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December 1995

US Army Corps
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Waterways Experiment
Station

Sediment Impact Assessment, Carlsbad, New Mexico

by Ronald R. Copeland

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Prepared for U.S. Army Engineer District, Albuquerque

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Waterways Experiment Station
3909 Halls Ferry Road
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Final report

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Prepared for U.S. Army Engineer District, Albuquerque
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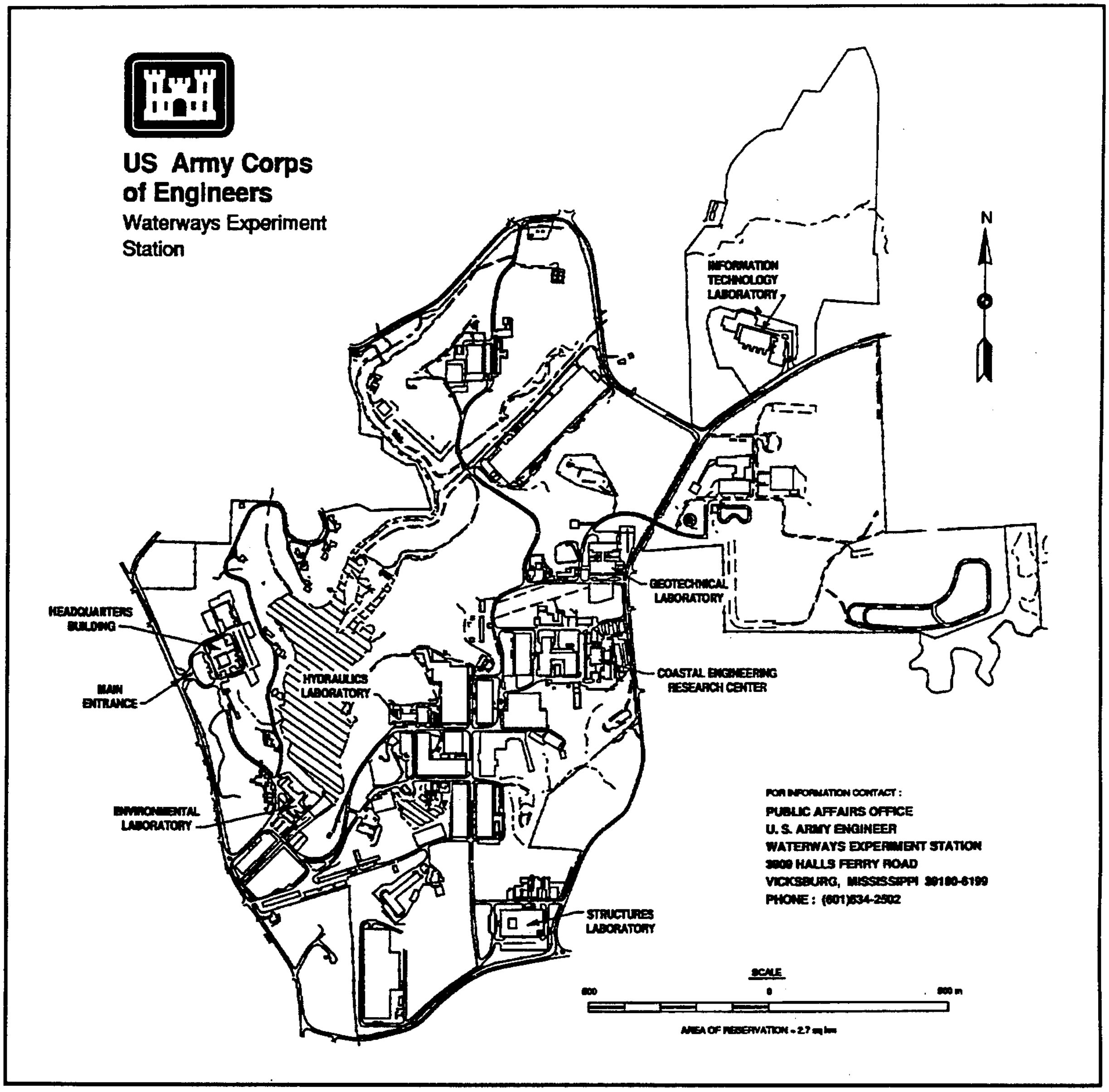

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Contents

Preface

This sediment impact assessment for the Pecos River and tributaries, near Carlsbad, NM, was conducted at the request of U.S. Army Engineer District, Albuquerque.

This investigation was conducted during the period November 1994 to February 1995 in the Hydraulics Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES), under the direction of Mr. Frank A. Herrmann, Jr., Director of the Hydraulics Laboratory, Mr. Richard A. Sager, Assistant Chief of the Hydraulics Laboratory, Dr. Larry L. Daggett, Acting Chief of the Waterways Division, Hydraulics Laboratory, Mr. William H. McAnally, Jr., Chief of the Waterways and Estuaries Division, Hydraulics Laboratory, and Mr. Michael J. Trawle, Chief of the Math Modeling Branch (MMB), Waterways Division. The project engineer for this study was Dr. Ronald R. Copeland, MMB, who also prepared this report. Technical assistance was provided by Mrs. Dinah N. McComas, MMB.

Mr. Bruce Beach served as the Hydraulic Project Engineer in the Albuquerque District and provided valuable contributions and review during the course of the study.

During the preparation and publication of this report, Dr. Robert W. Whalin was the Director of WES. COL Bruce K. Howard, EN, was the Commander.

Conversion Factors, Non-SI to SI units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acre-feet	4,046.873	cubic meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
inches	2.54	centimeters
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
pounds per square feet	47.88	Pascals
square miles	2.589998	square kilometers

1 Introduction

The city of Carlsbad is located on the Pecos River floodplain in southeastern New Mexico (Figure 1). The city has a population of about 25,000. The Pecos River Valley was one of the first U.S. Bureau of Reclamation irrigation projects; and irrigation structures significantly influence the characteristics of potential flooding in Carlsbad. Dams built on the Pecos River have effectively reduced the threat of flooding from the Pecos River itself. However, tributary streams still have the potential of providing sufficient runoff to produce flooding in Carlsbad. These tributaries include Rocky Arroyo, Dark Canyon Draw, and Hackberry Draw. Approximately 2,700 acres of urban land is contained in the Standard Project Flood floodplain. This includes much of the downtown business district and heavily populated residential areas.

At Carlsbad, the Pecos River has a drainage area of about 18,000 mi^2. Flood peaks on the Pecos River are reduced by a series of dams, including: Santa Rosa Dam, located 297 river miles upstream from Carlsbad; Sumner Dam, located 242 river miles upstream from Carlsbad; Brantley Dam, located 19 miles upstream from Carlsbad; and Avalon Dam located 7 miles upstream from Carlsbad (Figure 2). Brantley Dam effectively controls the Standard Project Flood from the Pecos River.

Rocky Arroyo enters the Pecos River 15 miles upstream from Carlsbad. The confluence is downstream from Brantley Dam and upstream from Avalon Dam. Avalon Dam has little flood control storage and floods from Rocky Arroyo will pass through Lake Avalon with little attenuation. Rocky Arroyo is the primary source of potential flooding in the City of Carlsbad from the Pecos River.

Two low head dams have been constructed on the Pecos River through the city of Carlsbad. These were initially constructed for hydropower production, but now provide recreation lakes along a four-mile reach. Upper Tansill Dam is located about one-half mile upstream from Highway 62; and Lower Tansill

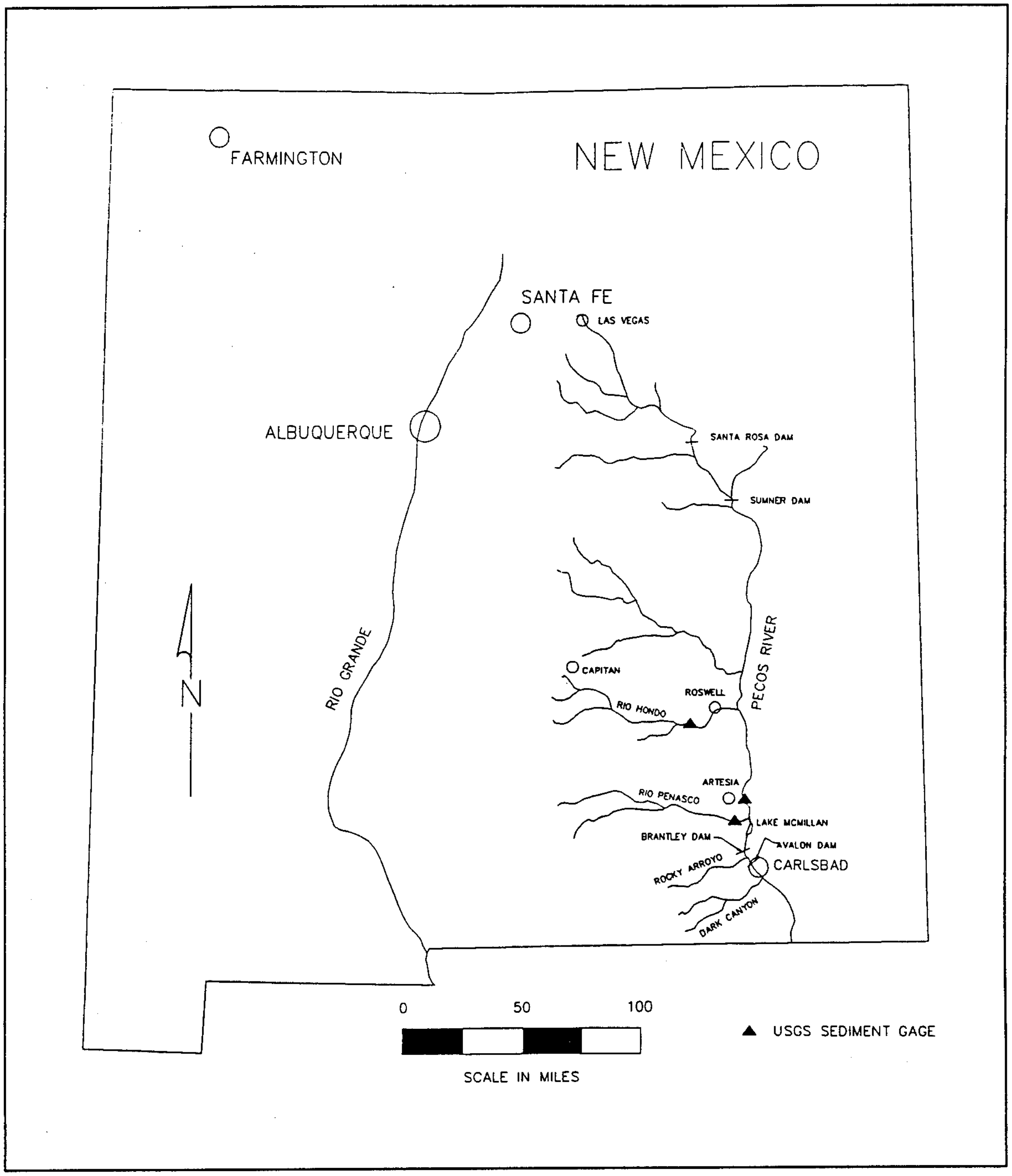


Figure 1. Vicinity map

Dam is located about one-half mile below Highway 62. Recreational development in the floodplain, and in the lakes themselves, have reduced channel capacity and increased the flood damage potential.

Dark Canyon Draw enters the Pecos River 0.7 mile downstream from Lower Tansill Dam. Floods on Dark Canyon Draw are flashy - characterized by high peaks and short durations. Potential flood flows from Dark Canyon

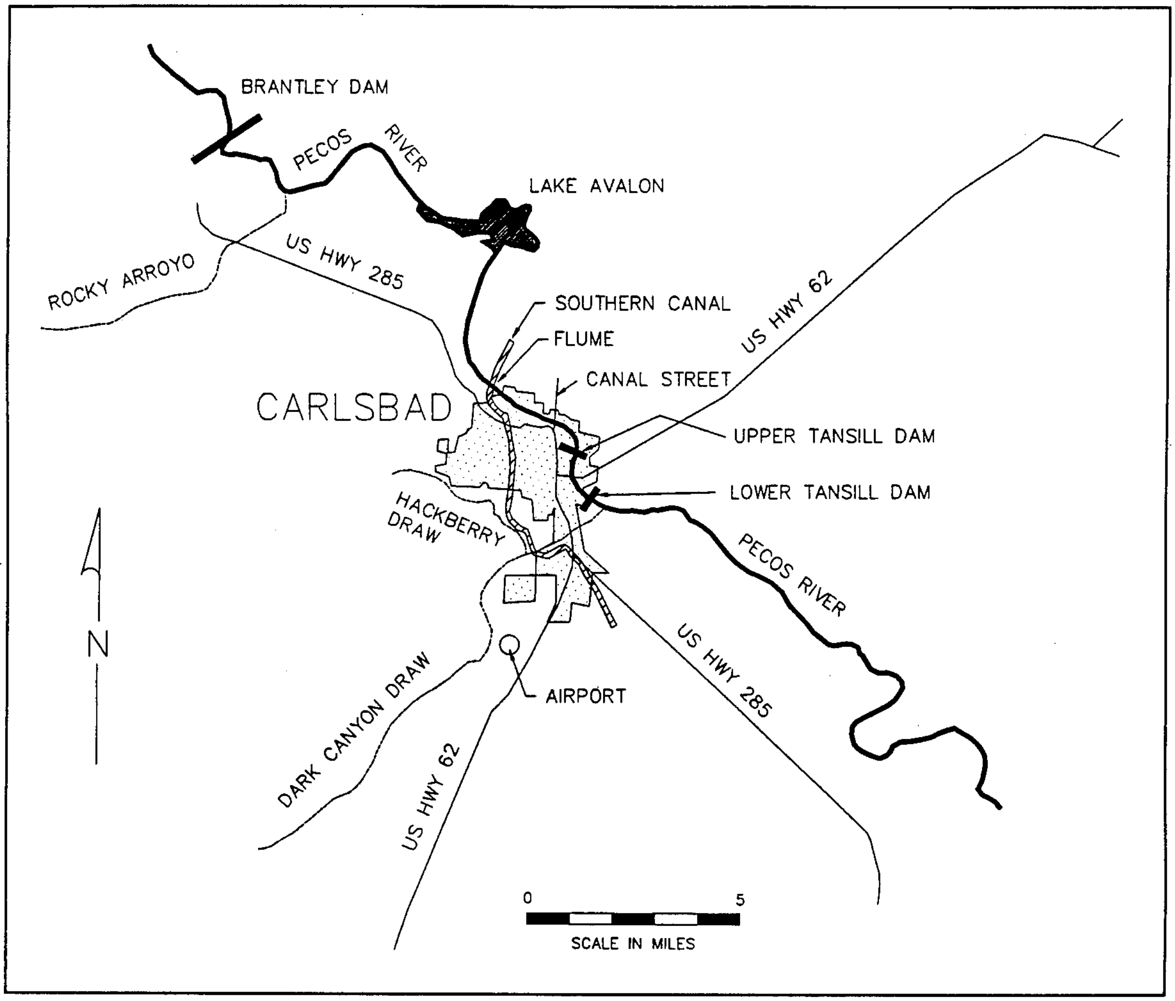


Figure 2. Location map

Draw would have about the same magnitude and would be relatively coincident with flood flows on the Pecos River generated from Rocky Arroyo. Therefore, runoff from Dark Canyon Draw would create a backwater on the Pecos River, inducing flooding in Carlsbad. The potential for additional flooding exists along Dark Canyon Draw itself as it passes through the southern part of the City of Carlsbad.

