RECONNAISSANCE INVESTIGATION OF SEDIMENT DISTRIBUTION, EROSION, AND TRANSPORT IN THE UPPER DESCHUTES RIVER, DESCHUTES COUNTY, OREGON, NOVEMBER 1986

By Kenneth A. Cameron and Jon J. Major

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DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
5400 MacArthur Boulevard
Vancouver, Washington 98661

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CONVERSION FACTORS

For the convenience of readers who prefer to use metric (International System) units rather than the inch-pound units used in this report, the following conversion factors are provided:

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3049	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow	
cubic feet per second (ft^3/s)	0.0285	cubic meters per second (m^3/s)

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NVGD of 1929)-- a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

A preliminary investigation of sediment distribution, erosion, and transport in the upper Deschutes River was conducted in response to the perceived problem that brown trout spawning gravels were being rendered unusable due to an accumulation of fine-grained sediment. Contrary to the contention that channel gravels are being covered by fine-grained sediment, examination of the river channel at several sites indicates that bed sediment is generally a thin veneer (mostly less than 0.6 feet) over local bedrock. This thin sediment veneer and numerous streambed exposures of local bedrock suggest that bed material commonly is redistributed and that most fine-grained sediments probably have a short residence time and are transported through the study reach.

The Shields criterion for bedload transport suggests that maximum discharges for the Deschutes River upstream from Pringle Falls subsequent to the operation of Wickiup Dam could transport bed material about 20 percent larger (up to about 17 millimeters) than pre-closure maximum discharges. Minimum discharges subsequent to dam closure, however, appeared capable of transporting only particles about one-half as large (up to about 6 millimeters) as pre-closure minimum discharges. Operation of Wickiup Dam appears to have had little effect on the size of transported bedload in the Deschutes River near Benham Falls.

Bank erosion, averaging 0.2 to 0.4 feet per year, appears to have started subsequent to the operation of Wickiup Dam and may have resulted from changes in the timing of high and low stages. Most of the eroded material is fine grained (less than 2 millimeter). Shields' bedload transport criteria suggest that this sediment should move through the upper Deschutes River and not cause appreciable sedimentation on the channel bed.

Substantial alteration of river stage following dam closure has resulted in subaerial exposure of channel-bar gravels during the brown trout spawning season, which lasts from October through December in the upper Deschutes basin. This factor, combined with a lack of gravel in the deeper part of the channel, appears to be a major contributor to reduction of the brown trout spawning habitat in the upper Deschutes River.

INTRODUCTION

Statement of Problem

Degradation of brown trout spawning gravels in the upper Deschutes River has been identified as a continuing problem by Federal, State, and local authorities responsible for river management. The number of brown trout redds in the Deschutes River between Wickiup Reservoir and Pringle Falls (fig. 1) decreased from 92 in 1954 to 1 in 1970 (Oregon Department of Fish and Wildlife, written comm., 1971). Since 1970, no brown trout redds have been found in the upper Deschutes River (T. Fies, Oregon Department of Fish and Wildlife, oral comm., 1986). Conversely, the number of brown trout redds in Spring River, a small tributary to the Deschutes River above Bend, has increased from zero in 1954 to 47 in 1971 (Oregon Department of Fish and Wildlife, written comm., 1971). A river-study workshop identified filling of spawning gravels by fine-grained sediment as having eliminated most, if not all, of the spawning habitat on the Deschutes River (Deschutes County River Task Force Committee, 1986). This perception of spawning habitat degradation by fine-sediment deposition suggests that a change in bed-material size has occurred since the closure of Wickiup Dam in 1949.

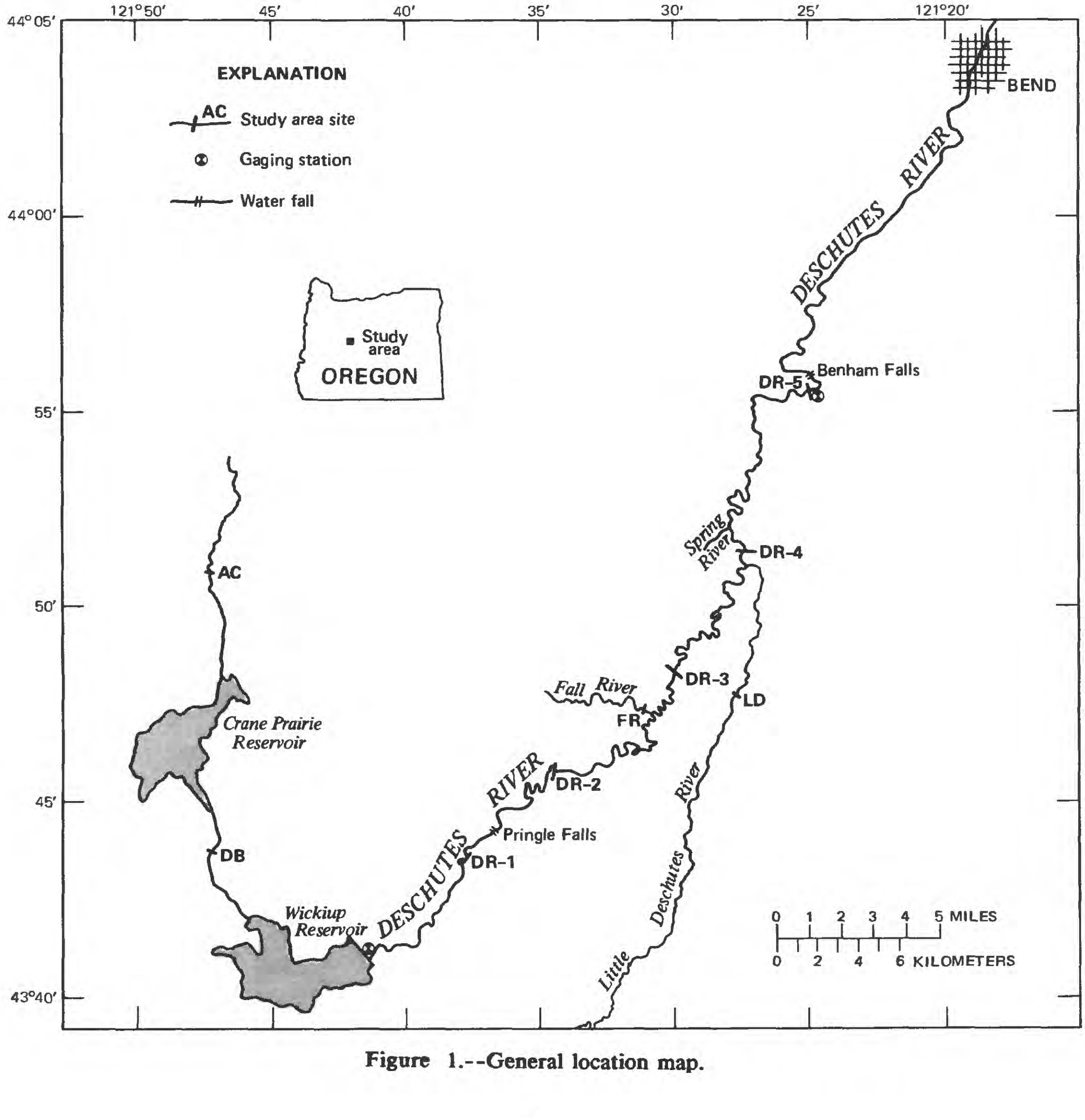

Figure 1.--General location map.

Purpose and Scope

In order to obtain information on sediment sources and transport needed to assess the nature of changes in bed sediment, a reconnaissance field investigation was conducted in November 1986 by the U.S. Geological Survey, in cooperation with the U.S. Forest Service. The field work was done during the brown trout spawning season, which lasts from October through December in the upper Deschutes River basin. During the investigation, the geologic, hydraulic, and sedimentologic characteristics of several reaches of the upper Deschutes River valley between Wickiup Dam and Benham Falls were evaluated. This report presents the results of that investigation. Background information is presented on the streambank stratigraphy of the study area, as is a geologic history of the river and a summary of the man-made effects. Also included are granulometric data from bed and bank material, analyses of bank and channel erosion, and estimates of maximum transportable particle size under different flow conditions. This data provides quantitative information on sediment distribution and transport in the upper Deschutes River and establishes a baseline data set for future studies.

