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**Cover photos:** *Top*—Sediment comes from a variety of sources including the watershed and bed and bank materials. For a successful restoration, the amount of sediment entering a stream reach must be balanced by the sediment transport capacity of the stream.

*Bottom*—An inventory of erosion types and the amount of sediment coming from these sources may be needed for design.

### Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

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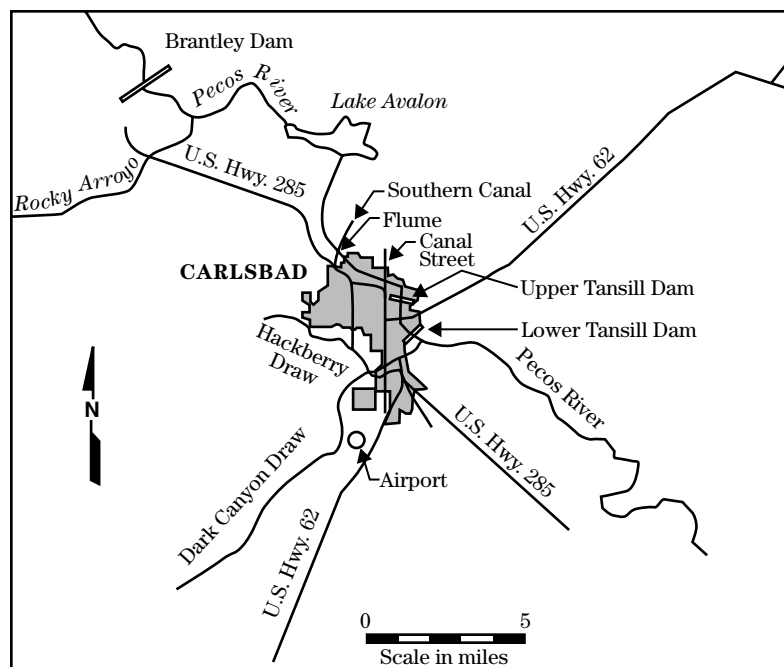
## Introduction

A sediment budget analysis was conducted by the U.S. Army Corps of Engineers (USACE) as part of the reconnaissance level planning study for a flood-damage reduction project for the City of Carlsbad, New Mexico (Copeland 1995). This example describes the sediment budget analysis used to identify the magnitude of possible sediment problems that might be associated with one of the proposed project designs. One potential source of flooding was Dark Canyon Draw, a tributary of the Pecos River (fig. TS13B-1). One of the flood damage reduction alternatives being considered was a bypass channel that would divert Dark Canyon Draw around the city of Carlsbad. The proposed diversion would begin near the city airport and flow northeasterly to the Pecos River to a location about 5 miles downstream from the city.

The sediment budget analysis was conducted to determine the magnitude of possible sediment degrada-

tion or aggradation problems that might occur with a proposed design for the diversion channel. Depending on the diversion channel design, several sedimentation and channel stability problems could occur. If a threshold channel is constructed that is designed with little or no sediment transport potential, then bed material delivered from upstream would deposit at the diversion entrance. Sediment deposits would have to be removed periodically. If a channel is designed to carry the incoming sediment load, the channel would undergo a period of adjustment as the bed and banks become established. Bed armoring could 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. Finally, if the diversion channel is too efficient in terms of sediment transport capacity, it could degrade and induce additional channel degradation upstream from the diversion location.

**Figure TS13B-1** Carlsbad and surrounding areas



## Field reconnaissance

Preliminary assessments of channel stability and potential sediment impacts were determined during the site assessment and investigation phase of the study conducted prior to the project design phase. Data collected during this phase of the study were used in the sediment budget analysis, which was conducted after channel design.

Dark Canyon Draw transitions from a wide, shallow alluvial channel, characteristic of southwestern United States alluvial fans, at its canyon mouth to an incised arroyo at its confluence with the Pecos River. Gravel mining is currently active in the lower reaches of Dark Canyon Draw between the Pecos River and the city airport and has been occurring for many years. The channel had been both widened and deepened due to the gravel mining. The channel also showed signs of incision/degradation upstream from the airport. The bed and banks of the incised channel were capable of supplying significant quantities of sediment to the stream. The bed surface of Dark Canyon Draw consisted primarily of coarse gravel and cobbles. Banks were generally composed of loose alluvial material ranging in size from clays and silts to boulders. The channel tended to migrate laterally, eroding banks, and creating remnant gravel bars in former channels. Armoring was generally observed in the existing low-flow channel. However, the channel would migrate at high flows, mobilizing significant amounts of sediment from the gravel bars and from eroded bank materials.