Hackberry Draw is a tributary of Dark Canyon Draw. Its natural runoff path has been cut off by the Southern Canal embankment, which acts as a diversion levee diverting flow into Dark Canyon Draw about 1.3 miles upstream from its confluence with the Pecos River. The Soil Conservation Service has constructed three flood detention basins in the watershed, one of which had to be breached due to the development of sinkholes at the structure. The detention basins were designed to provide protection for the 2-percent chance exceedance flood. The potential for flooding exists from Hackberry Draw if the canal embankment is washed out or overtopped.

Purpose

This sediment impact assessment was conducted as part of the reconnaissance level planning study for Carlsbad, New Mexico. The purpose of the sediment impact assessment is to identify the magnitude of possible sediment problems that might be associated with the proposed project. Recommendations are made for appropriate sediment studies at the next level of planning study. The sediment impact assessment provides an inventory of available sediment data and recommends data collection programs. Sediment impacts are generally determined at the reconnaissance level by comparing sediment transport and sediment yields for existing conditions and project conditions. However, in this study project conditions were unavailable. Therefore, a range of bed-material sediment yields were calculated using different sediment transport equations to obtain an idea of the magnitude of possible sediment deposition and/or erosion problems. Bed-material sediment transport was calculated using techniques based on uniform flow assumptions. Hydraulic parameters were determined from reach averaged values. The SAM hydraulic design package was used to make the calculations. In addition, total sediment yield was calculated to assess reservoir sediment storage requirements. This was accomplished using a regional regression equation. The regression equation was compared to measured deposition in reservoirs in the Pecos River watershed and to calculated average annual total sediment yields from sediment gaging stations in the Pecos River watershed.

Proposed Flood Control Alternatives

Flood Control alternatives to alleviate flooding in the city of Carlsbad include flood retention reservoirs, diversion channels, and channel improvements. Flood detention structures are being considered for both Dark Canyon Draw and Rocky Arroyo. Diversion channels are also being considered for Dark Canyon Draw and Rocky Arroyo. The Rocky Arroyo diversion channel would divert flow into Brantley Reservoir. The Dark Canyon Draw diversion channel would divert flow from Dark Canyon Draw, near the city airport, into the Pecos River, about five miles downstream from Carlsbad. Improvements on the Pecos River include replacement of the existing low dams with inflatable rubber dams, and channel improvements downstream from Dark Canyon Draw. Flood control alternatives for Hackberry Draw include enlarging the existing diversion channel, and improvements to the diversion levee to prevent overtopping and erosion.

2 Sediment Impact Assessment

Field Reconnaissance

A preliminary assessment of channel stability and potential sediment impacts were determined during a two day field reconnaissance in October 1994. The field reconnaissance was conducted by Dr. Ronald R. Copeland of the Waterways Experiment Station and Mr. Bruce Beach of the Albuquerque District. The field reconnaissance included site visits to the Dark Canyon Draw and Rocky Arroyo dam sites; the USGS gages on Dark Canyon Draw, Rocky Arroyo, and the Pecos River downstream from Dark Canyon Draw; and selected locations along the subject streams. This brief reconnaissance provided insight for general observations related to channel stability.

All of the channels in the study area appeared to be in a state of non-equilibrium. Rocky Arroyo and Dark Canyon Draw are incising. Extensive gravel mining, over a period of many years, has contributed to this incision. Gravel mining is currently active in the lower reaches of Dark Canyon Draw between the Pecos River and the city airport. Evidence of both very recent and older gravel mining was also observed near the mouth of Rocky Arroyo. The bed surfaces of Dark Canyon Draw and Rocky Arroyo consist primarily of coarse gravel and cobbles. Banks are generally composed of loose alluvial material ranging in size from clays and silts to boulders. The channels tend to migrate laterally, eroding banks and creating remnant gravel bars in former channels. Armoring is generally observed in the existing low-flow channel, however, at high flows the channel will migrate, mobilizing significant sediment from the gravel bars and from bank erosion. Hackberry Draw is a shaped trapezoidal channel with unprotected banks. Significant bank erosion is expected at high flows in this channel. The flow regime in the Pecos River has been drastically altered by the construction of dams beginning in 1891. Dams cut off the bed-material sediment load which typically induces degradation and armoring downstream. Reducing the peak flood discharges with reservoir storage tends to dampen this degradation trend. A distinct degradation trend was not observed during the brief field reconnaissance. In fact, it appears that reduced discharges downstream from the dams have allowed deltas to form at the mouths of Rocky Arroyo and Dark Canyon Draw. These deltas have pushed the Pecos River against hard left banks, and appear to have increased river bed elevations upstream.

Bed-material samples were collected for use in the sediment impact assessment during the field reconnaissance. Due to the limited scope of the sediment impact assessment, only a few samples were collected. Surface and subsurface samples were collected at the proposed dam sites on Dark Canyon Draw and Rocky Arroyo. A sample was collected from a mixed gravel bar located about one mile downstream from the canyon mouth of Dark Canyon Draw. Samples were collected at the USGS gages on Rocky Arroyo and on the Pecos River downstream from Dark Canyon Draw. A sample was collected from Hackberry Draw just upstream from the Southern Canal. Bed-material gradations determined from these samples are shown in Figures 3-6. In general, the channel beds consisted primarily of gravels and cobbles with a coarse surface layer consisting primarily of cobbles. The bed-material sampled in Hackberry Draw was finer, consisting primarily of coarse sand and gravel. Surface gradations were determined using the Wolman (1954) pebble count method. With this method, 100 pebbles are chosen in a random fashion from the bed and measured in the field. Sub-surface gradations were determined using either a pebble count or by sieving a sample collected with a shovel after the surface layer was removed.

Hydrology

Hydrographs used in the sediment impact assessment were developed by the Albuquerque District using the HEC-1 hydrograph package. These were used to calculated sediment yield for flood events. Hydrographs for the Pecos River, Rocky Arroyo, Dark Canyon Draw, and Hackberry Draw were provided. One-percent chance exceedance hydrographs for Dark Canyon Draw and Rocky Arroyo are shown in Figures 7 and 8.

Flow durations curves were developed from USGS mean daily flow records. These were used to determine average annual sediment yield. Flow duration curves were developed from 18 years of record at the Dark Canyon at Carlsbad gage; 29 years of record from the Rocky Arroyo at Highway 285 gage; and 55 combined years of record from the Pecos River at Carlsbad and Pecos River below Avalon Dam gages. Flow duration curves are shown in Figures 9-11.

Sediment Yield

Total sediment yield estimates are needed to provide sediment storage capacity in the proposed dams on Rocky Arroyo and Dark Canyon Draw. Total sediment yield includes all size classes of sediment. Sediment yield

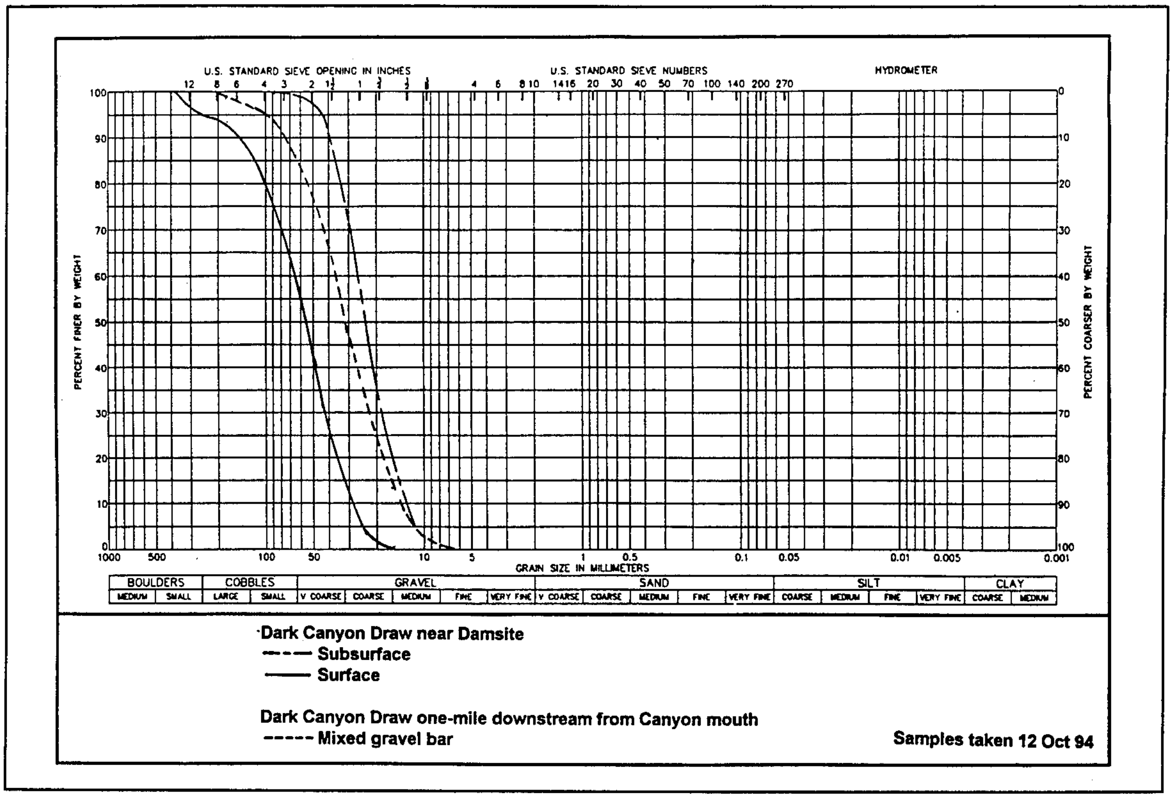


Figure 3. Bed-material gradations - Dark Canyon Draw

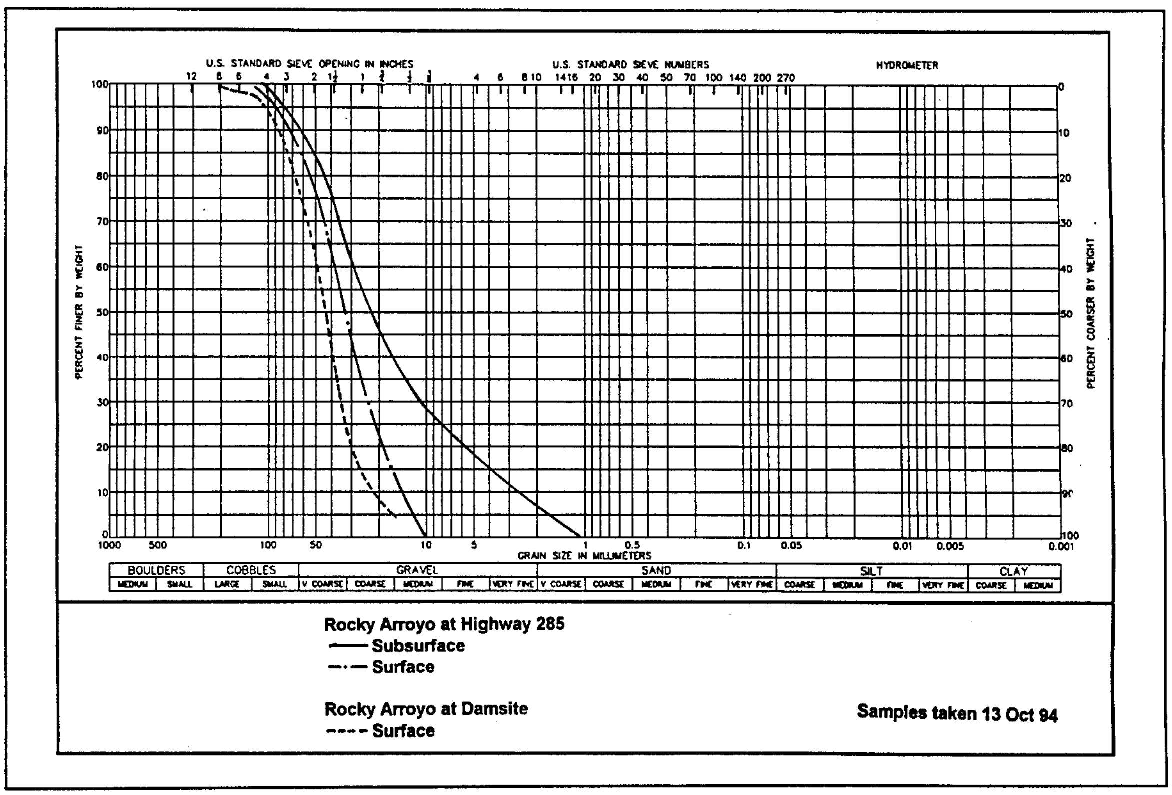
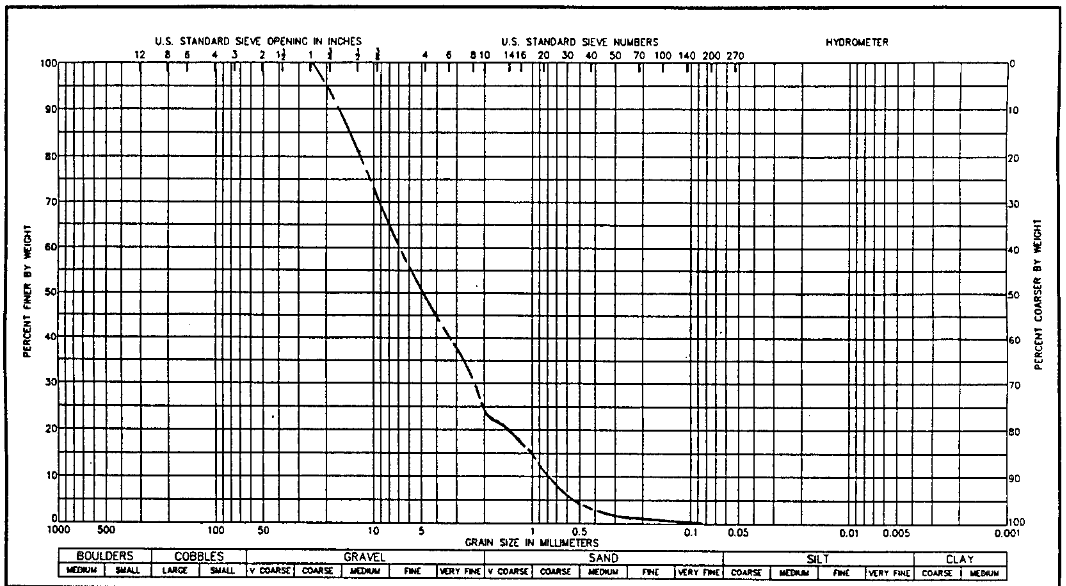


