Title
Updated flood frequencies and a canal breach on the upper Klamath River

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ABSTRACT

During the current water year, the upper Klamath River basin has experienced higher than normal winter and spring flows. In addition, a landslide breached a diversion canal downstream of the J.C. Boyle dam and caused secondary erosion and sedimentation in the "bypass" reach of the Klamath River. The peak flows and landslide may have influenced fish habitat and river geomorphology.

I updated existing flood frequency analyses for four gauges in the upper Klamath River basin using new annual peak streamflow data. I determined that the new flood frequencies reduce the return interval for bed mobility threshold flows at three sites, and increase the return interval of flows over the mobility threshold at two sites, suggesting that existing interpretations about sediment mobility and disruption of fish habitat in parts of the upper Klamath River basin may need to be refined. I also identified differences in flood frequency estimates based on the method used to analyze annual peak streamflow data.

I evaluated the effects of the December 2005 landslide that breached the canal feeding water to the JC Boyle powerplant. The landslide deposited sediment in the Klamath River and the subsequent closure of the canal resulted in increased flows in the river. I expect the effects of the canal breach on downstream fish habitats to be minor because of the short duration of the canal closure and the high flows in the river since January 2006 that likely mobilized the impinging sediment.

PROBLEM STATEMENT

The Klamath River basin has undergone significant anthropogenic change in the last 150 years. These changes started in the late nineteenth century with the draining of marshlands and diversion of water for irrigation to facilitate agricultural development. In the twentieth century, the construction of eight developments for hydroelectric power and irrigation further disrupted the natural flow of the upper Klamath Basin (PacifiCorp 2004; Bureau of Reclamation 2005). In recent decades, the power and agricultural demands supplied by the Klamath Project have sometimes conflicted with other needs, such as water of sufficient quality and quantity to support downstream fisheries, leading to conflicts between ranchers, farmers, fishermen, environmentalists, and Native American tribes.

In the first part of this project (Part I), I updated flood frequency analyses for four US Geological Service (USGS) gauges in the Upper Klamath River Basin: Link River, at Keno, below JC Boyle powerplant, and below Iron Gate Dam (Figure 1). These four gauges monitor flows at sites within the Klamath Hydroelectric Project (hereinafter the "Klamath Project"), which is run by PacifiCorp (Figure 2) (PacifiCorp 2004). As part of the recent re-licensing process for the Klamath Project conducted by the Federal Energy Regulatory Commission (FERC), PacifiCorp (2004) conducted an evaluation of the effects of the Klamath Project on sediment transport and river geomorphology. I generated new flood frequency analyses of the four gauges on the Klamath River for the period of record for each gauge through April 2006. I compared my results to PacifiCorp's estimates of flood frequency and the return interval of bed mobility which were based on the period of record for each gauge through Water Years 2001 or 2002, depending on the gauge. I sought to answer the following questions. First, how does including the additional years of flow data (2002 to 2006 for three gauges, 2003 to 2006 for one gauge) affect the results of the flood frequency analyses? Second, how do flood frequency analyses vary depending on the methodology used to analyze annual peak flow data? Third, how do the changed flood frequencies affect the computed frequency of bed mobilization?

In the second part (Part II), I evaluated the impacts of the slope and canal failure at the JC Boyle canal of the Klamath Project. On December 2, 2005, a landslide impacted the canal that diverts water to the JC Boyle powerplant, creating a hole in the canal that released water from the canal downslope into the Klamath River (Stuart 2006). I reviewed information about this incident, evaluate flows in the Klamath River bypass during and after the canal failure, and assessed the potential significance of the sediment deposited in the Klamath River by the landslide for aquatic habitats. The question I sought to answer is: is it likely that the landslide affected downstream aquatic habitats?

METHODS

For ***Part I***, I reviewed the PacifiCorp (2004) re-licensing report and analyzed flow data for four gauges in the Klamath Project area: Link River at Klamath Falls, OR (USGS 11507500); Klamath River at Keno, OR (USGS 11509500); Klamath River below John C. Boyle Powerplant, OR (USGS 11510700); and Klamath River below Iron Gate Dam, CA (USGS 11516530).[1] Specifically, I reviewed two sections of the PacifiCorp report addressing flood frequencies and sediment mobility: Section 5—"Analysis of Project Effects on Hydrology", and Section 6—"Analysis of Project Effects on Sediment Transport and River Geomorphology." Section 5 provides PacifiCorp's estimates of flood frequencies for the period of record of each gauge until the report was completed (Link River—WY 1904-2002; Keno—WY 1905-1913, 1930-2002; JC Boyle—WY 1959-2001; Iron Gate—WY 1961-2002). To determine flood frequencies, PacifiCorp used a computer program; the Flood Frequency Analysis (FFA) from the US Army Corps of Engineers' Hydrologic Engineering Center (HEC). The HEC-FFA program computed flood frequencies using annual peak flow data for each gauge (PacifiCorp 2004). Section 6 of PacifiCorp's (2004) report provides bed mobility

[1] In the remainder of the report I refer to these gauges as "Link River", "Keno", "JC Boyle", and "Iron Gate".

threshold flow estimates for each gauge. Section 6 also applies the flood frequencies listed in Section 5 to determine the return intervals and exceedance percentages for threshold flows.