Method of Investigation

The river was divided into five distinct geomorphic reaches between Wickiup Dam and Benham Falls, and one cross section was established within each reach (fig. 1; appendix). Data collected at each site include (1) a detailed cross-sectional survey of the river channel, with a description of bed material at all survey points; (2) samples of bed and bank material; and (3) slope of the present water surface, high-water surface, and, where possible, the channel thalweg, surveyed over a distance of more than 300 feet. In addition, the general streambank stratigraphy was determined and tree cores were taken at key locations to document rates of local bank erosion. A detailed description of each cross section is given in the appendix, and figures 2-6 are photographs from each study site.

Figure 2.--Upstream view of upper Deschutes River at cross-section DR-1.

Figure 3.--Downstream view of upper Deschutes River near cross-section DR-2. Cross-section traverses downstream end of gravel bar seen in upper right corner (see arrow).

Figure 4.--Downstream view of upper Deschutes River at cross-section DR-3.

Figure 5.--Upstream view of upper Deschutes River at cross-section DR-4.

Figure 6.--Upstream view of upper Deschutes River at cross-section DR-5.

GENERAL STRATIGRAPHY

General streambank stratigraphy of the upper Deschutes basin was compiled to identify potential sediment sources. Four primary units were identified (fig. 7). Divisions were based on texture (grain size, scale of bedding, etc.), cohesiveness, and composition.

The lowest exposed unit in the stratigraphic section in the study reach is a lacustrine, thinly bedded to laminate, sandy siltstone. Individual beds range in thickness from 0.8 to 8 inches, but extremely thin, non-fissile laminations are common. Sand-rich zones are scattered throughout the unit, and some diatomite beds (locally up to 7 feet thick) are found near the upper contact. The siltstone is cohesive, not easily eroded, and stands as vertical or high-angle banks and cliffs. Bedding planes are generally horizontal, though some small-scale soft-sediment deformation is occasionally observed. The base of the unit was not seen, but thicknesses up to 30 feet are common. This unit was observed at each study site.

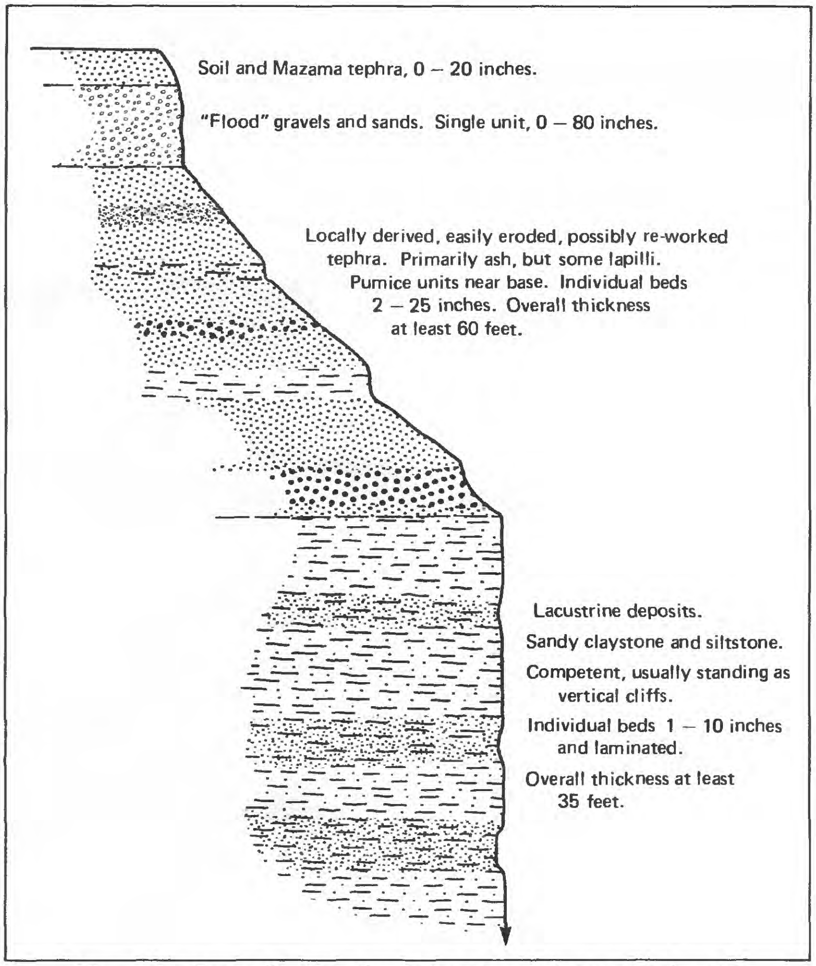

Figure 7.--Generalized stratigraphic column of streambank units along the upper Deschutes River.

Overlying the lacustrine siltstone is a thick (up to 65 feet observed) section of bedded, locally derived, fluvially reworked tephra (W. Scott, U.S. Geological Survey, written comm., 1987). Bed thickness ranges from 2 to 20 inches. Most beds are composed of ash- to fine-lapilli-size basaltic tephra, but some beds of lapilli-size, light-colored pumice are found near the base of the unit. Most of the pumiceous lapilli and a few beds of the basaltic ash have devitrified, and the resulting clay-rich layers are moderately cohesive. The majority of the unit, however, is very loose, easily eroded, and generally stands at angle of repose. This unit crops out at least as far downstream as DR-3.

Overlying the tephra is a poorly sorted mixture of sand and gravel observed to be as much as 7 feet thick. This unit, although easily eroded, is more cohesive than the underlying tephra. It generally stands at angle of repose in exposed banks, but was observed to stand vertically in sheltered areas. Individual clasts within this fluvial unit, which may be related to glacial outwash or prehistoric flooding, are generally well rounded. This unit was not observed downstream from DR-3.

The uppermost unit in the stratigraphic section along the upper Deschutes River is the 6,850-year-old Mazama tephra. This tephra is composed of ash- to fine-lapilli-size, light-colored pumice fragments and is generally mixed with the local soil. Maximum observed thickness of this tephra was about 1.3 feet. This tephra was observed at all study sites.

RIVER HISTORY

Terraced meander scars, oxbow lakes, and abandoned meander loops attest to past meandering of the Deschutes River. Between Wickiup Dam and Benham Falls, the river has a very low average gradient (0.0003), a high sinuousity (ratio of stream length to valley length = 2.1), and a tortuous channel pattern (Schumm, 1963). The meander pattern of the Deschutes River is a relict feature that was established at least several thousand years ago. However, the precise age of the meanders is unknown. They are younger than the locally derived tephra into which they are cut, but they are mantled by the Mazama tephra (6,850 years old). Prior to the closure of Wickiup and Crane Prairie dams, the river channel was relatively stable. Old-growth trees growing on tops of steep banks and along the insides of meander loops attest to that stability.

Most of the natural flow of the Deschutes River is derived from springs (Russell, 1905). Consequently, discharge was usually constant throughout the year. At a gaging station downstream from the site of Wickiup Dam, average monthly flows during the period 1906 to 1911 (fig. 8) ranged from a low near 650 ft^3/s in December to a high of less than 950 ft^3/s in March (Henshaw and Lewis, 1914). Extreme monthly averages at this site were 631 and 1550 ft^3/s. At the gaging station near Benham Falls during the same period, average October flows were about 1,500 ft^3/s and average May flows were about 2,000 ft^3/s; extreme monthly flows were 1,280 and 2,510 ft^3/s.