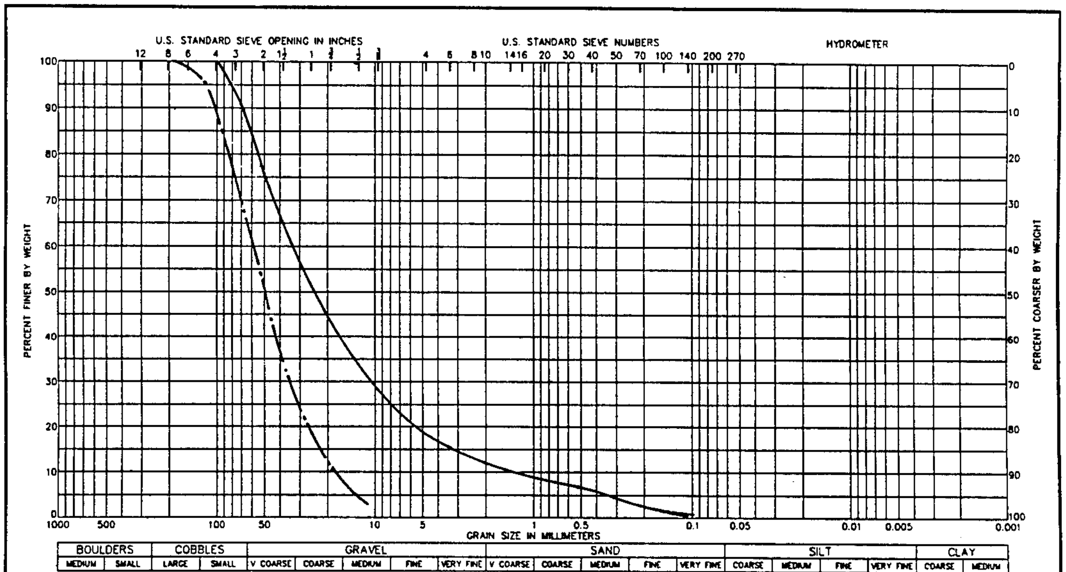
Figure 4. Bed-material gradations - Rocky Arroyo



Hackberry Draw just upstream from Southern Canal

Samples taken 13 Oct 94

Figure 5. Bed-material gradations - Hackberry Draw



Pecos River at USGS gage downstream from Dark Canyon Draw
——— Subsurface
—·— Surface

Samples taken 13 Oct 94

Figure 6. Bed-material gradations - Pecos River at USGS gage downstream from Dark Canyon Draw