Bed-material samples were collected during the field reconnaissance. Sample size class distributions were determined using the Wolman (1954) pebble count method and the volumetric bulk method. Due to the limited scope of the sediment impact assessment, samples were collected at only two sites. Both surface and subsurface samples were collected at the mouth of the canyon several miles upstream from the proposed diversion channel. There was no coarse surface layer at the second site, located on a gravel bar about 1 mile downstream from the canyon mouth. The thoroughly mixed bedform was an indication that active-layer mixing had occurred during the last flow event at this site (fig. TS13B-2). Median grain size ranged between 22 and 55 millimeters for all the samples. The gradation determined at the downstream site was selected as the representative gradation for the sediment

budget analysis because it was characteristic of a fully mobile bed. Bed-material gradations determined from these samples are shown in figure TS13B-3.

## Hydrology

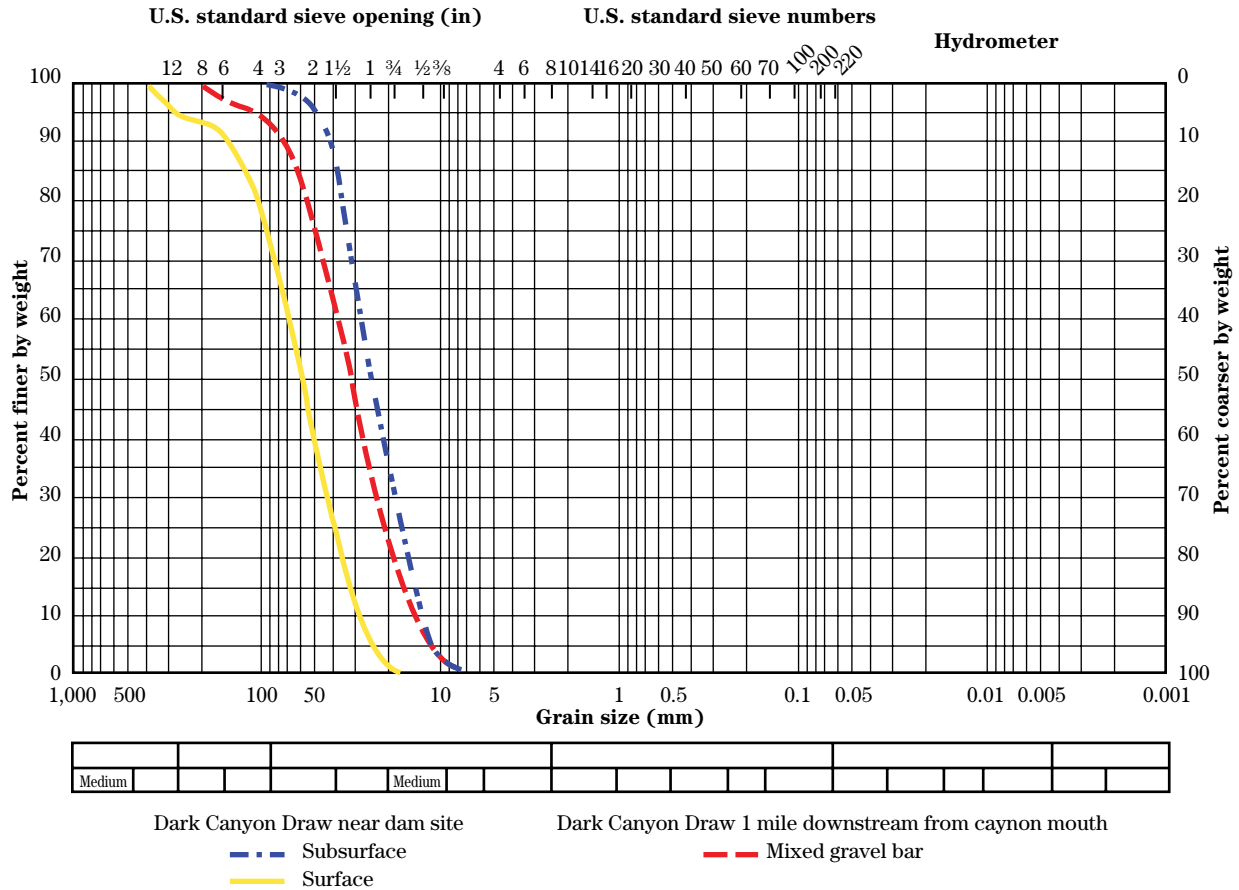
Hydrographs used in the sediment budget analysis were developed using the HEC-1 hydrograph package (USACE 1998b). These were used to calculate sediment yield for flood events. The peak discharge for the 1 percent exceedance flood was 2,000 cubic meters per second (75,000 ft<sup>3</sup>/s). The 10 percent chance exceedance hydrograph was assumed to have the same shape as the 1 percent chance exceedance flood. Discharges on the hydrograph were calculated by multiplying the 1 percent exceedance hydrograph by the ratio of the peaks. The peak discharge for the 10 percent chance exceedance was 570 cubic meters per second (20,000 ft<sup>3</sup>/s).