To update PacifiCorp's (2004) flood frequencies and sediment mobility analyses, I accessed and processed USGS data. First, I downloaded annual peak streamflow data from the USGS web site, http://waterdata.ugsg.gov/nwis. The USGS web site provided annual peak streamflow data for the Link River gauge from 5/12/1904 to 5/5/2005; for the Keno gauge from 3/28/1905 to 1913 and 1930 to 5/17/2005; for the JC Boyle gauge from 1/1/1959 to 5/17/2005; and for the Iron Gate gauge from 12/1/1960 to 2/18/2004. Second, I supplemented the annual peak data obtained through the USGS web site with provisional flow data through April 2006 provided by the Oregon (OR) and California (CA) offices of the USGS. I received fifteen minute flow data for the Link River gauge (10/1/2003 to 4/20/2006) and Iron Gate gauge (10/1/1988 to 4/19/2006), as well as thirty minute flow data for the Keno gauge (10/1/2003 to 4/20/2006) and JC Boyle gauge (10/1/2003 to 4/20/2006). I assembled and ranked annual peak streamflow data for Link River for WY 1904-2006 (Appendix 1) (4% more years than PacifiCorp 2004); Keno for WY 1905-1913, 1930-2006 (Appendix 2) (5% more years than PacifiCorp 2004); JC Boyle for WY 1959-2006 (Appendix 3) (11% more years than PacifiCorp 2004); and Iron Gate for WY 1961-2006 (Appendix 4) (10% more years than PacifiCorp 2004).

I determined flood frequencies for each gauge using two methods. First, I identified annual peak flows and calculated recurrence intervals and probabilities of recurrence for each gauge using standard flood frequency formulae (Dunne and Leopold 1978) (see Calculations section). I obtained updated flood frequencies based on the entire period of record through April 2006 for the Link River (1904-2006), Keno (1905-1913, 1930-2006), JC Boyle (1959-2006), and Iron Gate (1961-2006) gauges. Second, I plotted the return period and flow values on logarithmic graphs, added a trendline for the four gauges, and determined return intervals from the trendline. I compared my flood frequencies obtained by calculations and trendlines for the period of record through 2006 with

PacifiCorp's (2004) flood frequencies for the period of record through WY 2001 or 2002, depending on the gauge. In addition, I compared my calculated flood frequencies for the JC Boyle gauge for WY 1959-2001 with PacifiCorp's (2004) flood frequencies for the same period.

Finally, I used my flood frequency estimates to update PacifiCorp's (2004) estimates of the frequency of bed mobility at the Link River, Keno, JC Boyle, and Iron Gate gauges. I calculated return intervals for threshold flows based on the entire period of record through April 2006 for each gauge. I also calculated exceedance percentages for WY 2004-2006.

For ***Part II***, I reviewed information about the landslide and breach of the JC Boyle canal and analyzed hourly flow data for the JC Boyle gauge from December 2005 to April 2006. At approximately 10:30am on December 2, 2005, a 15-foot boulder released by a landslide impacted the canal and penetrated its outer edge (Stuart 2006, Associated Press 2005). The canal was shut down and drained, but not before water flowed from the canal, cutting a channel down the hillside and depositing sediment into the river. As a result of this breach and the shutdown of the canal, all of the flow measured at the gauge downstream of the JC Boyle power station was transported through the Klamath River bypass reach.

To evaluate the effects of the canal breach and channel impingement, I used information from a letter from Amy Stuart of the Oregon Department of Fish and Wildlife describing the incident and its significance for fish habitat (Stuart 2006) and provisional flow data for the USGS gauge on the Klamath River downstream of the JC Boyle power station. I also estimated flows in the Klamath River bypass from January 2006 to April 2006 by subtracting 2,850 cubic feet per second (cfs) from the JC Boyle gauge data. In Section 5 of the PacifiCorp (2004) report, the authors apply this conservative method of estimating flow in the Klamath River bypass, reasoning that the hydraulic capacity of the JC Boyle powerplant is 2,850 cfs; therefore during periods of higher-than-normal flow, the bypass flow may be estimated to be a maximum of 2,850 cfs less than the flow at the JC Boyle gauge.

RESULTS

For ***Part I***, two important findings emerge from a comparison of PacifiCorp's (2004) flood frequencies and the results I obtained using the calculation and trendline methods (Table 1). First, the addition of four years of annual peak flows for the Link River, Keno, and Iron Gate gauges plus the addition of five years of annual peak flows for the JC Boyle gauge (Figures 3-6) altered PacifiCorp's (2004) flood frequency analyses. The effects on flood frequencies of these additional years of data were minor, however, because the peak flows for WY 2002-2006 are well within the normal range of peak flows. I expected the influence of the additional years of flow data for the flood frequency analysis to be most significant for the JC Boyle and Iron Gate gauges, which have relatively few years of record, but for all four gauges I found that most updated values were within 10% of the PacifiCorp (2004) values (Table 1). Overall, my trendline estimates for short return intervals (1.25 to 5 years) were less than PacifiCorp's (2004) estimates at the Link River, JC Boyle and Iron Gate gauges. My trendline estimates for high return intervals (50 and 100 years) were lower than PacifiCorp's (2004) estimates at Link River, Keno, and Iron Gate, but higher at JC Boyle.

The second important finding is that estimates of flood frequency may vary considerably depending on the method used to calculate the return interval. Both PacifiCorp (2004) and I used annual peak streamflow data as the basis for our calculations, but our estimates of return intervals for some gauges vary from being significantly different to very similar. These differences could be due to the addition of several years of annual peak streamflow data, but they are also likely due to the differences between the HEC-FFA computer model and my methods of calculation (Appendices 1-4) and trendline (Figures 7-10).[2] For example, PacifiCorp's 100-year flood estimate for the Link River of 11,000 cfs is 15% higher than my estimate by calculation of 9,300 cfs; the validity of my calculated value is supported by my trendline estimate of 9,800 cfs (Table 1, Figure 7). As another

[2] The Keno, JC Boyle, and Iron Gate gauges did not have enough years of record to make complete return interval estimates based solely on calculation.

example, PacifiCorp's (2004) estimate of a 20-year return interval flow at JC Boyle gauge is 13,400 cfs, while my calculated estimate using the same years of analysis (1959-2001) yields a predicted flow of 11,300 cfs (17% less than PacifiCorp's value) (Table 2). On the other hand, some estimates of flood frequencies presented in Table 1 are very similar, such as the 2-year estimate for the Link River (PacifiCorp—3,890; Fahey calculation—3,850; Fahey trendline—3,650). It is therefore difficult to determine how much of the similarities and differences are due to updated data or variations in method, or both.

