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ASSESSMENT OF IMPACTS OF CLEARWATER POWER PROJECT (FERC NO. 8468) ON THE SEDIMENT OF OROFINO CREEK, IDAHO

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SCOPE AND OBJECTIVES OF ASSESSMENT

Background

Clearwater Hydro Limited Partnership has made application before the Federal Energy Regulatory Commission for a license for the Clearwater Power Project (No. 8468) on Orofino Creek, a tributary of the Clearwater River near Orofino, Idaho. The project involves the diversion of streamflow at Orofino Creek Falls to develop hydroelectric energy. As part of the license application process, additional information was requested from the developer regarding Orofino Creek sediment.

Purpose and Scope

The purpose of this report is to present the results of a study made to assess the project impacts on the sediment of Orofino Creek. The scope of this assessment encompasses the transport, scour, and deposition of sediment in the bypassed reach of Orofino Creek, the nearby upstream zone, and the downstream zone extending to the mouth of Orofino Creek, including a comparison of the sediment transport regime with and without the proposed project.

Objectives

The specific objectives of this assessment of project impacts on the sediment of Orofino Creek, in providing the requested additional information, are to:

(a) provide information sufficient to determine the size distribution and quantity of the existing sediment load (in tons/year) of the stream in the project area;

(b) provide an estimate of the quantity (in tons/year) and size distribution of the sediment that would be introduced to the stream resultint from project construction;

(c) provide characterization of the seasonal variations in transport capacity of the stream, to include probable depositional zones for sediments generated during project construction and operation; and

(d) provide a quantitative assessment of the impacts of reduced flow by scour and deposition of spawning gravels in the bypassed reach.

DESCRIPTION OF RELEVANT ASPECTS OF PROJECT

The license application provides a comprehensive description of the project. Aspects that are particularly relevant to sediment transport conditions are summarized here and elsewhere in this report as needed to expand my analysis or relate it to the application documents.

Location

The project site is about four miles east of Orofino, Idaho, on Orofino Creek, a tributary of the Clearwater River with a drainage area of 206 square miles. The watershed is generally mountainous. Near the project site, the highest elevations are as much as 1000 feet above the creek within a mile of the channel, producing steep-sided narrow canyons and valleys.

The project bypasses a local feature of Orofino Creek called Orofino Falls. The falls are actually a series of cascades of water plunging over huge boulders and bedrock outcrops where the canyon is particularly narrow. Individual local drops are as great as 20 or more feet. Across the entire falls, the creek drops nearly 100 feet over a distance of about 700 feet.

Project Features

The proposed project is essentially a run-of-river water bypass scheme to take advantage of the locally large drop of elevation of the creek over a short distance. To do so requires several structural components. These include: (1) a low diversion dam (6 ft. high by 65 ft. long) across the creek about 800 feet upstream of the upper end of Orofino Falls; (2) a water intake structure on the right bank of the creek adjacent to the diversion dam; (3) a low-pressure water transmission pipeline (6.5-foot diameter) along the hillside, generally following the ground contour line, around the falls for a distance of 6200 feet; (4) a surge tank to control pressure fluctuations in the transmission line resulting from turbine operation; (5) a high-pressure penstock (thick-walled pipeline) of 54-inch diameter extending 800 feet down the hillslope over a 228-foot vertical distance from the surge tank to the turbines; (6) a powerhouse with four turbine-generator units on the right bank of the creek behind a gravel bar; (7) a short tailrace channel to carry diverted flows back into Orofino Creek near the downstream end of the gravel bar; and (8) a 3-mile transmission line between the powerhouse and the town of Orofino.

Figure 1 shows the terrain near the project site and the location of the project water intake, water conveyance line, and water return point. About 5700 feet of the creek are by-passed through this system. Figure 2 shows the detailed topography and project components at the water intake site. Figure 3 shows the detailed topography and project components at the powerhouse and point of flow return to the creek.

Because the project is a run-of-river scheme, no water storage is required. Thus, the diversion dam is only intended to provide water head (elevation) so that the required discharge will enter the intake. Provision is made at the diversion dam for fish passage and sediment through-flow. The 6-foot height of the diversion dam will cause a small amount of local storage---less than one acre-foot---with a short backwater effect extending upstream about 120 feet to a channel constriction caused by basalt and basalt rubble outcrops.

The hydraulic capacity of the turbines is 150 cubic feet per second (cfs), based on four turbine units, each of different capacity (75, 38, 23, and 14 cfs) to allow efficient plant operation at all diverted flows. The total available hydraulic head for the powerplant is 228 feet and the net design head for the turbines is 195 feet.

Local Terrain

The terrain near the project is steep and mountainous. Local bedrock exposure occurs (basalt and granitic rock). Also, there are outcrops of large basalt rubble in some places along the stream. The hillside soils are of variable depth over the bedrock and can support stands of large trees. The soils near the channel are also of variable depth. In floodplain zones, a thin soil layer overlays alluvial gravel, cobbles, and boulders (eg., one-to-two feet thick a short distance upstream of the intake site) and supports limited riparian vegetation. This riparian vegetation appears to limit channel meandering. The stream

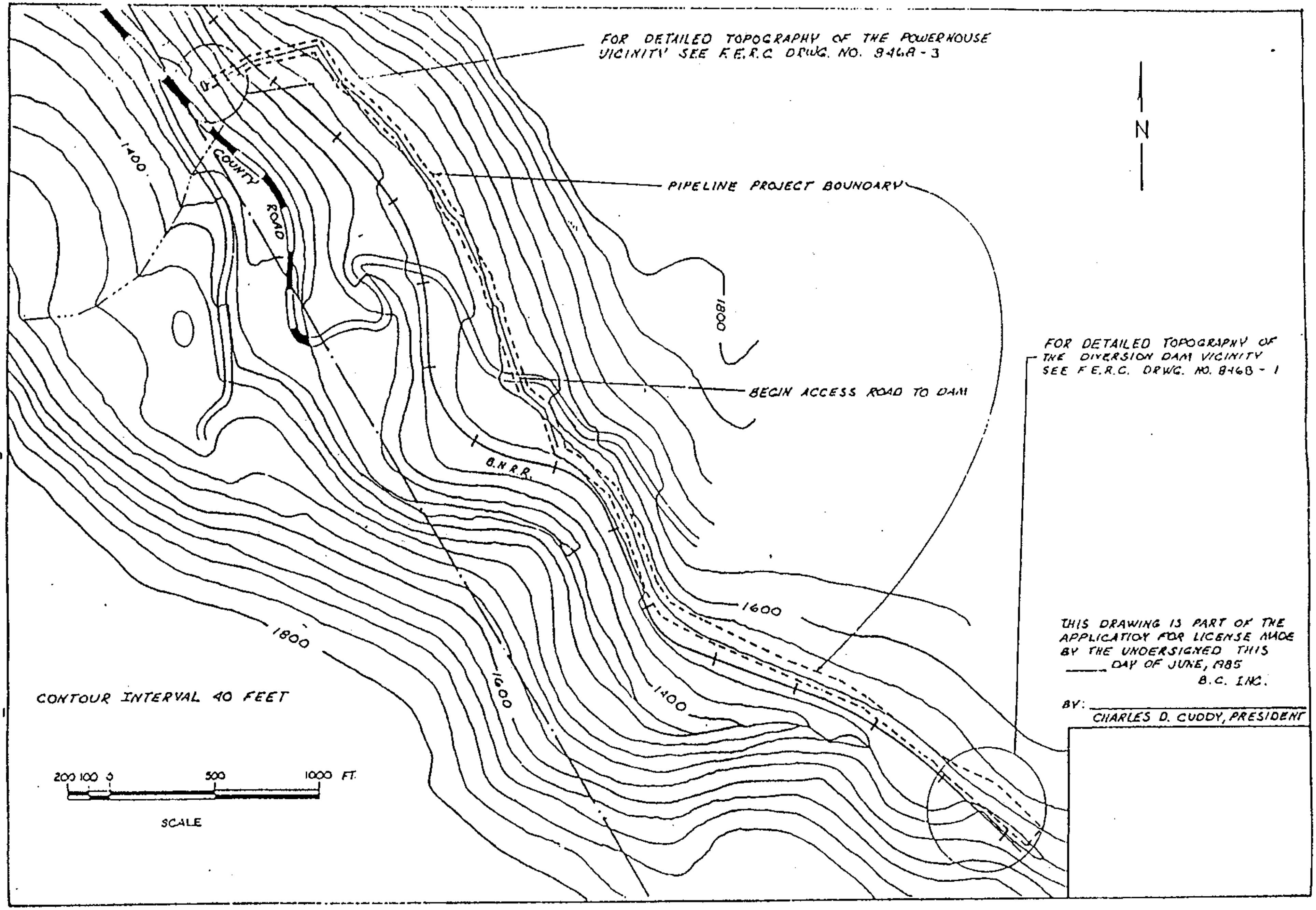

FIGURE 1. PROJECT L[illegible]TION MAP AND LOCAL TOPOGRAPHY

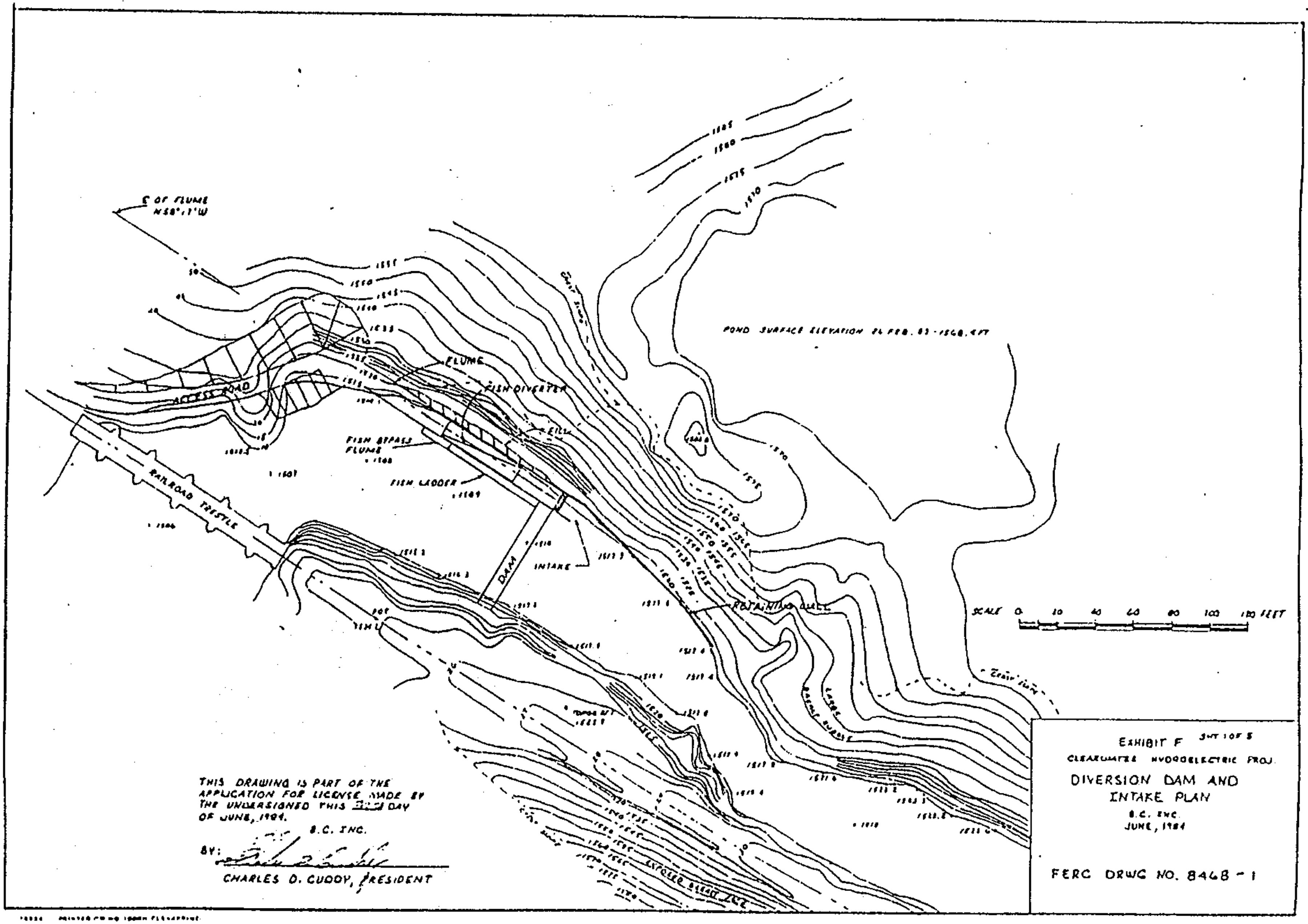

FIGURE 2. WATER INTAKE SITE AND LOCAL TOPOGRAPHY

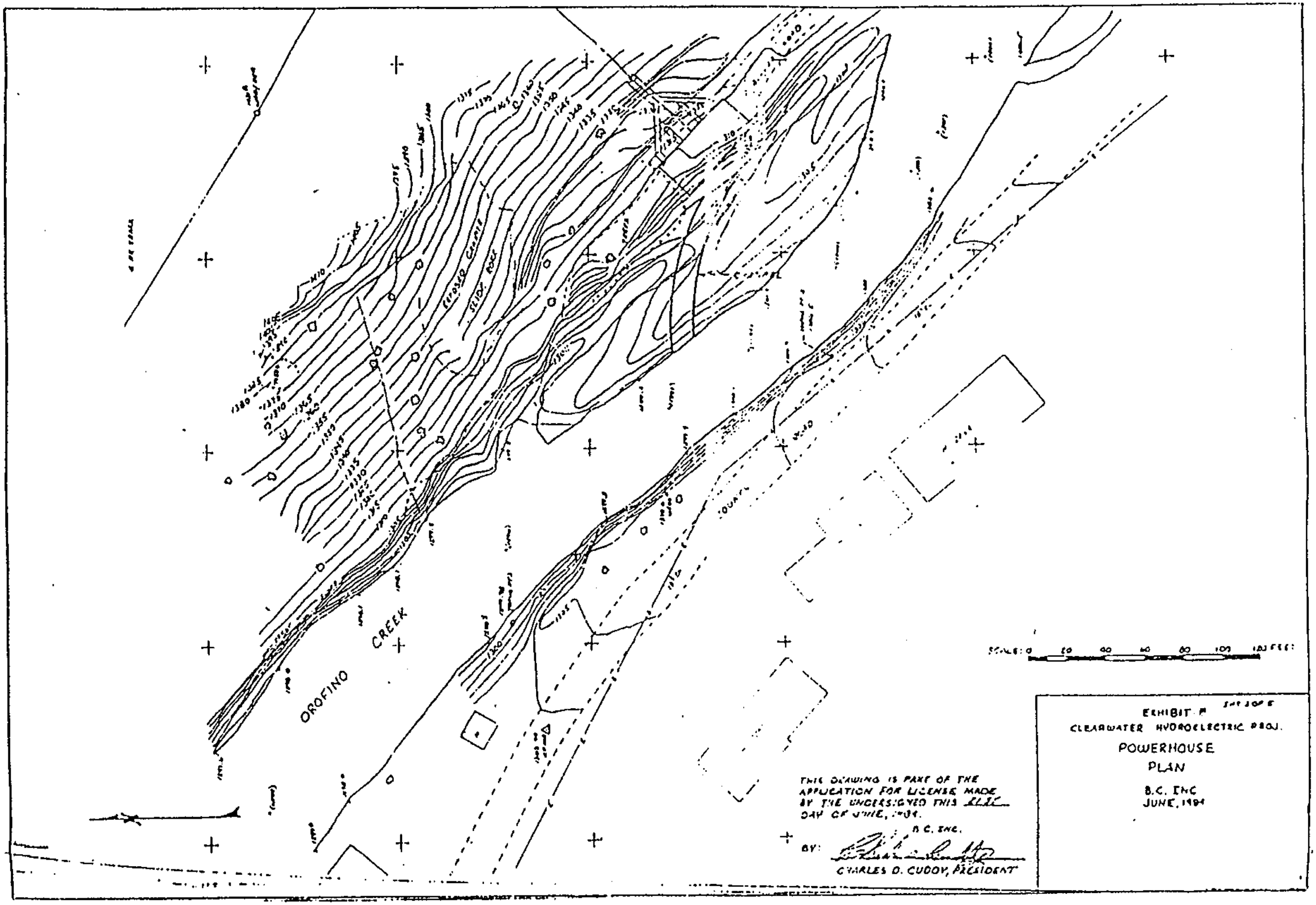

FIGURE 3. POWERHOUSE SITE AND LOCAL TOPOGRAPHY

occasionally cuts into the toe of hillslope soils and destabilizes the local stream bank, providing local sources of sediment for transport as bed load and suspended load (e.g., at the intake site).

STREAMFLOW DATA AND ANALYSIS

Analysis of the 1982 Flow Data

One year of detailed streamflow information is available for Orofino Creek. The U.S. Geological Survey operated station 13339800, Orofino Creek near Orofino, during the 1982 water year (October 1981 through September 1982). This station was at a bridge at river mile 4.7, which is within the proposed diversion reach but downstream of Orofino Falls. The obtained data are reproduced in Table 1.

The average discharge for the 1982 water year was 273 cfs. This is about 15% larger than the long-term average of 238 cfs estimated by Warnick. Also, the monthly pattern is somewhat different from Warnick's estimates (discussed in the following section). Nevertheless, the values are close enough to permit use of the daily data from 1982 for discussion of sediment transport conditions in the proposed diversion reach.

A flow-duration analysis of the 1982 record was made. The detailed results are shown graphically in Figure 4 and a simplified summary is given in Table 2. The chronological pattern of varying flow magnitude is evident from the flow-duration table. The relative duration of time that flows exceed any chosen discharge rate can be determined from the flow-duration graph.

Effect of Project Operation on 1982 Flow Data

The proposed project as described in the License Application would involve a total turbine hydraulic capacity of 150 cfs. Minimum instream flows for habitat protection have been proposed. These would be 50 cfs for March-through-June and 40 cfs for July-through-February. Thus, hydropower diversions would only occur when streamflow exceeds the minimum instream flows and the diversions would be within the range of 0-150 cfs. Whenever natural flows drop below the desired target flows of 50 or 40 cfs, all natural flow would be left instream but the target flows would be unsatisfied; at all other times the target flows would be fully satisfied.

TABLE 1. STREAMFLOW DATA FOR OROFINO CREEK NEAR OROFINO, 1982 WATER YEAR

CLEARWATER RIVER BASIN

13339800 OROFINO CREEK NEAR OROFINO, ID

LOCATION.--Lat 46°28'22", long 116°10'36", NE¼SE¼SW¼, sec.11, T.36 N., R.2 E. Clearwater County, Hydrologic Unit 17060306, on right bank at upstream side of county road bridge, 1.4 mi (2.25 km) upstream from Whiskey Creek, 4.7 mi (7.56 km) upstream from mouth, and 2 mi (3.22 km) southeast of Orofino city limits.

DRAINAGE AREA.--191 mi^2 (495 km^2).