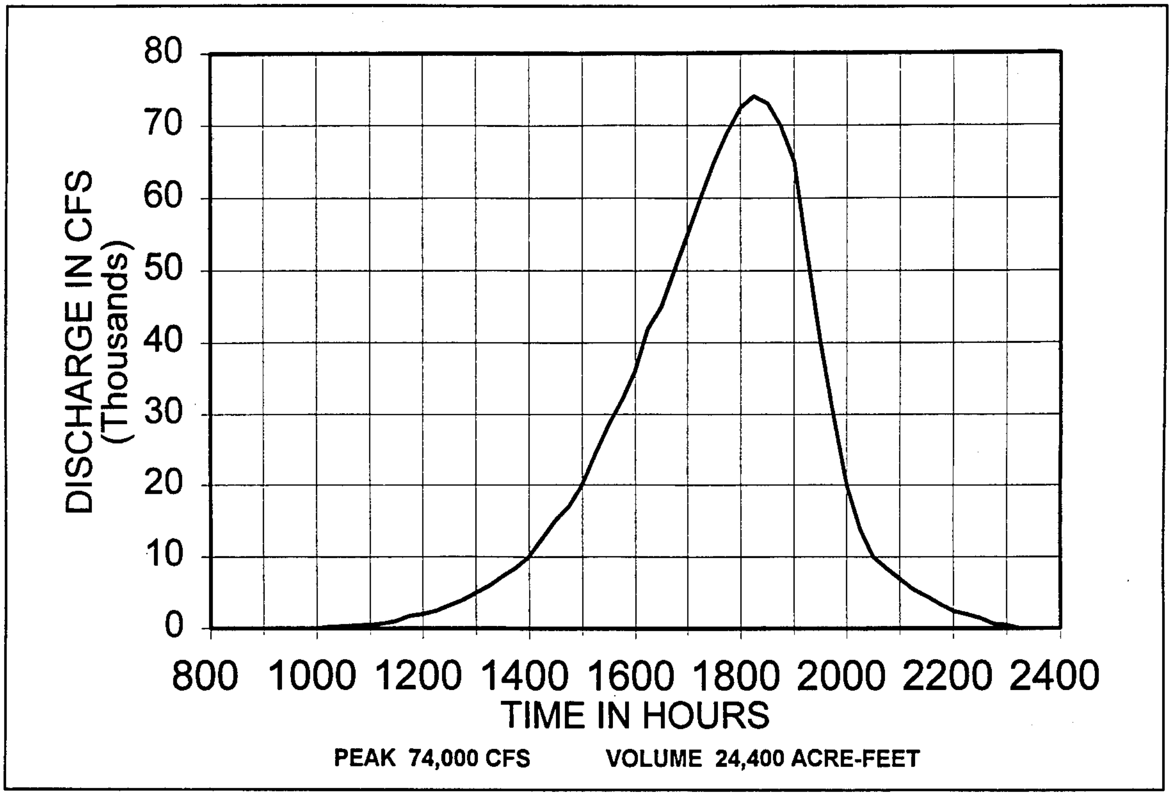


Figure 7. One-percent chance exceedance hydrograph - Dark Canyon Draw

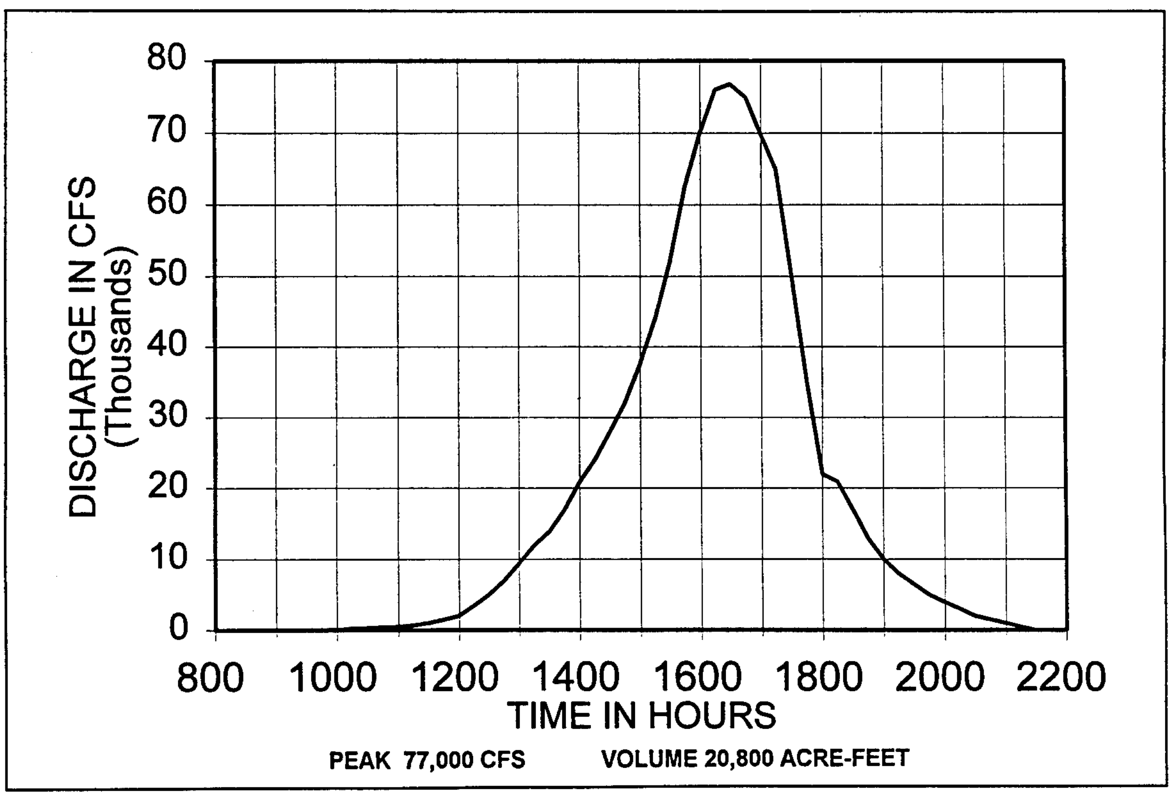


Figure 8. One-percent chance exceedance hydrograph - Rocky Arroyo

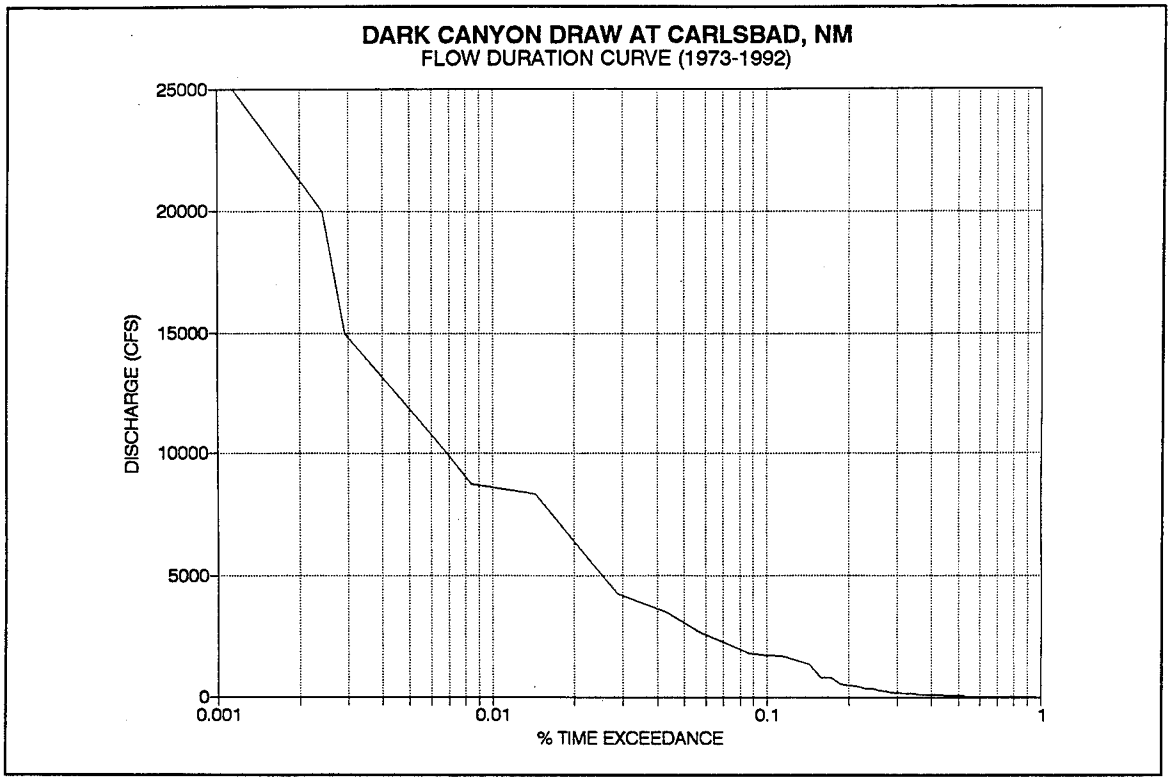


Figure 9. Flow duration curve-Dark Canyon Draw at Carlsbad

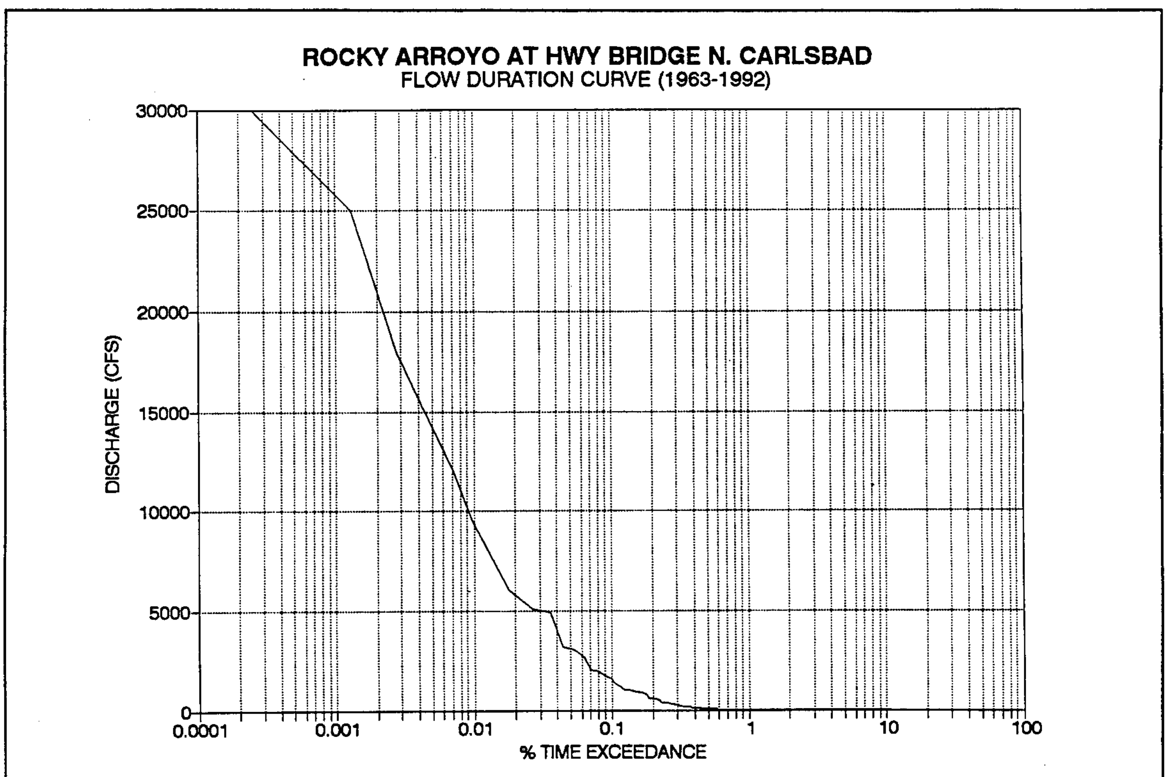


Figure 10. Flow duration curve - Rocky Arroyo at Highway Bridge near Carlsbad

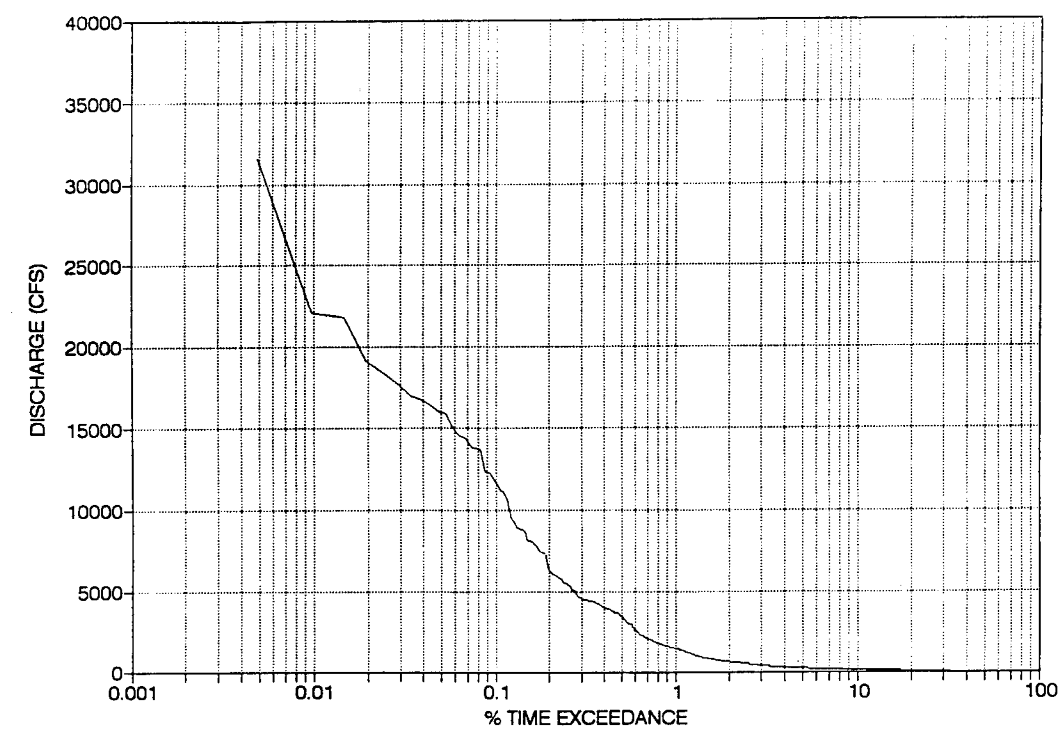


Figure 11. Flow duration curve - Pecos River

from a basin is a function of both watershed and channel characteristics. Typically, most of the sediment yield is produced from the watershed and from bank erosion. It consists primarily of finer sediment sizes that remain in suspension, and therefore, correlates poorly with the hydraulic characteristics of the stream. Total sediment yield is best determined using deposition surveys in reservoirs or from suspended sediment measurements.

Regional regression equations may be used to estimate average annual total sediment yield. The U.S. Bureau of Reclamation used such a technique for the Rio Penasco (USBR 1994). The Rio Penasco flows easterly into the Pecos River, as does Rocky Arroyo and Dark Canyon Draw. Its confluence with the Pecos River is located 36 miles upstream from Carlsbad. The USBR regression equation is based on reservoir deposition surveys from 28 reservoirs in the semi-arid southwestern United States (Strand and Pemberton 1982). The equation is:

$$QS = \frac{1.84}{A^{0.24}} \qquad (1)$$

Where *QS* is the total sediment yield in acre-feet/mi^2/year, and *A* is the sediment contributing drainage area in square miles. Since this regression equation was developed from reservoir sedimentation surveys, the trap efficiency of the reservoirs is not considered. Total sediment yield would be higher because trap efficiency is seldom 100 percent. Using this equation, average annual sediment yield was calculated for Rocky Arroyo and Dark Canyon Draw and is shown in the following tabulation.

Estimated Average Annual Total Sediment Yield Using USBR Regression Equation

	Drainage Area square miles	Sediment Yield ac-ft/mi^2/yr	Sediment Yield ac-ft/yr
Rocky Arroyo	246	0.49	120
Dark Canyon Draw	317	0.46	150

The applicability of the USBR regression equation was assessed using measured data from other reservoirs in the Pecos River drainage basin (Subcommittee on Sedimentation 1983, 1992; USDA-ARS 1978) and from measured suspended sediment data. Total sediment yield calculated from these data are plotted with the USBR regression curve in Figure 12. Most of the surveyed reservoirs were located near Capitan, New Mexico; one reservoir was near Las Vegas, New Mexico. Survey data was also available for Sumner and McMillan Reservoirs, on the Pecos River. Drainage areas for Sumner and McMillan Reservoirs were adjusted to account for reductions in contributing area due to upstream reservoirs. Sediment yields for the Pecos River near Artesia, New Mexico (44 river miles upstream from Carlsbad); the Rio Penasco near Dayton, New Mexico; and the Rio Hondo at Diamond A Ranch near Roswell, New Mexico were calculated using the flow-duration sediment-discharge rating curve method described in EM 1110-2-4000 (HQUSACE 1989, p 3-4). The confluences of the Rio Penasco and Rio Hondo with the Pecos River are located 36 and 106 miles upstream from Carlsbad, respectively. Suspended-sediment measurements are available for the Pecos River near Artesia between 1952 and 1978, for the Rio Penasco between 1952 and 1972, and for the Rio Hondo between 1952 and 1958. These measurements were used to develop total sediment load rating curves for each river. Flow duration curves were developed from the mean daily flow records at these gages; the maximum discharge of record was included in the curve at the zero percent exceedance point. The SAM hydraulic design package was used to integrate the sediment-discharge rating curves and the flow-duration curves. A sediment deposit specific weight of 70 lbs / ft^3 was assigned. Total average annual sediment yield per square mile from these calculations are plotted on Figure 12. Tabulated data used to determine average annual sediment yields are listed in Table 1.

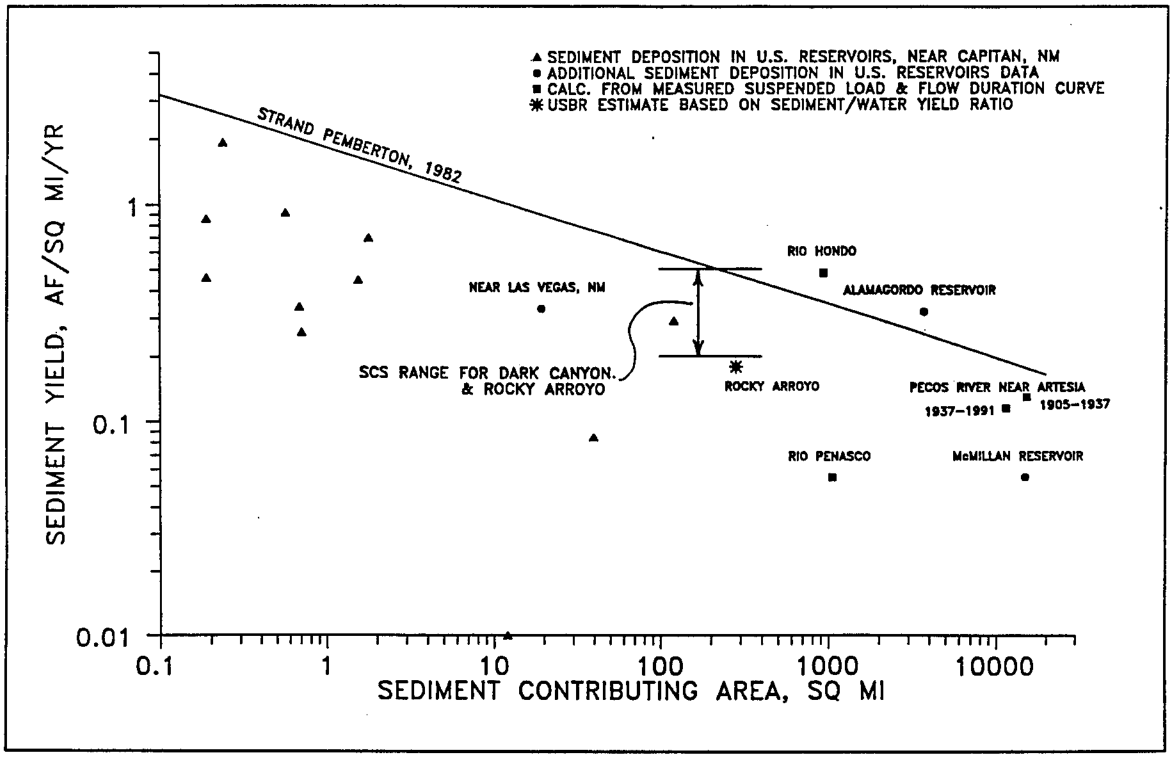


Figure 12. Total sediment yield - Pecos River Basin

The USBR estimated total sediment yield for Rocky Arroyo for the 14 years between 1979 and 1993. This estimate was based on the ratio method using data from Rio Penasco. With the ratio method, the ratio of average annual sediment yield to average annual water yield is determined for a watershed with both runoff and sediment data. This ratio is then multiplied times the annual water yield of a watershed with only runoff data to obtain annual sediment yields. Transposing a sediment yield ratio from one watershed to another ignores the effect of drainage basin size on the ratio and therefore, results can only be considered approximate. The USBR sediment yield estimate for Rocky Arroyo was 0.18 ac-ft/mi^2/yr and is plotted on Figure 12.

The Soil Conservation Service (USDA 1974) developed a generalized sediment yield map of the western United States for planning purposes. This map indicates that the annual total sediment yield for Rocky Arroyo and Dark Canyon Draw should be between 0.2 and 0.5 acre-ft/mi^2 . This range is indicated on Figure 12.

The reservoir surveys and measured suspended sediment data, for the Pecos River basin, indicates that the USBR regression curve may produce sediment yields too high for Rocky Arroyo and Dark Canyon Draw. More detailed investigations may result in lower calculated sediment yields. Detailed investigations of the watershed characteristics should be conducted in order to apply one of the several available sediment yield methods. Watershed characteristics of the Rio Penasco and the Rio Hondo should also be established to determine if these basins are similar enough to Rocky Arroyo and Dark Canyon Draw so that the measured suspended data may be used to refine the sediment yield estimates.

Dark Canyon Draw

Extensive gravel mining has occurred in the lower reaches of Dark Canyon over many years. The channel has been altered between the Pecos River confluence and the Carlsbad Airport. The channel also shows signs of incision/degradation upstream from the Airport. The bed and banks of the incised channel are capable of supplying significant quantities of sediment to the stream.

Bed-material gradations were determined at the Dark Canyon Draw dam site, and from a gravel bar located about one mile downstream from the canyon mouth. The bed-material consisted primarily of gravels and cobbles, and the Wolman (1954) pebble count method was used to sample the bed. Surface and subsurface gradations were determined at the dam site. There was no coarse surface layer at the downstream bed-material sampling site; indicating that active layer mixing was occurring during the last flow event in Dark Canyon Draw. Median grain size ranged between 22 and 55 mm. The gradation determined at the downstream site was selected as the representative gradation for this sediment impact assessment.

Two alternative proposals for flood control improvement on Dark Canyon Draw are under consideration. One is to construct a flood retention reservoir to reduce peak discharges; the other is to divert the entire channel away from the city of Carlsbad. The diversion would begin near the city airport and flow northeasterly to the Pecos River to a location about five miles below Carlsbad. Sediment considerations for the reservoir include sediment storage requirements behind the dam and the effect of reducing the bed-material sediment supply to the downstream channel. Sediment considerations for the diversion include the possibility of sediment deposition at the diversion channel entrance, and the stability of the diversion channel itself. A third alternative would be to construct a bypass channel for high flows along the route of the proposed diversion channel. Sediment considerations for this alternative would be stability of the bypass channel and the effect of reduced sediment carrying capacity of the channel downstream from the bypass during peak flows.

Sedimentation Concerns with a Reservoir

Determination of reservoir sediment storage is calculated from the estimated average annual total sediment yield. This sediment yield is for the total range of sediment sizes carried by the arroyo. For this reconnaissance level study, sediment yield is determined from the USBR regional sediment yield regression equation (Strand and Pemberton 1982). This method has been used by the USBR for similar studies in the Carlsbad area and for the sake of consistency is adopted herein. Average annual yield for Dark Canyon Draw at the dam site is 150 ac-ft/yr.

The sediment trap efficiency of the flood control reservoir will effect the requirements for sediment storage. Reservoir capacities and outlet release schedules have not been determined as yet, so trap efficiency cannot be calculated. The Brune-Dendy method outlined in EM 1110-2-4000 can be used to determine trap efficiency for the proposed reservoir. The method should be modified to treat a single storm event rather than average annual conditions. This calculation should be conducted at the next level of planning study.

An analysis of additional sediment data from the region, suggests that the estimated sediment yield from the regional regression equation may be on the high side. Analysis of the measured sediment data from nearby Rio Penasco indicates that a significantly lower total sediment yield may be appropriate. This hypothesis is supported by several reservoir deposition surveys in the Pecos River watershed. However, the regional regression equation does closely predict sediment yield rates from the Rio Hondo which is a somewhat more distant watershed. A comparative watershed investigation of the Rio Penasco, Rio Hondo, and Dark Canyon Draw could provide justification for reducing the preliminary sediment yield estimate. Application of the PSIAC (1968) sediment yield method is one way to assess the relative sediment yield potentials of the subject watersheds.

The construction of a flood-control reservoir may reduce downstream channel stability by eliminating the supply of bed-material sediment thus inducing degradation. This destabilizing effect is partially compensated for by reducing the magnitude of peak flood discharges. The bed-material of Dark Canyon Draw consists primarily of gravel and cobbles, so that if flows are reduced sufficiently, degradation will be very limited. Outlet release schedules were not available for this study, so this effect could not be determined. At the next level of planning study, potential for degradation can be assessed using threshold velocity criteria from EM 1110-2-1418. With a median bed-material size of about 30 mm and a water depth of five feet, a threshold velocity up to six ft/sec would be appropriate for channel stability considerations. If the threshold velocity is exceeded, degradation can be expected. The extent of degradation can be estimated using the HEC-6 numerical sedimentation model.