The results of my estimates of return intervals for bed mobility threshold flows are presented in Table 3. My recurrence interval for bed mobility flows increased from 0.7 to 1.0 year for the Link River gauge (42% increase), decreased from 2.0 to 1.8 years for the Keno gauge (10% decrease), decreased from 1.8 to 1.6 years for the JC Boyle gauge (11% decrease), and decreased from 8.7 to 7.8 years for the Iron Gate gauge (10% decrease). I attribute these differences to the fact that my return interval estimates are based on calculated values for the period of record of each gauge through April 2006, whereas PacifiCorp's (2004) estimates are based on HEC-FFA estimates using data from the period of record through 2001 for the JC Boyle gauge and through 2002 for the Link River, Keno, and Iron Gate gauges. The different methods and periods of record produce different estimates of return intervals for bed mobility threshold flows. The results suggest that bed mobility threshold flows may occur more often than PacifiCorp predicted at the Keno, JC Boyle, and Iron Gate gauges.

The results of my calculations of the percentage of flows exceeding the sediment mobility threshold for Water Years (WY) 2004 to 2006 are presented in Table 3. As with the recurrence intervals, the differences may be attributable to differences in source data. PacifiCorp's (2004) estimates of the frequency of bed mobility are based on daily mean flows from WY 1968-2001, while my update is based on fifteen minute flow data for the Link River gauge (10/1/2003 to 4/20/2006) and Iron Gate gauge (10/1/2003 to 4/19/2006), and hourly flow data for the Keno gauge

(10/1/2003 to 4/20/2006) and JC Boyle gauge (10/1/2003 to 4/20/2006). My estimates for WY 2004-2006 show that significant bed mobility may have occurred at Link River, through less often than predicted by PacifiCorp (2004) (24% versus 33%). However, high flows may have mobilized the bed more often than PacifiCorp estimated at Keno (11.7% versus 9% predicted by PacifiCorp) and JC Boyle (11.1% versus 7 percent predicted by PacifiCorp). Given the daily fluctuations in flow to meet power demands, the higher percentage at the gauge below the JC Boyle hydroelectric plant is not surprising (Figure 11). Using mean daily flows for the JC Boyle gauge would obscure the high flows during the daytime hours, thus underestimating the percentage of flows over the bed mobility threshold.

The bed mobility threshold may be significant for fish habitat. PacifiCorp's (2004) thresholds are based on the flow needed to move a median grain size of 34 mm (Table 6.7-14, PacfiCorp 2004), which is a medium-sized gravel (Table 4). Salmon and trout prefer gravel deposits less than 3 feet in length and width, and optimal salmon spawning gravels are greater than 8 mm (PacifiCorp 2004). Therefore, in the upper reaches of the Klamath River (above Iron Gate Dam) there is episodic disruption of gravels due to high flows that may potentially provide spawning habitats for aquatic species. Since some species, such as the Klamath River Lamprey (*lampetra similis*) and the Pit Klamath Brook Lamprey (*lampetra lethophaga*), have a multi-year life stage in gravel, the recent heavy flows of WY 2006 could have resulted in greater habitat disruption due to bed mobility than in recent years, although the high flows may also have removed fine sediment that can damage aquatic habitats by covering gravel and embedding substrate (Stuart 2006).

In ***Part II***, I determined that the December 2, 2005 breach of the JC Boyle canal diverted water through the Klamath River bypass for approximately eleven days, until December 13, 2005. PacifiCorp completed repairs on December 13, when fluctuations in flows at the JC Boyle gauge again become evident (Figure 12, Figure 13). This suggests that after December 13, PacifiCorp had completed emergency repairs and diverted water through the canal to feed the demand of the JC Boyle power station, resulting in decreased flows through the Klamath River bypass.

In the context of the overall operation of the Klamath Project, the effects of the landslide and breach of the canal will probably have minimal impacts on fish habitats. After the December 2 breach, the Oregon Department of Fish and Wildlife expressed concern "that the canal failure has the potential to impact the spawning substrate in the bypass reach since redband trout [*Oncorhynchus mykiss newberrii*] spawning occurs approximately 450 meters downstream of the canal and slope failure" (Stuart 2006). This species of redband trout spawns between March and May (PacifiCorp 2004); therefore the sediment from the channel impingement would not have covered trout eggs in the spawning area.

The high flows since January 2006 in the Klamath River bypass have likely mobilized the fine sediment that may have deposited on gravel habitats and impeded spring spawning. Based on hourly flow data, I estimated that the flow in the Klamath River bypass exceeded the bed mobility threshold for the JC Boyle gauge (approximately 2 miles downstream of the landslide) for a total of 264 hours between January 1, 2006 (12:00 am) and April 20, 2006 (4:00 am) (Figure 14). The greater threat to trout habitat may have been the high flows since January 2006, which may have mobilized gravel in the streambed. If the slide had taken place during a year of lower-than-normal flows, the sediment and gravel deposited in the Klamath River bypass by the landslide may have not have been mobilized, thereby presenting a risk to downstream fish habitats, but this year, the landslide's effects are likely to be small.

CONCLUSION

In comparing PacifiCorp's (2004) flood frequency estimates for four gauges in the upper Klamath River basin with my updated estimates based on provisional flow data, I identified differences that are likely due to a combination of the variations in source data and methodology. This finding suggests that flood frequencies may be affected by both the number of years of record and the method used to estimate return intervals. However, since the peak flows for WY 2002-2006 that I used to update the flood frequencies were well within the normal range of peak flows for the period of record for each gauge, the differences between my flood frequencies and those obtained by PacifiCorp (2004) are likely to be due primarily to differences in method. I recommend that future updates of flood frequencies for these gauges compare the results obtained by the same method (e.g. HEC-FFA) applied to two different periods of record or different methods (e.g. HEC-FFA and trendline) applied to the same period of record.