PERIOD OF RECORD.--October 1981 to September 1982 (discontinued). Published in Miscellaneous Streamflow Measurements in Idaho, 1984-1967, at a site approximately 2 mi (3.22 km) downstream.

GAGE.--Water-stage recorder. Altitude of gage 1,350 ft (411 m) from topographic map.

REMARKS.--Records poor.

EXTREMES FOR CURRENT PERIOD.--Peak discharge above base of 1,000 ft^3/s (283 m^3/s) and maximum (*).

Date	Time	Discharge (ft^3/s)	Discharge (m^3/s)	Gage height (ft)	Gage height (m)	Date	Time	Discharge (ft^3/s)	Discharge (m^3/s)	Gage height (ft)	Gage height (m)
Feb. 21	1600	*2590	73.3	a *22.81	6.952	Apr. 14	0415	1690	47.9	21.61	6.587
Mar. 11	1600	1080	30.6	a 20.61	6.282	Apr. 24	0145	1210	34.3	20.91	6.373

Minimum discharge, 26 ft^3/s (0.736 m^3/s) Sept. 9, gage height, 17.36 ft (5.291 m).
a-observed.

Rating table (gage height, in feet, and discharge, in cubic feet per second)
(Shifting-control method used May 10 to June 24, July 2-6, 9, 14, 22-29, Aug. 2-8, Aug. 30 to Sept. 30)

17.5	20	19.0	328
17.7	40	20.0	725
18.0	84	21.0	1260
18.4	164	23.0	2740

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1981 TO SEPTEMBER 1982
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	47	51	67	80	155	474	459	883	276	130	54	36
2	43	46	110	77	152	612	422	909	324	167	63	33
3	62	43	200	74	140	599	400	919	284	185	60	31
4	58	41	150	68	120	604	375	778	272	158	66	32
5	46	39	115	60	65	570	341	646	300	154	59	30
6	43	39	235	37	68	526	328	600	307	147	52	29
7	41	38	330	45	68	494	316	618	302	126	45	28
8	50	37	210	58	68	502	300	612	290	120	36	27
9	60	36	180	66	65	666	294	570	260	147	40	27
10	58	36	200	74	63	1020	319	520	253	120	45	45
11	90	36	220	77	62	1080	835	495	240	110	53	67
12	115	45	160	84	63	712	1470	489	233	107	55	114
13	80	90	150	88	64	666	1430	466	234	105	54	89
14	60	105	140	94	400	666	1470	495	243	134	53	56
15	54	82	260	98	953	538	2150	518	234	114	52	44
16	49	72	230	110	953	666	910	474	218	118	51	40
17	46	162	160	140	1360	550	835	465	201	109	50	38
18	43	210	140	135	1100	526	775	591	188	101	48	36
19	40	150	200	130	1720	482	666	487	172	94	46	33
20	40	110	316	125	1680	444	622	433	156	87	43	30
21	38	96	250	109	2580	403	662	421	143	84	41	30
22	37	118	210	92	1670	378	790	413	141	79	40	31
23	36	170	180	100	1140	389	975	399	140	76	38	30
24	36	140	160	130	730	418	1070	382	158	72	36	29
25	36	115	150	150	640	426	972	379	128	72	35	30
26	37	100	140	190	558	510	905	386	124	69	33	45
27	45	90	130	197	518	630	876	376	114	63	32	52
28	49	75	120	182	459	626	1030	377	124	60	31	44
29	54	66	105	173	—	635	1000	328	137	46	30	70
30	55	66	92	164	—	546	861	299	130	48	33	50
31	56	—	82	169	—	494	—	282	—	50	37	—
TOTAL	1604	2504	5392	3376	17614	17852	22858	16010	6316	3252	1411	1276
MEAN	51.7	83.5	174	109	629	576	762	516	211	105	45.5	42.5
MAX	115	210	335	197	2580	1080	1470	919	314	185	66	114
MIN	36	36	67	37	62	378	294	282	114	46	30	27
CFSM	.27	.44	.91	.57	3.29	3.02	3.99	2.70	1.11	.55	.24	.22
IN.	.31	.49	1.05	.66	3.43	3.48	4.45	3.12	1.23	.63	.27	.25
AC-FT	3180	4970	10700	6700	34940	35410	45340	31760	12530	6450	2800	2530

WTR YR 1982 TOTAL 99465 MEAN 273 MAX 2580 MIN 27 CFSM 1.43 IN 19.37 AC-FT 197300

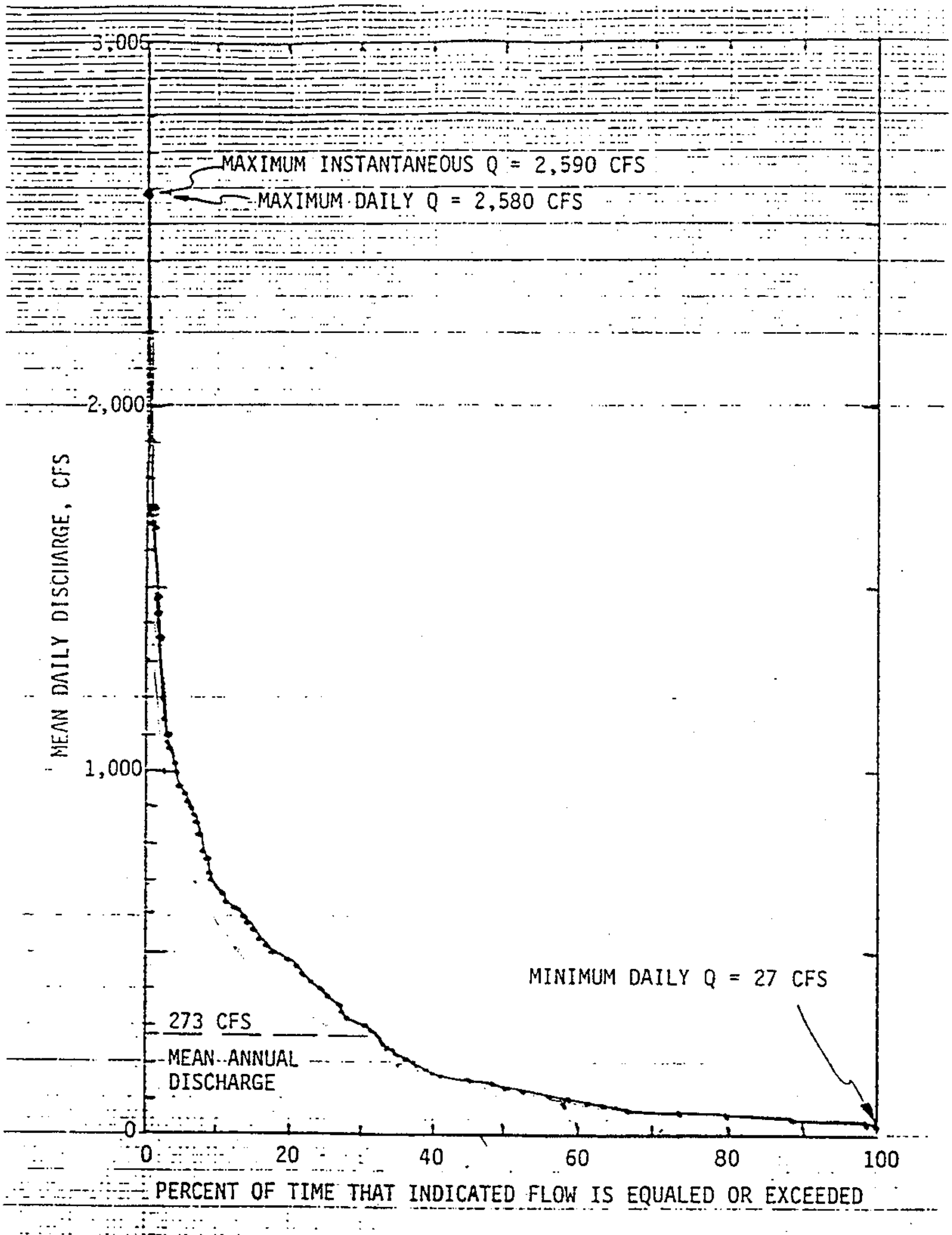

FIGURE 4. FLOW-DURATION CURVE FOR OROFINO CREEK NEAR OROFINO, 1982 WATER YEAR

TABLE 2. FLOW-DURATION CHARACTERISTICS FOR OROFINO CREEK NEAR OROFINO, 1982 WATER YEAR

Station: 13 3398 00 OROFINO CREEK NEAR OROFINO — Water Year: 1982

Discharge Q cfs	Number of days Discharge was Equal to or Greater than Indicated Value and Less than Next Indicated Value (By Month and for Year)													Cum. Total	Cum. % of Total
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year		
20	6	7		1							10	18	42	365	100
40	19	5		2						3	18	8	55	323	88.5
60	3	4	1	7	9					7	3	2	36	268	73.4
80	2	4	2	6						3		1	18	232	63.6
100	1	5	3	3					1	1		1	21	214	58.6
120			2	4	1				5	5			17	193	52.9
140		2	6	2	3				5	4			22	176	48.2
160		2	4	3					1	1			11	154	42.2
180			2	3					1	1			7	143	39.2
200		1	7						7				15	136	37.3
250			1				1	2	6				10	121	33.2
300			3			2	6	7	4				22	111	30.4
400					2	8	3	10					23	89	24.4
500					2	9		4					15	66	18.1
600					1	9	3	4					17	51	14.0
700					1	1	2	1					5	34	9.3
800							4	1					5	29	8.0
900					2		4	2					8	24	6.6
1,000					2	2	4						8	16	4.4
1,200					1								1	8	2.2
1,400							3						3	7	1.9
1,600					3								3	4	1.1
1,800					1								1	1	0.3
2,600													0	0	0

Applying this information to the 1982 data, 50 cfs would be in the diversion reach at all times during March-through-June unless the natural observed flow exceeds 200 cfs (50 + 150), at which times the diversion capacity would be fully satisfied and more water would be available for instream flow. The resulting instream flow would be the observed flow minus 150 cfs of diverted flow. Similarly, 40 cfs would be in the diversion reach at all times during July-through-February unless the observed flow exceeds 190 cfs (40 + 150), at which times the resulting instream flow would be the observed flow minus 150 cfs of diverted flow.

Table 3 shows the modified daily streamflows in the diversion reach if the project were operating in 1982 with diversions of up to 150 cfs whenever the proposed minimum instream flows were exceeded. Table 4 shows the corresponding modified flow-duration characteristics.

The shift in flow-duration characteristics that would have resulted from project operation in the 1982 water year is shown in Table 5 through comparison of the observed and modified conditions. It can be seen that the intermediate and larger flows are reduced by up to 150 cfs and are less likely to occur or be exceeded; the lowest flows are unaltered and the instream flows of either 40 or 50 cfs are protected unless natural flows diminish below these discharge levels. The flow-duration characteristics of daily discharge shown in Table 5 are of particular use for comparing sediment transport conditions with and without the proposed project.

Similarly, the monthly patterns of discharge with and without the proposed project are of use in evaluating sediment transport conditions. These patterns are shown in Table 6 and Figure 5.

<u>Warnick's Hydrologic Assessment</u>

Appendix A of the Supplement to Application For License, Clearwater Power Project No. 8468, dated January 16, 1985, presents the results of an hydrologic analysis of Orofino Creek by Calvin Warnick in 1984. As already noted, only one year of streamflow data were available for Orofino Creek near the proposed development site---the 1982 water year. By comparison with other records, Warnick generated a long-term average hydrograph of mean monthly flows and a long-term

TABLE 3 MODIFIED DAILY FLOWS IN OROFINO CREEK NEAR OROFINO, WITH PROJECT DIVERSIONS (1982 WATER YEAR)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
	MONTH AND MEAN DAILY DISCHARGE, CFS											
1	40	40	40	40	40	321	309	733	126	40	40	36
2						462	272	759	164			33
3			50			449	250	769	134			31
4			40			454	225	628	122			32
5		39				420	191	496	150			30
6		39	185	37		376	178	450	157			29
7		38	180	40		344	166	468	152			28
8		37	60			352	150	462	140			27
9		36	40			516	144	420	110		36	27
10		36	50			870	169	370	103		40	40
11		36	70			930	685	345	90			
12		40	40			562	1,320	339	83			
13						516	1,280	316	84			
14					250	516	1,320	345	93			
15					803	388	1,000	368	84			
16			80		803	516	760	324	68			
17		60	40		1,210	400	685	315	51			38
18		40			950	376	625	441	40			38
19			50		1,570	332	516	337				33
20			166		1,530	294	472	283				30
21	38		100		2,430	253	512	271				30
22	37		60		1,520	228	640	263				31
23	36		40		990	239	825	249			38	30
24	36				580	268	920	232			36	29
25	36				490	276	822	229			35	30
26	37				408	360	755	236			33	40
27	40			47	368	480	726	226			32	
28				40	309	476	880	227			31	
29					---	485	850	178			30	
30					---	396	711	149			33	
31		---			---	344	---	132	---		37	---
Mean Mon.	39	37	60	40	526	426	61[illegible]	66	81	40	38	35

= 189

TABLE 4. MODIFIED FLOW-DURATION CHARACTERISTICS OF OROFINO CREEK NEAR OROFINO, 1982 WATER YEAR, WITH PROJECT DIVERSIONS FOR HYDROPOWER

Station: 13 3398 00 OROFINO CREEK NEAR OROFINO   Water Year: 1982

Discharge Q cfs	Number of days Discharge was Equal to or Greater than Indicated Value and Less than Next Indicated Value (By Month and for Year)													Cum. Total	Cum. % of Total
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year		
20	6	7		1							10	18	42	365	100
40	25	22	23	30	13				14	31	21	12	191	323	88.5
60		1	3						1				5	132	36.2
80			1						5				6	127	34.8
100			1						2				3	121	33.2
120								1	3				4	118	32.3
140							2	1	4				7	114	31.2
160			1				3	1	1				6	107	29.3
180			2				1						3	101	27.7
200						2	2	6					10	98	26.8
250					1	4	1	3					9	88	24.1
300					2	10	1	9					22	79	21.6
400					2	8	1	6					17	57	15.6
500					1	5	2						8	40	11.0
600							4	1					5	32	8.8
700							4	3					7	27	7.4
800					2	1	4						7	20	5.5
900					2	1	1						4	13	3.6
1,000							1						1	9	2.5
1,200					1		3						4	8	2.2
1,400					3								3	4	1.1
1,600													0	1	0.3
1,800					1								1	1	0.3
2,600													0	0	0

TABLE 5 SUMMARY A COMPARISON OF FLOW-DURATION CHARACTERISTICS OF DAILY DISCHARGES FOR OROFINO CREEKS 1982 WATER YEAR, WITHOUT AND WITH PROPOSED PROJECT DIVERSIONS

DISCHARGE, CFS	PERCENT OF TIME DISCHARGE IS EQUALED OR EXCEEDED	
	NO DIVERSIONS	WITH DIVERSIONS*
20	100	100
40	88.5	58.5
60	73.4	36.2
80	63.6	34.8
100	58.6	33.2
120	52.9	32.3
140	48.2	31.2
160	42.2	29.3
180	39.2	27.7
200	37.3	26.8
250	33.2	24.1
300	30.4	21.6
400	24.4	15.6
500	18.1	11.0
600	14.0	8.8
700	9.3	7.4
800	8.0	5.5
900	6.6	3.6
1000	4.4	2.5
1200	2.2	2.2
1400	1.9	1.1
1600	1.1	0.3
1800	0.3	.0.3
2600**	0	0

* Up to 150 cfs, provided that 40 cfs (July–February) or 50 cfs (March–June) remain in the stream.

** Maximum value is 2580 cfs for no diversions and 2430 cfs with diversions.

TABLE 6. COMPARISON OF MEAN MONTHLY FLOW FOR OROFINO CREEK, CHARACTERISTICS : 1982 WATER YEAR, WITHOUT AND WITH PROPOSED PROJECT DIVERSIONS

Discharge Condition	Month and Mean Discharge, cfs												Average Annual Flow, cfs
	O	N	D	J	F	M	A	M	J	J	A	S	
Observed Mean Monthly Flow	52	84	174	109	629	576	762	516	211	105	46	42	273
Mean Monthly Diversion Flow	13	47	114	69	103	150	150	150	130	65	8	7	84
Mean Monthly Residual, Instream Flow	39	37	60	40	526	426	612	366	81	40	38	35	189

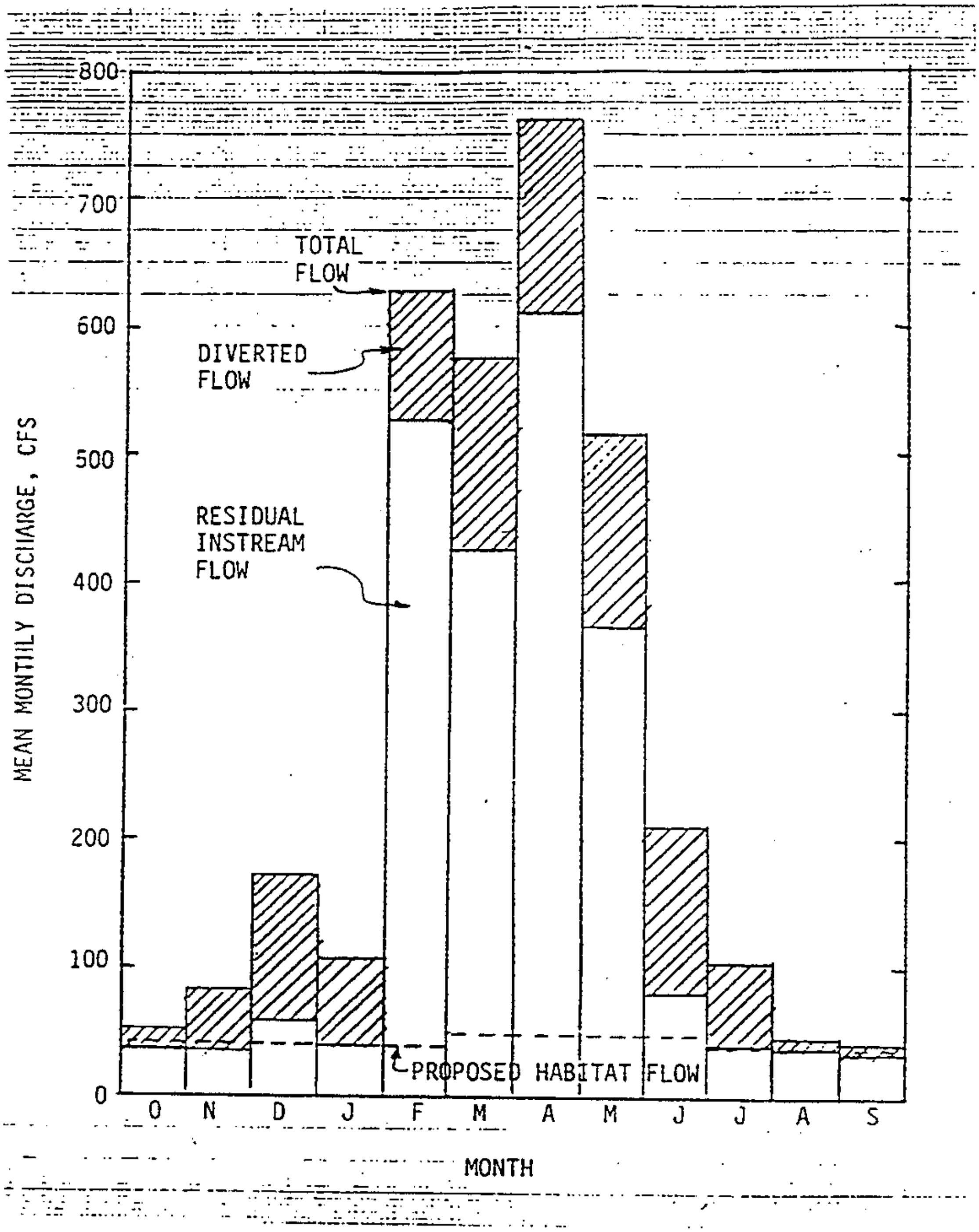

FIGURE 5. COMPARISON OF MEAN MONTHLY FLOW CHARACTERISTICS FOR OROFINO CREEK, 1982 WATER YEAR, WITH AND WITHOUT PROPOSED PROJECT DIVERSIONS

average flow-duration curve, as well as similar curves for critical low-flow conditions. These are summarized in Tables 7 and 8 and in Figure 6.