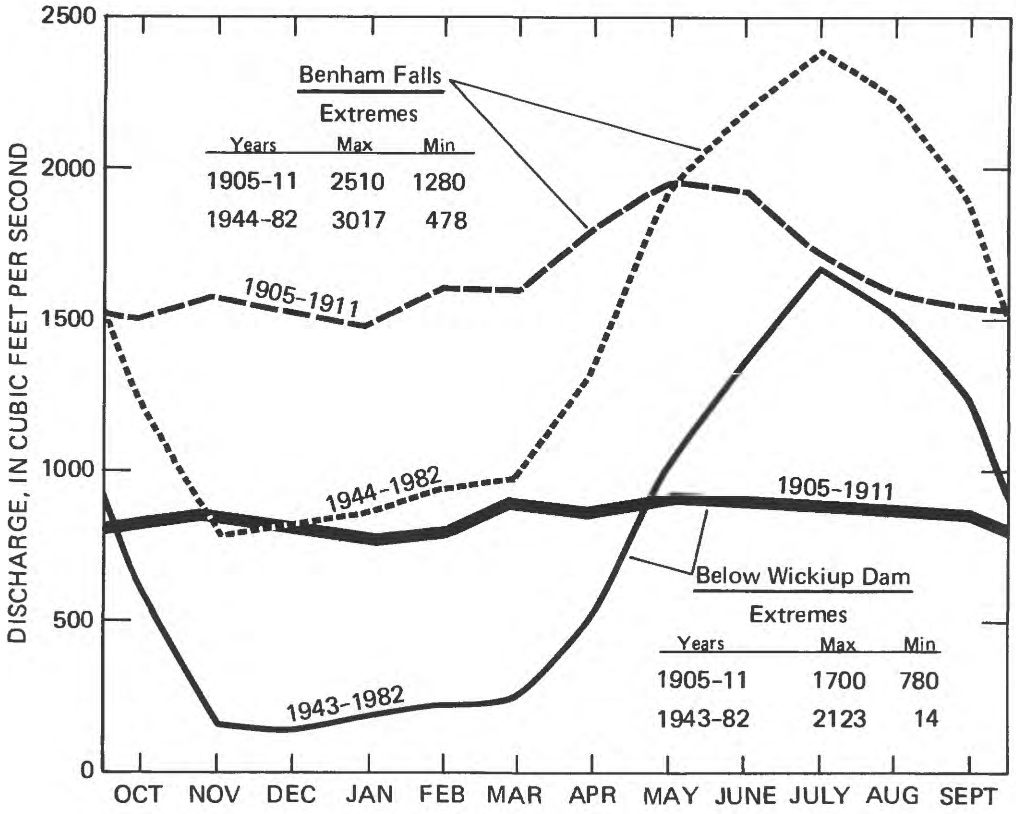

Figure 8.--Hydrographs of average monthly discharge of the upper Deschutes River near Wickiup Dam and Benham Falls before and after closure of Wickiup Dam.

Human intervention in the natural flow of the upper Deschutes River first occurred in 1902 with diversion of water from the Little Deschutes River into the Walker Basin irrigation canal, 24 miles upstream from the confluence of the Deschutes and Little Deschutes River (L. Mathisen, written comm., 1985). This remains the only major diversion of water from the Deschutes River upstream from Benham Falls. In 1922, Crane Prairie Dam on the Deschutes River and Crescent Lake Dam on a tributary to the Little Deschutes River, 36 miles southwest of the confluence of the Little Deschutes and Deschutes River, were completed. Wickiup Dam, which exerts the greatest influence on the flow of the upper Deschutes River, was completed in 1949. Since the closure of Wickiup Dam, seasonal flow of the upper Deschutes River has been substantially altered. Wintertime flow has been significantly reduced by reservoir storage, and spring and summer flows have been enhanced by release of water for irrigation. At the Wickiup Dam gaging station, average monthly flows during the period 1944 to 1982 ranged from 150 to 1,700 ft^3/s and extreme monthly flows were 14 and 2,123 ft^3/s. Average monthly flow at the Benham Falls gaging station, during the same period, varied between 800 and 2,400 ft^3/s and the extreme monthly flows were 478 and 3,000 ft^3/s (Friday and Miller, 1984). The timing of the peak and low monthly flows also has been affected. High monthly flows now occur about 2 months later, during July, and low monthly flows occur about 1 month later, in November.

GRANULOMETRIC DATA

To quantitatively characterize sediment distribution along the upper Deschutes River, 15 sediment samples were collected and analyzed by standard sieving methods (tables 1 and 2); seven were channel-bed material, two were from gravel bars, and four were channel-bank material. Two samples were bed material collected from the Little Deschutes and Fall Rivers. In this report, the sample identification provides both the collection site and sample number. For example, DR-1D refers to sample D collected at cross section DR-1. Although multiple samples were collected at each cross section, the analyses presented in the following discussion represent a bulk sample collected at a single point and not a composite of multiple samples.

Samples DR-1D and DR-2F were collected from subaerially exposed gravel bars and represent material collected from pits dug down to the water table. Sample DR-1D consists of about 67 percent gravel (between 4 and 32 millimeters) and 32 percent sand, and sample DR-2F contains about 43 percent gravel and almost 56 percent sand (fig. 9). Each of these gravel bars is armored with well-sorted gravel. Below the armor, the bars are very poorly sorted and composed mostly of gravelly sand.

Bed material, in general, decreases in size progressively downstream. More than 98 percent of the bed material upstream from Crane Prairie Reservoir is gravel (mean grain size of 26 millimeters), whereas near Benham Falls more than 25 percent of the bed material is silt and clay (mean grain size of 0.16 millimeters; table 2; fig. 9). Upstream from site DR-3, bed material generally exists only as a thin veneer (less than 1 foot thick) overlying the lacustrine siltstone "bedrock" (appendix). Downstream from site DR-3, increasing water depths made determination of bed-sediment thickness impractical. However, visible exposures of the siltstone on the channel bottom at DR-4 indicate that bed material is probably a veneer at that site also.

For comparison, bed material was analyzed from both Fall River and Little Deschutes River (fig. 10), major tributaries to the upper Deschutes River, because Fall River, at least, is considered a prime trout-spawning stream (Oregon State University, 1985). The single-sample analyses indicate that size characteristics of bed material from Fall River are very similar to those of bar and channel material from DR-1 and DR-2 on the upper Deschutes River.

Four samples of bank material from the upper Deschutes River were analyzed (table 1; fig. 11). In general, bank material is finer than bed material and does not contain a significant source of gravel except the relatively thin gravel-bearing fluvial deposit (fig. 7). Sample DR-2E is from the locally derived tephra unit, and though it contains a relatively high percentage of gravel-size material, most of that gravel is composed of low- density pumiceous lapilli. The low density of this pumice and resulting ease of transport prevents this material from becoming a major component of the bed sediment. Sample DR-3D is "bank" material collected from left edge of the channel rather than the flood plain (fig. 4). The abundance of gravel-size material at this site results from seasonal reworking of the channel edge and subsequent winnowing of fine material. The two downstream samples, DR-4A and DR-5B, represent surficial overbank floodplain deposits, material that is easily transported by the river.

Table 1.--Size-distribution analysis of individual samples

Sample	Weight percent of sample by class size, in millimeters															
	64	32	16	8	4	2	1	0.5	0.25	0.125	0.063	0.031	0.016	0.008	0.004	0.002
AC-1	--	48.5	23.4	19.1	5.8	1.7	0.8	0.3	0.3	--	--	0.1	--	--	--	--
DB-A	--	18.8	42.9	9.4	9.8	6.8	7.1	4.1	1.0	0.1	--	--	--	--	--	--
DR-1B	--	--	16.4	29.7	14.9	11.5	4.9	3.6	8.8	8.8	1.3	.1	--	--	--	--
DR-1D	--	--	8.6	26.2	18.7	13.5	7.1	5.1	12.5	7.3	0.9	.1	--	--	--	--
DR-2B	--	13.2	25.5	21.3	13.4	9.6	6.2	3.0	5.4	2.1	.2	.1	--	--	--	--
DR-2F	--	--	9.9	19.6	8.1	6.4	4.5	7.4	23.5	19.4	1.3	.3	--	--	--	--
DR-3A	--	--	--	18.2	26.8	8.7	5.5	7.4	18.7	11.2	2.7	.3	--	--	--	--
DR-4D	--	--	--	--	0.5	5.2	15.4	29.9	39.5	9.1	.3	.1	--	--	--	--
DR-5A	--	--	--	--	--	3.3	10.9	9.7	8.5	12.5	29.4	21.3	1.5	1.5	1.5	0.8
LD-1	--	--	--	8.6	7.3	10.3	10.2	20.3	37.5	5.6	.2	--	--	--	--	--
FR-1	--	--	4.6	26.1	26.9	14.0	10.7	4.7	6.2	5.8	.9	.1	--	--	--	--
DR-2E	--	--	--	4.4	12.8	23.4	25.7	6.6	11.1	11.3	3.1	1.6	--	0.2	--	--
DR-3D	--	--	--	10.1	15.5	18.6	13.5	7.0	7.8	5.9	11.5	9.6	0.2	.1	0.1	.1
DR-4A	--	--	--	--	.3	4.0	14.5	13.6	12.4	14.3	25.2	13.9	.5	.6	.1	.4
DR-5B	--	--	--	--	--	--	.2	.6	2.0	23.9	51.8	19.1	1.1	.6	.2	.4

