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**ELWHA RIVER
RESTORATION PROJECT,
Washington**

**Elwha Technical Series
PN-95-1**

**DEVELOPMENT OF
FLOOD HYDROGRAPHS**

**U.S. Department of Interior
Technical Service Center
Denver, Colorado
and
Bureau of Reclamation
Pacific Northwest Region
Boise, Idaho**



March 1995

**ELWHA RIVER
ECOSYSTEM AND FISHERIES
RESTORATION PROJECT
Washington**

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PEER REVIEW DOCUMENTATION

INTRODUCTION

The purpose of this analysis is to determine flood hydrographs at various locations on the Elwha River on the Olympic Peninsula of northwestern Washington. Various recurrence-level floods are analyzed for flooding conditions on the Elwha River for use in determining the effects of removing Glines Canyon and Elwha Dams, and restoring the Elwha River to natural flow conditions in order to increase anadromous fish production.

HISTORY OF THE STUDY AREA

The Elwha River is a coarse-bed stream located on the Olympic Peninsula of northwestern Washington. The river, which drains an area of approximately 325 square miles at the mouth, flows northward 45 miles from the base of Mount Olympus to the Strait of Juan de Fuca, near the town of Port Angeles, Washington. The Elwha River study area ranges from sea level to 4500 feet elevation. Figure 1 shows the location of the study area.

Elwha Dam, the lower of the two dams on the river, was built between 1910-1913. Lake Aldwell, behind Elwha Dam, has a storage capacity of 8,100 acre-feet at an elevation of 188 feet.

Glines Canyon Dam was built between 1925-1927. Lake Mills, behind Glines Canyon Dam, has a storage capacity of 40,530 acre-feet at an elevation of 590 feet. Both dams were built to provide electrical power to the city of Port Angeles. Neither dam has fish passage facilities to assist the movement of anadromous fish up and down the river.

FLOOD HISTORY OF THE ELWHA RIVER

Since 1898, flows have been recorded on the Elwha River at McDonalds Bridge, which is located below Glines Canyon Dam and upstream of Elwha Dam. There have been three different means of measuring flows at the stream gauge:

- 1) By a wire-weight gauge (from October 8, 1897 to December 31, 1901);
- 2) At a point 200 feet downstream from the present location (from December 9, 1918 to May 1, 1936); and
- 3) At the present location, based on the datum of 1929.

The two periods of recorded flows are 1898-1901 and 1918-1994. Flows from 1898 through 1926 represent unregulated, or natural, flows. Since 1927, flows at the stream gauge reflect minor

regulation by Glines Canyon Dam.

Floods in the Elwha River basin are generally the product of rain on saturated ground, and in rare cases, rain on snow-covered ground. The major floods recorded at the stream gauge have generally occurred between November and March, which coincides with the rainy season. Precipitation ranges from over 100 inches per year at the upper end of the study area to approximately 40 inches at the mouth. The average rainfall for the 1948-1992 period for the Elwha Ranger Station is 54.65 inches. Approximately 75 percent falls between November and March.

Table 1 is a listing of the 5 largest recorded peak flows for the period before the construction of Glines Canyon Dam.

Table 1.—Five Largest Peak Flows Prior to Construction; 1898-1926	
Date	Flow (cfs)
11-18-1898	41,600
11-27-1902	33,600
03-11-1900	30,200
12-12-1922	21,400
12-20-1901	20,600

The major purpose for Glines Canyon and Elwha Dams is the production of hydroelectric power. For this reason, the reservoir level at Glines Canyon is maintained as high as possible during the flood season, in order to maintain the head for power production.

Normally, with a reservoir having an overflow spillway, one can expect to get a small reduction in peak flows by routing the flood flows through the dam; however, Glines Canyon Dam has a gated spillway. In 1979, the reservoir stored water on December 17, resulting in the average daily flow being reduced from 19,050 cfs to 18,900 cfs. In 1980, the average daily flow on December 26 was increased from 18,114 cfs to 19,700 cfs. Similarly in December 1989, the average daily flow went from 11,864 cfs to 12,400 cfs. Also, in November 24, 1990, the average flow went from 21,156 cfs to 21,400 cfs. Similar flow increases were also present in January 1992.

Table 2 lists the 5 largest peak flows for the period after construction of Glines Canyon Dam. The highest stage recorded at the stream gauge was 24.2 feet on November 26, 1950.