Diversion Channel

The proposed diversion channel has the most potential for sedimentation and channel stability problems. Depending on the diversion channel design, several problems could occur. If a threshold channel is constructed - that is, a channel designed with little or no sediment transport potential - bed-material delivered from upstream will deposit at the diversion entrance.

Sediment deposits will have to be removed periodically . If a channel is designed to carry the incoming sediment load, there will be a period of adjustment for the channel, as the bed and banks become established. Bed armoring may progress quickly or slowly, with extensive degradation, depending on the consistency of the material through which the diversion channel is cut and the sequence of annual runoff that occurs.

The bed-material sediment yield of Dark Canyon Draw is important when considering sediment transport and channel stability questions. The bed-material sediment load consists of the sediment sizes that exchange with the streambed as it is transported downstream. The bed-material yield is relatively small compared to the total sediment yield as the bed of Dark Canyon Draw consists primary of gravels and cobbles. The wash load component of the total sediment yield will be transported through the system to the Pecos River, unless it is trapped by a reservoir or introduced into a ponded area. The magnitude of potential aggradation or deposition problems in the Dark Canyon channel can be determined by calculating bed-material sediment yield through a typical reach of the channel. The typical reach chosen for this analysis is about two miles long and is located adjacent to the Carlsbad Airport. The reach is considered to be in a state of non-equilibrium due to its proximity to gravel mining operations. A reach further upstream, less influenced by gravel mining operations, would be preferred for determining long-term sediment yield. However, the existing backwater model does not extend any further upstream. Additional upstream cross-section surveys should be included in more detailed sediment studies.

Average values for hydraulic variables were determined for a range of discharges using the reach-length weighted averaging procedure in the SAM hydraulic design package. Hydraulic variables at cross-sections were calculated from a HEC-2 numerical model prepared by the Albuquerque District.

Sediment transport was calculated using several sediment-transport equations available in the SAM program. The equations chosen were equations that included at least some data from gravel-bed rivers in their development. As can be seen from the sediment-discharge rating curves, shown in Figure 13, there is a wide range in predicted sediment transport. There are no available data on Dark Canyon Draw to aid in the selection of a transport equation. However, the guidance program in the SAM hydraulic design package identified the North Saskatchewan and Elbow Rivers in Saskatchewan, Canada, as having a similar median bed grain size, depth, velocity, and slope as Dark Canyon Draw at high flow. The guidance program determined from the available set of equations in the guidance program that the Schoklitsch equation (Shulits 1935) best reproduced measured data on the North Saskatchewan and Elbow Rivers. Based on the comparison of calculated sediment transport rating curves using different sediment transport functions shown in Figure 13, the Schoklitsch equation will produce a relatively low sediment yield. In order to cover the uncertainty range in the calculated bed-material sediment yield, two additional sediment-transport equations were chosen to calculate yield. The Parker equation

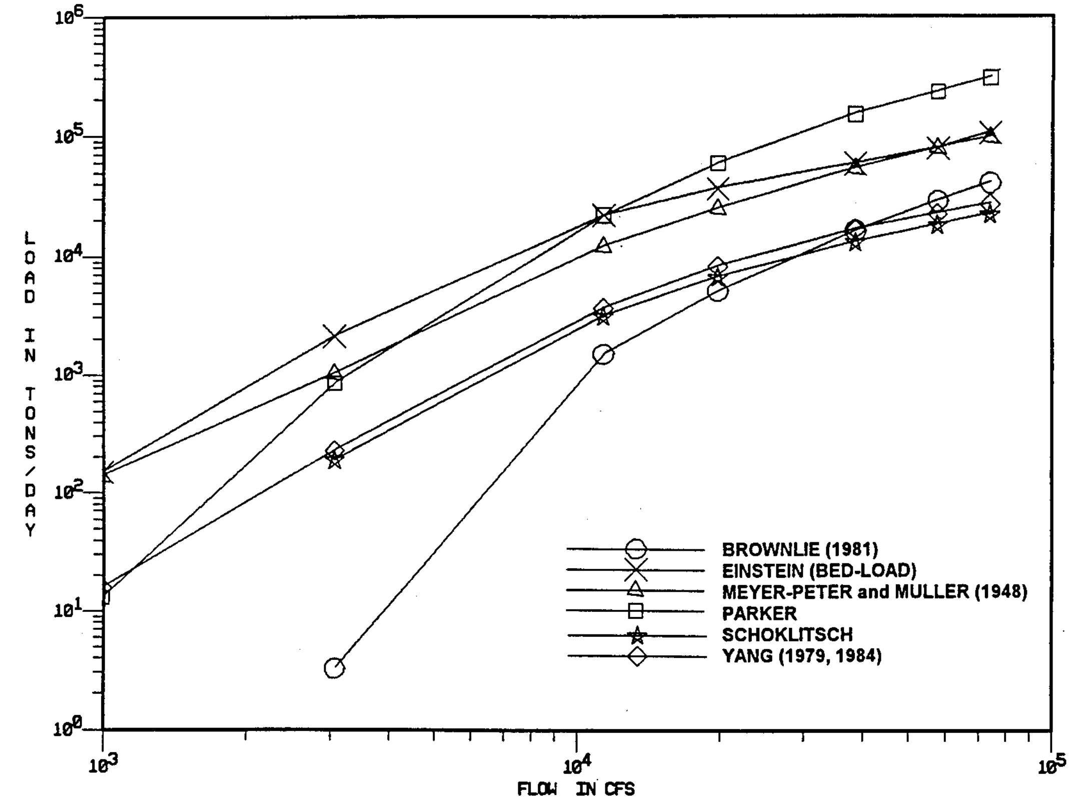


Figure 13. Bed-material sediment-transport rating curves - Dark Canyon Draw

(Parker 1990) was used to represent a high sediment transport rate, and the Einstein (1950) equation was chosen to represent an intermediate sediment transport rate.

Bed-material sediment yield was calculated using the flow-duration sediment transport curve method. Sediment yields were calculated for the one-percent and ten-percent chance exceedance floods, and for average annual conditions. The one-percent chance hydrograph was calculated by the Albuquerque District using the HEC-1 hydrograph package. The peak discharge was 75,000 cfs. The ten-percent chance exceedance hydrograph was assumed to have the same shape as the one-percent chance exceedance flood; discharges on the hydrograph were calculated by multiplying the one-percent chance exceedance hydrograph by the ratio of the peaks. The ten-percent chance exceedance peak discharge was 20,000 cfs. Average annual sediment yield was calculated using a flow duration curve developed using mean daily flows from 18 years of record at the USGS gage at Dark Canyon Draw. Durations of published peak flows greater than the maximum mean daily flow were added to the flow duration data by assuming the historical flood hydrographs had shapes similar to the one-percent change exceedance hydrograph. Bed-material sediment yields calculated using three different sediment transport equations are listed in the following tabulation.

Calculated Bed-Material Sediment Yield Dark Canyon Draw			
	Sediment Yield - Cubic yards[1]		
Sediment Transport Function	One-percent exceedance flood 70,000 cfs	Ten-percent exceedance flood 20,000 cfs	Average Annual
Schoklitsch	3,100	690	230
Einstein	14,800	4,300	1,700
Parker	36,200	5,400	1,500

[1]Sediment yield volume calculated assuming specific weight of deposit of 93 lbs/ft^3

The calculated bed-material sediment yield can be used to assess the magnitude of aggradation/degradation problems. For example, quantities from the above table may be used to estimate deposits that would occur at the entrance to a diversion channel designed for threshold conditions. A diversion channel designed to carry some of the inflowing bed-material load would deposit only a portion of the quantities tabulated above.

Typically, sediment impacts of alternative flood control measures are evaluated in the reconnaissance level planning study. However, alternative designs for a diversion or bypass channel were unavailable at the time this sediment impact assessment was conducted. Therefore, an example diversion channel design for Dark Canyon Draw was developed, and a sediment budget analysis preformed. A similar methodology can be used when alternative designs are developed by Albuquerque District.

The stable channel method in the SAM hydraulic package was used to develop dimensions for the example diversion channel. The criteria chosen for the diversion channel design were; 1) a composite channel geometry with a low flow channel designed to carry the effective discharge, and 2) the rest of the channel designed to carry the one-percent chance exceedance flood with a velocity of less than 6 ft/sec on the overbank. Assigned side slopes were 1V:3H, with a side slope Manning's roughness coefficient of 0.05. The effective discharge is the discharge that transports the largest percentage of the bed-material sediment load. This was determined by integrating the flow duration curve for Dark Canyon Draw and a sediment-transport rating curve developed using the Einstein formula. A plot of percentage of bed-material load versus discharge increment is shown in Figure 14; an effective discharge of 8500 cfs was indicated.

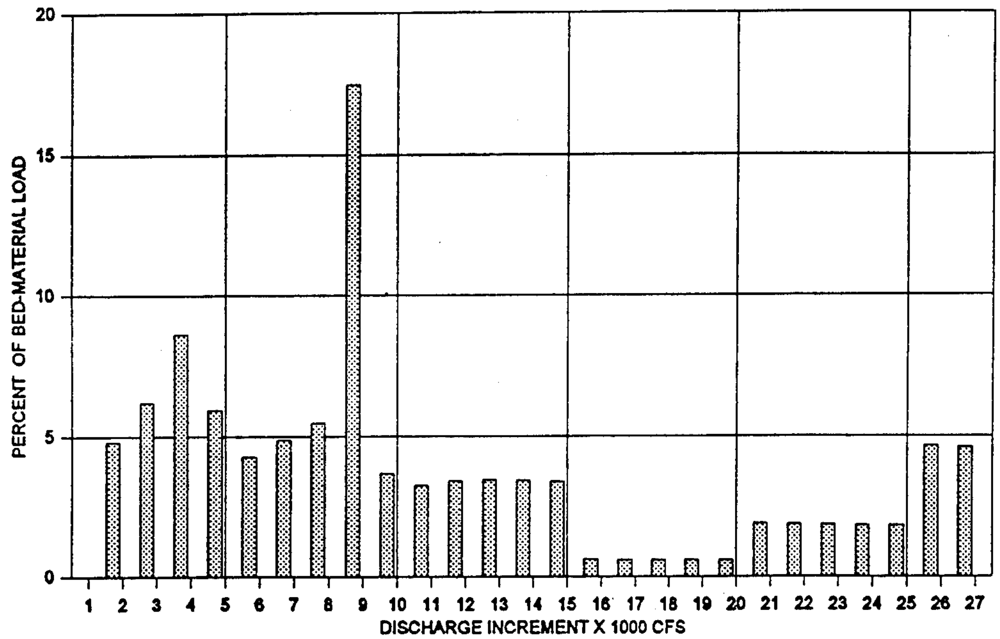


Figure 14. Effective discharge - Dark Canyon Draw

The stable-channel design method in the SAM hydraulic design package was used to size the low-flow channel. This method provides channel dimensions that will transport the incoming bed-material sediment load for a specified discharge. The method uses the Brownlie (1981) equation to calculate sediment transport and roughness on the channel bed. This equation was not developed for gravel-bed streams, and predicts lower sediment transport rates, for the effective discharge in Dark Canyon Draw, than other tested equations (Figure 13). This apparent deficiency in the sediment-transport equation is accounted for later by testing the resultant cross-section geometry using other transport equations. The inflowing sediment load was determined from the reach averaged hydraulic parameters in the reach of Dark Canyon Draw adjacent to the airport. The bed-material gradation in the diversion channel was assumed to be the same as in Dark Canyon Draw. This is a reasonable assumption for the long-term condition in the diversion channel, but not for initial conditions. The transition from initial to final conditions would have to be determined using a numerical model such as HEC-6. The average slope between Dark Canyon Draw at the airport and the Pecos River is 0.0047. The ground slope is steeper at the airport and becomes very mild as it crosses the Pecos River floodplain. A more detailed analysis should include different channel geometries due to variation in slope.

The stable channel curve for 8,500 cfs is shown in Figure 15. This curve defines combinations of width and slope that would provide for movement of

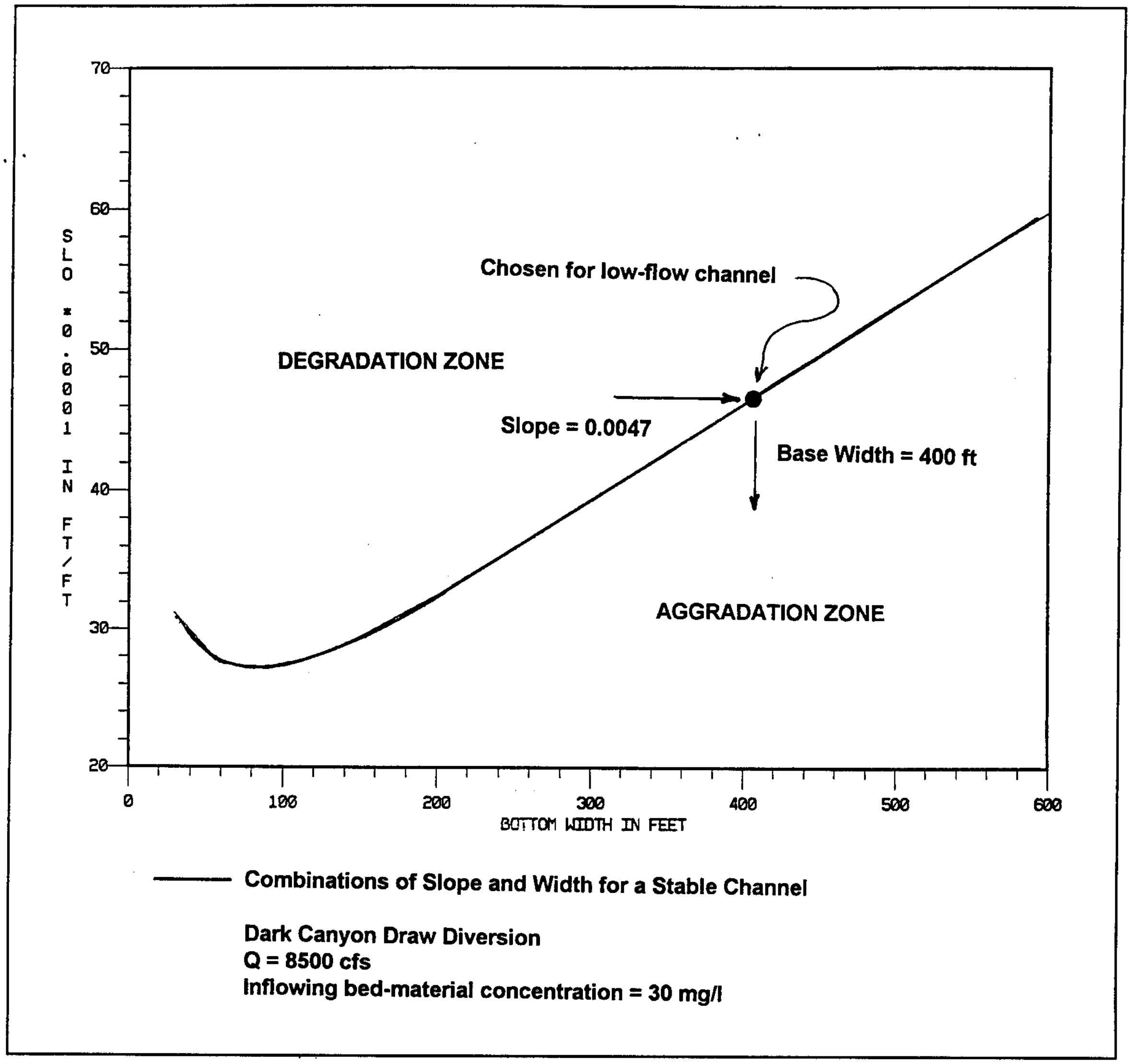


Figure 15. Stable-channel dimensions curve - Dark Canyon Draw Diversion

the inflowing sediment load through the diversion channel. The average slope for the diversion channel, if no drop structures were employed, would be 0.0047. With this slope, the stable channel method suggests that a base width of about 400 ft would be stable. The calculated depth was 3.5 ft.