Comparison of Time Periods

Warnick's analysis provides a longer-term perspective to supplement my analyses. It is seen from Table 7, for example, that the mean annual discharge in 1982 was about 15% larger than the estimated long-term average and that the monthly patterns differed somewhat. The flow-duration characteristics also differed moderately. Comparison of Figure 4 with Table 8 gives the following:

% exceedence	1982		long-term
10	690	=	690
20	480	>	393
30	305	>	219
40	170	>	148
50	130	>	98

Such differences are not surprising when station-specific data are compared with regionalized data and when comparisons are made for different time periods.

There is sufficient similarity between the one-year and long-term analyses to allow use of the one-year data for estimating longer-term effects of the project on sediment transport. Use of the 1982 data is particularly advantageous because actual data for daily flows can be used to analyze the effects of project diversions on sediment transport. The narrow time-base of major runoff events (e.g., 14 days in February 1982) makes use of daily flows (rather than monthly flows) essential in developing a realistic flow-duration relationship for sediment transport calculations.

TABLE 7. MEAN MONTHLY DISCHARGE DATA FOR OROFINO CREEK NEAR OROFINO FALLS, FROM WARNICK'S ANALYSIS

Month of Water Year	Monthly Discharge Observed in 1982 W.Y., Orofino Cr. @ Orofino, cfs *	Monthly Discharge Long-Term Average Conditions, cfs **
Oct.	52	45
Nov.	84	73
Dec.	174	145
Jan.	109	95
Feb.	629	540
Mar.	576	500
Apr.	762	615
May	516	465
June	211	230
July	105	140
Aug.	46	40
Sept.	42	35
Average Annual Discharge, cfs	273	238

* From Warnick's Table 6 and Table 2.1 of Supplement to Application For License, Clearwater Power Project No. 8468, dated January 16, 1985

** Based on Warnick's Table 7 as modified for Figure 2.1 of Supplement.

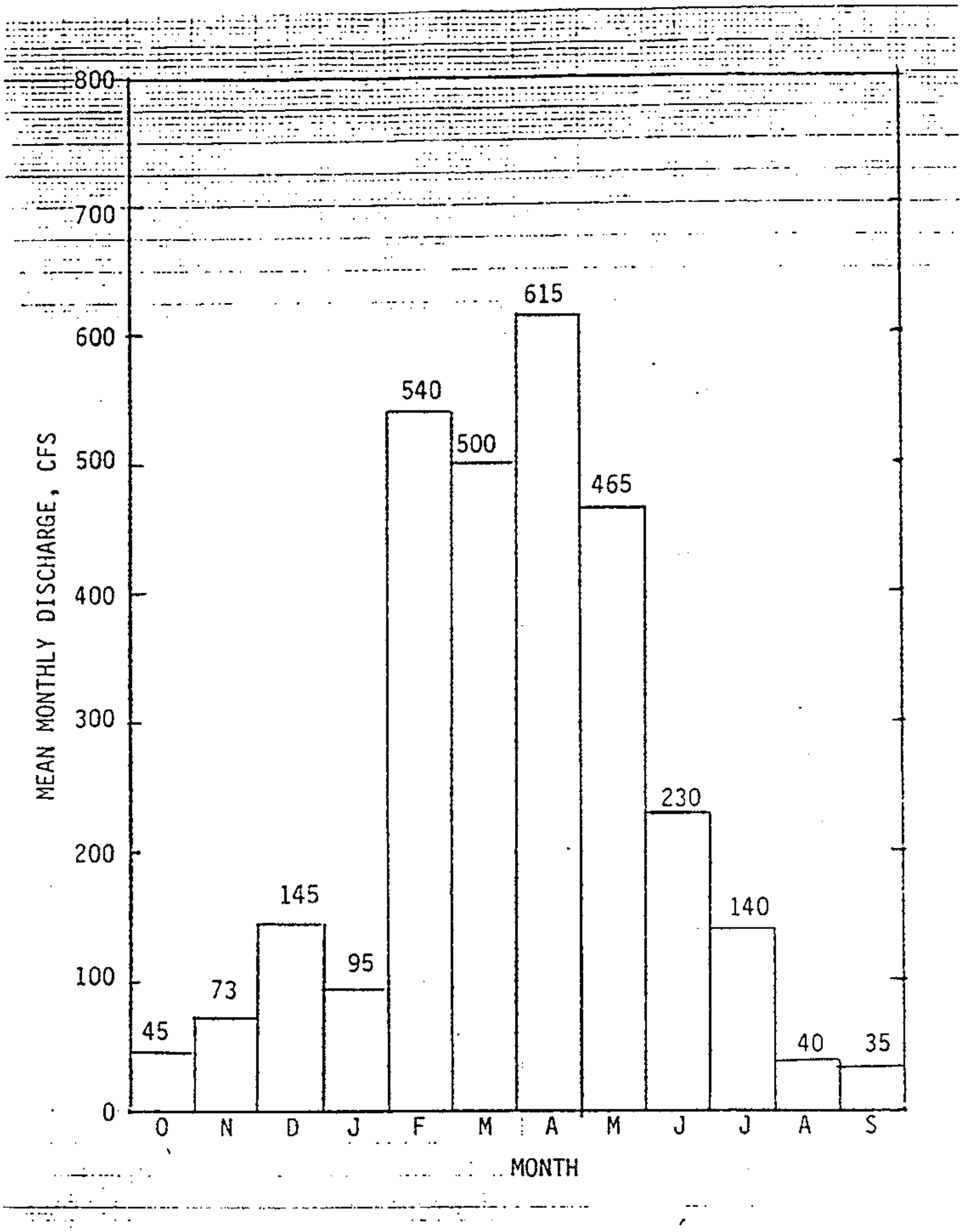

FIGURE 6. ESTIMATED MEAN MONTHLY DISCHARGES FOR LONG-TERM AVERAGE CONDITIONS AT OROFINO FALLS (AFTER WARNICK)

TABLE 8. LONG-TERM FLOW-DURATION DATA FOR OROFINO CREEK NEAR OROFINO FALLS, FROM WARNICK'S ANALYSIS

Percent of Time Flow is Equaled or Exceeded	Corresponding Discharge, ft3/s	
	Average Conditions *	Critical Low-Flow Conditions **
0	1666	1600
2		1326
5		813
10	690	604
20	393	221
30	219	101
40	148	70
50	98	56
60	70	38
70	56	33
80	43	28
90	32	24
99		16
100	19	4

* From Warnick's Table 2
** From Warnick's Table 5

CHANNEL DATA AND ANALYSIS

Basin Topography Near Site

Between river mile 15 (near Rudo) and its mouth, Orofino Creek flows in a narrow canyon with occasional alluvial floodplain lands that are typically only 100-200 feet wide. The ridges are about 1000 feet above the stream and are about one mile distant. Thus, hillslopes have an average steepness of about 20% (1000 ft./mile) but are often much steeper near the channel. Figure 7 (presented in three sheets) shows the basin topography along the lower 15 miles of Orofino Creek. The topography in the immediate vicinity of the proposed hydropower development was presented earlier in Figure 1.

Channel Slope Near Site

Orofino Creek's channel has an average slope of 72 feet/mile or 1.4% (0.014) over the lower 15 miles. Figure 8 (presented in two sheets) shows this channel profile. The data supporting Figure 8 were obtained from measurements made on the USGS 7½-minute topographic maps shown in Figure 7 (reduced in Figure 7 for convenience of presentation). The relevant data are summarized in Table 9. Based on my scale of river miles, the diversion reach extends between RM 4.35 and RM 5.45 (an official river mile index for Orofino Creek was not available for use).

Figure 8 and Table 9 indicate that in many places the short reaches of the creek between mapped contour lines can be combined into longer reaches of similar slope. This has been done and is shown in the upper portion of Table 10. Further combination is done in the lower portion of Table 10 so that the average channel slope through the proposed diversion reach can be compared with the general channel slopes upstream and downstream.

Table 10 shows that the average channel slope through the proposed diversion zone is four times steeper (179/45) than the general channel slope upstream of the intake site over a distance of almost two miles. The slope through the diversion zone is also almost three times steeper (179/65) than the general channel

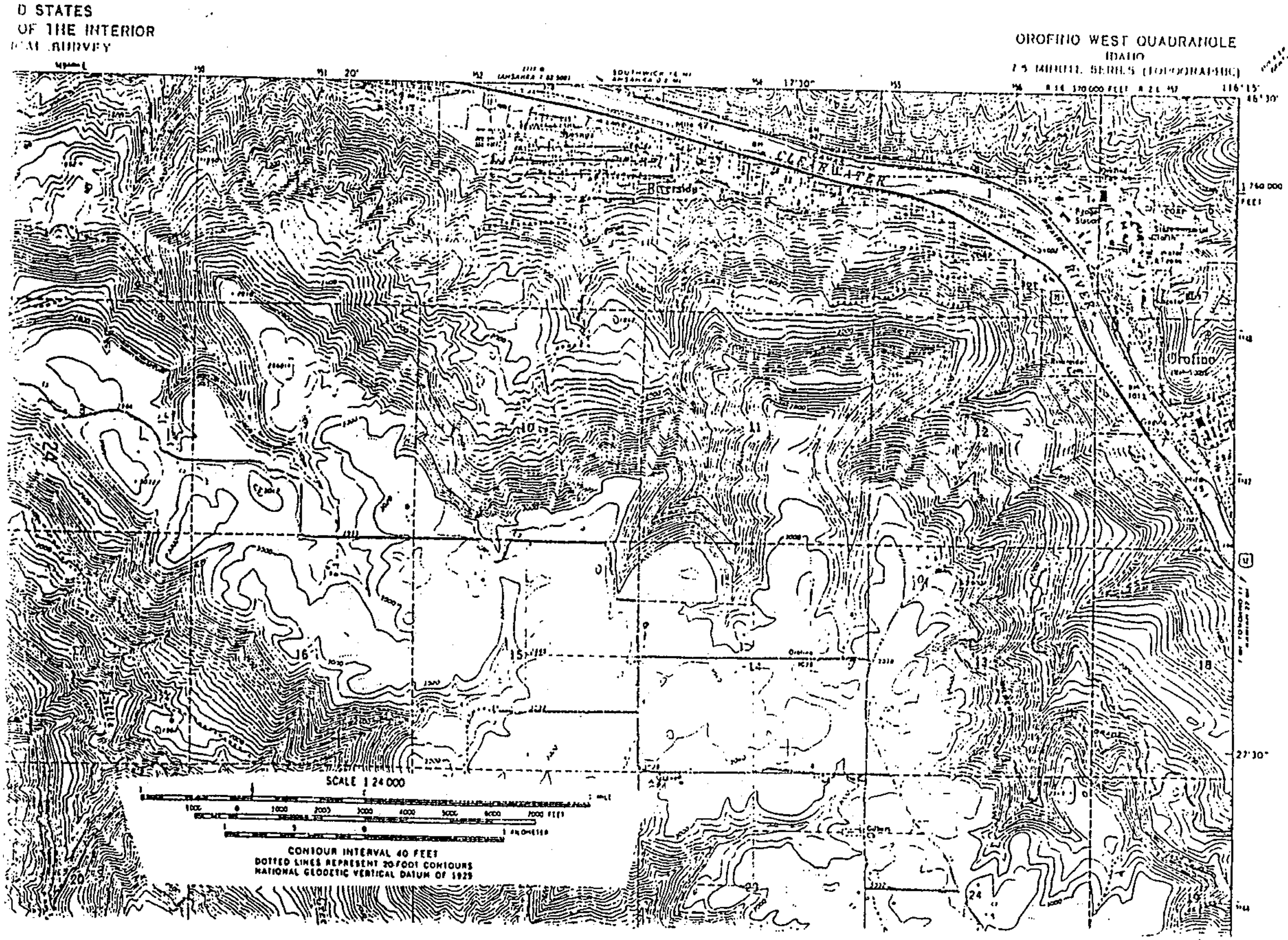

FIGURE 7, SHEET 1/3. BASIN TOPOGRAPH[illegible] ONG THE LOWER 15 MILES OF OROFINO CREEK

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

OROFINO EAST QUADRANGLE
IDAHO
7.5 MINUTE SERIES (TOPOGRAPHIC)

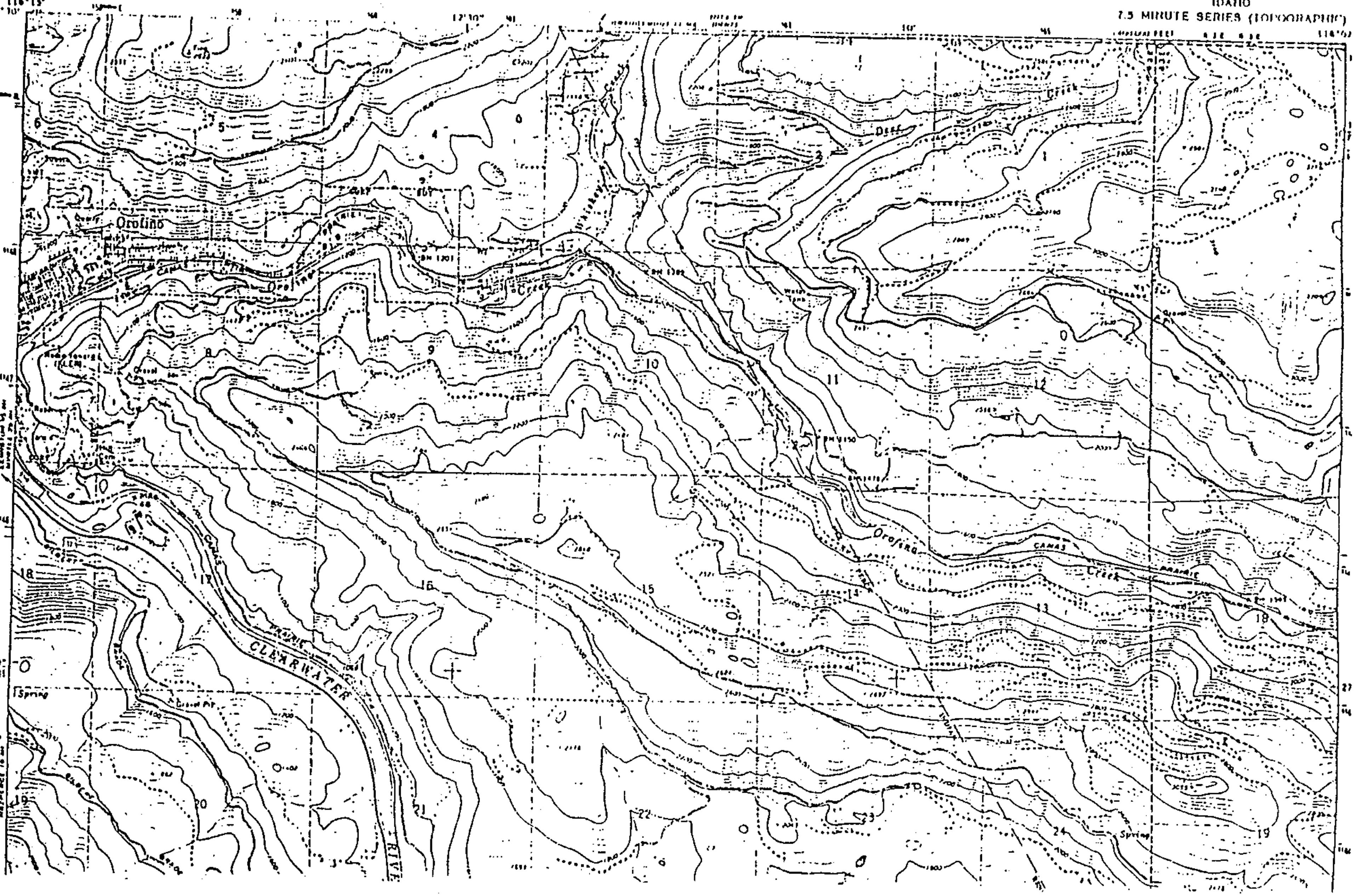

FIGURE 7, SHEET 2/3. BASIN TOPOGRAP . . Cont'd.

