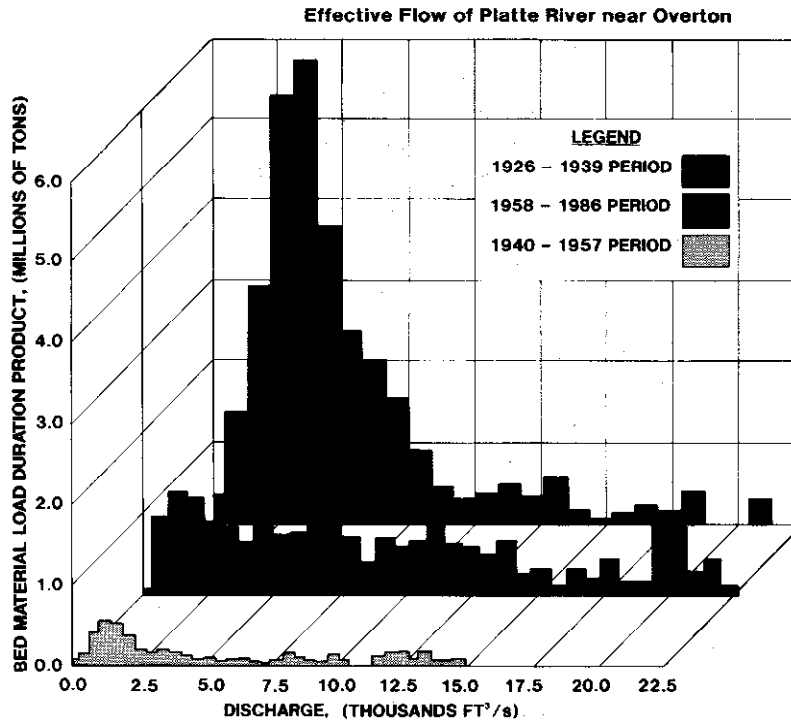


Figure 1. - Effective Discharge of the Platte River near Overton

RESULTS AND DISCUSSION

Initial Width-Discharge Relationship

The initial relationships between discharge and channel width (figure 2) were determined using the Velocity-Xi Adjusted Einstein Equation and measurements of channel width, slope, and bed material size gradation. The first two lines of table 2 list the basic data used in the analysis. Figure 2 shows that channel width varies considerably with discharge for the 1938 conditions. Changes only in hydrology during this period (natural or man caused) would have a direct impact on channel width. For example, a reduction in the effective discharge, from 3,900 ft³/s to 1,600 ft³/s, would account for 89 percent of the channel narrowing that occurred between 1938 and 1983; even if the sediment discharge relationship remained unchanged. The channel during this period responded to changes in discharge mainly by changes in channel width. Both velocity and depth changed relatively little with changes in flow. For discharges ranging from 500 ft³/s to 10,000 ft³/s the computed velocity only varied from 1.9 ft/s to 2.6 ft/s and the computed depth only varied from 0.5 ft to 0.8 ft. The roughness coefficient of 0.0170 computed for this period is dependent upon the transport equation, effective discharge, and channel width.

For the 1983 conditions, channel width only varies slightly with discharge for flows greater than 1,600 ft³/s. The differences in the two curves shown in figure 2 are due to the reduction in the bed material load supplied to Platte River and the coarsening of the streambed. The curve representing the 1983 conditions shows a decrease in channel width for increases in discharge beyond 1,600 ft³/s. For discharges greater than 20,000 ft³/s, the analysis shows that the channel approaches a constant width of approximately 400 ft. This is mainly due to the relatively coarse bed material used in the analysis. As the discharge increases, more velocity is needed to transport a bed material load equal to the incoming sediment supply and a narrower channel is needed to increase the velocity. For discharges ranging from 500 ft³/s to 10,000 ft³/s the computed velocity increased from 1.5 ft/s to 5.3 ft/s and the computed depth increased from 0.5 ft to 3.3 ft. The roughness coefficient computed for this period was 0.0215.