The width of the overbank channel was determined by trail and error using the criteria of a maximum velocity of 6 ft/sec on the overbank. Roughness on the overbank was calculated using the Brownlie roughness predictor. The total width of the overbank was determined to be 2800 ft. The geometry of the final chosen geometry is shown in Figure 16.

The potential for aggradation/degradation in the diversion channel for a ten- and one-percent chance exceedance flood and for average annual conditions was determined using the sediment budget approach. Bed-material sediment yield was calculated using three sediment transport equations and compared to the calculated bed-material sediment yield in the existing Dark

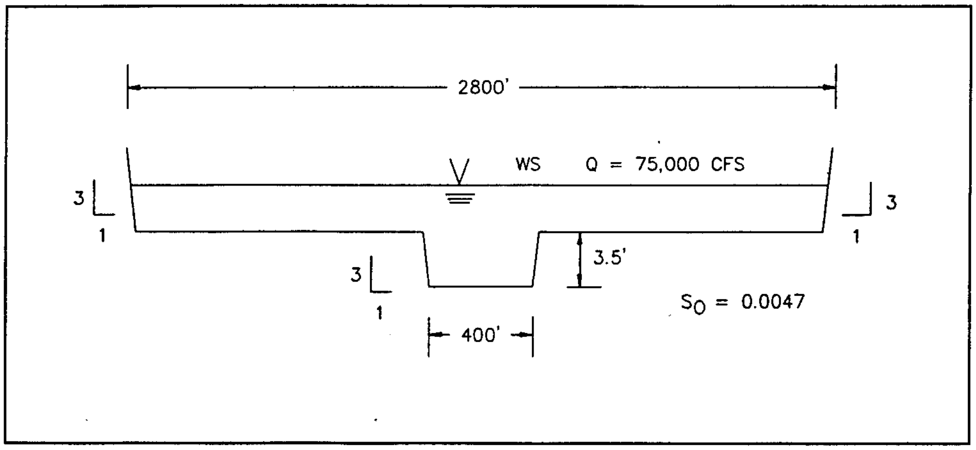


Figure 16. Cross-section Dark Canyon Draw Diversion

Canyon Draw. Bed-material sediment transport was assumed to occur only in the low flow channel in the diversion. Calculated bed-material sediment yield and its percentage of the total bed-material yield calculated for Dark Canyon Draw is shown below. This tabulation indicates that deposition will occur in

Calculated Bed-Material Sediment Yield
Diversion Channel

Sediment Transport Function	One-percent exceedance flood		Ten-percent exceedance flood		Average Annual	
	Cubic yards[1]	Percent of Inflow	Cubic yards[1]	Percent of Inflow	Cubic yards[1]	Percent of Inflow
Schoklitsch	2,050	66	590	86	190	82
Einstein	9,800	66	3,800	88	1,600	94
Parker	22,400	62	4,500	83	1300	87

[1] Sediment yield volume calculated assuming specific weight of deposit of 93 lbs/ft^3

the diversion channel for all cases tested. For the one-percent chance exceedance flood, between 34 and 38 percent of the inflowing bed-material sediment load will deposit in the diversion channel. For the ten-percent chance exceedance flood, between 12 and 17 percent of the inflowing bed-material load will deposit. For average annual conditions, between 6 and 18 percent of the inflowing sediment load will deposit. A range of the quantities of deposition can be determined from these calculations, recall that the Schoklitsch equation produced sediment transport quantities closest to the measured data from a river with similar characteristics. The procedure outlined above may be used to evaluate the potential sediment impacts of other alternatives as they are developed. The SAM hydraulic design package can be used to make the calculations.

In the final design study, it will be necessary to evaluate the temporal development of a diversion or bypass channel using a numerical sedimentation model. In this sediment impact assessment, the bed material gradation was assumed to already be developed. A more detailed study will require knowledge of the existing soil profile through which the channel will be cut. The armoring process will have to be simulated with the numerical model. In addition, the slope of the diversion channel will vary between the city airport and the Pecos River. This requires a more detailed analysis of spacial variability in the sedimentation processes.

Rocky Arroyo

Rocky Arroyo has an incised channel from its canyon mouth to the Pecos River. The downstream reach of the arroyo between the USGS gage at Highway 285 and the Pecos River has recently been reworked. This reach and the adjacent alluvial plain was apparently used as a borrow area during the recent construction of Brantley Dam. During the field reconnaissance, no signs that any significant flow had occurred since the reworking were observed. The stability of the new channel is uncertain. Upstream from Highway 285, the banks of Rocky Arroyo consist of a variety of materials, including both cemented and loose alluvium. Abundant sediment material is available in the banks and bed of Rocky Arroyo.

Bed-material gradations were determined at the Rocky Arroyo dam site and at the USGS gage at Highway 285. The bed-material consisted primarily of gravels and cobbles. Surface gradations at the two sites were obtained using the Wolman (1954) pebble count method. The surface layer median grain size at the dam site was 43 mm and 32 mm at the gage. A subsurface sample was taken at the USGS gage, and the gradation obtained by sieving. The subsurface gradation, which had a d_{50} of 19.5 mm, was used in the sediment transport calculations.

Alternative proposals for flood control improvement on Rocky Arroyo are similar to those under consideration for Dark Canyon Draw. One is to construct a flood retention reservoir to reduce peak discharges; the other is to divert the entire channel into Brantley Reservoir. Sedimentation considerations for the reservoir include sediment storage requirements behind the dam and the effect of reducing the bed-material sediment supply to the downstream channel. Sediment considerations for the diversion include the possibility of sediment deposition at the entrance to the diversion channel, and the stability of the diversion channel itself. Consequences associated with these proposed alternatives are the same as described for Dark Canyon Draw.

There were no plans available for flood control alternatives on Rocky Arroyo for this sediment impact assessment. Therefore, only estimates of sediment yield were calculated. Determination of reservoir sediment yield was calculated using the USBR regional regression equation (Strand and Pemberton 1982). As discussed in the section of Dark Canyon Draw, this method may predict total sediment yields that are too high for the specific watersheds near Carlsbad. More detailed watershed investigations will be required to produce a higher confidence level for total sediment yield quantities. Calculated average annual yield at the Rocky Arroyo dam site was 120 ac-ft/yr. Bed-material sediment yield was also calculated for Rocky Arroyo at the gage site. A range of bed-material sediment yield was calculated to obtain an idea of the magnitude of potential sediment aggradation or degradation that could occur during major flood events and on an average annual basis.

There were no available surveys or topographic mapping of Rocky Arroyo to obtain cross-sections for hydraulic calculations. An approximate cross-section was estimated during the October 1994 field reconnaissance by pacing. The approximate cross-section is shown in Figure 17. An average bed slope of 0.0053 was obtained from a USGS quad map. This approximate data was used to calculate normal depths for a range of discharges using the SAM hydraulic design package.

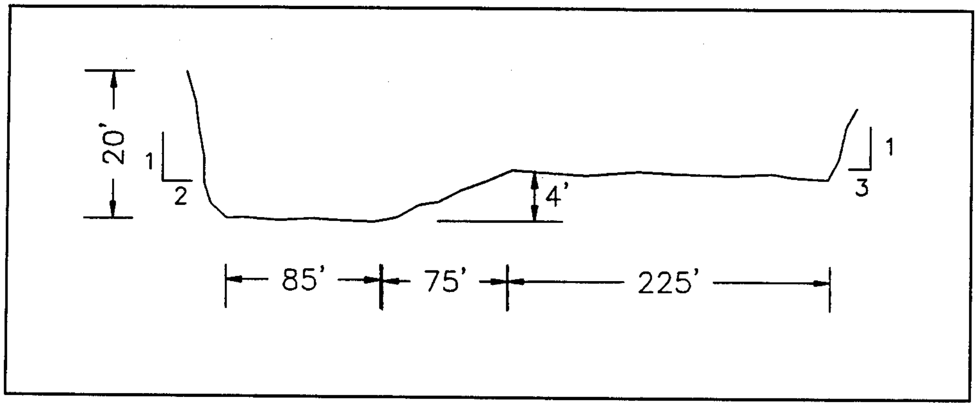


Figure 17. Cross-section sketch - Rocky Arroyo at USGS gage

The same sediment transport equations used for Dark Canyon Draw were used to calculate bed-material sediment transport in Rocky Arroyo; these were the Schoklitsch, Einstein, and Parker equations. Sediment-transport rating curves for Rocky Arroyo at the USGS gage are compared in Figure 18. The Parker equation predicted the highest sediment transport when the discharge exceeded 1000 cfs. The lowest predicted transport rate was predicted by the Schoklitsch equation. The Einstein equation predicted an intermediate sediment transport rate. Sediment transport calculated using these equations provide a reasonable range of expected sediment transport.

Bed-material sediment yield was calculated using the flow-duration sediment-transport curve method. Sediment yields were calculated for the one-percent and ten-percent chance exceedance floods, and for average annual conditions. The one-percent chance exceedance hydrograph was calculated by the Albuquerque District using the HEC-1 hydrograph package. The peak discharge was 82,500 cfs. The ten-percent chance exceedance hydrograph was assumed to have the same shape as the one-percent chance exceedance flood; and discharges at each point on the hydrograph were calculated by multiplying the one-percent chance exceedance hydrograph by the ratio of the peaks. The ten-percent chance exceedance peak discharge was 22,000 cfs. Average annual sediment yield was calculated using a flow duration curve

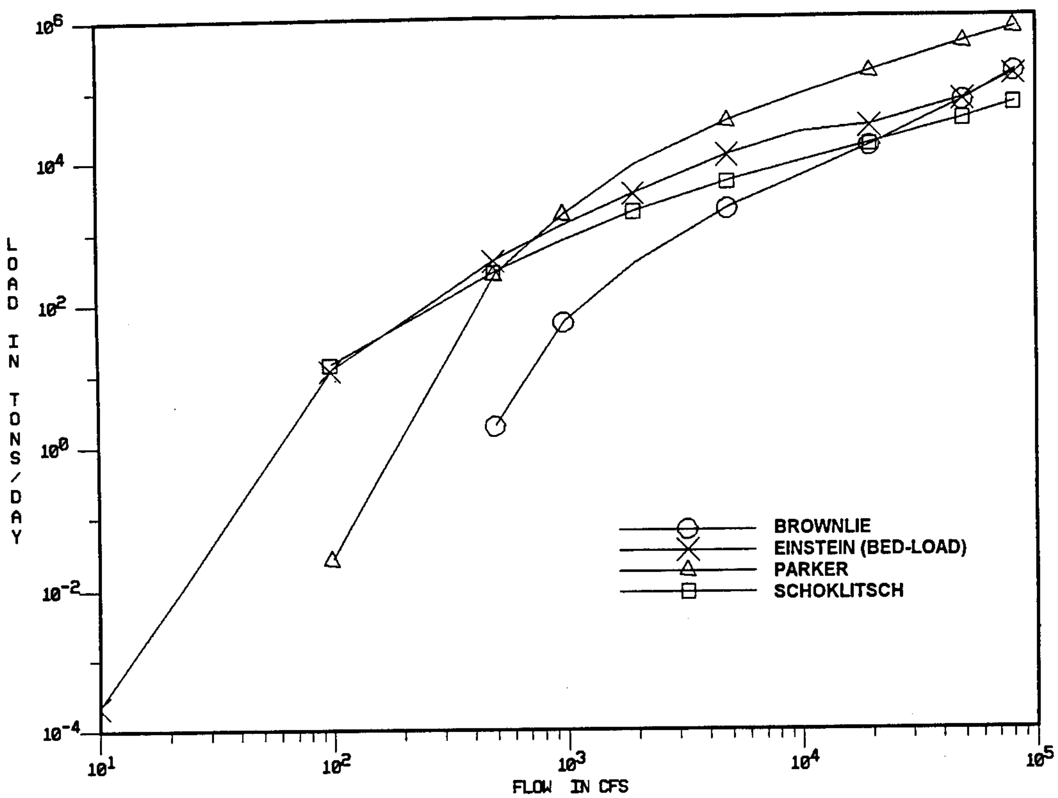


Figure 18. Bed-material sediment-transport rating curves - Rocky Arroyo

developed using mean daily flows from 29 years of record at the USGS gage at Highway 285. Durations of published peak flows greater than the maximum mean daily flow were added to the flow duration data by assuming the historical flood hydrographs had shapes similar to the one-percent chance exceedance hydrograph. Calculated sediment yields are tabulated in the following table.

**Calculated Bed-Material Sediment Yield
Rocky Arroyo**

Sediment Transport Function	Sediment Yield - Cubic yards[1]		
	One-percent chance exceedance flood 82,500 cfs	Ten-percent chance exceedance flood 22,000 cfs	Average Annual
Schoklitsch	7,100	2,100	1,600
Einstein	15,600	4,400	3,300
Parker	77,100	18,900	10,300

[1]Sediment yield volume calculated assuming specific weight of deposit of 93 lbs/ft³

Quantities from the above table may be used to estimate potential deposits that could occur at the entrance to a threshold design diversion channel and at the delta of the arroyo at the Pecos River.