A flow-duration curve was developed from 18 years of U.S. Geological Survey (USGS) mean daily flow data from the Dark Canyon at the Carlsbad gage. Durations of published peak flows greater than the maximum mean daily flow were added to the flow-duration data by assuming that the historical flood hydrographs had

**Figure TS13B-2** Mixed-gravel bedform, Dark Canyon Draw



**Figure TS13B-3** Bed-material gradations, Dark Canyon Draw



shapes similar to the 1 percent chance exceedance hydrograph. The flow-duration curve is shown in figure TS13B-4.

### Average hydraulic parameters

A typical reach in the existing Dark Canyon Draw channel was selected from a HEC-2 backwater model (USACE 1990b). The typical reach chosen for this analysis was about 2 miles long and located adjacent to the Carlsbad Airport. The reach was considered to be in a state of nonequilibrium due to its proximity to gravel mining operations. A reach further upstream, less influenced by gravel mining operations, would have been preferred for determining long-term sediment yield. However, the existing backwater model did not extend any further upstream. It was recommended that additional cross-sectional surveys be obtained upstream for more detailed sediment studies.

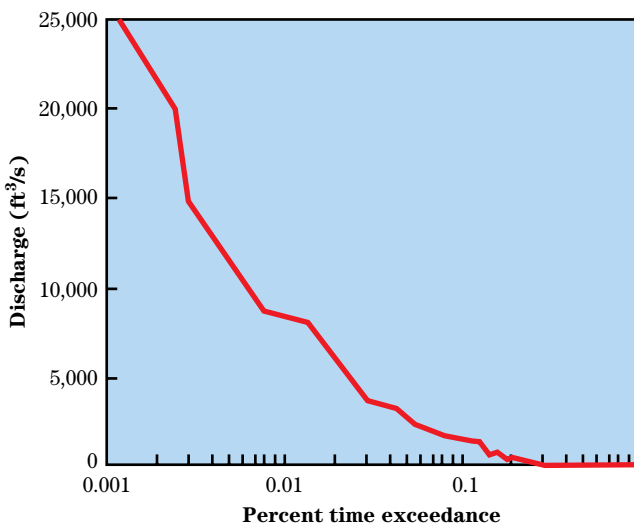
Water-surface elevations and hydraulic variables were calculated using the HEC-2 model for a range of discharges. Average values for hydraulic variables were then determined using the reach-length weighted averaging procedure in SAM (Thomas, Copeland, and McComas 2003).

### Sediment transport rating curve

The bed-material sediment yield from 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 they are transported downstream. The bed-material yield is most likely to be relatively small compared to the total sediment yield because the bed of Dark Canyon Draw consists primarily 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.