Table 2.-- Summary of sediment size distributions from the study area

[See table 1 for sample identification; mm = millimeter]

Sample number	Percent gravel (>2 mm)	Percent sand (0.062-2mm)	Percent silt and clay (<0.062 mm)	Mean size (mm)
		Bed material		
AC-A	98.5	1.4	0.1	26
DB-A	87.7	12.3	--	13
DR-1B	72.5	27.4	0.1	3.4
DR-1D[1/]	67	32.9	0.1	2.7
DR-2B	83	16.9	0.1	8.5
DR-2F[1/]	43.6	56.1	0.3	1.3
DR-3A	53.7	46	0.3	1.8
DR-4D	5.7	94.2	0.1	0.5
DR-5A	3.3	71	25.7	0.16
LD-A	26.2	73.8	--	0.98
FR-A	71.6	28.3	0.1	3.3
		Bank material		
DR-2E	40.6	57.8	1.6	1.3
DR-3D	44.2	45.7	10.1	0.92
DR-4A	4.3	80	15.7	0.23
DR-5B	--	78.5	21.5	0.09

1/ gravel bar

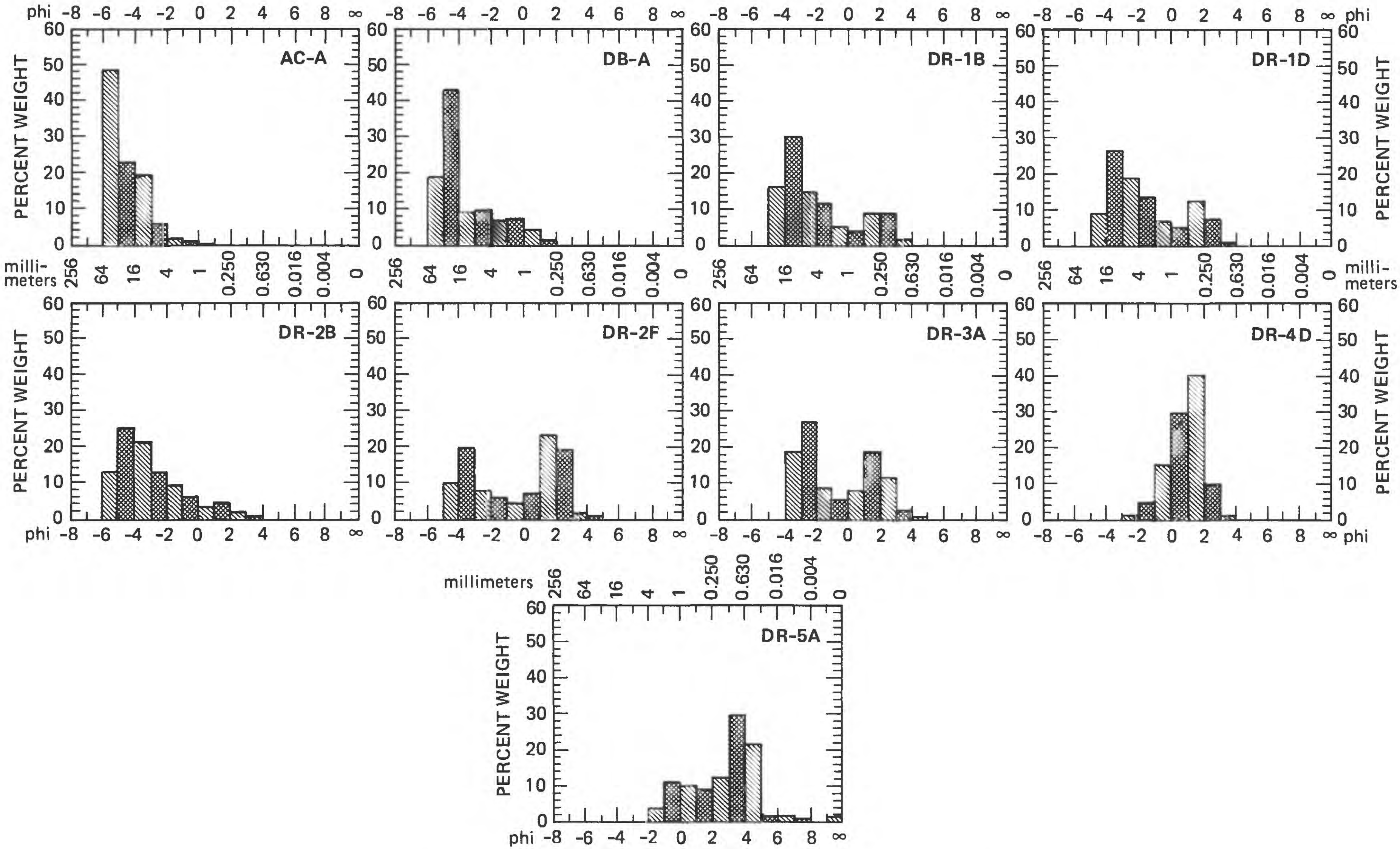

Figure 9.--Histograms of bed-material samples collected from upper Dechutes River.

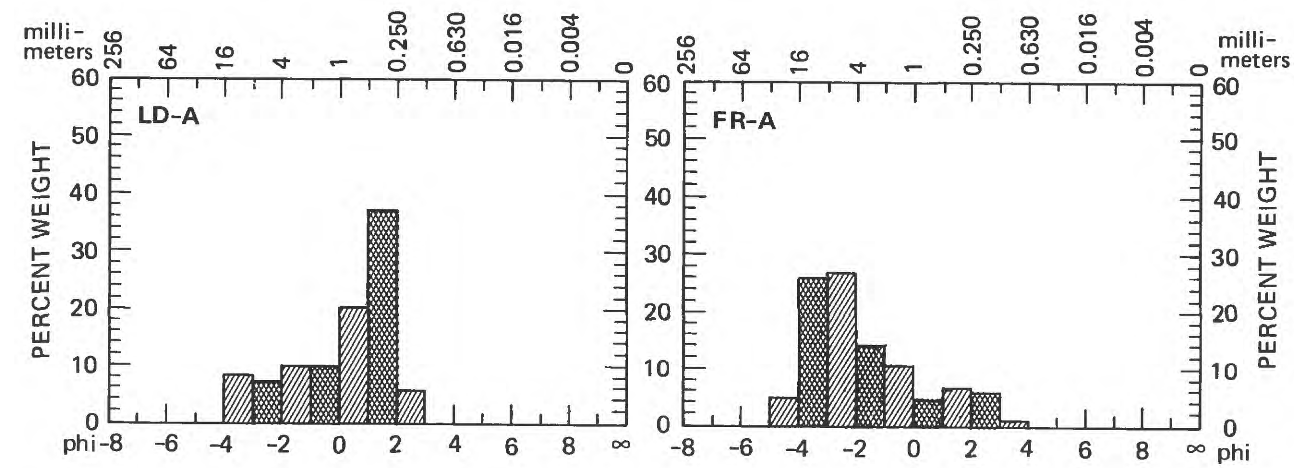

Figure 10.--Histograms of bed-material samples collected from Little Deschutes and Falls Rivers.