Pecos River

Sediment supply to the Pecos River through Carlsbad is limited by upstream reservoirs. Avalon Dam, located about seven river miles upstream from Carlsbad, was initially constructed in 1891. It was destroyed and rebuilt in 1893. Avalon Dam was washed out again in 1904, and reconstructed in 1907. Mc Millan Reservoir, located about 24 river miles upstream from Carlsbad was completed in 1893; and was intentionally breached in 1988 after the completion of Brantley Dam downstream. Brantley Dam, located about 19 river miles upstream from Carlsbad, was completed in 1981, but impoundment of water did not begin until 1988. These dams have significantly reduced bed-material sediment yield to the Pecos River through Carlsbad for over one-hundred years. Sumner Dam was constructed 242 river miles upstream from Carlsbad in 1937, and Santa Rosa Dam was constructed about 297 river miles upstream from Carlsbad in 1980. These two reservoirs somewhat reduced total sediment loads in the Pecos River. However, data at Artesia, which is about 44 river miles upstream from Carlsbad, show that differences in total sediment yield has been relatively unaffected by Sumner Dam. Brantley Dam should significantly reduce total sediment yield to the Pecos River at Carlsbad. The U.S. Bureau of Reclamation estimates a trap efficiency of 86 percent for Brantley Reservoir. Bed-material sediment yield should not be affected too much because Avalon Dam, downstream, already effectively captures all the bed-material supplied to it. Rocky Arroyo, with a drainage area of 295 mi^2, Spencer Draw, with a drainage area of 28 mi^2, and Dagger Draw, with a drainage area of 47 mi^2, are the only sediment producing tributaries downstream from Brantley Dam. Avalon Dam should capture most of the bed-material load delivered by these tributaries. The contributing drainage area downstream from Avalon Dam is only 19 mi^2, leaving only about four miles of the Pecos River, upstream from the Southern Canal flume, where bank and bed erosion could supply bed-material load. Sediment removal from Upper or Lower Tansill Reservoirs is not a normal maintenance procedure. In fact, Jim Harrison, an official from the Carlsbad Department of Public Works stated during an interview, that to the best of his knowledge, no sediment had ever been removed from the reservoirs. He stated that some material is occasionally removed at the swimming beaches and replaced with blow sand.

Bed-material sediment transport and yield were calculated assuming equilibrium transport, even though it would probably require a major flood event to mobilize enough bed and bank material upstream from Carlsbad to attain these conditions. The bed-material gradation used to calculate sediment transport was the subsurface gradation from the Pecos River at the USGS gage downstream from Dark Canyon Draw. This was the only available bed gradation for the Pecos River. A more accurate determination of bed-material yield should be obtained at the next level of planning study by obtaining several bed-material samples along the four-mile stretch of the Pecos River upstream from Carlsbad. This should include a determination of the gradation of the existing coarse surface layer so that the discharge at which the armor layer destruction occurs can be determined. The potential for bank erosion and bar erosion should also be determined. In addition more cross-section data is required in order to better define hydraulic conditions in this supply reach.

Bed-material sediment yield upstream from Carlsbad and through the recreation reservoirs in Carlsbad was calculated using three sediment transport equations: Parker, Einstein, and Schoklitsch. The calculations were made to determine sediment trap efficiency of the reservoirs on an average annual basis and for a one-percent chance exceedance flood. The flow duration curve for the average annual calculations was based on combined mean daily flow data from two USGS gaging stations - the Pecos River at Carlsbad between 1938 and 1950 , and the Pecos River below Avalon Dam between 1951 and 1993. 1938 was chosen as the starting year for the flow duration curve because Sumner Dam was completed in 1937. The one-percent chance exceedance flood hydrograph was taken from the HEC-1 model developed by the Albuquerque District. Average hydraulic parameters were determined for four reaches from HEC-2 backwater models prepared by the Albuquerque District. Lower Tansill Reservoir was defined by 12 cross-sections, starting 970 feet upstream from Lower Tansill Reservoir, and extending to Upper Tansill Reservoir. Lower Lake Carlsbad was defined by 17 cross sections, starting 450 feet upstream of Upper Tansill Dam, and extending to Canal Street. Upper Lake Carlsbad was defined by six cross-sections starting 3400 feet upstream of Canal Street and extending 4000-feet upstream. The supply reach upstream from the Southern Canal Flume was defined by three cross-sections, the first only 350 ft upstream from the flume. Hydraulic parameters at this cross-section were affected by the flume. The SAM hydraulic design package was used to calculate sediment yield. Calculated trap efficiencies are tabulated below for average annual conditions and for the one-percent chance exceedance flood.

Trap Efficiency of Existing Dams on Pecos River
Average Annual

Equation	Bed-material Sediment Yield, cubic yards[1]	Percent of Bed-material Load Upstream from Southern Canal Flume Passing		
	Upstream from Southern Canal Flume	Upper Lake Carlsbad	Lower Lake Carlsbad	Lower Tansill Reservoir
Parker	460	4	0	0
Einstein	2200	7	0	0
Schoklitsch	2100	9	1	1

[1]Sediment volume calculated assuming a specific weight of deposit of 93 lbs/ft^3

Trap Efficiency of Existing Dams on Pecos River One-percent chance exceedance flood				
	Bed-material Sediment Yield, cubic yards[1]	Percent of Bed-material Load Upstream from Southern Canal Flume Passing		
Equation	Upstream from Southern Canal Flume	Upper Lake Carlsbad	Lower Lake Carlsbad	Lower Tansill Reservoir
Parker	1500	75	48	18
Einstein	4700	61	32	32
Schoklitsch	1900	52	32	29

[1]Sediment volume calculated assuming a specific weight of deposit of 93 lbs/ft^3

As can be seen from the tables, the average annual bed-material load is almost all trapped in the upper portion of Lake Carlsbad. For the one-percent chance exceedance flood between 18 and 32 percent of the inflowing bed-material sediment load passes through the recreation lakes, with deposition in all reaches of the lakes.

One flood-control alternative is to replace the existing dams with inflatable dams that would be lowered during floods. The effect of this alternative on sediment yield was assessed. The Albuquerque District's HEC-2 model was modified by removing the dam cross sections and new hydraulic parameters calculated. Calculated trap efficiencies are tabulated below:

Trap efficiency without dams on Pecos River One-percent chance exceedance flood					
	Bed-material sediment yield Upstream from Southern Canal Flume		Percent of Bed-material load upstream from Southern Canal Flume passing		
Equation	Cubic yards[1]	Percent Increase[2]	Upper Lake Carlsbad	Lower Lake Carlsbad	Lower Tansill Reservoir
Parker	1800	16	89	190	18
Einstein	5200	9	75	98	32
Schoklitsch	2000	7	67	84	30

[1]Sediment volume calculated assuming a specific weight of deposit of 93 lbs/ft^3
[2]Percentages are based on unrounded calculated bed-material yields

The removal of existing dams caused a reduction in backwater upstream from Upper Tansill Dam, but had less effect on water surface elevations in Lower Tansill reservoir, where backwater from Dark Canyon Draw dominates the downstream boundary condition. Bed-material sediment inflow from the supply reach increased between 7 and 16 percent depending on which sediment transport equation was used. Sediment transport capacity was much greater in Lake Carlsbad, especially in the lower reach. This indicates scour will occur in the lower reach of Lake Carlsbad, and deposition in Lower Tansill Reservoir. A more thorough investigation of existing bed gradations in the recreation lakes is called for in the next level of planning study. If the beds of the recreation lakes are found to consist primarily of sand size material, core samples should be taken to determine the depth of the finer deposits, as these will most likely scour during flood flows.

Hackberry Draw

The most significant sediment problem that could occur on Hackberry Draw is sediment deposition at the transition from the existing channel to the diversion channel. Deposition will occur because the stream-bed gradient abruptly changes from about 0.0030 to 0.0007. The magnitude of the deposition problem may be determined using the sediment budget approach - comparing sediment yields through both the diversion channel and Hackberry Draw. This approach is approximate, because the deposition process is unsteady, varying with time and distance along both of the channels.

Effective hydraulic parameters for sediment transport calculations were obtained from HEC-2 backwater models prepared by the Albuquerque District for the Hackberry Diversion and for Hackberry Draw upstream from the Southern Canal. These effective hydraulic parameters were average values representing 4000 feet of the diversion channel downstream from the point where Hackberry Draw is intercepted by the Southern Canal; and about 4000 feet of Hackberry Draw upstream from the backwater influence of the Standpipe Road bridge (1500 to 5500 ft upstream from the Southern Canal).

The bed-material gradations for both Hackberry Draw and the Hackberry Diversion were based on a single bed-sample taken from Hackberry Draw just upstream from the Southern Canal. The smallest ten percent of the sampled bed was ignored for sediment transport calculation as recommended by Einstein (1950). The gradation should reflect sediment transport conditions into the deposition zone created by stream-gradient transition. The sediment transport calculations were for bed-material load only. In this case, bed-material load is considered to be the sediment load of particles greater than 0.4 mm. For this sediment impact assessment, which is intended to determine only the magnitude of the sediment problem, it is reasonable to use the same bed-material gradation in the diversion channel as in Hackberry Draw itself. However, more detailed studies will require a more complete definition of the bed-material gradations, both upstream from Standpipe Road, and in the diversion channel itself. Bed-material gradation will change with both time and distance along the channels during flood events, especially in deposition zones.

Sediment transport was calculated using several different sediment-transport functions in order to obtain a reasonable range of probable deposition quantities. Sediment-transport functions developed for streams with coarse bed-material were considered. Sediment-transport rating curves for Hackberry Draw and Hackberry Diversion are shown in Figures 19-20. These figures demonstrate the significant difference in sediment transport potential calculated using different transport functions. The highest sediment-transport rates were obtained using the Laursen-Copeland function (Copeland and Thomas 1989); the next highest were obtained using the Parker (1990) and Yang (1973, 1984) functions. The Parker function considers only sediment sizes greater than 2 mm. The rating curves were similar for the Ackers-White (1973), Einstein (1950), Meyer-Peter Muller (1948), and Toffaleti (1968)-Schoklitsch (Shulits 1935) functions. The SAM-AID module, which compares the hydraulic and sediment characteristics of the subject stream to the data sets used to develop several sediment transport equations, suggested using the Ackers-White, Laursen-Copeland, and Yang functions. The U.S. Bureau of Reclamation uses the Einstein Total Load function, with a modified Xi factor, for streams in this region (USBR 1994). These four functions were used to make sediment yield calculations.

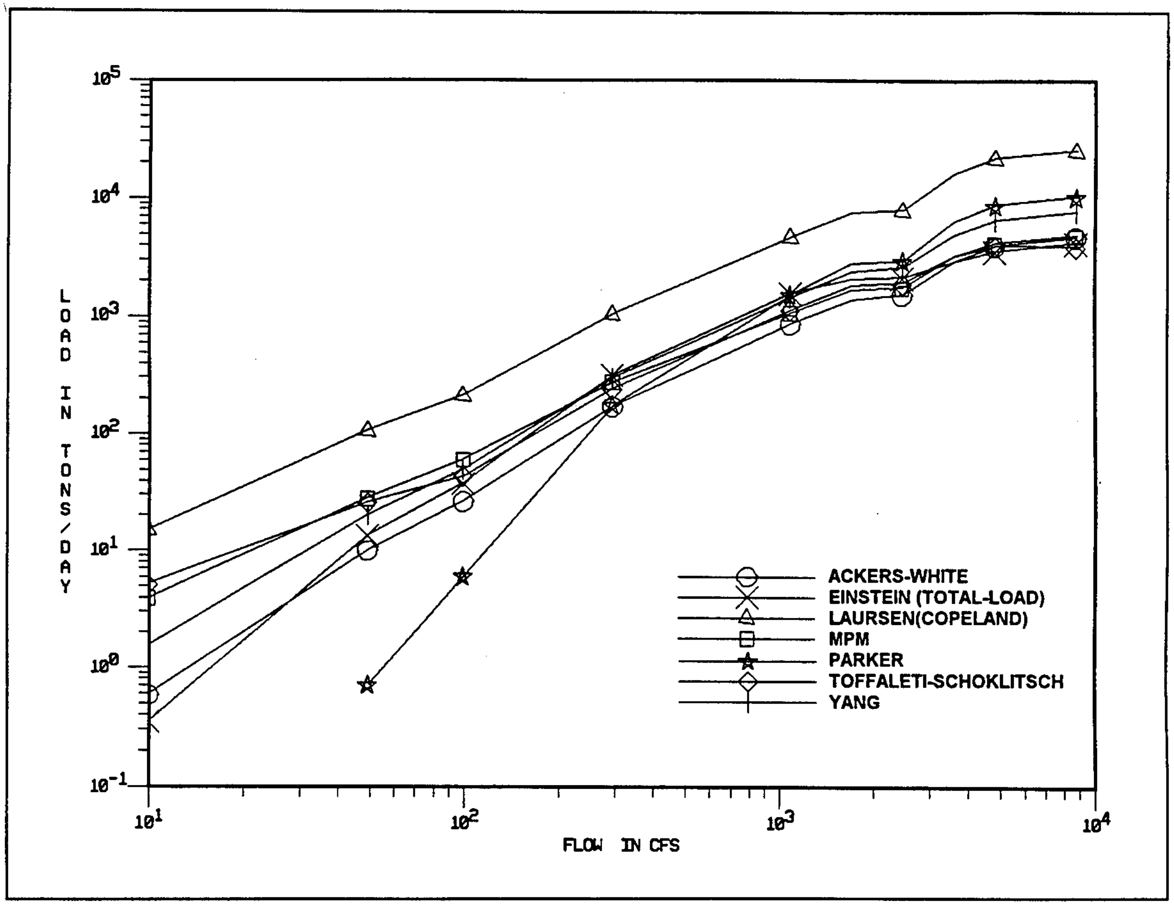


Figure 19. Bed-material sediment-transport rating curves - Hackberry Draw

Sediment yield calculations were determined for the one-percent chance flood, the ten-percent chance flood, and for average annual conditions. The flood yields were based on hydrographs calculated using the HEC-1