With my updated flood frequency estimates, I determined that bed mobility threshold flows may occur more often at the Keno, JC Boyle, and Iron Gate gauges than predicted by PacifiCorp. Higher-than-normal flows that mobilize the streambed may disrupt fish habitats, and changes in flood frequency estimates may affect decision making about fisheries management and water demands in the upper Klamath River basin.

The December 2005 landslide and breach of the JC Boyle canal occurred during a period of relatively low flow in the Klamath River bypass. Although some fine sediment was deposited in the river as a result of the breach, it was likely washed downstream by high flows in the Klamath River since January 2006. The effects of the landslide and canal breach on downstream aquatic habitats are likely to be minimal.

CALCULATIONS

Recurrence Interval (RI):

RI=(n+1)/m

Where “n” is the number of years of record, and m is the rank of the year

Probability of Occurrence (P):

P=(1/RI)*100

Where RI is the Recurrence Interval

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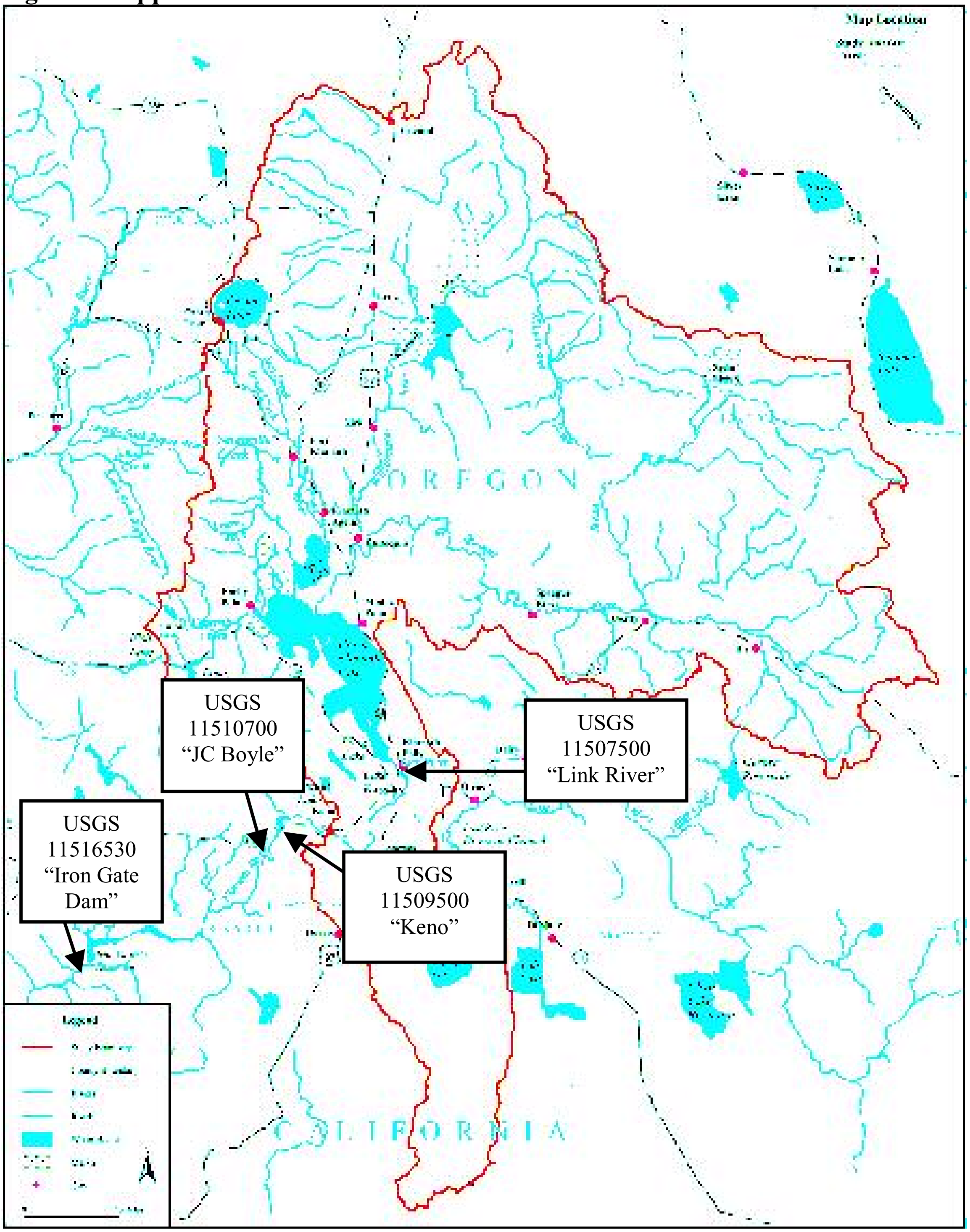
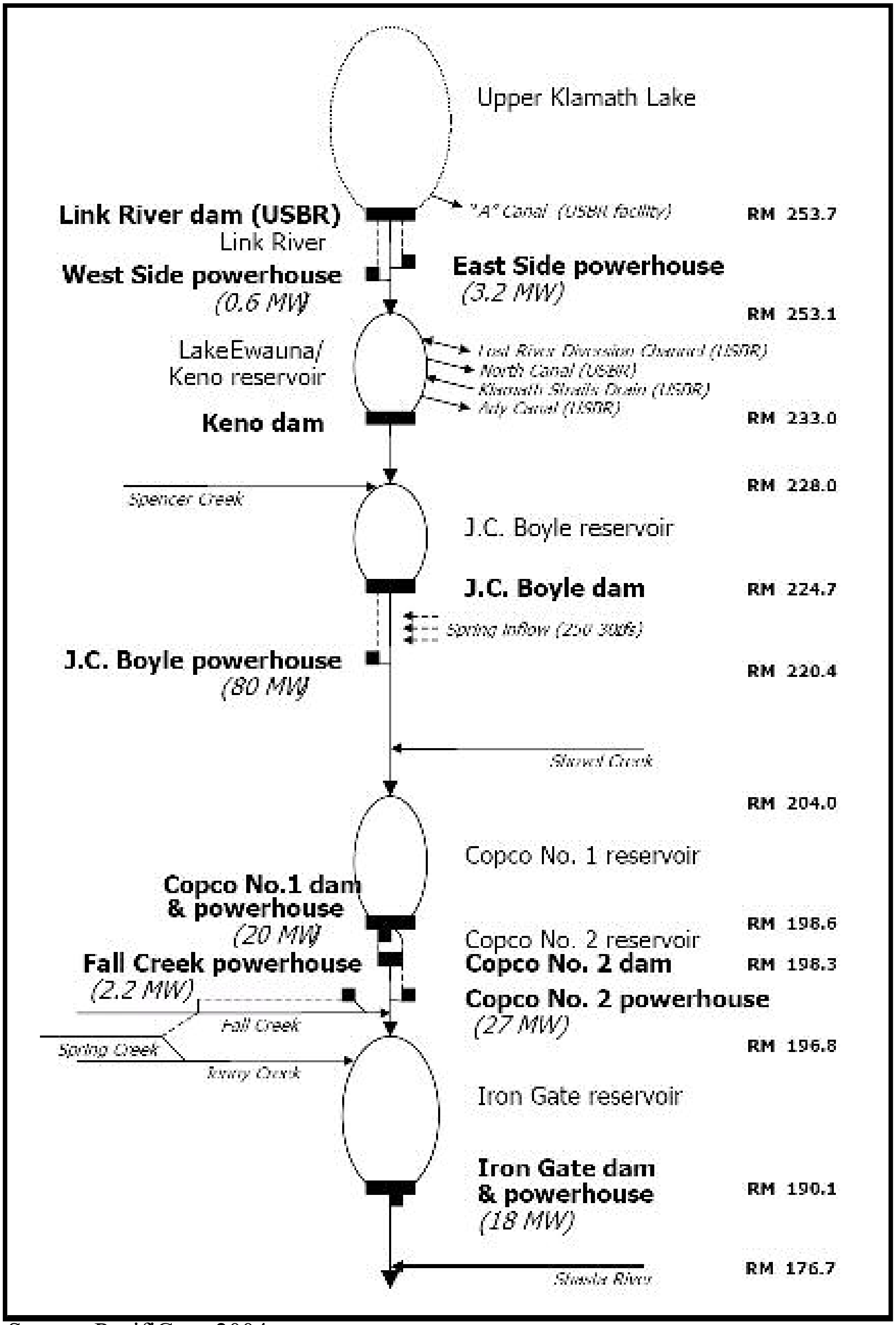
Figure 1. Upper Klamath Basin