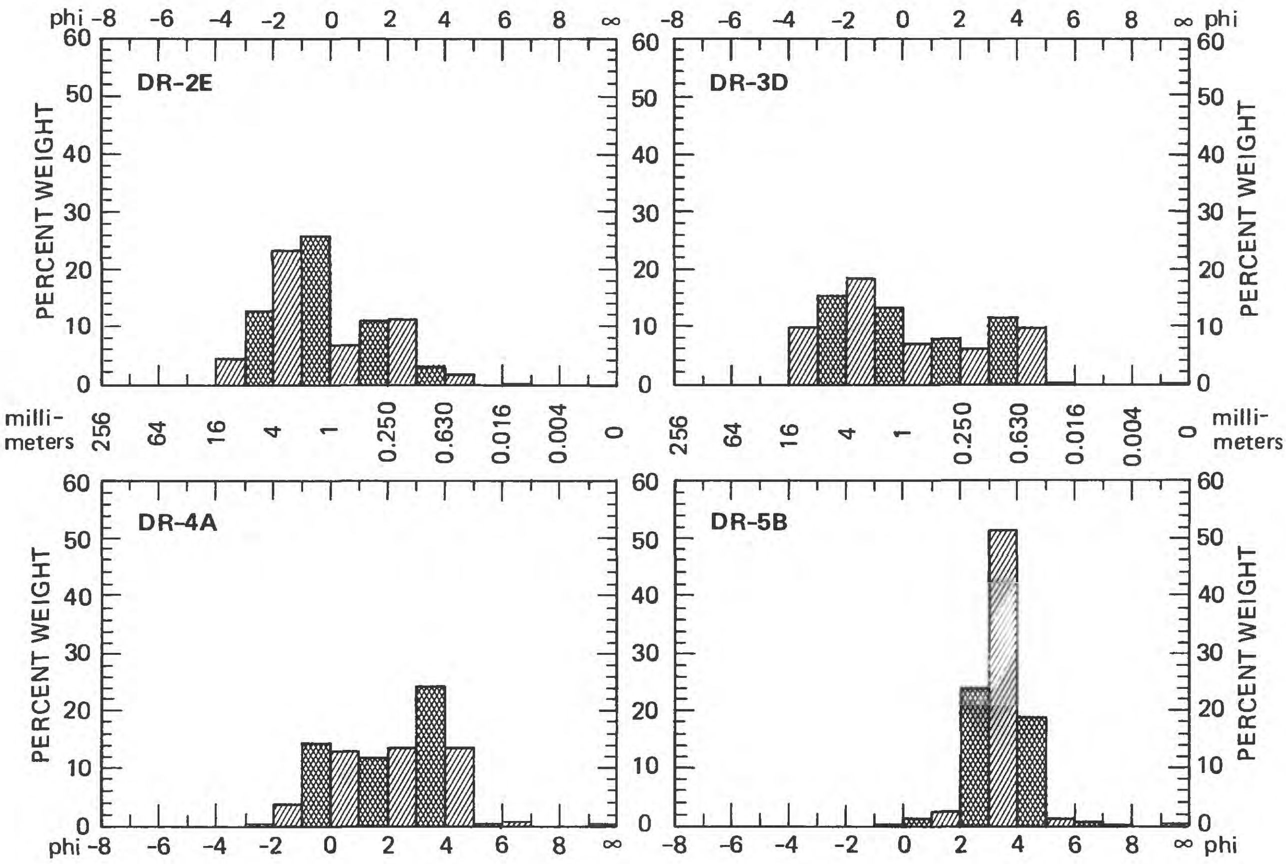

Figure 11.--Histograms of bank-material samples collected along upper Deschutes River.

EROSION

Influx of sediment into the upper Deschutes River from tributaries is negligible because of the hydrologic regime of the upper Deschutes basin, which is dominantly spring-fed, receiving low precipitation amounts and little associated surface runoff. Therefore, the source of any sediment problem in the upper Deschutes River must result from erosion of existing near-stream material, either the banks or the channel.

Dendrochronological Determination of Bank Erosion Rates

Dendrochronologic analyses indicate an apparent increase in bank erosion at two locations along the upper Deschutes River since about 1950. A limited number of trees were cored to examine changes in tree-growth rate. Trees were chosen that had a significant proportion (greater than 25 percent) of their root base exposed by undercutting. It is assumed that exposure of the root base would slow the growth rate of the tree, which would be reflected in a thinning of annular growth rings. Only straight, mature (generally over 1.5 feet in diameter) Ponderosa pines with no vegetative competition were cored. All undercut trees were cross-dated with "control" trees to ensure that ring sequences were complete.

The first coring site is located about 0.3 miles upstream from DR-2, on the top of the left bank. This large cutbank (part of which is shown in fig. 3) was identified as one of the most actively eroding banks along the upper Deschutes River (E. Felix, U.S. Forest Service, oral comm., 1986). Two trees were cored; a "test" tree that had approximately 25 percent of its root base exposed by erosion and a "control" tree that was located 60 feet back from the top of the bank. Exposed roots of the undercut tree extended river-ward along an angle that reflected the slope of the pre-erosion ground surface. At its distal end, the root turned abruptly downward, which is interpreted as the location of the top of the pre-erosion bank (fig. 12). The distance from the present bank to the down-turned part of the root is a direct measure of the bank erosion. At this site, approximately 7 feet of erosion has occurred.

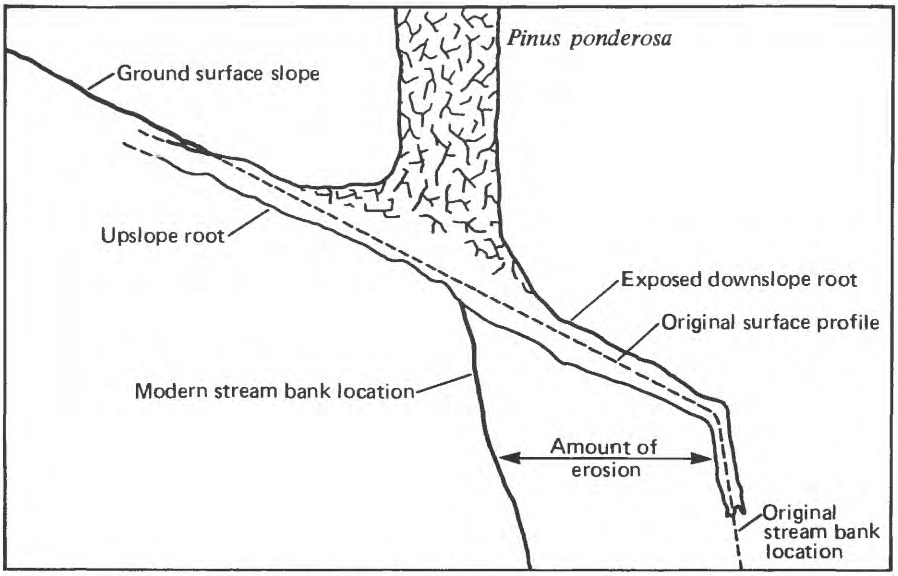

Figure 12.--Diagram showing amount of bank erosion along upper Deschutes River calculated from root exposure of trees.

Examination of the prepared cores indicates a thinning of the annular rings starting in 1953. An average of 7 feet of erosion over that 33-year time span yields an erosion rate of 2.5 inches per year. This value should be considered a maximum rate. Although thinning of the rings is first observed for 1953, the roots may have been exposed a few years prior to the detected change in growth rate; however, the percentage of exposed root base may not have been sufficient to noticeably affect growth rates. This would happen if bank erosion occurred at a slow, steady rate, rather than by rapid, periodic events.

The second coring site is located at Bull Bend, 150 to 300 feet upstream from DR-1. Three undercut trees along the top of the left bank and one control tree in the middle of the meander neck were cored. Maximum erosion rates of 5.2, 3.1, and 2.8 inches per year were calculated based on 5 to 7 feet of erosion beginning in 1973, 1960 and 1963, respectively. These rates of erosion are within the range of previous estimates made during a ground-based photogrammetric erosion study in 1978 (Century Testing Laboratory, Inc., 1978).

All cored trees were rooted in either the locally derived tephra unit or in the gravel-bearing fluvial deposit. Because these units are easily eroded, they are potential sediment sources.