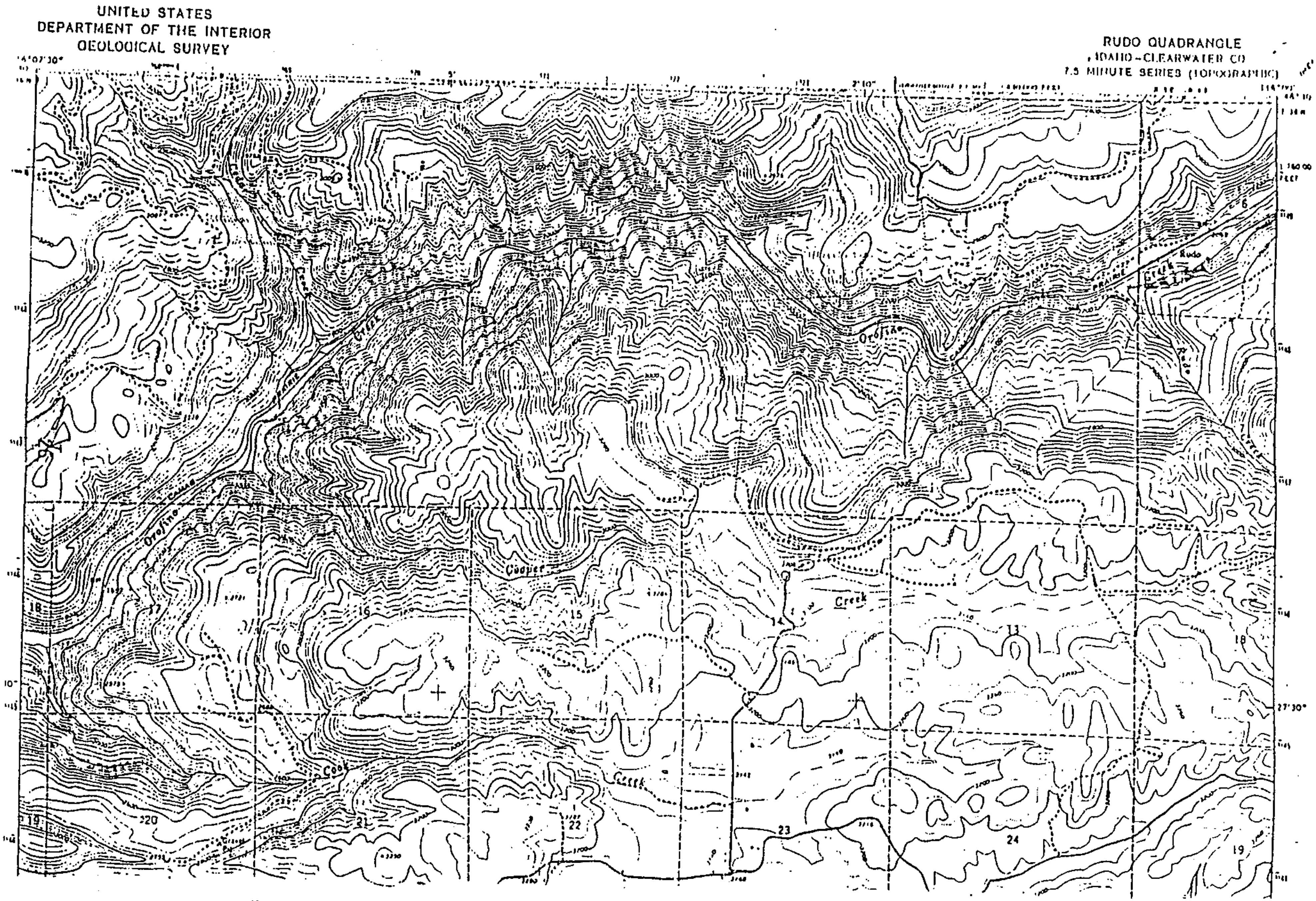

FIGURE 7, SHEET 3/3. BASIN TOPOGRAP . . Cont'd.

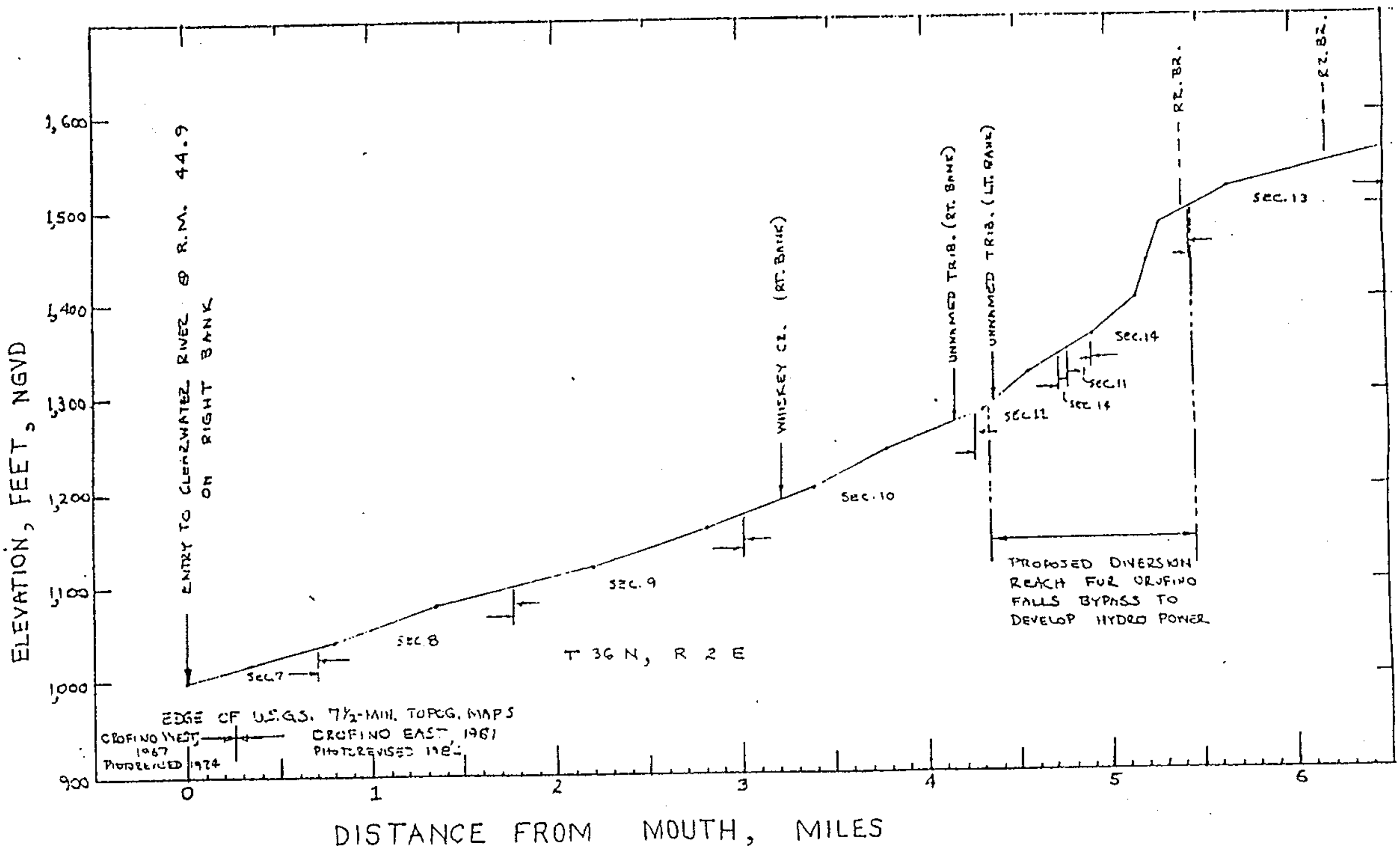

FIGURE 8, SHEET 1/2. CHANNEL PROFILE ALONG LOWER 15 MILES OF OROFINO CREEK

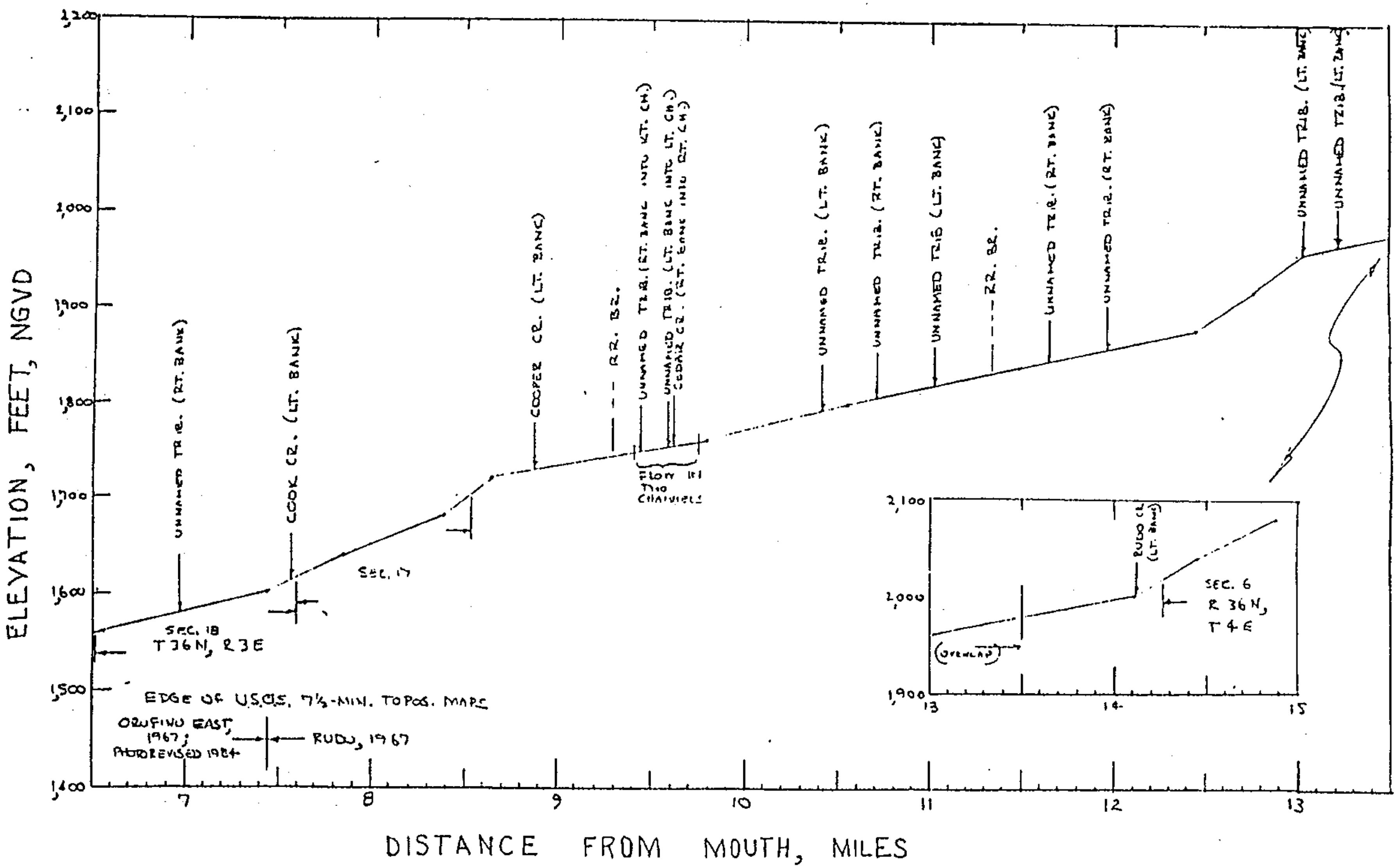

FIGURE 8, SHEET 2/2. CHANNEL PROFILE . . . Cont'd.

TABLE 9. PROFILE OF LOWER 15 MILES OF OROFINO CREEK, BASED ON TOPOGRAPHIC MAPS*

Distance from Mouth, miles	Contour Line, ft., NGVD	ΔL, miles	ΔZ, feet	Slope $S = \frac{\Delta Z}{\Delta L}$ ft/mile	ft/ft.
0.0	≈ 1000				
		0.80	40	50	0.009
0.80	1040				
		0.55	40	73	0.014
1.35	1080				
		0.85	40	47	0.009
2.20	1120				
		0.62	40	65	0.012
2.82	1160				
		0.57	40	70	0.013
3.39	1200				
		0.39	40	103	0.019
3.78	1240				
		0.53	40	75	0.014
4.31	1280				
		0.24	40	167	0.032
4.55	1320				
		0.36	40	111	0.021
4.91	1360				
		0.24	40	167	0.032
5.15	1400				
		0.06	40	667	0.126
5.21	1440				
		0.07	40	571	0.108
5.28	1480				
		0.37	40	108	0.020
5.65	1520				
		0.91	40	44	0.008
6.56	1560				
		0.88	40	45	0.009
7.44	1600				
		0.41	40	98	0.018
7.85	1640				
		0.53	40	75	0.014
8.38	1680				
		0.26	40	154	0.029
8.64	1720				
		1.15	40	35	0.007
9.79	1760				
		0.76	40	53	0.010
10.55	1800				

Proposed Diversion Reach Rm 4.33 – 5.45

TABLE 9. Continued

Distance from Mouth, miles	Contour Line, ft., NGVD	ΔL, miles	ΔZ, feet	Slope $S = \frac{\Delta Z}{\Delta L}$ ft/mile	ft/ft.
10.55	1800				
		0.93	40	43	0.008
11.48	1840				
		0.96	40	42	0.008
12.44	1880				
		0.32	40	125	0.024
12.76	1920				
		0.28	40	143	0.027
13.04	1960				
		1.07	40	37	0.007
14.11	2000				
		0.34	40	118	0.022
14.45	2040				
		0.43	40	93	0.018
14.88	2080				

End of reaches analyzed

* Data sources: U.S.G.S. 7½-Minute Topographic Maps
Orofino West, 1967; photorevised 1984
Orofino East, 1967; photorevised 1984
Rudo, 1967
Contour intervals shown are 40 feet, based on National Geodetic Vertical Datum of 1929 (NGVD)

TABLE 10. GENERALIZED PROFILES OF LOWER OROFINO CREEK FOR REACHES OF SIMILAR SLOPE

Distance from mouth, miles	Contour Line, ft, NGVD	ΔL, miles	ΔZ feet	Mean Slope ft/mile	Mean Slope ft/ft.
0.00	≈1000				
		3.39	200	59	0.011
3.39	1200				
		0.92	80	87	0.016
4.31 (Proposed Diversion Reach begins)	1280				
		0.84	120	143	0.027
5.15	1400				
		0.13	80	615	0.117
5.28	1480				
		0.37	40	108	0.020
5.65 (Proposed Diversion Reach ends)	1520				
		1.79	80	45	0.008
7.44	1600				
		0.94	80	85	0.016
8.38	1680				
		0.26	40	154	0.029
8.64	1720				
		1.15	40	35	0.007
9.79	1760				
		2.65	120	45	0.009
12.44	1880				
		0.60	80	133	0.025
13.04	1960				
		1.07	40	37	0.007
14.11	2000				
		0.77	80	104	0.020
14.88	2080				

Distance from mouth, miles	Contour Line, ft, NGVD	ΔL, miles	ΔZ feet	Mean Slope ft/mile	Mean Slope ft/ft.
0.00	≈1000				
		4.31	280	65	0.012
4.31 (Proposed diversion reach begins)	1280				
		1.34	240	179	0.034
5.65 (Proposed diversion reach ends)	1520				
		1.79	80	45	0.008
7.44	1600				

slope downstream of the powerhouse site over a distance of more than four miles to the mouth of Orofino Creek. Within the proposed diversion reach, the main part of Orofino Falls account for a localized drop of 80 feet in 0.13 mile (based on contour lines) and the entire falls account for almost 100 feet of drop, but the remainder of the reach also has a slope that is considerably steeper than the upstream or downstream reaches of the creek (see the profile in Figure 8).

The Clearwater River passes the mouth of Orofino Creek with an average slope of about 7 ft/mile (0.0013). This is about one-tenth of the slope of Orofino Creek's downstream reach from the powerhouse site to the mouth.

Channel Shape in Diversion Reach near Powerhouse Site

The flattest slopes of Orofino Creek within the diversion reach occur near the powerhouse site. This local stretch represents a zone of interest for considering sediment transport effects of the proposed project.

A clear representation of the channel slope and cross-sectional shape characteristics near the proposed development site is available from Chapman's 1983 instream-flow analysis (summarized in Appendix B of the Supplement to Application For License, Clearwater Power Project No. 8468, dated January 16, 1985). The measurements were obtained at several transects along a 300-foot reach located about 1/8 mile upstream of the proposed powerhouse outflow point.

Table 11 summarizes the channel hydraulic data obtained by Chapman. Average channel width, cross sectional area, and water surface slope were determined at a calibration discharge of 59 cfs. Figure 9 shows a longitudinal profile of the reach at this discharge.

The lower 200 feet of this reach represent a steep subreach of fairly constant water surface slope. For this subreach, the following hydraulic characteristics were determined from Table 11 for the calibration condition:

TABLE 11. SUMMARY OF CHANNEL HYDRAULIC DATA FOR 300-FOOT REACH ABOUT 1/8-MILE UPSTREAM OF POWERHOUSE SITE, FROM CHAPMAN STUDY AT Q = 59 CFS

Transect Station, feet	Lowest Thalweg Elevation, Feet*	Water Surface Elevation, Feet*	Cross-Sectional Area, A, ft²	Width at Water Surface, T, ft.	Mean Velocity, V, ft/sec	Discharge, Q, ft³/sec	Maximum Depth, ymax, ft
0	92.5	94.56	50	46	1.35	59	2.1
24	93.2	95.01	37	37	2.33	59	1.8
47	94.0	95.82	38	39	2.03	59	1.8
126	95.0	97.68	39	30	2.12	59	2.9
196	97.5	99.92	59	47	1.80	59	2.4
214	97.9	100.30	56	49	1.46	59	2.4
244	98.2	100.48	56	46	1.54	59	2.3
280	97.9	100.58	47	42	2.02	59	2.7
301	98.5	100.64	39	36	2.33	59	2.1
Averages			47	41	1.89	59	2.3

Average water surface slope $= \frac{\Delta W.S.El.}{\Delta L} = \frac{6.08}{301} = 0.020$

Average water surface slope from sta. 0 to sta. 196 = 0.027
" " " " " " 244 " " 301 = 0.003

* Local datum used.