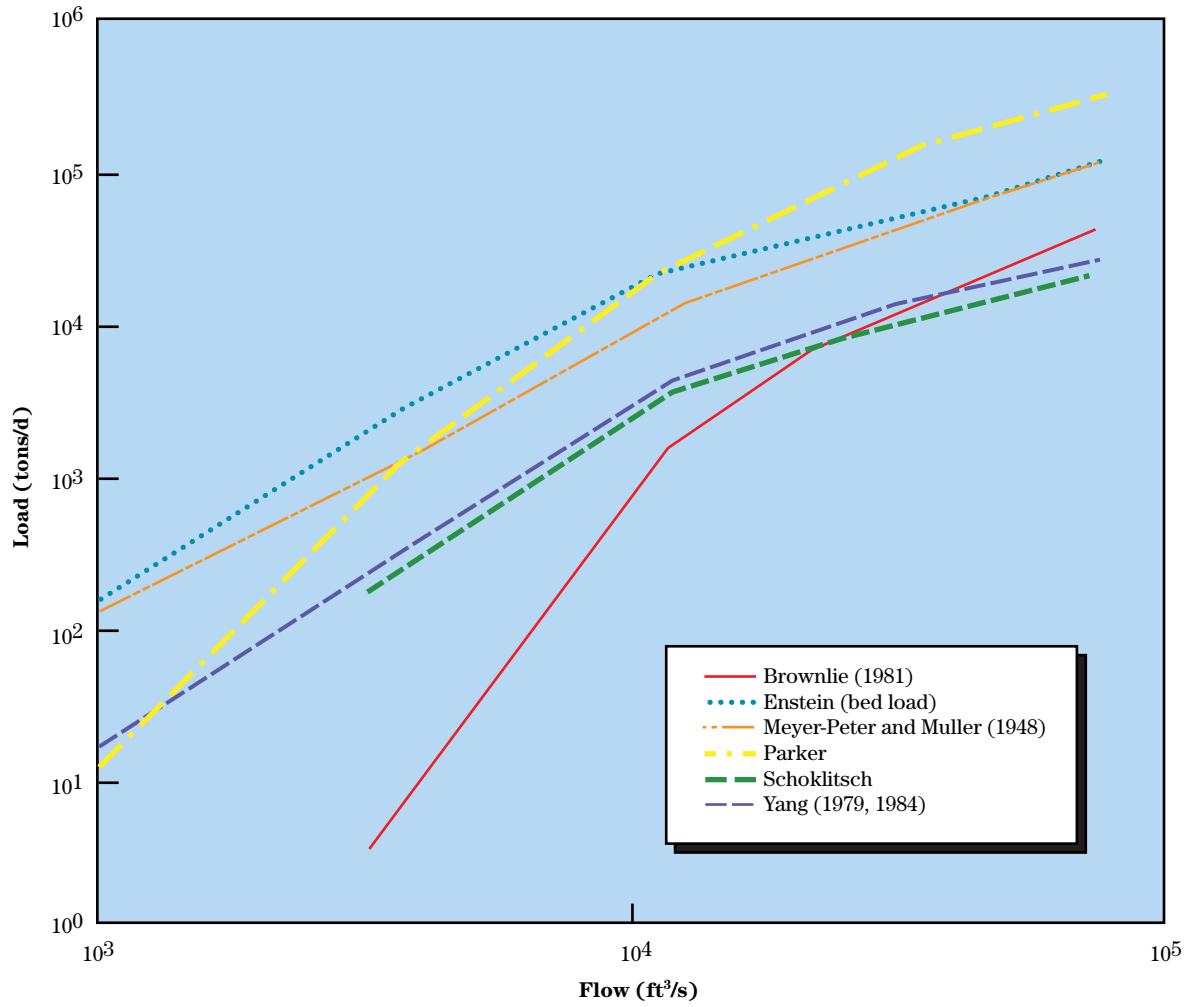
Sediment transport was calculated using several sediment transport equations available in the SAM program. The equations chosen included at least some data from gravel-bed rivers in their development. As can be seen from the sediment discharge rating curves (fig. TS13B-5), predicted sediment transport rates cover a wide range. No data are available on Dark Canyon Draw to aid in the selection of a transport equation. However, the guidance program in SAM identified the North Saskatchewan and Elbow Rivers in Saskatchewan, Canada, as having similar median bed grain sizes, depths, velocities, and slopes as Dark Canyon Draw at high flow. The guidance program from the available set of equations in SAM determined that the Schoklitsch equation (Shulits 1935) best reproduced measured data on the North Saskatchewan and Elbow Rivers. Calculated sediment transport rating curves were compared using different sediment transport functions, as shown in figure TS13B-5. The conclusion is that the Schoklitsch equation will produce a relatively low sediment yield. 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 (Parker 1990) was used to represent a high sediment transport load, and the Einstein (1950) equation was chosen to represent an intermediate sediment transport load.