Riparian Area

The operation of Wickiup Dam for irrigation has substantially altered the magnitude and distribution of flow rates in the upper Deschutes River (fig. 8). River flow has been significantly reduced in winter and greatly enhanced in the spring and summer. Prior to Wickiup Dam, river discharge had a similar seasonal distribution (lower discharge in winter than in summer, fig. 8), but had a markedly less pronounced variation in stage. Accentuated seasonal fluctuation of stage subsequent to dam operation has resulted in a broad streamside zone between high and low stage that is barren of the protective plant cover needed for bank stabilization (figs. 2, 4, and 5).

In many areas, this barren zone is typified by fine-grained deposits that are easily erodible (typically the local tephra, fluvial gravel, or overbank deposits; fig. 7). Specific estimates of erosion rates for this material were not made during this investigation. However, frost heave was observed to be an active process that disaggregates bank material to a depth of about 0.5 inches. The loosened material is susceptible to erosion by streamside activity (such as human and animal traffic) during times of low water and by river currents and wave activity, especially boat wakes (Garvin, 1977), during times of high water. However, the competence of the river, even during low flows, is sufficient to transport fine material beyond the study reach. Because it is easily transportable and relatively fine-grained, erosion of material from riparian areas would probably increase river turbidity.

Channel Area

Aerial photographs taken in 1943 and 1973 were compared to determine changes in channel morphology as a result of operation of Wickiup Dam. Both sets of photographs were taken during similar river discharge, so bank and near-channel exposures were approximately equivalent. No substantial streamside erosion was observed during the period bracketed by the photographs. Location and size of exposed gravel bars and banks do not appear to have changed during the 30 years between photographs. Furthermore, few newly denuded banks appear during that time interval.

In addition to a general lateral stability, the Deschutes River also is vertically stable. Although considerable amounts of sediment (mostly sand and gravel upstream from DR-3 and sand downstream from DR-4) are found along the channel edges and in channel bars, the channel center is usually devoid of sediment cover, and the river flows directly on exposed "bedrock". This "bedrock," composed of thinly bedded lacustrine siltstone, is moderately cohesive and resistant to rapid erosion or incision and usually breaks into plates a few inches thick by tens of inches across. These plates generally are too large to transport and are found near their source (fig. 13). Smaller pieces of siltstone, however, often are transported and deposited in downstream gravel bars, where they compose as much as 10 percent of the clasts.

Sand was observed moving along segments of the channel bed at relatively low flows (about 100 ft^3/s in the channel immediately downstream from Wickiup Reservoir and about 600 ft^3/s near Benham Falls at the time of this study). Some sand is trapped by the common water plant Elodea sp. (probably densis; Peck, 1961). This plant grows in dense, oval, mound-shaped masses about 3 feet long, 2 feet wide, and several inches thick, and occurs in all but the deepest parts of the channel (fig. 3). The plant itself covers only the mound surfaces; mound interiors are composed of trapped sediment. Examination of this trapped sediment reveals it to be primarily sand-size. Plant death or mechanical disruption of the mounds releases trapped sediment into the flow, making it available for transport.

Figure 13.--"Plates" (below water surface, lower center of photograph) formed by erosion of siltstone bedrock at Bull Bend (site DR-1)

BEDLOAD TRANSPORT

Shields' (1936) function was used to assess, for different hydraulic conditions, which sizes of bed material particles can be expected to remain stable (motionless) on the bed and which sizes can be expected to be transported downstream. The function is based on the premise that for every size of particle on the bed there is some critical bed shear stress that must be exceeded before particles of that size will move. Shields' experimental work showed that critical shear stress, sediment and fluid densities, fluid viscosity, and grain diameter could be combined into two dimensionless terms that define a threshold curve of incipient particle motion. Values of the dimensionless terms, computed for a given grain size from a specified shear stress, that plot above this threshold curve represent a condition sufficient to cause that size of particle to move; values below the curve represent an insufficient condition for mobility. By assuming values for the sediment and fluid densities and viscosity and knowing the water depth and channel gradient, the function can be used to estimate the mobility of different sizes of particles.

Although the Shields diagram is a commonly applied method for determining stream competence, it was developed for small laboratory flumes under controlled conditions. Under natural-flow conditions, variations in bed shear stress may be caused by large turbulent eddies, which can generate local shear stresses several times more than the average bed shear stress. Therefore, this technique is used only to estimate the competence of the Deschutes River, and caution is needed when extrapolating the Shields criterion of competency to large-scale natural flows (Blatt and others, 1972).

Threshold particle sizes were computed downstream from Wickiup Dam and at site DR-5 near Benham Falls. Downstream from Wickiup Dam, water depth was obtained from historical gaging-station records. Channel gradient was assumed to be similar to that at site DR-1, 7 miles downstream and in the same geomorphic reach. At DR-5, water depth was obtained from historical gaging- station records and channel gradient was measured near the present cableway.

Prior to operation of the dam, gravel-size particles as large as 11 to 14 millimeters apparently were capable of entrainment near Wickiup Dam by low (580 ft^3/s) and high (960 ft^3/s) flows, respectively (table 3). Subsequent to operation of the dam, low flows (20 to 90 ft^3/s) could apparently entrain particles only as large as 3 to 6 millimeters, whereas high flows (2,130 ft^3/s) could entrain gravel as large as about 17 millimeters. Near Benham Falls, dam operation appears to have had little effect on bedload transport. Both pre- and post-closure flows appear capable of entraining particles only as large as fine gravel (2 to 3 millimeters).

These results suggest that redds, which ideally have particle sizes in the range of 19 to 50 millimeters (T. Fies, Oregon Department of Fish and Wildlife, oral comm., 1986), will become armored as all finer material is removed from the surface. It is interesting to examine the grain-size distribution of the two sampled gravel bars in light of these Shield function results. Each bar has a bimodal size distribution (fig. 9). In both bars, the coarse mode is centered about a size range of 8 to 16 millimeters, a range near the upper limit of material that can be moved during high flow, but which remains at rest during low flow.

Table 3.-- Maximum transported particle size as computed from the Shields diagram

[ft, feet; ft^3, cubic feet; s, second; mm, millimeter]

Year	Slope (ft/ft)	Depth (ft)	Mean velocity (ft/s)	Discharge (ft^3/s)	Threshold size (mm)
		Deschutes River near Wickiup Dam			
1939	0.0012	3.95	1.70	583	11.0
1939	do.	5.07	2.15	962	14.0
1952	do.	1.89	1.00	91	6.0
1952	do.	6.73	3.10	2,130	17.0
1975	do.	0.82	1.11	21	3.0
		Deschutes River near Benham Falls			
1933	0.0001	6.10	1.28	960	2.0
1933	do.	7.52	1.80	1,760	2.0
1952	do.	7.83	2.46	3,130	3.0
1975	do.	7.60	0.94	857	2.0
1975	do.	10.5	1.81	2,280	3.0

The fine mode, however, is centered about a size range of 0.25 to 0.5 millimeters. Because this size range is capable of being transported by even the lowest flows, its presence indicates that it is protected from transport by the surface armoring of the bars and suggests that it probably has accumulated slowly over a longer time interval than the 37 years since closure of the dam, perhaps by slow, continuous bank erosion.

The Shields diagram also can be used to compute the minimum grain size that should remain at rest on a channel bed under given hydraulic conditions and when the average grain size of the bed material exceeds a diameter of about 6.5 millimeters (Henderson, 1966, p. 415). The minimum stable particle sizes for the channel bed near Wickiup Dam for various depths of water are given in table 4.