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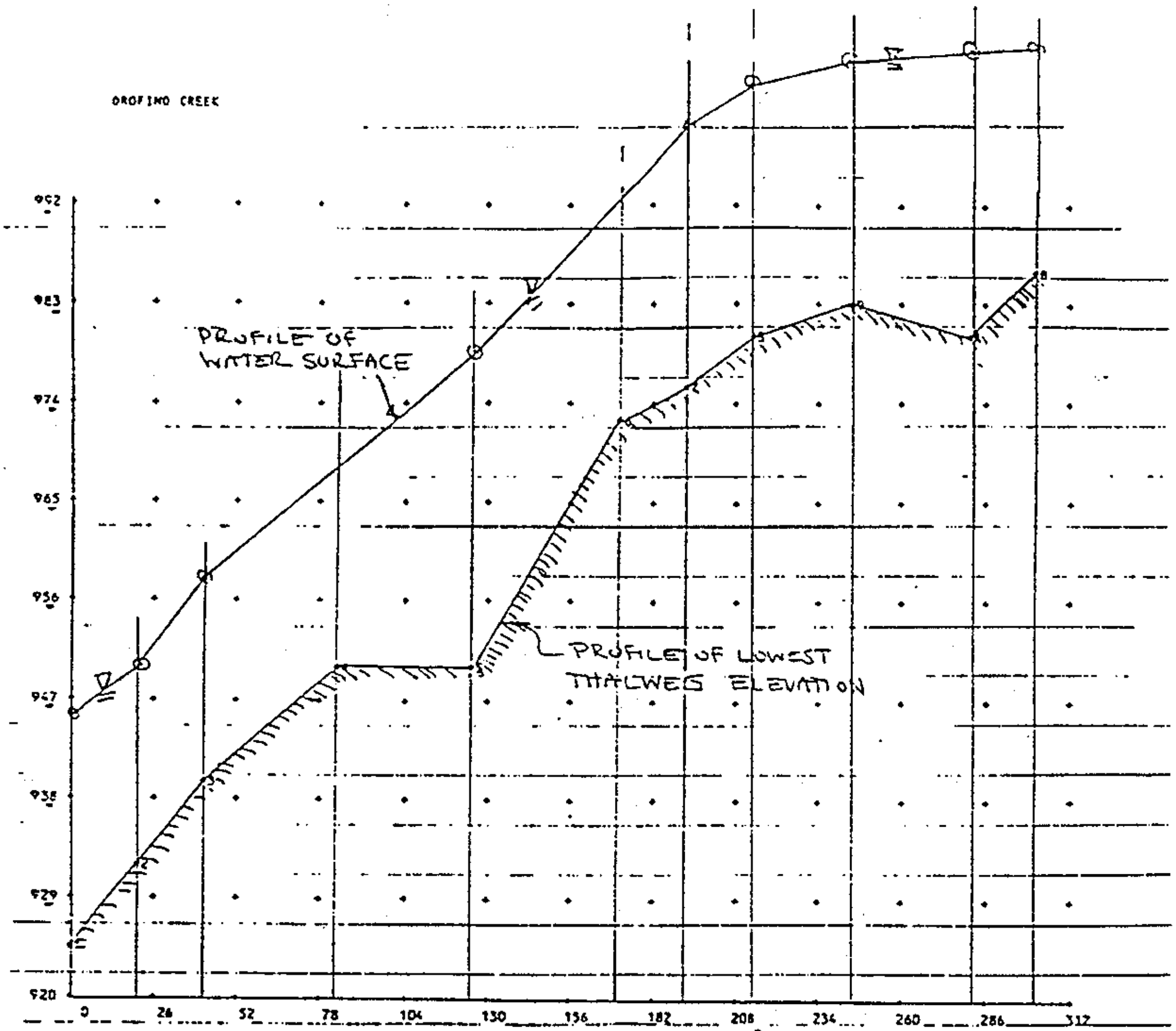

FIGURE 9. LONGITUDINAL PROFILE OF 300-FOOT REACH UPSTREAM OF POWERHOUSE SITE

discharge, Q	=	59 cfs
cross-sectional area, A	=	44.6 ft^2
top width, T	=	39.8 ft
mean depth, $\bar{D}$ = A/T	=	1.12 ft
maximum depth, y max	=	2.20 ft
approximate wetted perim., P	=	T + 2 $\bar{D}$ = 42.0 ft
approximate hydraulic rad. R	=	A/P = 1.06 ft
mean velocity, $\bar{V}$ = Q/A	=	1.32 ft/s
mean water surface slope, S	=	0.0273
average channel roughness, n	=	$(1.486\ A\ R^{2/3}\ S^{1/2})\ /\ Q$ = 0.193

Thus, the channel is wide and shallow. Boulders protrude from the bed through the water surface and cause tumbling flow and "whitewater" conditions. Note: the unusually large calculated channel roughness (Manning "n") of 0.193 is inconsistent with (four or more times larger than) tabulated values for coarse bed material. But use of such tabulated values should be limited to flows where the bed roughness is well-submerged. The exposed boulders generate considerable head loss in the flow due to colliding, accelerating, and decelerating water; such head loss is in excess of the frictional resistance normally associated with well-submerged bed particles and describable using Manning's n.)

The upper 60 feet of this reach represent a flat subreach of constant water surface slope. For this subreach, the following hydraulic characteristics were determined from Table 11 for the calibration condition:

discharge, Q	=	59 cfs
cross-sectional area, A	=	47.3 ft^2
top width, T	=	41.3 ft
mean depth, $\bar{D}$	=	1.15 ft
maximum depth, y max	=	2.4 ft
approx. wetted perimeter, P	=	43.6 ft
approx. hydraulic radius, R	=	1.08 ft
mean velocity, $\bar{V}$	=	1.25 ft/s
mean water surface slope, S	=	0.0028
average channel roughness, n	=	0.067

The various hydraulic parameters are all slightly different numerically from those at the downstream subreach, the most notable changes being the mean water surface slope (much flatter) and the average channel roughness (much lower). The calculated roughness of 0.067 is more consistent with coarse submerged bed material (few protruding boulders, little tumbling flow, and little or no white-water conditions).

Channel Shape Upstream of Intake Site

There is a natural narrow constriction of the canyon about 120 feet upstream of the intake site. The railroad fill adds slightly to the constricting effect by preventing any space for a floodplain.

Upstream of this constriction the valley widens slightly and an alluvial floodplain exists on both sides of the channel for about two miles (see Figure 7). Farther upstream, the creek flows through a narrow canyon for about five miles. The slope of the creek through the floodplain zone is flatter than in the up-stream canyon or in the immediate vicinity of the constriction and intake site.

In conjunction with bed material sampling, a limited amount of cross section data was obtained at a short stretch (60 feet long) about 400 feet upstream of the constriction. Table 12 summarizes the data obtained. Also shown in this table are several hydraulic parameters calculated or assumed for the cross section. No direct velocity or slope measurements were made but estimates were made based on observed conditions. The smoothness of the water surface and the well-submerged bed material except near the left edge of water (a low bar) indicate that the slope may have been flatter than the 0.008 ft/f mean slope for the two-mile reach and the roughness coefficient may have been similar to that observed at the upper subreach near the powerhouse site (0.067). Using S = 0.006 and n = 0.067 with the channel shape data gives Q = 165 cfs, a little less than the estimated discharge of 200 cfs. It seems likely that the bed at this site did not have as many boulders as in the reach downstream of Orofino Falls near the powerhouse site. Recalculating the flow with a slightly smaller roughness value of n = 0.055 gives Q = 200 cfs, which agrees with the field estimate made from observation of the velocities.

Stage-Discharge Relation for Channel Upstream of Intake

The cross section measurements and hydraulic data obtained at the cross section upstream of the intake site can be used to develop a relation of water

TABLE 12. SUMMARY OF CROSS SECTION DATA FOR CLEARING CREEK ABOUT 500 FEET UPSTREAM OF THE INTAKE SITE, OCTOBER 26, 1985

Distance from left edge of water, ft.	Water depth (−) or bar/bank height (+), ft *		Cross-sectional area of water, ft²	Estimated water velocity, ft/s
0	0.0	L. edge wtr.		
			1.40	
5.6	−0.5			
			5.55	
13.0	−1.0			> 2 ft/s
			5.63	
17.5	−1.5			
			16.98	
27.2	−2.0			
			4.95	≈ 3 ft/s
29.5	−2.3			
			5.38	
32.0	−2.0			
			11.02	
37.8	−1.8			
			12.24	
44.6	−1.8			> 2 ft/s
			7.60	
49.5	−1.3			
			6.33	
55.0	−1.0			
			1.80	
57.4	−0.5			
			0.48	
59.3	0.0	R. edge wtr.		
62.0	+3.7	top of bank	79.33	
−17.5	+1.5	top of bar		
−33.6	+0.5	pool W.S. of bank		
−33.6	+4.2	top of bank		

* maximum observed water depth at cross sections 30 ft upstream and downstream was 2.5 ft.

cross-sectional area, A = 79.33 ft²
top width, T = 59.3 ft
mean depth, $\bar{D} = A/T$ = 1.34 ft
maximum depth, y_{max} = 2.3 ft
approximate wetted perimeter, P = 59.6 ft
approximate hydraulic radius, $R = A/P$ = 1.33 ft

assumed mean velocity, V = 2.5 ft/s
assumed discharge, $Q = AV$ = 200 ft³/s
assumed local channel slope, S ≤ 0.008
assumed local channel roughness, n ≥ 0.05
check: $Q = \frac{1.486}{n} A R^{2/3} S^{1/2} = 142.6 \frac{S^{1/2}}{n} \leq 255$ cfs

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level vs. creek discharge for use in determining the input sediment transport rates for the diversion reach.

For convenience, a slightly simplified cross section (less irregularities) was used. This is shown in Table 13 and was used to determine the cross-sectional area, A, wetted perimeter, P, and hydraulic radius, R, at several stages of water level. A channel slope, S, of 0.006 ft./ft. and a channel boundary roughness, n, of 0.055 were then assumed for the reach, based on the discussion in the preceeding section of this chapter. From these, the discharge was calculated for each stage. Results of these computations are summarized in Table 14 and in Figure 10. Once the stage reaches 4 feet, larger discharges will spread out over the floodplain with relatively little increase of stage unless backwater effects occur due to the canyon constriction 400 feet downstream.

TABLE 13. SIMPLIFIED CROSS SECTION FOR OROFINO CREEK ABOUT 500 FEET UPSTREAM OF THE INTAKE SITE

Distance from left edge of water, feet	Water depth (-) or bar/bank height (+), feet	Remarks
- 34	+ 4.0	top of left bank
- 34	+ 0.5	base of left bank
- 18	+ 1.5	top of bar
0	0.0	left edge of water, 10/26/85
30	- 2.3	
55	- 1.0	
59	0.0	right edge of water, 10/26/85
62	+ 1.5	top of gravel on bank
62	+ 4.0	top of right bank

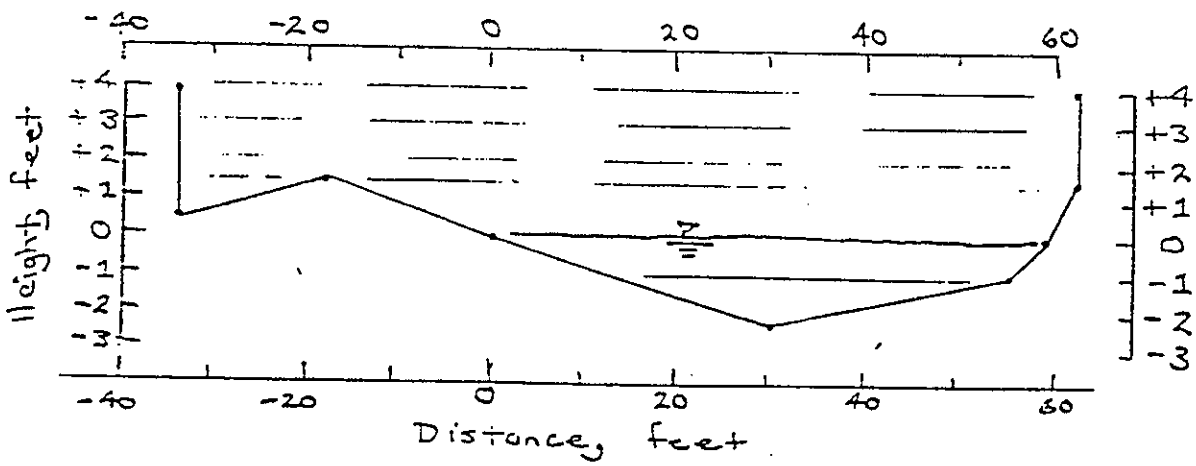

TABLE 14. STAGE DISCHARGE RELATION FOR OROFINO CREEK ABOUT 500 FEET UPSTREAM OF THE INTAKE SITE

Stage, y feet	Cross-Sectional Area, A ft^2	Wetted Perimeter, P ft	Hydraulic Radius R ft	Discharge, Q ft^3/s
+ 4.0	394.0	102.7	3.84	2,022
+ 3.0	298.0	100.7	2.96	1,285
+ 2.0	202.0	98.7	2.05	682
+ 1.5	154.0 {146.0*, 8.0}	97.7 {80.7, 17.0}	1.58 {1.81, 0.47}	465*
0.0	77.8	59.2	1.31	195
- 1.0	27.3	38.1	0.72	46
- 2.3				0

* Includes main-channel flow plus side-channel flow, assuming that the side channel is connected to the main channel at this stage but not at lower stages.

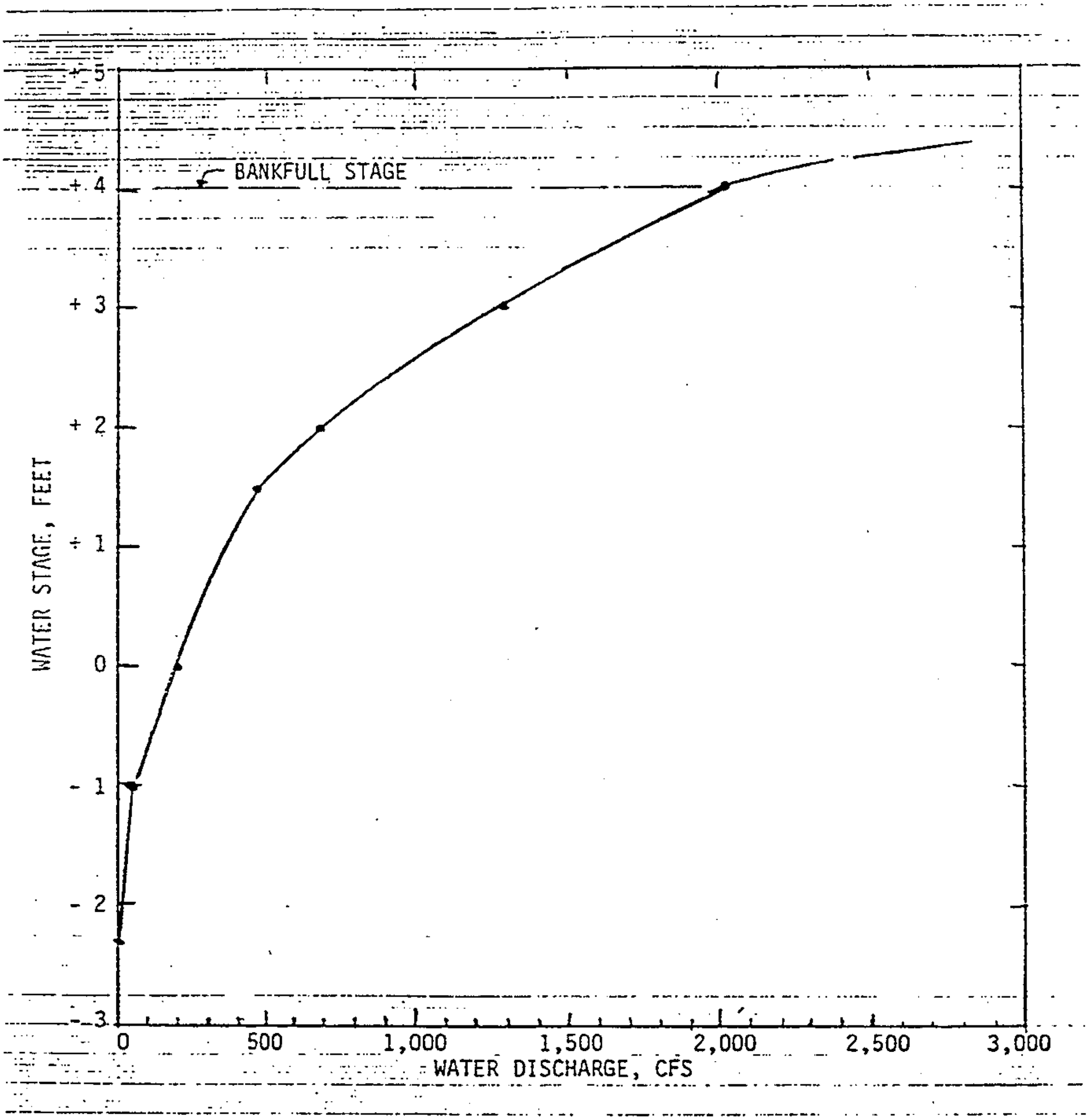

FIGURE 10. STAGE-DISCHARGE RELATION FOR OROFINO CREEK ABOUT 500 FEET UPSTREAM OF INTAKE SITE

Reported Bed Characteristics

Chapman's work (cited earlier, in supplement to application for license) provides the most relevant reported description of the bed material and bed condition in lower Orofino Creek. He notes that Orofino Creek "is best characterized as a cobble/boulder stream with steep riffles, only a few pools, and some fast glides". He found almost no potential spawning gravel between the falls and the powerhouse; the gravel encountered was mixed with boulders and was "compacted with fines".

Observed Bed Characteristics

My observations spanned a longer reach---from upstream of the intake site to the mouth of Orofino Creek. The findings supplement those of Chapman in considerable detail yet tend to generally concur with his observations.

Bed material samples were collected for laboratory analysis from three locations: (1) in the flatter reach about 500 feet upstream of the intake site where channel cross section measurements were also made; (2) in a protected zone of gravel accumulation just downstream of the railroad bridge at the intake site; and (3) in the large mid-channel bar at the mouth of Orofino Creek, a short distance downstream of the railroad bridge. The general bed condition and the sizes of bed material present were identified in the general vicinity of the sampling sites and at several other stretches of Orofino Creek between the sampling locations.

The results of sieve analyses to determine the distributions of particle sizes for the three samples are shown in Tables 15, 16, and 17 and in Figure 11. It is important to note that Sample 1 was obtained from surface material after first removing cobbles 4 or more inches in size, whereas samples 2 and 3 were obtained from subsurface material after first removing the surface material.