Source: Bureau of Reclamation (2005)

Figure 2. The Klamath Hydroelectric Project



Source: PacifiCorp 2004.

Figure 3. Hydrograph for Link River at Klamath Falls, OR
WY 1904-2006
USGS 11507500

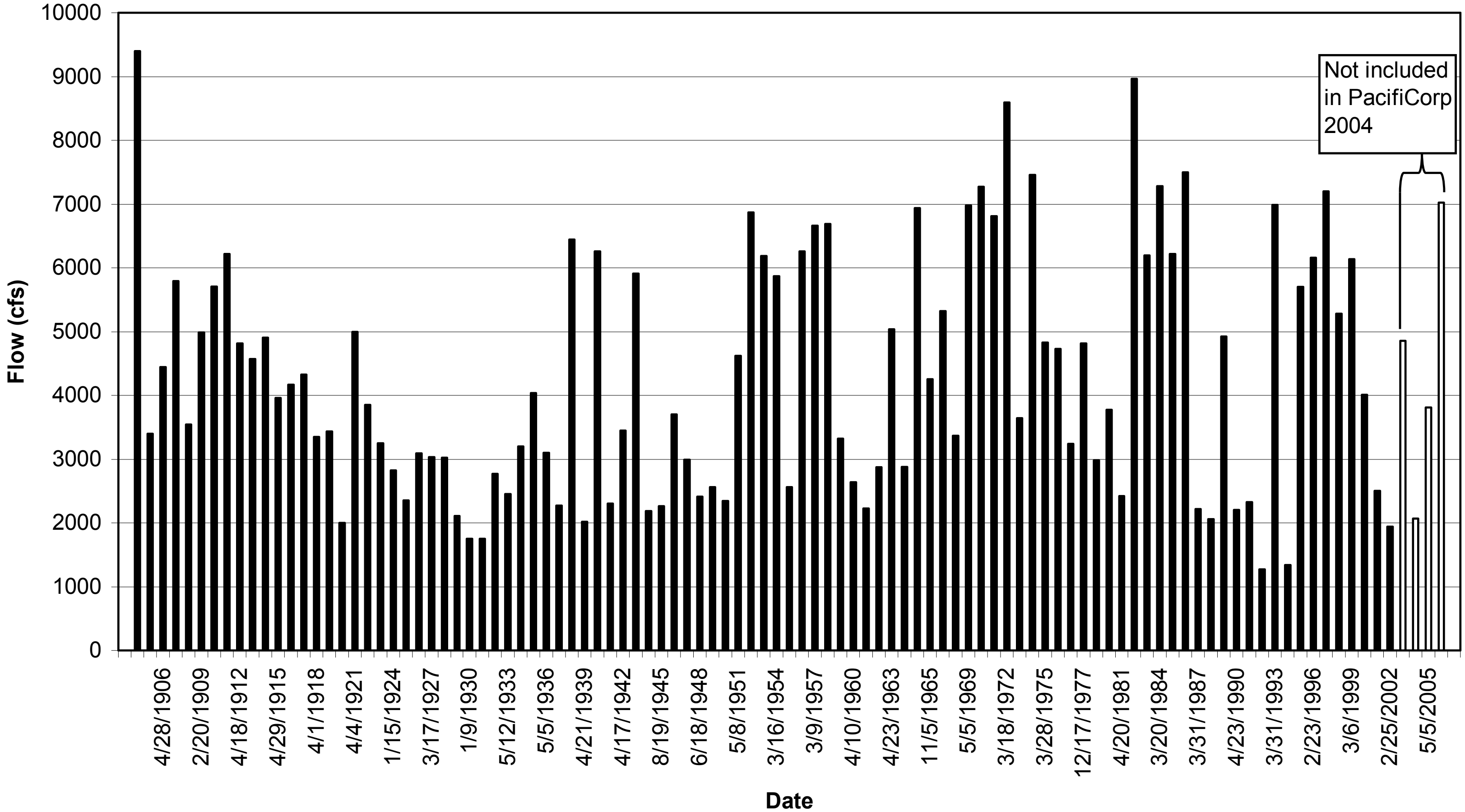


Figure 4. Hydrograph for Klamath River at Keno, OR
WY 1905-1913, 1930-2006
USGS 11509500

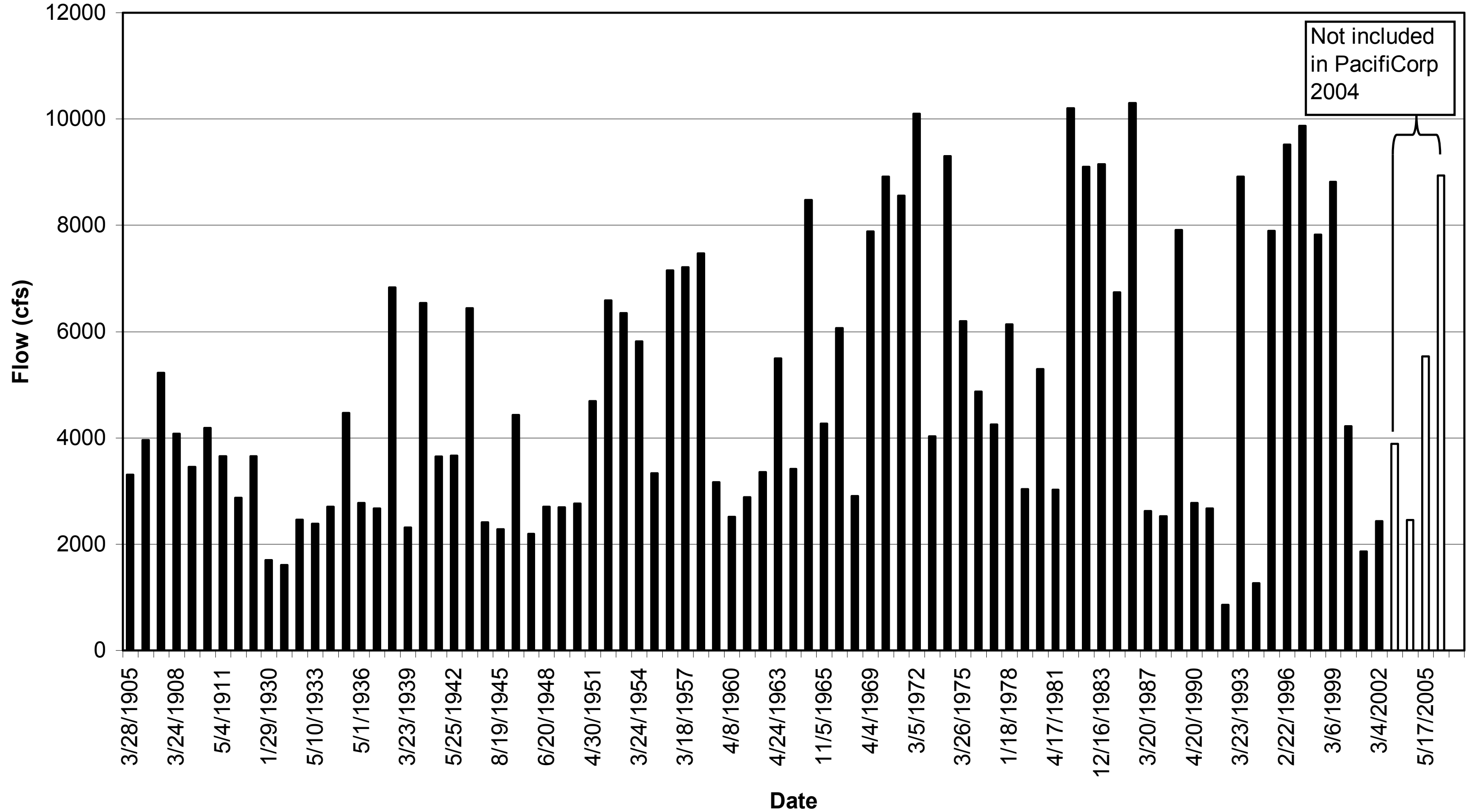


Figure 5. Hydrograph for Klamath River below John C. Boyle Powerplant, Near Keno, OR
WY 1959-2006
USGS 11510700