Table 4.-- Minimum stable particle size for bed material of the Deschutes River near Wickiup Dam, as calculated from the Shields diagram (channel gradient = 0.0012)

Water depth (feet)	Minimum stable diameter (millimeters)
2.0	8
2.5	10
3.0	12
3.5	14
4.0	16
4.5	18
5.0	20
5.5	22
6.0	24
6.5	26
7.0	28
7.5	30
8.0	32
8.5	34
9.0	36
9.5	38
10.0	40

CONCLUSIONS

No evidence was found to support the contention that channel gravels in the upper Deschutes River are being covered by fine-grained sediment. On the contrary, a thin veneer of sediment on the channel bottom and numerous streambed exposures of bedrock generally indicate that most fine-grained sediment probably has a short residence time and is transported through the study reach. Numerous large gravel bars were observed throughout most of the study reach. Size analyses of the sediment composing the gravel bars suggest that they have a size distribution similar to the bed material in Fall River, a stream considered to be a prime spawning area. Substantial alteration of the timing and magnitudes of high and low flows caused by operation of Wickiup Dam, particularly the significant reduction of wintertime flows, has left gravel bars exposed during the brown trout spawning season. This factor, combined with the lack of gravel in deeper water, appears to severely limit the availability of spawning habitat in the upper Deschutes River.

Bank erosion rates were determined by dendrochronological methods at two locations along the Deschutes River showing substantial erosion. As much as 7 feet of erosion has occurred since 1950, at rates that average about 3 inches per year. At both sites, erosion appears to have started subsequent to the operation of Wickiup Dam. Most of the eroded material is sand-size and smaller. By using the criteria of the Shields function, it was determined that sediment should move through the upper Deschutes River and not cause appreciable sedimentation on the channel bed.

To better define sedimentation processes in the upper Deschutes River, a more intense program of sediment-transport measurement is needed. In particular, it would be desirable to sample both bedload and suspended sediment in the spring when the irrigation water is released. Because release of water during spring represents one of the greatest changes in flow rate in the upper Deschutes River, bedload and suspended sediment data collected at this time could provide information for verification of the bedload transport theory. Quantitative information of sediment movement is perhaps the most essential information needed for planning mitigative measures in the rehabilitation of trout spawning in the upper Deschutes River.

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APPENDIX

Location and Description of Deschutes River Cross Sections

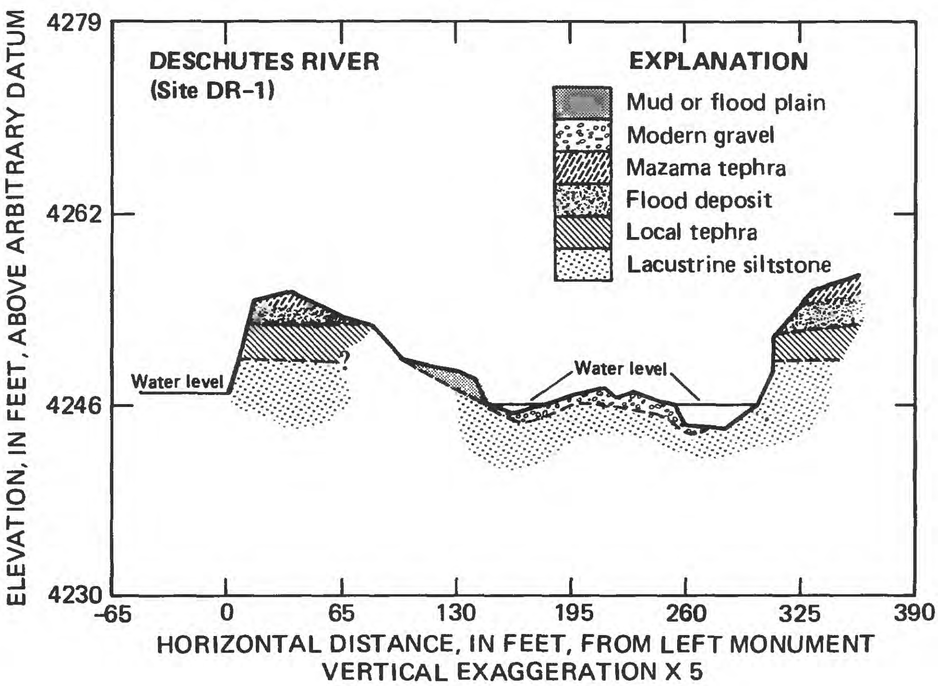
Cross-section 1 (DR-1) Bull Bend

Location: S1/2,NE1/4,Sec 27, T21S, R4E

Reach description: This section is centered in the reach bounded by Wickiup Dam and Pringle Falls.

Instrument site is located on north side of road at lowest point on meander neck. Section bearing = N33E (033). Cross section traverses downstream segment of river meander at Bull Bend.

The high-water channel width is 180 feet, of which 30 feet is bare or sparsely covered bedrock, 127 feet is gravel covered (maximum measured depth of gravel is 15 inches), and the remainder is gravelly talus and silt. Maximum channel depth is about 2 feet at low water and 5.5 feet at high water. The right bank, composed of locally derived tephra and a gravel- bearing fluvial deposit, may be eroding slowly. The left bank is composed of grass covered silt and clay, and is probably a depositional area. A gravel bar was partially exposed at low water level near the left bank (fig. A-1).



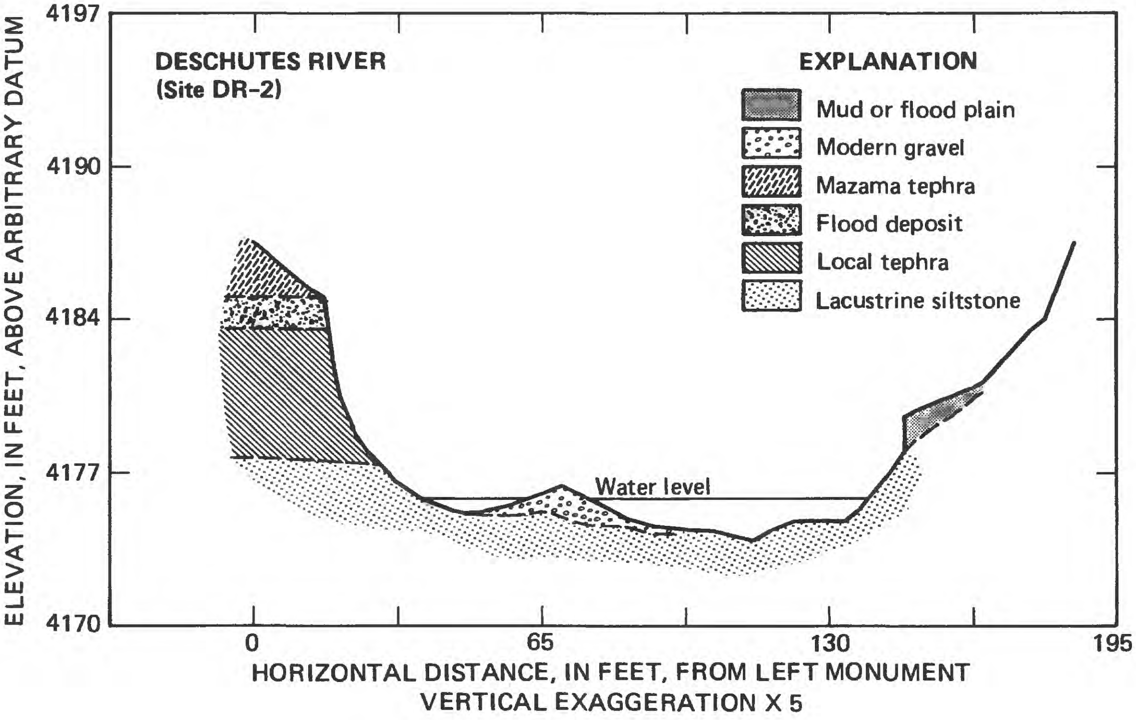
Cross-section 2 (DR-2)

Location: SW1/4,SE1/4,Sec 7, T21S, R10E

Reach description: This section is centered in the reach bounded by Pringle Falls and the mouth of Fall River.

Instrument site is located at top of left bank west of intersection of Forest Service Road 550 and Deschutes River. Upstream from cross section is an exposed cut bank several tens of feet high. Cross section bisects large gravel bar at left edge of channel. Section bearing = S44W (224).

The high-water channel is 127 feet wide, of which 72 feet is bare or sparsely covered bedrock, 32 feet is mixed sand and gravel (maximum measured depth of sand and gravel is 10 inches), and the remainder is gravelly talus and silt. Maximum channel depth is about 1.6 feet at low water and 4 feet at high water. The left bank is composed of tephra and gravel-bearing fluvial deposits, which may be eroding slowly. The right bank is composed of siltstone and grass covered silt and clay, and is probably a depositional area. A gravel bar was partially exposed at low water level near the left bank (fig. A-2).