Bed in Flatter Reach Upstream of Intake Site

The bed surface in the flatter reach upstream of the intake site is predominantly boulders and cobbles with sheltered gravel. The largest boulder found in

TABLE 15. PARTICLE SIZE CHARACTERISTICS FOR SAMPLE 1

SUMMARY OF SIEVE ANALYSES
BED MATERIAL SAMPLES

Project: OROFINO CREEK

SAMPLE #1

Sampling Date: 10/26/85

River and Reach: OROFINO CREEK ABOVE INTAKE SITE

Cross Section: ABOUT 500 FT. UPSTREAM OF INTAKE SITE

Location on X-Section: IN WATER NEAR LEFT EDGE OF WATER

Type of Sample: 4 SHOVEL SCOURS OF SURFACE MATERIAL FROM AMONG BOULDERS AFTER MOVING BIGGEST COBBLES (≥4") OUT OF THE WAY

Summary from Wet and Dry Sieving

Summarized by: DAC / PCK

US Std. Sieve Size or Number	Sieve Opening, mm	Sample Retained, g	Percent Retained	Cumulative Percent Retained	Cumulative Percent Finer
NOTE: ALL MATERIAL ≥ 4" WAS SHOVELED OUT OF THE WAY BEFORE SAMPLING					
4"	101.6	0	0.00	0.00	100.00
3"	76.2	4389	34.85	34.85	65.15
2-1/2"	64.0	2875	22.83	57.68	42.32
2"	50.8	896	7.11	64.79	35.21
1-1/2"	38.1	2210	17.55	82.34	17.66
1"	25.4	515	4.09	86.43	13.57
3/4"	19.05	469	3.72	90.15	9.85
1/2"	12.70	179	1.42	91.58	8.42
3/8"	9.52	154	1.22	92.80	7.20
1/4"	6.35	128	1.02	93.81	6.19
# 4	4.76	102	0.81	94.62	5.38
# 8	2.38	127	1.01	95.63	4.37
# 16	1.19	130	1.03	96.67	3.33
# 30	0.590	188	1.49	98.16	1.84
# 50	0.297	154	1.22	99.38	0.62
#100	0.149	58	0.46	99.84	0.16
#200	0.074	16	0.13	99.97	0.03
#230	0.0625	2	0.02	99.98	0.02
Pan	---	2	0.02	100.00	0.00

Total Wt. = 12,594 g

TABLE 16. PARTICLE SIZE CHARACTERISTICS FOR SAMPLE 2

SUMMARY OF SIEVE ANALYSES
BED MATERIAL SAMPLES

SAMPLE #2

Project: OROFINO CREEK

Sampling Date: 10/26/85

River and Reach: OROFINO CREEK BELOW INTAKE SITE

Cross Section: IN WAKE ZONE BELOW RAILROAD BRIDGE

Location on X-Section: ON BAR NEAREST LEFT BANK

Type of Sample: SUBSURFACE MATERIAL AFTER REMOVING SURFACE LAYER

Summary from Wet and Dry Sieving

Summarized by: DAK/PCK

US Std. Sieve Size or Number	Sieve Opening, mm	Sample Retained, g	Percent Retained	Cumulative Percent Retained	Cumulative Percent Finer
4"	101.6	0	0	0	
3"	76.2	0	0.00	0.00	100.00
2-1/2"	64.0	931	9.38	9.38	90.62
2"	50.8	227	2.29	11.67	88.33
1-1/2"	38.1	1241	12.51	24.17	75.83
1"	25.4	1806	18.20	42.37	57.63
3/4"	19.05	1540	15.52	57.89	42.11
1/2"	12.70	626	6.31	64.20	35.80
3/8"	9.52	374	3.77	67.97	32.03
1/4"	6.35	226	2.28	70.24	29.76
# 4	4.76	142	1.43	71.67	28.33
# 8	2.38	276	2.78	74.46	25.54
# 16	1.19	521	5.25	79.71	20.29
# 30	0.590	1161	11.70	91.40	8.60
# 50	0.297	663	6.68	98.09	1.91
#100	0.149	145	1.46	99.55	0.45
#200	0.074	32	0.32	99.87	0.13
#230	0.0625	5	0.05	99.92	0.08
Pan	—	8	0.08	100.00	0.00

Total Wt. = 9,924 g

TABLE 17. PARTICLE SIZE CHARACTERISTICS FOR SAMPLE 3

SUMMARY OF SIEVE ANALYSES
BED MATERIAL SAMPLES

Project: OROFINO CREEK   SAMPLE #3

Sampling Date: 10/26/85

River and Reach: OROFINO CREEK AT MOUTH

Cross Section: ON GRAVEL BAR DOWNSTREAM of RAILROAD BRIDGE

Location on X-Section: IN MID-BAR

Type of Sample: SUBSURFACE MATERIAL AFTER REMOVING SURFACE LAYER

Summarized by: DAC / PCK

Summary from Wet and Dry Sieving

US Std. Sieve Size or Number	Sieve Opening, mm	Sample Retained, g	Percent Retained	Cumulative Percent Retained	Cumulative Percent Finer
NOTE: THE LARGEST MATERIAL SEEN IN THE VICINITY HAD A MEDIAN SIZE OF 5-6 INCHES.					
4"	101.6	0	0.00	0.00	100.00
3"	76.2	3770	27.42	27.42	72.58
2-1/2"	64.0	1688	12.28	39.69	60.31
2"	50.8	2359	17.16	56.85	43.15
1-1/2"	38.1	2674	19.45	76.30	23.70
1"	25.4	2151	15.64	91.94	8.06
3/4"	19.05	243	1.77	93.71	6.29
1/2"	12.70	0	0.00	93.71	6.29
3/8"	9.52	2*	0.01	93.72	6.28
1/4"	6.35	3*	0.02	93.75	6.25
# 4	4.76	2*	0.01	93.76	6.24
# 8	2.38	6*	0.04	93.80	6.20
# 16	1.19	12*	0.09	93.89	6.11
# 30	0.590	160	1.16	95.05	4.95
# 50	0.297	370	2.69	97.75	2.25
#100	0.149	217	1.58	99.32	0.68
#200	0.074	68	0.49	99.82	0.18
#230	0.0625	11	0.08	99.90	0.10
Pan	---	14	0.10	100.00	0.00

Total Wt. = 13750 g

* all or most of material is organic

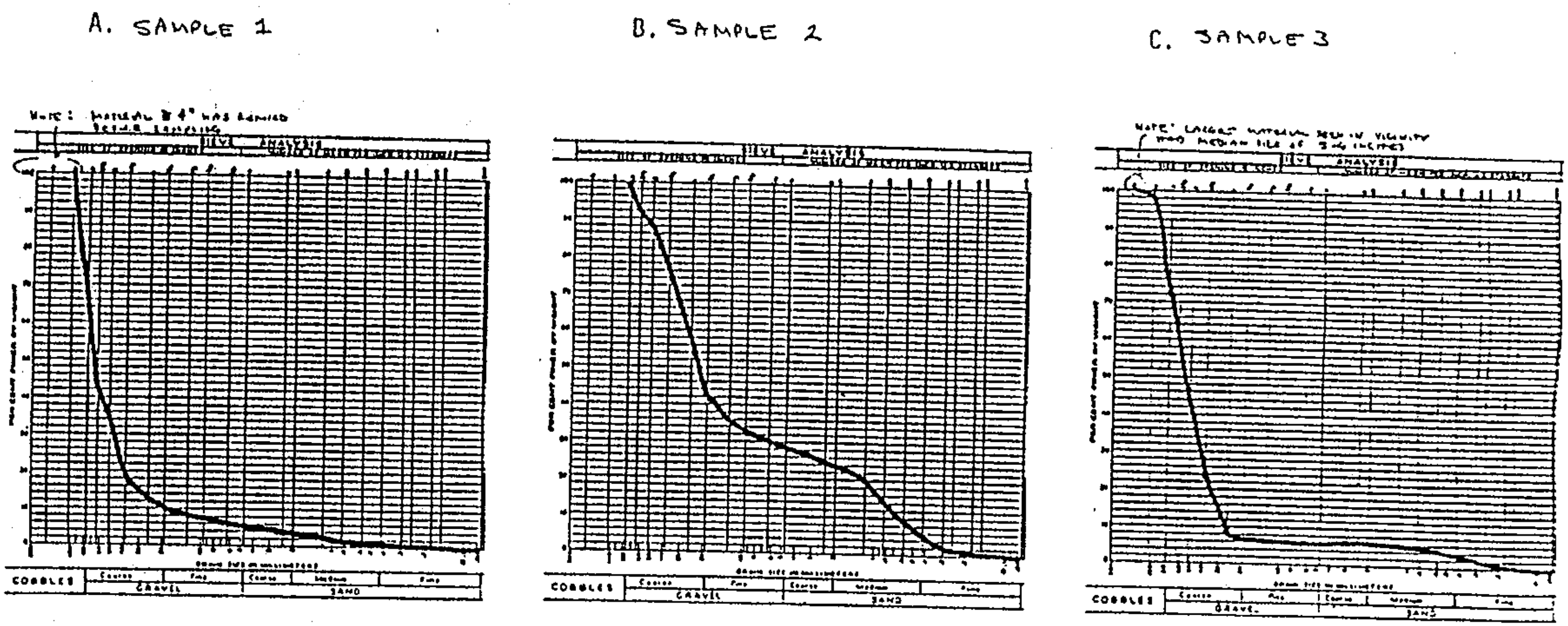

FIGURE 11. PARTICLE SIZE DISTRIBUTION CURVES FOR OROFINO CREEK BED MATERIAL SAMPLES

the 50-foot reach of channel measured about 40 x 40 x 30 cm in its major, median and minor axes (three mutually perpendicular axes). Other large boulders were 40 x 30 x 30 cm and 35 x 30 x 25 cm. Thus, the typical median diameter of largest boulders present in this reach is about 33 cm (13 inches). More than half of the surface area of the creek bed is covered with cobbles and boulders larger than 4 inches (10 cm) in median size, based on "foot contact" at three transects and direct visual observation in shallow water and on the creek banks and exposed high-water bed.

The sheltered gravel and some of the sheltering small cobbles are represented by sample 1 and constitute 95% of the total weight of that sample. Smaller particles present include the full range of sand sizes and a very small amount of "fines" in the silt-clay range of sizes. This is shown in Table 15 and Figure 11A.

Gravel Bed Material in Protected Zones

Even in areas of moderately steep gradient, such as just downstream of the railroad bridge near the intake site, pockets of gravel accumulate. This is direct evidence that gravel is transported through the lower creek as bed load. For example, strips of gravel and small cobbles can be found in the wake zones behind angular boulders of basalt rubble up to 3 feet in size in mid-channel. The rubble probably comes from the canyon constriction just upstream of the intake site or from railroad riprap and is not subject to regular bed load transport, based on its angularity. By comparison, "rounded" angular basalt that has been subjected to bed load transport can also be found in the vicinity but is not much larger than 1 foot in maximum size---suggesting a maximum size for use in bed load calculations.

Sample 2, the size analysis for which is shown in Table 16 and Figure 11 B, represents typical gravel that moves as part of the bed load but can deposit in wake zones and backwash areas. The exposed surface was very much like the coarsest 75% of the subsurface material but was washed clean of sands, whereas the void spaces below the surface were able to retain an appreciable amount of sand. Probably because of the strong currents through this reach, little silt or clay was able to settle out in this wake zone downstream of the bridge piers and abutment. One curiosity about sample 2 that is also evident for sample 3 is the bimodal distribution of particle sizes: abundant gravel and medium-fine sand but relatively little fine gravel and coarse sand. This may be either a manifestation of basin geology or of the relative timing of different bed load transport processes---the answer is presently unknown but the bimodal distribution effect has been observed in other gravel-bed rivers, including the Snake-Clearwater system.

Bed in the Falls Reach

The creek bed at the falls is characterized by huge boulders many feet in size and by bedrock outcroppings. The excessive energy of the flow allows little or no opportunity for bed load to deposit or accumulate in this reach.

Bed in the Lower Diversion Reach

Between the falls and the powerhouse site, Chapman's description of the boulder/cobble bed is an apt characterization. Boulders reach lengths of 2 feet or more and have median diameters of 1 - 1½ foot. Narrow side bars, where conditions allow their formation, are gravel/cobble in surface appearance or contain gravel sheltered by cobbles and boulders. In the stronger flows, cobbles are sheltered by boulders.

Bed From the Powerhouse Site to the Mouth of Orofino Creek

As in the lower diversion reach, the bed between the powerhouse site and the creek mouth is predominately cobbles and boulders. The banks have a similar appearance. There are few bars, due mainly to the narrowness of the channel and the confining banks and bank vegetation. Those bars that could be seen had cobble surfaces.

Bed at the Mouth of Orofino Creek

The mouth of Orofino Creek widens moderately over the last few hundred feet between the railroad bridge and the Clearwater River. At the time viewed, the Clearwater River was low and a large central bar was exposed in the mid-channel zone of the mouth of Orofino Creek. The creek flow divided down the left and right sides of the bar, with some of the right-side flow cutting through the bar to the left side near the mid-length of the bar. This long bar was low in surface elevation and would regularly be inundated either when Orofino Creek was in high stage, including times of bed load transport, or when the Clearwater River was in high stage, regardless of the flow in Orofino Creek. The backwater effects of the Clearwater River probably do not extend very far up Orofino Creek past the railroad bridge, based on the narrowness and steep slope (compared to the Clearwater) of Orofino Creek upstream of the bridge.

The nature of bed material deposited at the mouth of Orofino Creek can be postulated from the observed geomorphic features and various hydraulic conditions. The gravel bar at the creek mouth represents an excellent trap for bed load when both Orofino Creek and the Clearwater River are at high stage. When Orofino Creek is at high stage and transporting bed load but the Clearwater River is at low stage, it is likely that some of the coarser Orofino Creek bed load deposits on the bar; the remainder, together with all smaller bed load, is carried across the bar or through the stronger flow at either side and enters the Clearwater River. When the Clearwater River is at high stage but the stage of Orofino Creek is receeding, it is likely that the smaller-sized bed load still in motion in Orofino Creek will have some opportunity to come to rest on the bar.

Sample 3, the size analysis for which is shown in Table 17 and Figure 11 C, was collected so that it would depict the smaller-sized bed load deposits and any trapped suspended load deposits. At the bed surface, such sizes would be likely to be washed across the top of the bar and into the Clearwater River. The largest exposed bed material seen on the bar near the sampling site included cobbles up to 9 inches long and 4 inches wide. The typical median diameter of these large cobbles was about 5-6 inches (say 125-150 mm). Some of these were seen in the subsurface zone adjacent to the spot where sample 3 was collected, but by chance none happened to be part of the sample itself. About one-third of the sampled material is classified as small cobbles. Most of the remainder is coarse-to-medium gravel. The void spaces among these cobbles and gravel contain a moderate amount of medium-to-fine sand as well as small organic debris and the roots of vegetation that is attempting to grow on the bar (it has had a summer season to do so, with no hydraulic disturbance).

Composite Representative Bed Material for Lower Orofino Creek

The alluvial bed material in the lower reaches of Orofino Creek, from just upstream of the intake site to the Clearwater River, can be characterized in a composite form as follows. The surface bed material is primarily cobbly (2½ - 10 inch median size) with boulders (median diameter of 10 inches or larger). Gravel (1/5 - 2½ inch median size) is also present in the bed and tends to be sheltered from the flow in protected wake zones and pockets among the boulders. Sand is present in the voids of the larger material beneath the exposed surface. However, there is little silt or clay evident in the subsurface material. The subsurface material appears to be somewhat bimodal in its size distribution, with relatively little fine gravel or coarse sand present compared to the amount of larger gravel smaller sand present. There are a few small bars in the reach. These consist of gravel and cobbles rather than sand (by contrast, many sand bars are evident in the Clearwater River between Orofino Creek and the Snake River).

A composite particle size distribution can be estimated for the surface and subsurface material in the lower reaches of Orofino Creek between the intake vicinity and the creek mouth. This was done on an areal basis from the sample data and associated visual observations. The results are shown in Table 18 and Figure 12. The overall median size of bed material is about 4 inches. About 60% is coarser than coarse gravel and about 10% is smaller than gravel, leaving 30% in the gravel size range. This gravel is mainly sheltered by the cobbles and boulders present in the bed.

Specific Gravity of Bed Material

The specific gravity was determined for gravel present in the bed material samples when those samples were analyzed for particle size characteristics. It was found that the bed material has a specific gravity of 2.8, a value which is quite representative of basaltic bed material. A summary of the laboratory analysis is given in Table 19.

TABLE 18. ESTIMATED REPRESENTATIVE BED MATERIAL CHARACTERISTICS FOR LOWER OROFINO CREEK FROM NEAR THE INTAKE SITE TO THE CREEK MOUTH

Type of material	Estimated % of total bed	
	Surface	Subsurface
Exposed bedrock, tight or broken rubble	3	3
Boulders, 10-inch - to - 3 feet	17	13
Cobbles, medium-to-large (5-10 inches)	25	25
Cobbles, small-to-medium (2½-5 inches)	25	20
Gravel, medium-to-large (3/4-2½ inches)	20	19
Gravel, small-to-medium (5⁻mm - 3/4 inch)	5	6
Sand, coarse (1^+ - 5^- mm)	3	5
Sand, fine-to-medium (64 μ - 1^+mm)	2	7
Silt and clay	0	2
	100 %	100 %

PARTICLE SIZE DISTRIBUTION CURVE
BED MATERIAL SAMPLES

Project: OROFINO CREEK

Sampling Date:

River and Reach: OROFINO CREEK --- LOWER 6 MILES

Cross Section:

Location on X-Section: } COMPOSITE REPRESENTATION

Type of Sample:

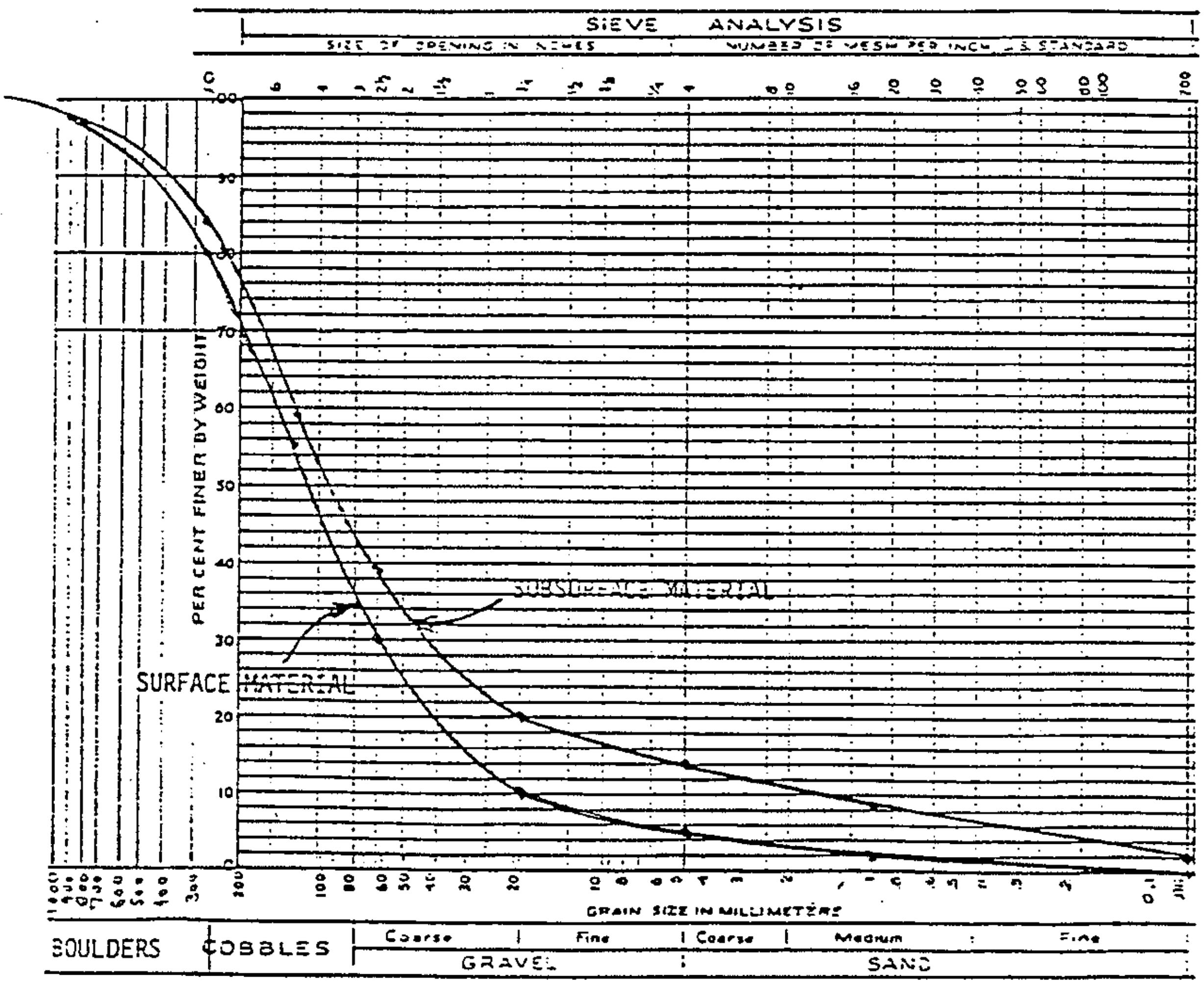

FIGURE 12. ESTIMATED REPRESENTATIVE PARTICLE SIZE DISTRIBUTION CURVES FOR BED MATERIAL IN LOWER OROFINO CREEK

TABLE 19. SPECIFIC GRAVITY OF BED MATERIAL IN LOWER OROFINO CREEK(1)

Size range of particles, inches	Number of particles used	Weight of sample in air, SSD,(2) grams	Weight of sample submerged in water, grams	Weight of sample in air, oven dried, grams	Specific Gravity, G_s (3)	
					SSD	Oven dried
1½ - 2	18	2710	1730	2674	2.765	2.833
1 - 1½	36	2182	1396	2151	2.776	2.849
Average value for each type of determination					2.77	2.84
Overall average specific gravity					$\bar{G}_s$ = 2.81	

1. Based on sample 3, taken at mouth of Orofino Creek.
2. SSD = saturated, surface dry (saturated cracks and pores but dry outer surface).
3. $$G_s = \frac{\text{Weight in air}}{\text{(Specific weight of water)}\cdot\text{(Volume of solids)}}$$
$$= \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight submerged}}$$

Particle Shape Characteristics of Bed Material

Gravel particles present in the bed material samples were also analyzed for particle shape characteristics. It was found that their shape factor is about 0.5 (minor axis divided by geometric mean of major and median axis) and that the relative length is about 1.4 (ratio of major to median axis). The laboratory results are summarized in Table 20.