Table 2.—Five Largest Peak Flows After Construction; 1927-1992	
Date	Flow (cfs)
11-26-1950	30,000
11-23-1991	28,700

12-26-1981	27,700
12-21-1934	26,700
12-17-1980	26,100

DEVELOPMENT OF ANNUAL FLOOD FLOWS

From the discussion above, it is evident that the changes in peak daily natural flows and the peak daily regulated flows are minimal and variable. The elevation of the water surface at the start of the flood will determine whether water is stored for future power generation, or released to protect the dam. Since the differences between the natural and regulated flows are small, it was assumed that there would be negligible differences between natural and regulated flows.

The entire length of record (1898-1902/1920-1992) at the stream gauge at McDonalds Bridge was used in the computation of the peak flow frequency curve. The peak flow was based on a log Pearson Type III analysis. Figure 2 shows a plot of the peak inflow frequency curves for Elwha River at McDonalds Bridge.

DEVELOPMENT OF FLOOD HYDROGRAPHS

For the purposes of this study, flood hydrographs were computed for Glines Canyon Dam, the area between Glines Canyon and Elwha Dams, and the area between Elwha Dam and the mouth of the river. Flood hydrographs were developed with return periods of 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-years using the annual flows.

The July through October seasonal flows were used to develop runoff hydrographs with 50-, 20-, 10-, and 4-percent chances of occurrence during this period. All of the hydrographs have a 15-day duration.

METHODOLOGY TO DETERMINE YEARLY FLOOD HYDROGRAPHS

The following methodology was used to develop the yearly flood hydrographs that were needed:

- a. Using the frequency statistics based on a log Pearson Type III analysis; of the daily flows for the entire period of record (1898-1902/1920-1992) at the McDonalds Bridge stream gauge, the following table showing the recurrence level values for the yearly events was developed:

Table 3.—Recurrence-level Values for Yearly Events						
Recurrence Interval		Average Flows (cfs)				
Years	Peak	1-day	3-day	5-Day	7-Day	15-Day
2	13,500	8,500	6,600	5,500	4,900	3,800
5	20,600	13,200	9,700	7,900	6,900	5,100
10	25,600	16,700	12,000	9,600	8,300	5,900
25	32,300	21,600	15,000	11,800	10,100	7,000
50	37,400	25,600	17,400	13,400	11,400	7,700
100	42,800	29,900	19,800	15,100	12,800	8,500
200	48,300	34,400	22,300	16,900	14,200	9,300
500	55,900	41,000	25,800	19,300	16,200	10,300

- b. The balanced hydrograph approach was used to develop the recurrence-level hydrographs. A 15-day flood duration was chosen based on inspection of the flow records. With the balanced hydrograph approach, the following assumptions were made:
 1. The peak flow is part of the 1-day volume;
 2. The 1-day volume is part of the 3-day volume;
 3. The 3-day volume is part of the 5-day volume;
 4. The 5-day volume is part of the 7-day volume;
 5. The 7-day volume is part of the 15-day volume.
- c. The values in Step “a” were adjusted prior to developing the hydrographs. The average 3-day flow was multiplied by 3, and the 1-day flow was subtracted. The resultant number was divided by 2 to get an average flow for days 2 and 3 of the 3-day flow. The same procedure was used to determine flows for days 4 through 7, and days 8 through 15.

Table 4 shows the computed daily flow values.

Table 4.—Computed Daily Flow Values						
Recurrence Interval		Average Flows (cfs)				
Years	Peak	Day 1	Days 2-3	Days 4-5	Days 6-7	Days 8-15
2	13,500	8,500	5,650	3,850	3,400	2,838
5	20,600	13,200	7,950	5,200	4,400	3,525
10	25,600	16,700	9,650	6,000	5,050	3,800
25	32,300	21,600	11,700	7,000	5,850	4,288
50	37,400	25,600	13,300	7,400	6,400	4,463
100	42,800	29,900	14,750	8,050	7,050	4,738
200	48,300	34,400	16,250	8,800	7,450	5,013
500	55,900	41,000	18,200	9,550	8,450	5,138

The yearly recurrence-level hydrographs at the Elwha River stream gauge at McDonalds Bridge near Port Angeles were developed by trial and error. The hydrographs were assumed balanced if all the different durations were within 10 percent of the computed value.