**Figure TS13B-4** Dark Canyon Draw, Carlsbad, NM, flow-duration curve (1973-1992)





**Figure TS13B-5** Bed-material sediment transport rating curves, Dark Canyon Draw



## Diversion channel design

The following criteria were chosen for the diversion channel design:

- a composite channel geometry with a low-flow channel designed to carry the effective discharge
- the overbank flow designed using threshold criteria for the 1 percent chance exceedance flood

Assigned side slopes were 1V:3H, with Manning’s roughness coefficient of 0.05 for the side slope. The project cross section for the diversion channel to be evaluated with the sediment budget analysis is shown in figure TS13B–6.

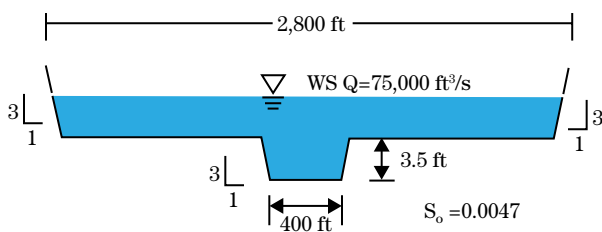
## Sediment budget

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 existing channel and comparing it to calculated sediment yield in the project reach.

Bed-material sediment yield was calculated for the existing channel using the flow-duration sediment transport curve method and SAM. Sediment yields were calculated for the 1 percent and 10 percent chance exceedance floods using synthetic hydrographs, and for average annual conditions, using the flow-duration curve. Bed-material sediment yields were calculated using three different sediment transport equations. Results are shown in table TS13B–1.

Sediment yield was determined in the diversion channel using the same procedure that was used to calculate sediment yield in the typical reach of the existing channel. Sediment trapping efficiency was then determined for flood hydrographs and for average annual conditions.

**Figure TS13B–6** Cross section, Dark Canyon Draw diversion channel



**Table TS13B–1** Calculated bed-material sediment yield<sup>1/</sup>, Dark Canyon Draw

Bed-material transport function	1 percent exceedance flood		10 percent exceedance flood		Average annual	
	m <sup>3</sup>	yd <sup>3</sup>	m <sup>3</sup>	yd <sup>3</sup>	m <sup>3</sup>	yd <sup>3</sup>
Schoklitsch	2,400	3,100	530	690	180	230
Einstein	11,300	14,800	3,300	4,300	1,300	1,700
Parker	27,700	36,200	4,100	5,400	1,100	1,500

<sup>1/</sup> Sediment yield volume calculated assuming specific weight of deposit of 1,500 kg/m<sup>3</sup> (93 lb/ft<sup>3</sup>)

The potential for aggradation or degradation in the diversion channel for a 10 and 1 percent chance exceedance floods 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 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 in table TS13B-2. This tabulation indicates that deposition will occur in the diversion channel for all cases tested. For the 1 percent chance exceedance flood, between 34 and 38 percent of the inflowing bed-material sediment load will be deposited in the diversion channel. For the 10 percent chance exceedance flood, between 12 and 17 percent of the inflowing bed-material load will be deposited. For average annual conditions, between 6 and 18 percent of the inflowing sediment load will be deposited. A range anticipated deposition rates 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.

## Further analysis

At the next level of planning, it would be necessary to evaluate the temporal development of the diversion channel using the HEC-6 numerical sedimentation model. In this sediment impact assessment, the bed-material gradation was assumed to be already developed. A more detailed study would require knowledge of the existing soil profile through which the channel will be cut. The armoring process would then be simulated with a numerical model. In addition, the slope of the diversion channel will vary between the diversion point and the Pecos River. This requires a more detailed analysis of spatial variability in the sedimentation processes.

**Table TS13B-2** Calculated bed-material sediment yield<sup>1/</sup>, diversion channel

Sediment transport function	1 percent exceedance flood			10 percent exceedance flood			Average annual		
	m <sup>3</sup>	yd <sup>3</sup>	% of inflow	m <sup>3</sup>	yd <sup>3</sup>	% of inflow	m <sup>3</sup>	yd <sup>3</sup>	% of inflow
Schoklitsch	1,600	2,050	66	450	590	86	150	190	82
Einstein	7,500	9,800	66	2,900	3,800	88	1,200	1,600	94
Parker	17,100	22,400	62	3,400	4,500	83	1,000	1,300	87

<sup>1/</sup> Sediment yield volume calculated assuming specific weight of deposit of 1,500 kg/m<sup>3</sup> (93 lb/ft<sup>3</sup>)