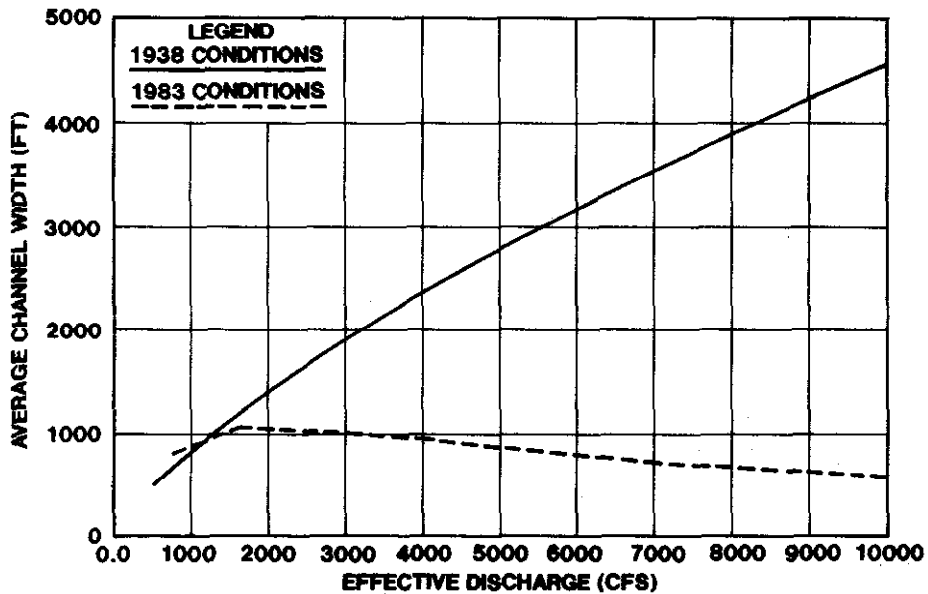


Figure 2. - Platte River Width-Discharge Relationship Near Overton
14-21

Group No.	Time Period	Effective Discharge ft ³ /s	Channel Width ft	Channel Slope	Manning's n	Transport Equation	D ₅₀ mm
1	1938	3,900	2,313	0.00116	0.0170	Velocity-Xi	0.406
	1983	1,600	1,050	0.00121	0.0215	Velocity-Xi	0.802
2	1938	3,900	2,313	0.00116	0.0126	Yang	0.406
	1983	1,600	1,050	0.00121	0.0353	Yang	0.802
3	1938	5,582	2,313	0.00116	0.0192	Velocity-Xi	0.406
	1983	9,377	1,050	0.00121	0.0184	Velocity-Xi	0.802
4	1983	1,600	1,050	0.00121	0.0247	Velocity-Xi	0.627
	1983	1,600	1,050	0.00121	0.0280	Velocity-Xi	0.406

Table 2. - Data Summary for Sensitivity Analysis

Variation in Sediment Transport Equations

The analysis was repeated using the Yang sediment transport equation (table 2, group 2) and the results are shown in figure 3. The results are basically the same using either the Velocity-Xi Adjusted Einstein or Yang sediment transport equations. For the 1938 conditions, use of the Yang equation yields a channel width of 4,300 ft for a discharge of 10,000 ft³/s compared to a width of 5,500 ft using the Velocity-Xi equation. Use of either equation gives virtually the same results for the 1983 conditions. The computed roughness coefficient using the Yang equation is less for the 1938 conditions but greater for the 1983 conditions (table 2, group 2).