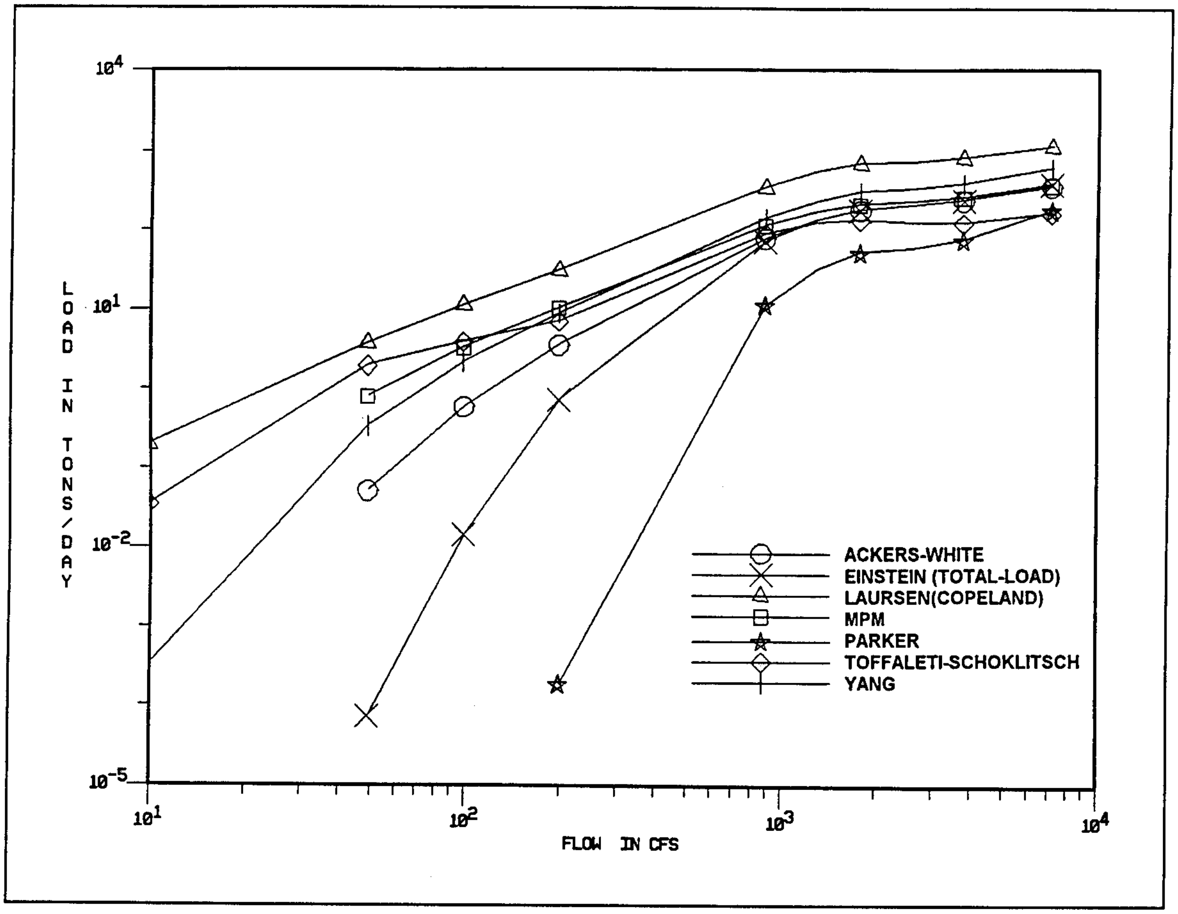


Figure 20. Bed-material sediment-transport rating curves - Hackberry Diversion

hydrograph package by the Albuquerque District. Average annual sediment yield was calculated from the following equation:

$$Y_{AVE} = 0.006Y_{500} + 0.009Y_{100} + 0.015Y_{50} + 0.04Y_{25} + 0.08Y_{10} + 0.20Y_5 + 0.40Y_2 \quad (2)$$

Where Y is the sediment yield, the subscript AVE indicates average annual, and the numbered subscripts refer to the return period of the associated flood hydrograph. This equation is based on a numerical integration of the sediment yield - percent exceedance curve for an annual series, and provides approximate average annual sediment yields when a flow duration curve is unavailable.

Sediment deposition was determined by subtracting the sediment yield for the diversion channel from the sediment yield of Hackberry Draw. Calculated quantities are listed below.

Transport Function	Deposition cubic yards[1]		
	One-percent chance exceedance flood 4,900 cfs	Ten-percent chance exceedance flood 1,700 cfs	Average annual
Laursen-Copeland	1500	510	200
Yang	430	140	50
Einstein	330	140	50
Ackers-White	260	80	30

[1]Sediment volume calculated assuming a specific weight of deposit of 93 lbs/ft^3

The calculated deposition quantities may be used to obtain a reasonable range for average-annual dredging costs for the reconnaissance level study. Deposition during floods will result in reduction of conveyance capacity. Average depths of deposition can be estimated from the calculated deposition quantities by assuming an appropriate length for the deposition zone and determining the average channel width for that zone. For example, if a 200-ft-long deposition zone, and a 70-ft-wide channel is assumed, deposition depths between 0.5 and 3.0 ft can be calculated. The length of the deposition zone may be estimated based on experience in the region. At the next level of study, a HEC-6 numerical model of the reach should be conducted to define the depth and extent of the deposition zone.

3 Recommendations and Conclusions

Recommendations for a More Detailed Sediment Study

Required sediment analyses at the next level of planning study will depend on which alternatives are considered for study. In general, alternatives that consider reservoir storage will need to be concerned with both total sediment yield and bed-material sediment transport. Bed-material sediment transport is the most important portion of the sediment load for alternatives that involve diversions and channel improvements. Calculations in the sediment impact assessment were based on the assumption of steady, uniform flow conditions. More detailed studies will need to address the dynamic changes that occur in the channel with changes in the sediment loading. Temporal changes are especially important in diversion alternatives, where the initial bed condition may be significantly different from the bed condition in the existing channel.

Cross-section surveys are required at several locations to better determine hydraulic conditions in reaches where sediment is supplied. Cross-section surveys should be continued further upstream on Dark Canyon Draw, in order to get as far as possible from the influence of the gravel mining operations. There were no cross-section data available on Rocky Arroyo. Cross-section surveys should be obtained upstream of the proposed diversion, and downstream to the Pecos River. Currently there were only three cross-sections on the Pecos River upstream from the Southern Canal flume, one of which is influenced by the backwater from the flume. A few more cross-sections upstream are needed to better define the inflowing hydraulic conditions. Cross-sections will also be required in the Pecos River at the confluence of the proposed diversion channel upstream to the downstream boundary of the existing HEC-2 backwater model, which is about two miles downstream from Lower Tansill Dam.

Sediment data at existing gages in the watershed should be analyzed to determine which sediment transport function is the best predictor for this region. Data are available at Pecos River near Artesia, Rio Hondo at Diamond A Ranch near Roswell, and Rio Penasco near Dayton. The assessment should focus only on the bed-material load. A field reconnaissance will be necessary to gather bed-material gradations at these gage sites. The sampling program should account for both lateral and longitudinal variations in the bed-material gradation at the gages. This will require taking samples at several points at each cross-section. Both surface and subsurface gradations should be obtained. A judgement will have to be made as to whether channel bed conditions are similar to those that existed when the suspended sediment samples were collected and whether the streams are similar to the streams in the Carlsbad study area.

More detailed total sediment yield predictions will be required if reservoir alternatives are considered. A watershed yield method such as the PSIAC method should be employed. This will require a fairly detailed watershed investigation by a team of specialists. The Rio Penasco and Rio Hondo watersheds should also be evaluated. These have measured sediment yields, which can be used to check and adjust PSIAC rating factors.

Trap efficiencies for planned reservoirs will need to be determined. The Brune-Dendy approach outlined in EM 1110-2-4000 (HQUSACE 1989) can be modified to treat single storm events. Reservoir operating rules are required to conduct a trap efficiency study.

Potential degradation and resultant channel instability downstream from dams should be evaluated. Cross-sections of the existing channel between the dam and the Pecos River would be required in order to determine hydraulic parameters. First, it should be determined if threshold conditions are exceeded with dam releases. This can be accomplished using methods outlined in EM 1110-2-1418 (HQUSACE 1994). Both surface and subsurface bed-material gradations should be obtained from the existing channel at one to two mile intervals. Surface gradations should be used to determine critical thresholds. If threshold conditions are not exceeded, then it can be concluded that the channel would not degrade. If threshold conditions are exceeded a numerical sedimentation model would be required to determine the extent of potential degradation. Subsurface gradations are used in the sediment transport model.

Potential aggradation and/or degradation in proposed diversion channels will need to be evaluated using a numerical sedimentation model. Temporal and spacial variations will significantly influence sedimentation processes. The new channel bed will have to adjust to a sediment load imposed from immediately upstream, a load that will vary with time and location along the channel; and hydraulic parameters will vary with the alignment and slope of the designed channel. Borings of the soil profile along the proposed alignment will be necessary in order to determine the initial characteristics of the new channel boundaries.

The response of the Pecos River through the city of Carlsbad to flood control alternatives cannot be evaluated until the characteristics of the existing channel bed is determined. This may require some core sampling if initial surface sampling indicates a fine sand bed. The depth of the sand bed could be determined by coring or acoustical instrumentation. It is expected that a coarse layer exists at some elevation, and that this layer would probably be stable even for peak flood conditions. The sediment impact assessment indicates that there is a potential for degradation in the lower reach of Lake Carlsbad which would induce deposition in Lower Tansill Reservoir for the dam removal alternative. The severity of this trend will depend on the gradation of the bed material in the existing channel. This trend may be evaluated with the HEC-6 numerical sedimentation model.

There will be uncertainty associated with any sediment calculations performed in the detailed sediment study, even with the numerical model. It will be necessary to conduct a sensitivity study as part of the detailed sediment study.

Conclusions

The proposed flood control alternative that has the most significant potential for sedimentation problems is the construction of diversion channels. If these channels are designed as threshold channels, continuous maintenance problems would be expected at the inlet to the diversion. The design of a channel to carry most of the inflowing bed-material sediment load would significantly reduce maintenance requirements and reduce or eliminate the need for grade control structures. The design of a channel that more nearly replicates the natural existing channel would require relatively detailed sedimentation analysis including a numerical sedimentation study.

Potential sedimentation problems from Rocky Arroyo and Dark Canyon Draw are considered moderate; even though the existing channels should be considered unstable. Floods on these arroyos have a short duration, about eight hours, restricting the time allowed for sediment accumulation or scour. The channels of these streams are generally incised so that general aggradation during any given flood is unlikely to cause a problem. General degradation, that could be induced by construction of an upstream dam, would be dampened by the ample supply of course material in the bed. Long-term degradation, localized bank erosion, and lateral migration of the channels are expected to continue with or without upstream dams. The extent of degradation can be estimated using the HEC-6 numerical sedimentation model.

Hackberry Draw has a relatively small drainage area and will produce less runoff than Rocky Arroyo or Dark Canyon Draw. However, the change in sediment transport potential is severe where it is intercepted by the Southern canal embankment. In addition, the banks of the improved channel are unprotected and are subject to severe erosion during a major flood. There is potential for significant deposition at the intersection of the Southern Canal and a detailed sediment study, including a numerical sedimentation model, is warranted to assess both long-term maintenance and deposition during floods.

Sedimentation problems along the Pecos River appear to be relatively minor. This conclusion is based primarily on the reported lack of existing problems. Bed-material load has been cut off to the Pecos River for over one-hundred years, and there does not appear to be any major degradation occurring. However, during most of this time the river through Carlsbad has been ponded by low head reservoirs, which provide grade control. The probable consequence of using deflatable dams during floods, is the removal of fine sediments that have accumulated in the pools upstream from Lower and Upper Tansill Dams. Higher velocities with the deflated dams will induce more bank erosion and cause more damage to recreational facilities through Carlsbad. It may also result in significant deposition in Lower Tansill reservoir. Given the uncertainty related to the existing condition of the Pecos River bed and the fact that the Pecos is a major river, it would be prudent to inventory the existing channel bed characteristics, and evaluate the effect of flood control improvements using a numerical sedimentation model.

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Table 1
Reservoir Deposition Survey Data

Reference, Reservoir/Gage, Location	Years of Record	Drainage Area[1] square miles	Specific gravity of sediment deposit[2] lbs/ft^3	Deposition Rate $AF/mi^2/yr$
Subcommittee of Sedimentation, 1992:				
Upper Hondo #1, Salado Creek near Capitan, NM	23.2	121.6	87	0.290
Pecos Arroyo #1, Pecos Arroyo near Las Vegas, NM	19.5	19.4	71	0.330
Subcommittee of Sedimentation, 1983:				
Sumner (Alamogordo) Reservoir, Pecos River near Ft Sumner, NM[3]	52.0	3749**	76.1	.320
USDA-ARS, 1978:				
McMillan Reservoir, Pecos River near Carlsbad, NM	62.5	13,241**	62.4	0.062
Bancroft # 7, Salado Creek near Capitan, NM	10.67	12.0	75*	0.010
Bancroft # 9, Salado Creek near Capitan, NM	10.67	0.57	75*	0.920
Bancroft # 11, Salado Creek near Capitan, NM	10.67	0.69	75*	0.340
Pearson #6, Salado Creek near Capitan, NM	10.58	0.19	75*	0.860
Pearson #8, Salado Creek near Capitan, NM	10.58	0.24	75*	1.930
Pearson #9, Salado Creek near Capitan, NM	10.92	1.56	75*	0.450
Pearson #10, Salado Creek near Capitan, NM	10.58	0.71	75*	0.260
Pearson #18, Salado Creek near Capitan, NM	10.58	1.80	75*	0.700
Pearson #20, Salado Creek near Capitan, NM	10.58	0.16	75*	0.460
Bonito, Bonito Creek, Kraut Gulch near Capitan, NM	9.00	39.9	----	0.0840
USBR Official File[4]				
Rocky Arroyo	14	285	----	0.180
Lake Avalon (1907-1979)	72	1,080	76.7	0.034
Lake Avalon (estimated since 1979)	14	1,080	70*	0.011

(Continued)

1 ** Excludes areas above upstream reservoirs.
2 * The specific weight of the sediment deposit has been estimated based on measured data from other reservoirs in the area.
3 These calculations include data from: United States Bureau of Reclamation (USBR), 11 March 1994. Official File memo, ALB-430, Control no. 94000933, Folder I.D. 3900, "1994 Pecos River Reservoirs' Storage Entitlement (Water Storage)."
4 USBR, op. cit.

Table 1 (Concluded)				
Reference, Reservoir/Gage, Location	**Years of Record**	**Drainage Area[1]** **square miles**	**Specific gravity of sediment deposit[2]** **lbs/ft[3]**	**Deposition Rate** **$AF/mi^2/yr$**
Calculated from USGS data				
Rio Hondo at Diamond A Ranch near Roswell, NM	53	947	75*	0.481
Rio Penasco at Dayton, NM	40	1,060	75*	0.052
Pecos River near Artesia, NM (1905-1937)	32	15,300	75*	0.130
Pecos River near Artesia, NM (1937-1991)	54	11,500**	75*	0.115

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13. ABSTRACT *(Maximum 200 words)*

A sediment impact assessment was conducted for the Pecos River and three tributaries in Carlsbad, NM, as part of a reconnaissance level planning study. The purpose of the study was to identify the magnitude of sediment problems that might be associated with proposed flood-control projects, and to recommend appropriate sediment studies for the next level of planning study. The study employs the sediment budget approach to assess channel stability in the study reach. Total sediment yield estimates were made for preliminary sizing of debris basins and/or reservoirs. Channel stability, in terms of aggradation and degradation potential, was assessed. Recommendations for more detailed sediment studies were made.

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