TABLE 20. PARTICLE SHAPE CHARACTERISTICS OF BED MATERIAL IN LOWER OROFINO CREEK[1]

Particle size range, inches	Number of particles analyzed	Statistical parameter (mean or standard deviation)	Particle weight, grams	Axis lengths, mm[2]			Shape factor, $\frac{c}{\sqrt{ab}}$	Relative length, a/b
				a	b	c		
2 - 2½	10	$\bar{X}$	234	85	60	31	0.45	1.42
		s	55	15	5	8	0.12	0.26
1½ - 2	18	$\bar{X}$	76	56	40	26	0.56	1.42
		s	19	7	4	5	0.13	0.23

1. Based on bed material from samples 1,2, and 3.

2. Represented by three mutually perpendicular axes, these being the longest for the particle (the a axis) and the longest (b) and shortest (c) perpendicular pair in the largest cross section perpendicular to the a-axis.

SEDIMENT TRANSPORT ANALYSIS

Basic Principles Involved

The transport of sediment in a stream is subject to two controlling conditions: (1) sediment must be available for transport by the flow and (2) the flow must be capable of transporting the available sediment. Each condition can limit the sediment discharge past any given site on a stream. Thus, sediment availability and flow capability form a double-condition that is useful for evaluating sediment transport and the impacts of all types of activities upon the sediment transport regime. In greater detail, important aspects of this double-condition also include the sizes of sediment available and the fluid mechanisms for transporting sediment.

For mountainous drainage basins it is typical that a full range of alluvial sediment sizes is present. The types and their size ranges include: clay and colloidal matter (<2 μm), silt (2 - 62μm), sand (62μm -2mm), gravel (2 - 64 mm), cobbles (64mm -256mm or 2½ - 10 inches), and boulders (>2.56mm or >10 inches). Small sediment particles can be easily carried in suspension in mountainous streams due to the great amount of turbulence generated in the steep, rough channels by the shallow flows. Larger sediment is carried along the bed of such streams in a rolling, tumbling, sliding, bouncing manner; its weight prevents it from being supported by the fluid in suspension but the shear stress exerted by the moving fluid can exceed the static resisting ability of the particles. Thus, the fluid mechanisms result in two manners of sediment transport---as suspended load and as bed load.

Sediment transport is also describable in terms of the sources of sediment present. By this description, sediment transport involves bed material load and wash load. Bed material load is the moving sediment derived from the bed of the stream, whether being transported as bed load or as suspended load. Wash load is the moving sediment that has sizes too small to be found in appreciable amounts in the bed of the stream. Most of the wash load is carried in suspension, although the coarsest wash load may also move as bed load if flow conditions are not too turbulent.

The original source areas of sediment are likely to be on the watershed. However, once watershed sediments enter the channel (e.g., by bank erosion or land erosion) they are transported in accord with channel processes. The larger entering sediment becomes part of the bed material; slow progressive sorting can occur in the downstream direction over the following days, months, years, or centuries due to differences in transport capability. The smaller entering sediment may wash through the channel rather quickly unless it enters slackwater areas or settles out due to diminished velocities on the falling stages of a runoff event.

Silt and clay are always carried in suspension in mountainous streams. Gravel and cobbles always move as bed load, even though much bouncing can occur through rapids. Sand, being of intermediate size, can be carried in suspension through the steeper, swifter reaches of a stream and as bed load elsewhere. Under the right hydraulic conditions the smaller sand grains may move in suspension while the coarse sand grains move as bed load.

The flow capability to transport the available sediment depends on various hydraulic parameters. These include the water discharge, channel slope, channel width, water depth, water velocity, boundary resistance due to vegetation and debris, boundary resistance due to bed shape (bars, riffles, dunes), and boundary resistance due to the surface roughness caused by the bed material itself. The flow transport capability also depends on the sediment sizes present (sediment availability within various ranges of particle size).

For small particles that are commonly carried in suspension, a generally valid rule is that the flow will transport all material available. This was amply demonstrated by the extremely large suspended sediment concentrations in the Toutle-Cowlitz Rivers briefly after the Mt. St. Helens 1980 eruptions. Under more natural circumstances, the suspended sediment concentrations will reflect watershed conditions that produce erosion and overland flow. For a stable set of land use conditions, a good correlation can be expected between water discharge and suspended sediment concentration in the stream. Hence, a given condition of suspended sediment availability will allow statistical lines of best data fit (rather than physical relationships) that can be used as prediction equations, together with the streamflow hydrograph, for the suspended load in the stream.

For larger particles that are commonly carried as bed load, physical relationships (rather than statistical fits of data) can be developed and used for predicting the bed load. Several different bed-load prediction equations exist. Each is based on a limited range of data, parameters, and physical conditions compared to the total range of conditions and parameters that influence bed load transport. Most are based on laboratory studies, where the measured flow parameters can be more closely controlled, and have only limited field confirmation. Consequently, when several equations are applied to the same data set, the predictions of bed load rate and amount can differ by an order of magnitude (tenfold) or more.

General Approaches for Determining Sediment Transport

Locational Approaches

Sediment transport in a river can be determined by several approaches. One way to categorize these is in accord with the location where the determination is made. Thus, the sediment transport in a river might be evaluated based on the input to the river, the throughput at a river reach, or the output from the river.

The use of watershed models allows determination of the sediment production from the land surface or the sediment yield at the watershed outlet (usually a small creek entering a larger stream). This approach fits the "input" category, as the watershed sediment output corresponds to sediment input to the river from its tributary streams. Bank erosion is another means for sediment input to a river.

River output approaches include the measurements of accumulating sediment deposits over time at the lower end of a river where the flow enters a lake or reservoir and the transport capability is greatly reduced. A dredged zone at the mouth of a river entering another river offers a means for trapping the coarser part of the passing sediment load and thus provides a partial measure of sediment output from the river.

Throughput approaches are based on the measurement and/or calculation of the total sediment load (bed load plus suspended load) passing some cross section of the river. Local dredged areas that serve as sediment traps allow an alternate means for partial measure of the throughput (e.g., "scalped" bars).

Preferred Approach for Orofino Creek

The narrow canyons of Orofino Creek near Orofino Falls cause most of the drainage basin to be situated well upriver, rather than local. Thus, watershed sediment yield models for the local canyon drainage area would not be representative of the typical sediment load in the stream. Similarly, the canyon reaches of the creek upstream of Orofino Falls regulate the throughput of sediment from watershed areas farther upstream. Hence, river input approaches involving the watershed will not adequately describe sediment transport near the falls nor impacts of flow diversion on the sediment transport regime.

River output approaches likewise are not of particular use in assessing project impacts on lower Orofino Creek. This is because the gravel bar at the mouth of the creek is affected by flow in Clearwater River and not all of the bed load is deposited at the creek mouth. While the coarsest material may deposit, sand and small-medium gravel can move through the riffles along the bar and be carried downstream in the Clearwater River.

This leaves throughput approaches, including use of bed material information, as the most representative means for estimating the sediment transport regime near the falls. This approach also allows estimation of the impacts of water diversion on that regime.

This choice also could have been reached directly (rather than by default) by recognizing that the bed material characteristics and hydraulic data for reaches spanning the project site could be used for computation of the sediment load near the falls. There is very little tributary inflow for several river miles upstream of the falls. Therefore, most of the sediment load (other than from bank erosion) is derived from within the channel. Its transport can be described by bed material samples and bed load calculations. Additional information about the sediment load can be gained from observation of general bed material characteristics.

Orofino Creek Sediment Transport Conditions Indicated by Bed Material Characteristics

Inspection of the bed material in lower Orofino Creek, from upstream of the intake site to the mouth, allows several statements about bed material transport.

From observations described earlier (Sediment Data and Analysis) it appears that the bulk of the bed load transported in lower Orofino Creek is in the size ranges of gravel and cobbles (between 2 mm and 10 inches), with sand transported in lesser quantities. Bed material transport is inhibited at most flows by the stabilizing and hiding effects provided by medium-sized and large cobbles (between 4 and 10 inches) and by small boulders (10 to 18 inches in size). Only the smallest boulders experience much transport, and that probably only occurs at the largest discharges and over short distances. It is most likely that the larger discharges mainly dislodge them occasionally and displace them a short distance downstream.

In sample 1, taken after the removal of cobbles larger than 4 inches, 35% of the material protected by those cobbles was smaller than 2 inches and 14% of the protected material was smaller than 1 inch. This shows that the larger particles exert a major "hiding" effect to allow smaller particles to reside at the bed surface when general bed load transport is not occurring.

Relatively little small-sized gravel and sand is found in the exposed areas of the bed surface but these sizes occur in subsurface material. It is likely that these materials readily move through lower Orofino Creek whenever available for transport at moderate-to-large flows. After large flows, restabilization of the bed allows some sand and small gravel to deposit. Thereafter, much of the remaining exposed sand and small gravel will continue to move downstream toward the Clearwater River unless a protected zone can be found for deposition.

The lack of significant accumulations of silt or clay in the bed suggests that silt and clay particles wash through the lower reaches of the creek whenever they are available for transport.

Sediment Transport Analysis Using Reach Upstream of Intake Site

The reach about 500 feet upstream of the intake site provides favorable conditions for evaluating the local sediment transport regime of Orofino Creek in the project area. Under natural conditions, the sediment load from this reach moves past the intake site and through the zone of the falls to the lower reaches of the creek.

Bed material in a river undergoes a repeating cycle of transport-deposition-rest-scour-transport during individual runoff events and over longer periods. Hence, the bed material carried through this part of Orofino Creek from upstream sources can be expected to deposit in the bed within the reach and to later rescour and move downstream. (Only wash load is likely to experience near-continuous motion through the lower part of Orofino Creek.) For that reason, bed material sampling was conducted (sample 1 and related observations, as already discussed) to allow description of the size distribution of the sediment load and calculation of the magnitude of the natural sediment load in the project area. For the latter purpose, hydraulic characteristics of this reach have also been determined (see tables and figures already presented).

Bed Shear Stress and Incipient Motion

The average shear stress exerted on the boundary (bed and banks) of Orofino Creek by the flow can be determined. This can be done as a function of water level and discharge near the intake site using the rating curve of Table 14 and Figure 10 along with the representative simplified cross-sectional channel shape shown in Table 13. The channel slope used to calculate the boundary shear stress can be taken from Tables 9 and 10 and Figure 8 and the associated discussion.

The average boundary shear stress is calculated from the formula

$$\bar{\tau}_o = \gamma R S$$

where γ = specific weight of water (62.4 lb / ft^3)

R = hydraulic radius

S = channel slope, for steady uniform flow.

The local bed shear stress along the boundary can also be calculated. However, for purposes of the present analysis the use of the average stress along the boundary is adequate.

The general slope through this part of Orofino Creek is about 0.008 ft/ft. However, the sampling cross section has a somewhat flatter local slope of about 0.006 ft/ft (see earlier discussion of channel data and analysis). Therefore, S = 0.006 ft/ft was used to calculate the shear stress for scouring of bed material.

The critical value of bed shear stress is commonly used to determine incipient motion of bed particles. The critical boundary shear stress is that stress which can cause a previously stable particle to move. Incipient motion refers to the beginning of bed material motion as hydraulic forces increase on a bed particle. Relations between particle size and critical shear stress have been widely published. Figure 2.44 in ASCE's Manual 54, Sedimentation Engineering, has been used for analyses made in this study. Particles larger than the critical size for a given shear stress are considered stable whereas smaller particles are susceptible of motion.

Table 21 shows the results of shear stress and incipient motion calculations for the reach upstream of the intake site. Figure 13 provides a convenient way of relating incipient motion to streamflow by showing the smallest stable particle size over the range of likely flows. In each case, incipient motion is contingent upon the particle being exposed to the flow rather than protected from the flow by larger particles.

Figure 13 can be used in relation to field conditions as follows. At a flow of 200 cfs, Figure 13 shows that particles smaller than about 23+ mm (about 1 inch) would be scoured from the bed if exposed to the flow. Sample 1, taken from the bed after removing cobbles 4 inches or larger in size, shows that about 14 percent of the remaining bed surface was covered by particles smaller than 1 inch (see Table 15 and Figure 11). If the amount of bed surface covered by the larger cobbles is also taken into account, then the relative amount of material smaller than 1 inch might be reduced to about 5 percent. In either case, the amount of material smaller than 1 inch is not large and could easily occur in the protective wake zones behind the larger cobbles. Thus, the information in Figure 13 is consistent with field observations made at one flow condition and indicates the movement of exposed particles smaller than 1 inch in size until they reach protective zones behind larger particles. (In fact, it was possible to detect motion of small gravel around my feet when I intentionally dislodged cobbles while wading across the creek---the dislodged particles had been stable due to hiding

TABLE 21. BED SHEAR STRESS, INCIPIENT MOTION, AND STABILITY OF EXPOSED PARTICLES FOR OROFINO CREEK ABOUT 500 FEET UPSTREAM OF INTAKE SITE

Stage, feet	Discharge, Q cfs	Hydraulic radius, R feet	Average boundary shear stress, $\bar{\tau}_o$ lb/ft^2	Mean size of smallest stable bed particle,* millimeter	inch
4.0	2,022	3.837	1.44	70	2.8
3.0	1,285	2.960	1.11	50	2.0
2.0	682	2.047	0.77	37	1.5
1.5	465	1.576	0.59	29	1.1
0.0	195	1.312	0.49	23	0.9
-1.0	46	0.715	0.27	13	0.5

* Source: Figure 2.44, ASCE Manual 54, Sedimentation Engineering

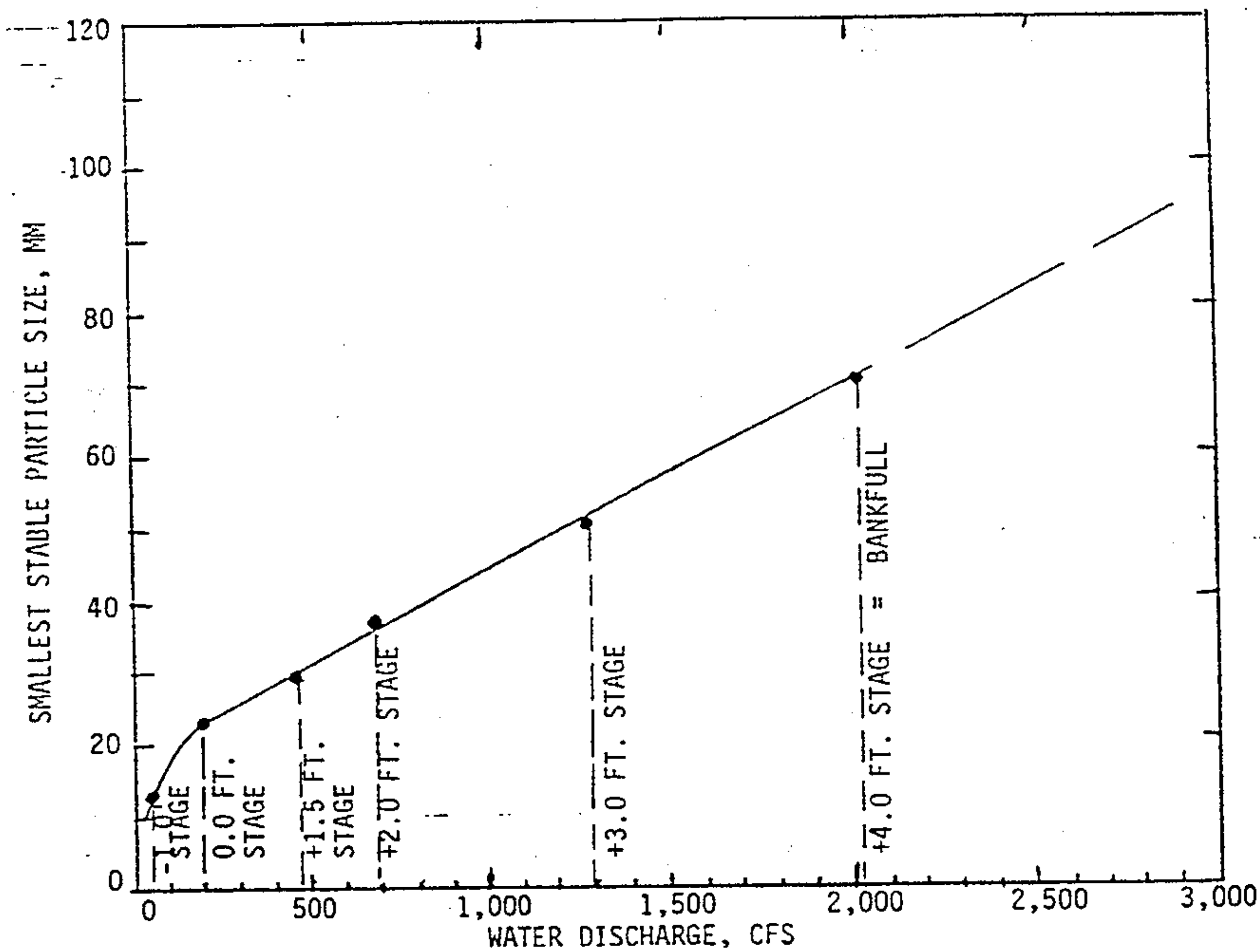

FIGURE 13. SMALLEST STABLE EXPOSED PARTICLES AS FUNCTION OF DISCHARGE FOR OROFINO CREEK ABOUT 500 FEET UPSTREAM OF INTAKE SITE

behind or beneath cobbles but moved as soon as exposed to the flow.) The flow-duration curve for Orofino Creek near the falls (Figure 4 and Table 2) indicates that this degree of bed stability can be expected about 63% of the time (200 cfs is exceeded about 37% of the time).