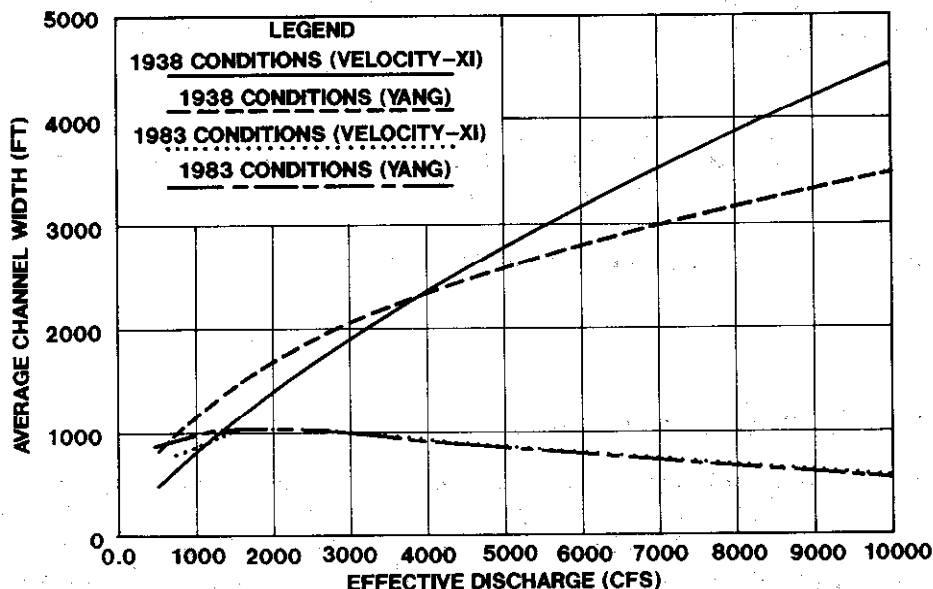


Figure 3. - Sensitivity of the Sediment Transport Equation

Variation in Effective Discharge

The curves presented in figure 1 show that a relatively narrow range of discharge (1926-39) transported most of the bed material load. The effective discharge (3,900 ft³/s) for the 1929 to 1939 period is close to the discharge which transports 50 percent of the accumulated bed material load (5,580 ft³/s). However, for the 1958 to 1986 period, there is considerable difference between the effective discharge (1,600 ft³/s) and the discharge which transports 50 percent of the accumulated bed material load (9,380 ft³/s). The initial analysis was repeated using the Velocity-Xi equation and the discharge which would transport 50 percent of the accumulated bed material load (table 2, group 3). Although the magnitude of channel width for a given discharge is different from the initial analysis, the basic relationship between water discharge and channel width did not change for either time period (figure 4). Even if the effective discharge were different by an order of magnitude for the 1983 conditions, the analysis still shows that (for larger flows) channel width does not significantly vary with discharge.

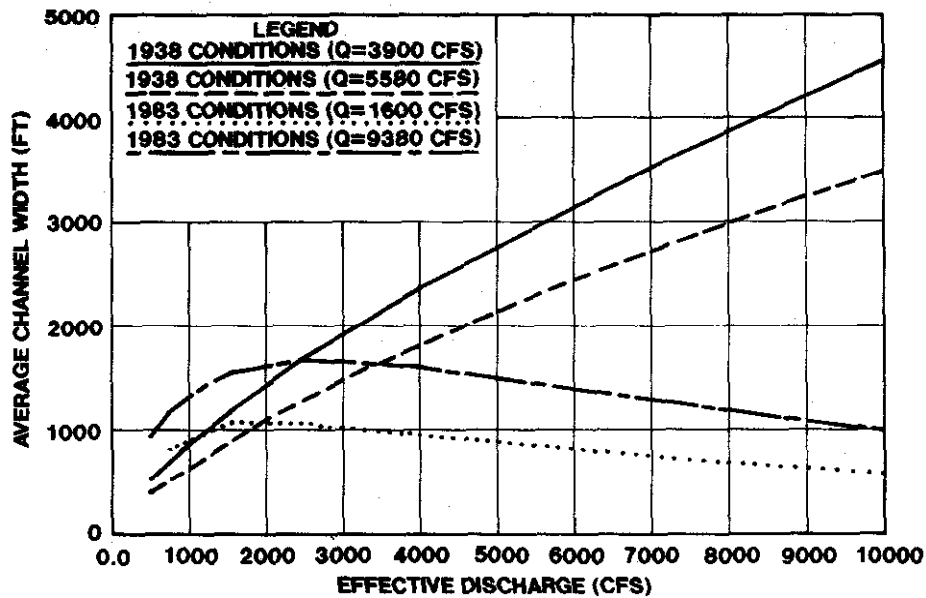


Figure 4. - Sensitivity of the Effective Discharge

Variation in Bed Material Size Gradation

The bed material size gradation, representing 1983 conditions, is the average of the eight medium-sized samples collected on the Platte River. The initial analysis was repeated for the 1983 period using finer bed material size distributions and the Velocity-Xi equation (table 2, group 4). One analysis was performed using the average of the seven finest bed material samples (D_{50} of 0.627 mm) and another analysis was performed using the same bed material size gradation associated with the 1938 conditions (D_{50} of 0.406 mm). Figure 5 shows that the results of the analysis can be sensitive to variations in bed material size gradation. Changing the bed material to a finer grain size distribution can eliminate the negative slope of the width-discharge curve representing the 1983 conditions. There was not much change in the width-discharge relationship when the D_{50} was changed from 0.802 mm to 0.627 mm. However, there was a noticeable change in the width-discharge curve when the D_{50} was changed from 0.627 mm to 0.406 mm. A threshold bed material size distribution may exist where all gradations coarser would yield a similar width-discharge relationship for a given sediment transport equation.