- d. In order to determine the flood hydrographs at the three desired locations, adjustments were made to the computed hydrographs. The computed hydrographs for the three desired locations were adjusted based on the ratio of the square root of the drainage areas for each location. The following table shows the drainage area at each site and the factor used to compute the new runoff hydrograph:

Table 5.—Drainage Areas and Conversion Factors, Elwha River Basin		
Drainage Area		
Location	Square Miles	Factor
Elwha River at Glines Canyon Dam	255	0.9736
Elwha River at McDonalds Bridge	269	1.0000
Elwha River at Elwha Dam	318	1.0873
Intervening Area (Glines to Elwha)	63	0.1137
Elwha River at Mouth	325	1.0992
Intervening (Elwha Dam to Mouth)	7	0.0119

For Glines Canyon Dam, the stream gauge hydrograph ordinates were multiplied by 0.9736 to obtain the flood hydrographs. For the intervening area between Glines Canyon and Elwha Dams, the stream gauge hydrograph ordinates were multiplied by 0.1137 to obtain the flood hydrographs. For the intervening area between Elwha Dam and the mouth of the river, the stream gauge hydrograph ordinates were multiplied by 0.0119 to obtain the flood hydrographs.

Figures 3 and 4 show the natural flow flood hydrographs for the Elwha River at Glines Canyon Dam. Figures 5 and 6 show the natural flow flood hydrographs for the intervening area on the Elwha River between Glines Canyon and Elwha Dams. Figures 7 and 8 show the natural flow flood hydrographs for the intervening area on the Elwha River between Elwha Dam and the mouth of the Elwha River.

METHODOLOGY TO DETERMINE SEASONAL FLOOD HYDROGRAPHS

The July through October period would be the best time for construction activities in the Elwha River. Therefore, runoff hydrographs with 50-, 20-, 10-, and 4-percent chances of recurrence during this period were developed. These hydrographs were provided with the stipulation that a particular yearly recurrence interval not be included. For the yearly analysis, we might have a 2-year flood; however, in the seasonal analysis we would have a flood with a 50 percent chance of occurring during the months of July through October (**not a 2-year flood**).

The following methodology was used to develop the yearly flood hydrographs:

- a. Using the frequency statistics for July through October flow conditions for the Elwha River stream gauge at McDonalds Bridge near Port Angeles, WA, the following table showing the probability of recurrence for the seasonal events was computed:

Table 6.—Computation for Probability of Recurrence for the Seasonal Events					
Probability (percent)	Average Flows (cfs)				
	1-day	3-day	5-Day	7-Day	15-Day
50	3,100	2,500	2,300	2,100	1,800
20	4,800	3,700	3,300	3,000	2,500
10	6,200	4,600	4,000	3,600	2,900
4	7,600	5,600	4,800	4,200	3,300

- b. The balanced hydrograph approach was used to develop the seasonal hydrographs. A 15-day flood duration was chosen based on the need of the hydrograph to recede to 2,000 cfs by the end of the routing period. The 2,000 cfs represents the ability of the outlet works at Glines Canyon Dam to pass flood flows without having to store any of the inflows. The same assumptions, as used in the yearly analysis, were made for the seasonal floods.

- c. As with the yearly flow hydrographs, the values in step “a” were adjusted prior to developing the seasonal hydrographs. The same assumptions, as used in the yearly analysis, were made for the seasonal floods. The following table shows the computed flow values.

Table 7.—Computation for Flow Values					
Probability (percent)	Average Flows (cfs)				
	Day 1	Days 2-3	Days 4-5	Days 6-7	Days 8-15
50	3,100	2,195	2,000	1,600	1,538
20	4,800	3,150	2,700	2,250	2,062
10	6,200	3,800	3,100	2,600	2,287
4	7,600	4,600	3,600	2,700	2,513

The seasonal hydrographs at the Elwha River stream gauge at McDonalds Bridge near Port Angeles were developed by trial and error. Peak flows were estimated based on a relationship between instantaneous peak flows and the maximum 1-day flows. The value of the peak flow is not as valuable as the amount of time the reservoir inflow stays above a particular value; i.e., the outlet or spillway capacity.

- d. In order to determine flood hydrographs at the three desired locations, adjustments were made to the computed hydrographs. The computed hydrographs for the three sites were adjusted based on the ratio of the square root of the drainage areas for each location to the drainage area of the stream gauge. The flows at each location were developed following the procedures discussed above for the yearly values.

Figure 9 shows the July through October seasonal hydrographs for the Elwha River at Glines Canyon Dam. Figure 10 shows the July through October seasonal hydrographs for the intervening area on the Elwha River between Glines Canyon and Elwha Dams. Figure 11 shows the July through October seasonal hydrographs for the intervening area on the Elwha River between Elwha Dam and the mouth of the river.