The movement of small cobbles of 2½ inch size (64 mm) or larger, according to Figure 13, should begin when flows increase past 1800 cfs. This happens about 0.3% of the time (Figure 4 and Table 2) or about 1 day per year.

The largest observed flow in Orofino Creek in 1982 (2590 cfs---see Table 1 or Figure 4) should have caused motion of bed material as large as about 4 inches in size, by extrapolation of Figure 13, as well as all smaller exposed material in the reach. (Note: The use of Figure 13 with larger sediment sizes undoubtedly has limitations due to the relatively large exposure surfaces of the particles and the shallowness of the flow (below 4-foot stage), compared to deeper flow conditions likely to have prevailed in rivers where data were collected to develop particle stability relations. Cobble mobility in Orofino Creek might occur at somewhat lower flows than just indicated from use of Figure 13, which nevertheless provides the best available estimate.)

Bed Load Transport

The large values of relative roughness for Orofino Creek, based on the ratio of typical bed material size to water depth, cause bed load transport to occur beyond the limits of most sediment transport conditions. The large bed material sizes themselves place Orofino Creek transport conditions outside the range of tested validity for virtually all sediment transport formulas.

The one formula that appears to most closely represent the Orofino Creek conditions is that developed by Parker, Klingeman, and McLean (published in ASCE Journal of the Hydraulics Division in April 1982). The equation is based upon extensive field data from several rivers in the Pacific Northwest and western Canada, including the Snake-Clearwater system. It reflects the armoring of subsurface material by coarse surface material which occurs in Orofino Creek. It also reflects the appreciable hiding of smaller particles among larger particles in the surface layer which also occurs in Orofino Creek.

The bed load transport relation for Orofino Creek near the intake site was developed from the Parker formula using a median subsurface particle size of 54 mm. This choice was made from data for sample 3 (Table 17 and Figure 11C), similar to material observed near the site of sample 1 except for the absence of large cobbles and small boulders (which would cause the median subsurface size to be larger).

The bed load function for Orofino Creek near the intake site is shown in Table 22 and Figure 14. By interpolation, general bed load transport is initiated at flows of about 1,000 cfs for the smallest third of the bed. Initiation of movement for the limiting 1 3/4-inch size is confirmed at this flow in Figure 13, based on a totally different source of information. The middle third of sizes experience general bed load transport at a flow between 1,285 and 2,022 cfs. For the 2 - 3/4 inch limiting size, Figure 13 shows motion to be initiated at about 2,000 cfs. Again, this is reasonable confirmation from an independent source.

The annual bed load transport can be determined by combining information from Table 22 and Figure 14 with the annual flow-duration characteristics presented in Figure 4 and Table 2, and the observed daily flows reported in Table 1. The results are presented in Table 23. It is seen that an annual load of about 36,000 lbs. (18 tons) is estimated for 1982, which was shown earlier to be a fairly typical year.

The bed load function presented in Table 22 and Figure 14 was checked using the Meyer-Peter and Müller formula, which was developed for gravel-bed rivers. In using this formula, a weighted mean particle size of 56 mm was calculated for the subsurface bed material, based on sample 3. This very closely agrees with the median value used in the Parker formula. However, the Meyer-Peter and Müller calculations gave zero bed load transport over the range of discharges up to 2,600 cfs!

An alternative calculation was made using a simplified version of the Einstein formula in which no hiding effects were considered for the small particles. A representative size (D 35) of 45 mm was used. The resulting bed load transport rate at 2,600 cfs was nearly 700 times larger than calculated by the Parker formula! Because other evidence strongly supports a bed load relation of the order of magnitude given by the Parker formula, one can conclude that hiding effects

TABLE 22. BED LOAD FUNCTION FOR OROFINO CREEK
ABOUT 500 FEET UPSTREAM OF INTAKE SITE

Water discharge, cfs	Bed load discharge, lb/hour			
	Largest third[1]	Middle third[2]	Smallest third[3]	Total
2,600	36	241	590	867
2,022	4	56	213	273
1,285	~0	~0	4	4
682	~0	~0	~0	~0

1. The largest 33% of subsurface material has $D > 2^3/_4$ inch. Thus, this fraction of bed load transport represents cobbles.
2. The middle 33% of subsurface material has $2^3/_4\text{-in.} > D > 1^3/_4\text{-in.}$ Thus, this fraction of bed load transport represents coarse gravel.
3. The smallest 33% of subsurface material has $D < 1^3/_4$-inch. Thus, this fraction of bed load transport represents fine-to-medium gravel and sand.

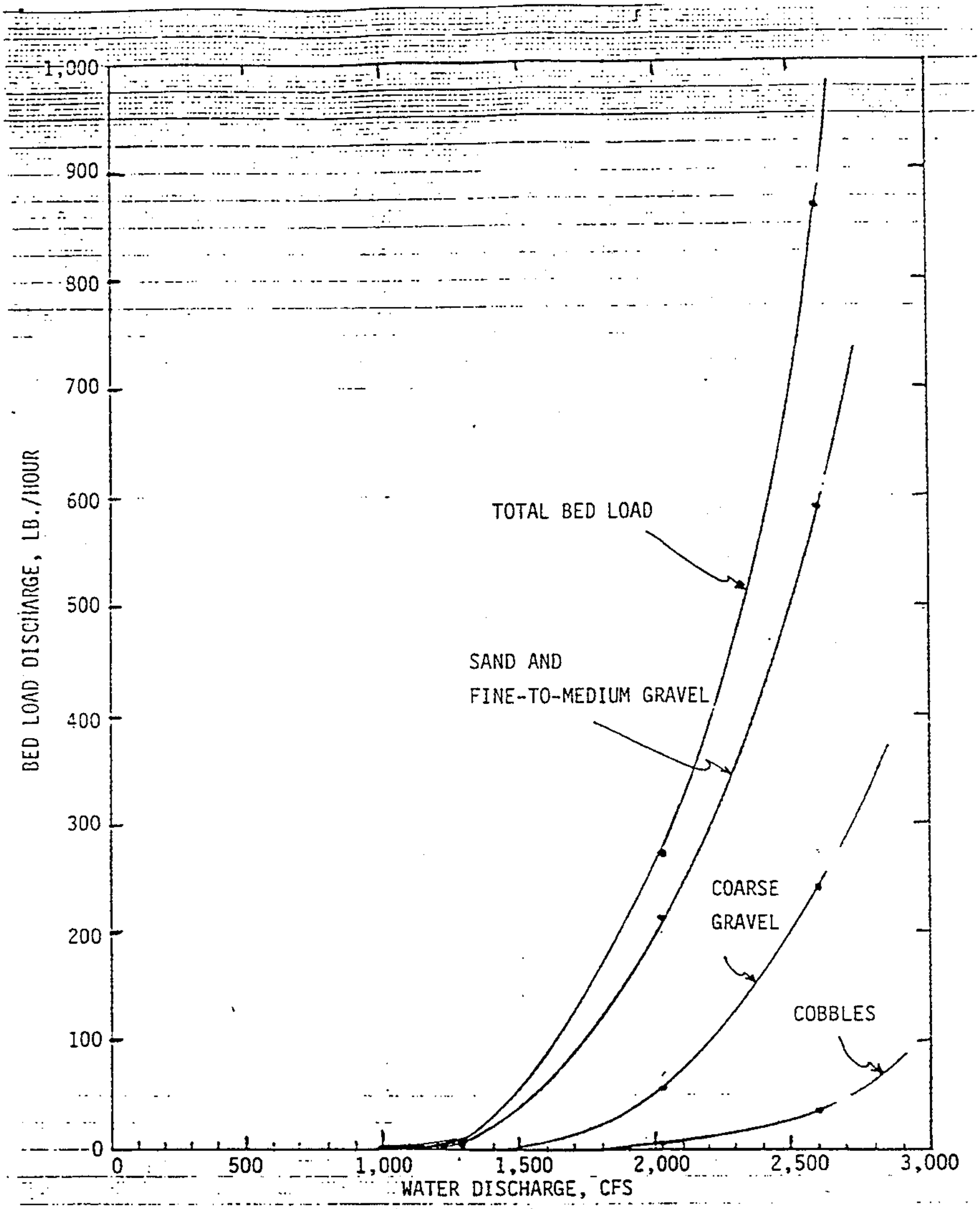

FIGURE 14. BED LOAD FUNCTION FOR OROFINO CREEK
ABOUT 500 FEET UPSTREAM OF INTAKE SITE

TABLE 23. ANNUAL BED LOAD TRANSPORT FOR OROFINO CREEK NEAR INTAKE SITE, BASED ON 1982 WATER YEAR

Discharge, cfs	Amount of time exceeded, decimal fraction	Incremental time, hours	Representative discharge, cfs	Corresponding bed load transport rate, lb/hr	Total bed load transport for interval, lb
2,600	0				
		24	2,580	830	19,920
2,500	0.0027				
		0.2	2,450	640	128
2,400	0.00272				
		0.2	2,350	540	108
2,300	0.00274				
		0.2	2,250	450	90
2,200	0.00276				
		0.2	2,150	370	74
2,100	0.00278				
		0.1	2,050	306	31
2,000	0.00279				
		0.1	1,900	220	22
1,800	0.003				
		70	1,700	135	9,450
1,600	0.011				
		70	1,500	63	4,410
1,400	0.019				
		26	1,300	12	312
1,200	0.022				
		193	1,100	5	965
1,000	0.044				
		193	950	0	0
900	0.066				

Total annual transport = 35,510 lb

are extremely important for Orofino Creek. In effect, the cobbles and small boulders dictate the bed load transport conditions for all sediment sizes present in the bed.

Erosion Potential Along Pipeline and Likely Impact on Project

The water transmission pipeline bypasses the falls and extends over one mile between the intake structure and the powerhouse. The pipeline route generally follows the ground contour line, having only a small downhill slope in the direction of flow (see route in Figure 1).

The cross slopes along the pipeline route vary from 13 degrees to 34 degrees, based upon horizontal distances of 300 to 840 feet between the 1400-foot and 1600-foot contours. Such cross slopes are steep enough to be subject to soil erosion. Therefore, an inspection was made of the pipeline route and of the railroad right-of-way paralleling and slightly downhill from the pipeline route. No erosion scars were evident; all disturbed soils near the railroad (except in rock cuts) were well revegetated.

Only one well-defined watercourse is crossed by the pipeline route, an intermittent stream that was dry at the time of inspection. Where this watercourse approaches the railroad right-of-way it is "paved" with broken rock . This dissipates the energy of the tumbling water and prevents erosion quite well. Therefore, the hillslope condition was found to be quite stable.

Excavation for the pipeline will disturb the soil and allow the opportunity for rain-caused erosion. This can be controlled by minimizing the width of the disturbed zone, protecting the adjacent soil cover from damage, and replanting the disturbed soil with grasses as soon as the pipeline installation is complete. The disruption of local drainage will be very limited. Where the pipeline crosses watercourses the disturbed soil surface can be riprapped or otherwise protected against erosion, as previously done by the railroad. Furthermore, the railroad right-of-way below the pipeline will limit any downhill soil erosion that might occur in the period after construction while new soil cover is growing. Therefore, no long-term erosion impact is expected from pipeline construction. The short-term impact is expected to be a slight increase in suspended sediment during the first winter after pipeline construction. This will not be detrimental to the streambed environment in Orofino Creek.

DISCUSSION AND CONCLUSIONS

Existing Sediment Load

Field observations, sampling, and calculations show that sizes of particles transported in Orofino Creek near the project site cover a very wide range: Bed load includes sand, gravel, cobbles, and small boulders. The corresponding sizes range from 64 µm to about 1½ foot. Suspended load includes silt and clay. The suspended load in steeper reaches of the stream also includes sand that elsewhere moves as bed load.

The majority of the transported particles move only briefly. General bed load transport only occurs for flows above approximately 1,000 cfs. This discharge was exceeded for only 385 hours (16 days) in the 1982 water year. In contrast, suspended load occurred whenever small particles in the silt-clay sizes were available for transport.

The total bed load for Orofino Creek near the project site was calculated to be about 36,000 lbs or 18 tons in 1982. This may seem small in comparison with other streams. The calculated amount can be used as an order-of-magnitude estimate. It is supported by differing computational approaches and field evidence. It is explainable in terms of the hiding effect that large particles offer to smaller particles in the bed. Furthermore, the large cobbles and small boulders and the wide, shallow channel are conducive to a high degree of bed stability.

The existing bed load transport regime in Orofino Creek appears to be supply-limited. Three arguments can be raised for this: (1) the very coarse bed surface limits the transport of smaller bed material that is also present; (2) there are few bars or side-channel source areas for bed load in the lower part of the creek; and (3) the steep gradients, locally narrow channel, and occasional large discharges provide a large transport capability compared to the availability that is restricted by the coarse bed surface. Therefore, bed load transport in the lower six miles of Orofino Creek is less than the hydraulic conditions alone would dictate.

The total suspended load for Orofino Creek near the project site was not estimated, as no measurement data were available. A statistical fit of such data is suitable to use, due to the many potential sources for such load. However, the creek bed did not show evidence that the suspended bed had any noticeable role in modifying the bed material composition; the void spaces among coarse particles were filled with sand and small gravel rather than silt and clay.

Sediment Load Due to Project Construction

The primary source of new sediment that might be added to the stream is from the hillside at the intake site. Presently, that hillside shows signs of past erosion, probably largely the result of channel cutting at the toe of the slope.

If hillslope material enters the creek due to construction, it is estimated that roughly half would be likely to be transported downstream to the Clearwater River as suspended load. The remainder would be transported downstream as bed load, mainly in the gravel and small cobble size ranges.

Hillslope erosion due to project construction would interfere with intake construction and its subsequent use. Therefore, it is in the best interest of the developer to stabilize the toe of that hillslope to prevent erosion. The developer has addressed this problem in the FERC application materials and has presented a plan to control hillslope erosion. Assuming that these measures are implemented, very little new sediment will be introduced to the stream because of project construction.

Initially, an estimated 2 - 10 cubic yards of material might be dislodged at most and could enter the stream as the work area is prepared for retaining wall construction. Thereafter, another one or two cubic yards of material might enter the stream from disturbed areas. Thus, the maximum added sediment load to the stream from construction might be about 10 tons in the first year and one or two tons more in the second year. Thereafter, the hillslope should remain stable.

Seasonal Characteristics of Sediment Transport

The transport capability of the stream for bed load is restricted to periods when flows can exceed about 1,000 cfs. Hence, bed load transport is very much limited to the season of rainfall and snowmelt. In the 1982 water year, this was February-April (see Table 1). In other years, it could include other winter-spring months. In general, bed load transport is a winter-spring phenomenon.

The transport capability of the stream for suspended load depends upon the availability of small particles more than on the river discharge. Therefore, suspended load transport could occur in any month. However, at low flows of summer and early autumn the size of particle carried in suspension will be quite small because of reduced velocities and turbulence. Large silt and fine sand that is routinely carried in suspension by winter high-water flows is likely to settle out in backwash areas of the stream if it enters the creek in the summer.

Like the existing suspended sediment load, new sediment of small size will generally be washed through Orofino Creek toward the Clearwater River with little opportunity for deposition. At very high creek levels, there may be some over-bank deposition of fine sediment on the limited floodplain. But the majority of suspended load should reach the Clearwater River rather quickly.

Also, like the existing bed load, new sediment of coarser size will generally move through the creek in a progression of deposition-erosion events. Any new cobbles will move relatively short distances (up to a few hundred feet at most) before deposition and will probably remain at rest until streamflows exceed about 2,000 cfs (once or twice a year). Gravel and sand will be more widely distributed in the downstream direction (up to several hundred feet), much of it depositing in wake zones behind boulders and large cobbles. Some of the smaller gravel and sand may reach the Clearwater River during the following year or two if large discharges occur. Some may remain in the channel for several years with only relatively infrequent disturbance.

The zone just upstream of the intake diversion dam is likely to detain much of the limited new sediment added to the creek from project construction. The structure will have the backwater effect of retarding the velocity near the intake retaining wall. This will diminish the likelihood of hillslope toe erosion but will also retard bed load transport locally. However, the structure includes provisions for sediment sluicing to control deposition behind it. Hence, the amount of deposition of existing bed load and new bed load material can be controlled to some extent.

Impacts of Reduced Flow on Gravel Scour and Deposition

Project development will not alter the delivery of bed load and suspended load to the intake site from upstream. Construction will add some sand, gravel, and cobbles to the bed load and finer material to suspension for one or two years. The intake structure will cause some impoundment of gravel and cobbles behind it. This may roughly offset the introduction of new material from construction.

Downstream of the intake site, the flows that carry suspended load will continue to remain capable of carrying whatever suspended load is available. There may be a slight reduction in the limiting sand sizes capable of being carried in suspension.

Downstream of the intake site, the reduced flows due to project diversions will offer less bed load transport capability than under existing conditions. However, the channel slope throughout the diversion reach is considerly steeper than upstream of the intake site. Thus, under present conditions the diversion reach can easily transport all bed load delivered to it from the flatter reach upstream of the intake site. The result of this greater capability is that the bed in the diversion reach is everywhere coarser than that upstream of the intake. Even with project diversions, the transport capability will remain large enough to move gravel and cobbles. Table 5 shows that flows will continue to exceed 1,000 cfs about 2.5% of the time. Also, the increased slope throughout the reach will increase the shear stress causing incipient motion and bed load transport, so that diversion flows smaller than (for example) 1,000 cfs in the diversion reach will be capable of doing the same transporting of bed load as the 1,000 cfs upstream flows. Thus, there is a tradeoff between slope and discharge that should keep bed load moving as well as before. At locally flat gradients near the powerhouse site there could be some gravel and cobble deposition among the cobbles and boulders that comprise the bed there.

The above discussion can be rephrased with respect to spawning gravels in the bypassed reach. There should be no additional scour but possibly a slight reduction in scour of the few spawning gravel deposits in the diversion reach. There could be a slight increase in the deposition of spawning-size gravel in the diversion reach because of reduced flows. However, the limited bed load transport from upstream makes the likely magnitude of such deposition rather small. There could also be some deposition of spawning-size gravel behind the diversion structure due to limited trapping of the hillslope sediment introduced by construction and of the normal bed load from upstream.

Conclusions

Based upon the preceeding analysis, the proposed project should have only a very minor impact on the sediment of Orofino Creek. The existing bed load transport is limited in amount due to the coarse size of the majority of particles present and is limited in time of occurrence to the winter-spring runoff season. The bypassed reach is steeper than upstream and downstream reaches, so that entering sediment will continue to move through it even with the proposed diversion flows. Construction activities will add only a small amount of bed load and suspended load to the stream and for only the first year or two after construction starts. There will be little impact of construction or flow diversion on scour and deposition of spawning gravel in the bypassed reach.

In summary, the proposed project will not have any notable impacts, either adverse or beneficial, on Orofino Creek's sediment transport regime and streambed environment; the project impacts are negligible or neutral with respect to the sediment of Orofino Creek.