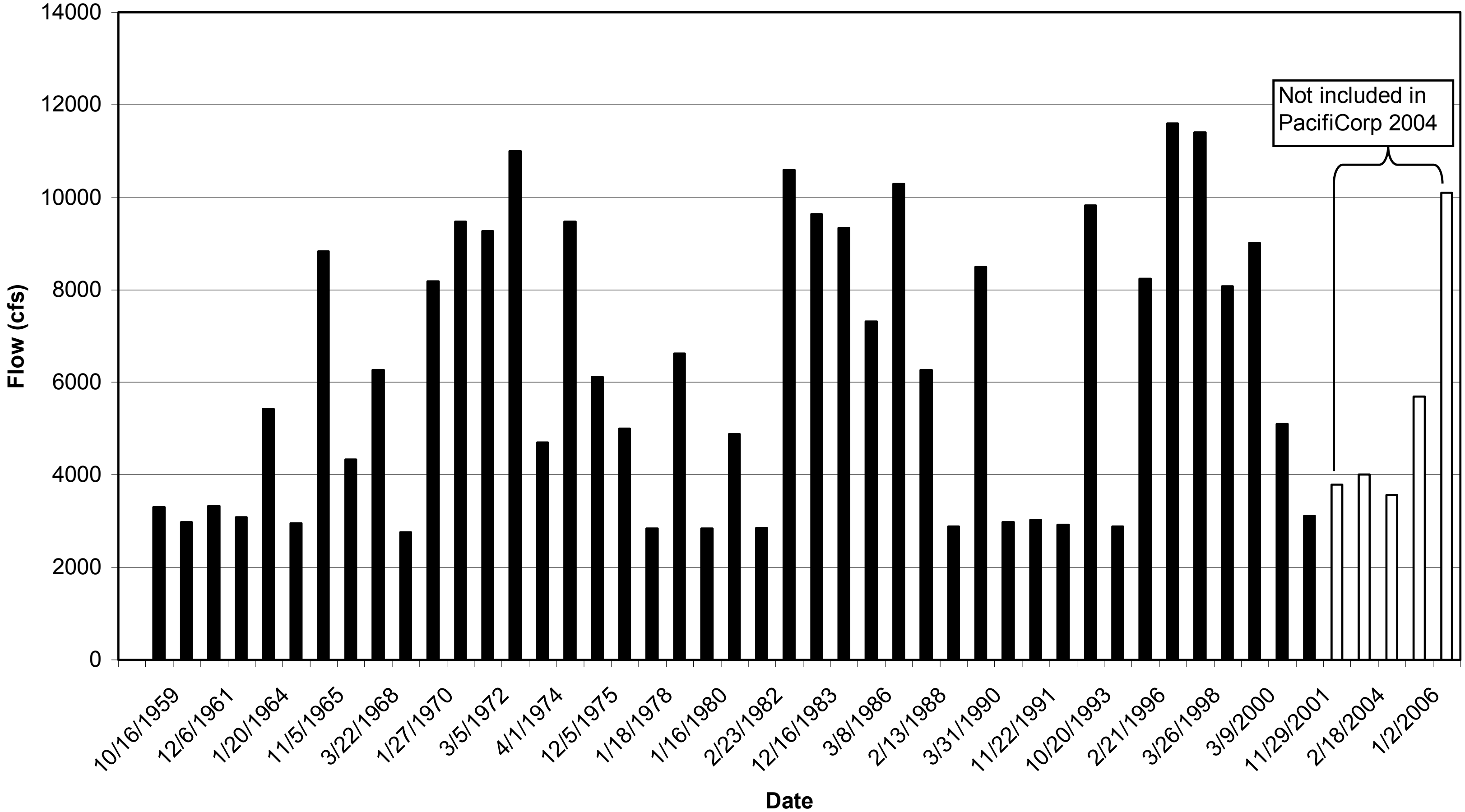


Figure 6. Hydrograph for the Klamath River below Iron Gate Dam, CA
WY 1961-2006
USGS 1156530