Figure 5 also shows the change in the width-discharge relationship for the 1938 and 1983 conditions due only to changes in the bed material load-discharge rating curves and changes in roughness coefficient. Even if the bed material size distribution had remained unchanged from 1938 to 1983, the rate of channel widening with increasing discharge is significantly less under 1983 conditions than under 1938 conditions.

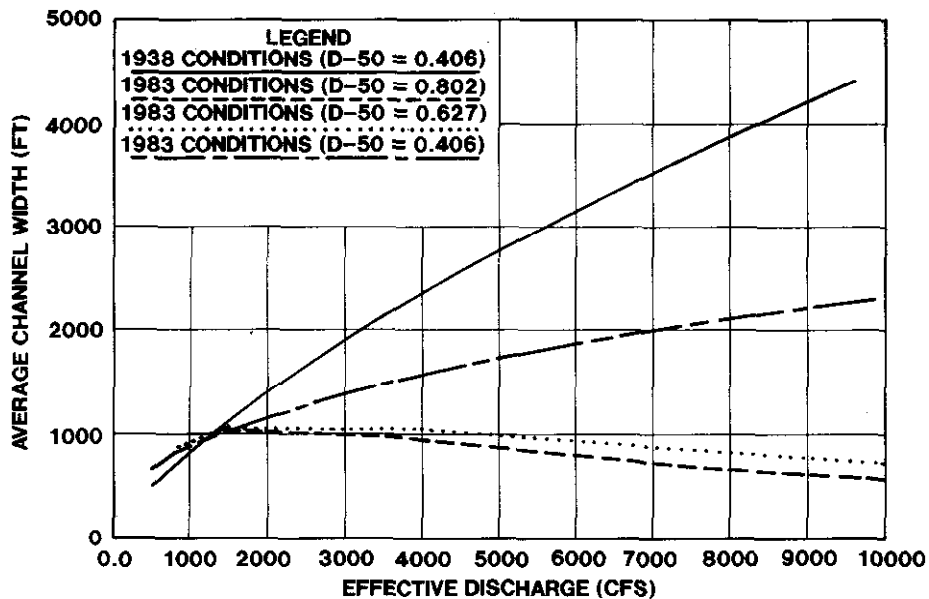


Figure 5. - Sensitivity of Bed Material Size Gradation

CONCLUSIONS

The initial width-discharge relationships shown in figure 2 for the Platte River near Overton are qualitatively correct.

Comparison of the width-discharge curves for the 1938 and 1983 conditions shows that the channel has primarily remained narrow due to a reduction in the bed material load supplied to the Platte River. The reduction in bed material load has also resulted in coarsening the bed with concurrent narrowing.

Changes in the hydrology in 1938 would cause changes in channel width. Because of the reduction in supply of sediments from 1938 to 1983, an increase in the effective discharge will not result in a substantial change in channel width. However, a decrease in the effective discharge would cause further narrowing of the channel under 1983 conditions.

This approach can be used to qualitatively predict the impacts of future changes in hydrology or sediment for specific reaches of the Platte River.

REFERENCES

- Lyons, J. K. and Randle, T. J., 1988, "Platte River Channel Characteristics in the Big Bend Reach," Bureau of Reclamation, Denver Office, Denver, CO, 29 p.
- Pemberton, Ernest L., 1972, "Einstein's Bed-Load Function Applied to Channel Design and Degradation," Sedimentation Symposium to Honor Professor H.A. Einstein, pp. 16-1 to 16-28, Colorado State University, Fort Collins, CO.
- Simons, D. B. and Senturk, Fuat, 1977, "Sediment Transport Technology," Water Resources Publications, Fort Collins, CO, pp 44.
- Yang, Chih Ted, 1973, "Incipient Motion and Sediment Transport," Journal of the Hydraulics Division, ASCE, vol. 99, No. HY10, pp. 1679-1704.