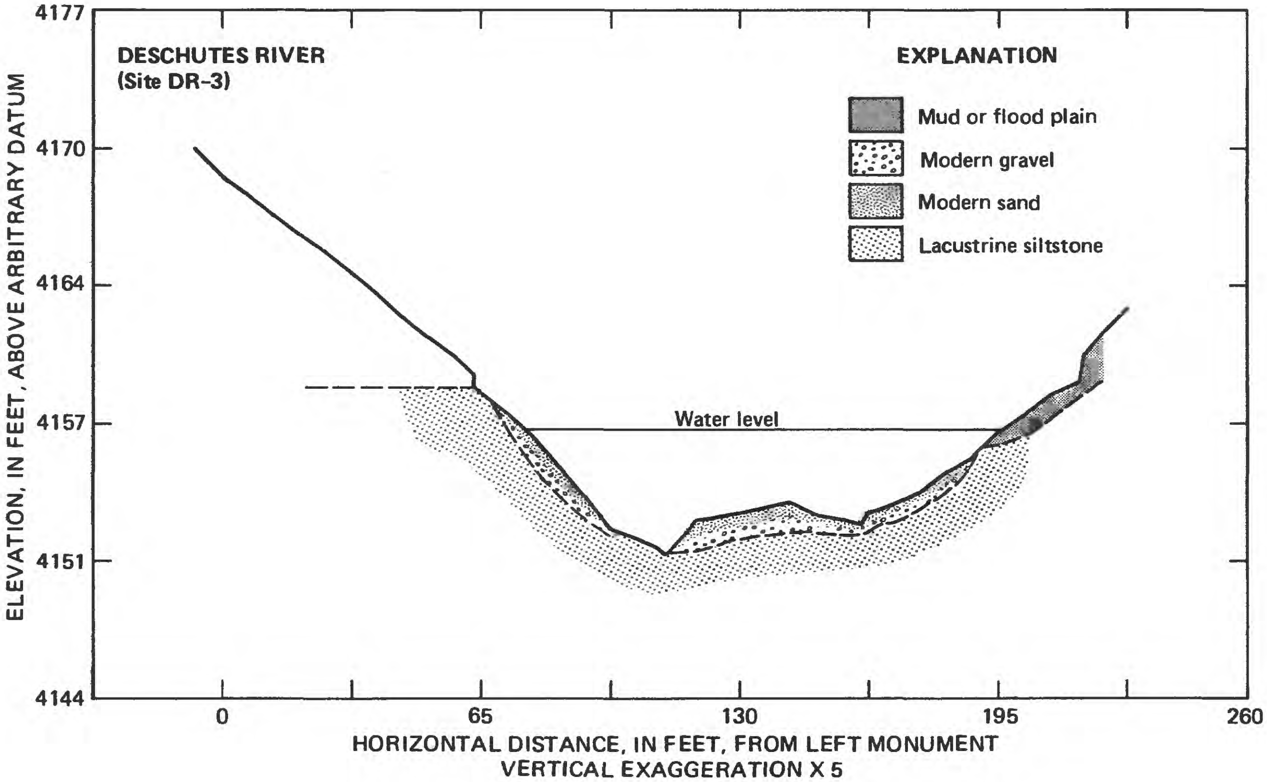
Cross-section 3 (DR-3)

Location: NE1/4,SW1/4,Sec 26, T20S, R10E

Reach description: This section is centered in the reach bounded by the confluence of Fall River and the mouth of the Little Deschutes River.

Instrument site is located on left bank southwest of Forest Service Road 990. Section bearing = S26E (154).

The high-water channel width is 130 feet, of which 78 feet is sand and gravel (maximum measured depth of sand and gravel is 15 inches), 30 feet is bare or sparsely covered bedrock, 14 feet is silt and clay (maximum measured depth of silt and clay is 15 inches), and the remainder is gravelly talus. Maximum channel depth is about 4.3 feet at low water and 6.5 feet at high water. The left bank consists of "bedrock" covered by a thin (2 inch) coating of sand and gravel, and appears to be stable. The right bank consists of grass covered silt and clay, and is probably a depositional area (fig. A-3).



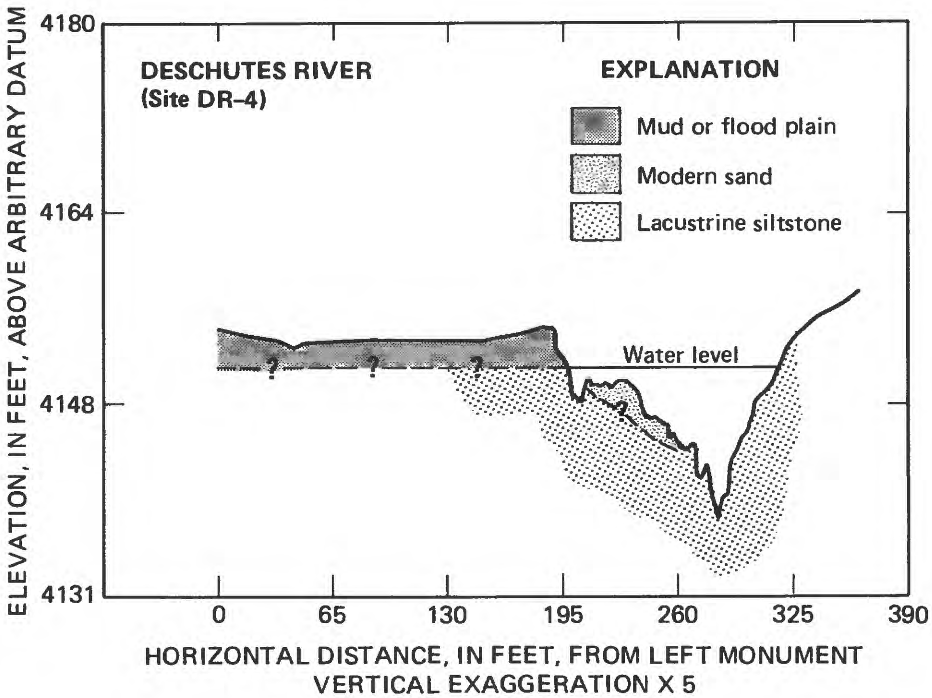
Cross-section 4 (DR-4)

Location: NW1/4,NE1/4,Sec 7, T20S, R11E

Reach description: This section is centered in the reach bounded by the confluence of the Little Deschutes River and the mouth of Spring River.

Cross section is measured by sounding off upstream side of Forest Service Highway 40 bridge. Instrument site is located on right bank boat ramp to measure channel gradient. Section bearing = E-W (090).

The high-water channel width is 135 feet, of which 56 feet is sand of unknown thickness, 16 feet is known bare bedrock, 60 feet is presumed to be bare bedrock (water depth precluded accurate determination), and the remainder is silt and clay. Maximum channel depth is about 10 feet at low water and 12.7 feet at high water. The left bank is part of a broad, grass covered floodplain at least 300 feet wide. The right bank is a public boat ramp, which has been extensively modified. A sand bar of unknown thickness exists near the left bank (fig. A-4).



Cross-section 5 (DR-5)

Location: SW1/4,NE1/4,Sec 16, T19S, R11E

Reach description: This section is near the downstream end of the reach bounded by the mouth of Spring River and Benham Falls.

Cross section was sounded off Oregon State Water Resources Department cableway upstream from Benham Falls. Instrument site located on right bank directly under the cableway measure channel gradient. Section bearing = N58E (058).

The high-water channel width is 115 feet, of which 39 feet is sand covered, and the remainder presumed to be silt and clay covered. Owing to the deep water depth, bottom conditions could not be precisely determined. Maximum channel depth is about 10 feet at low water and 11.5 feet at high water. Both banks are flanked by grass covered, muddy areas of overbank deposition (maximum measured depth of silt and clay is 3 feet). A sand bar of unknown thickness occupies the channel center (fig. A-5).