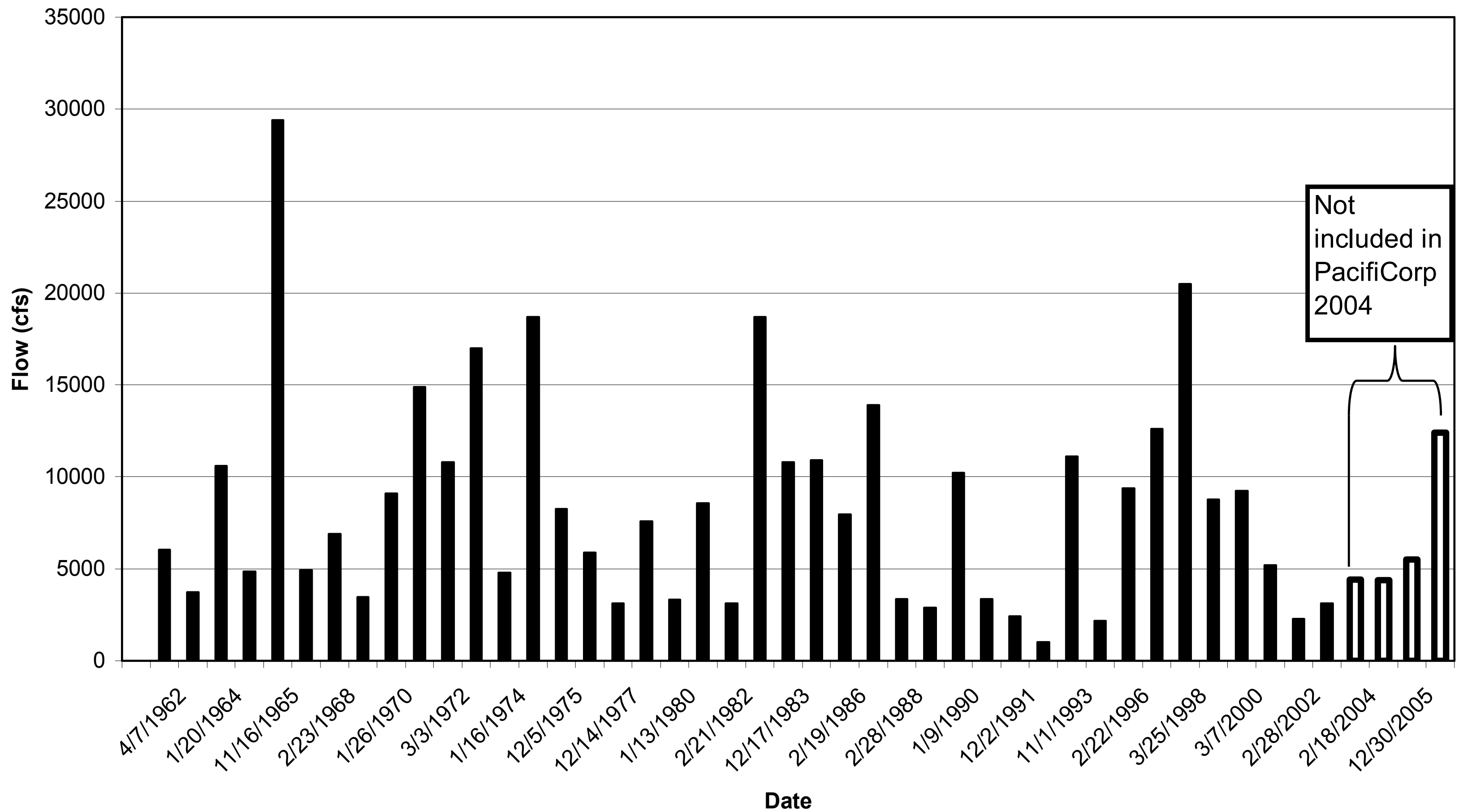


Figure 11. Hourly Flow on the Klamath River below JC Boyle Powerplant, OR 10/1/2005 to 4/20/2006 USGS 11510700

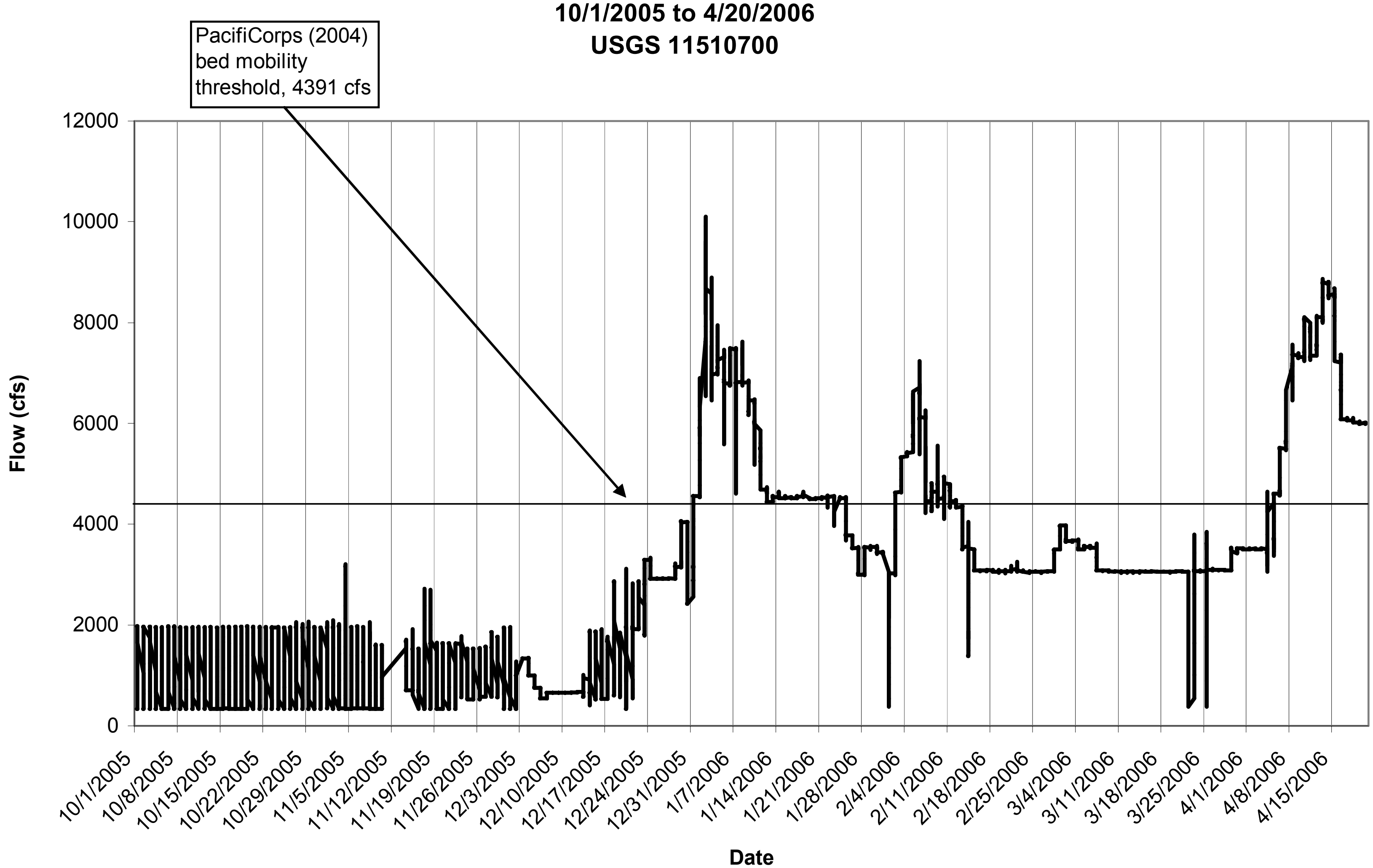


Figure 12. Flow during 11/28/2005 to 12/15/2005 on the Klamath River Below JC Boyle Powerplant, OR USGS 11510700

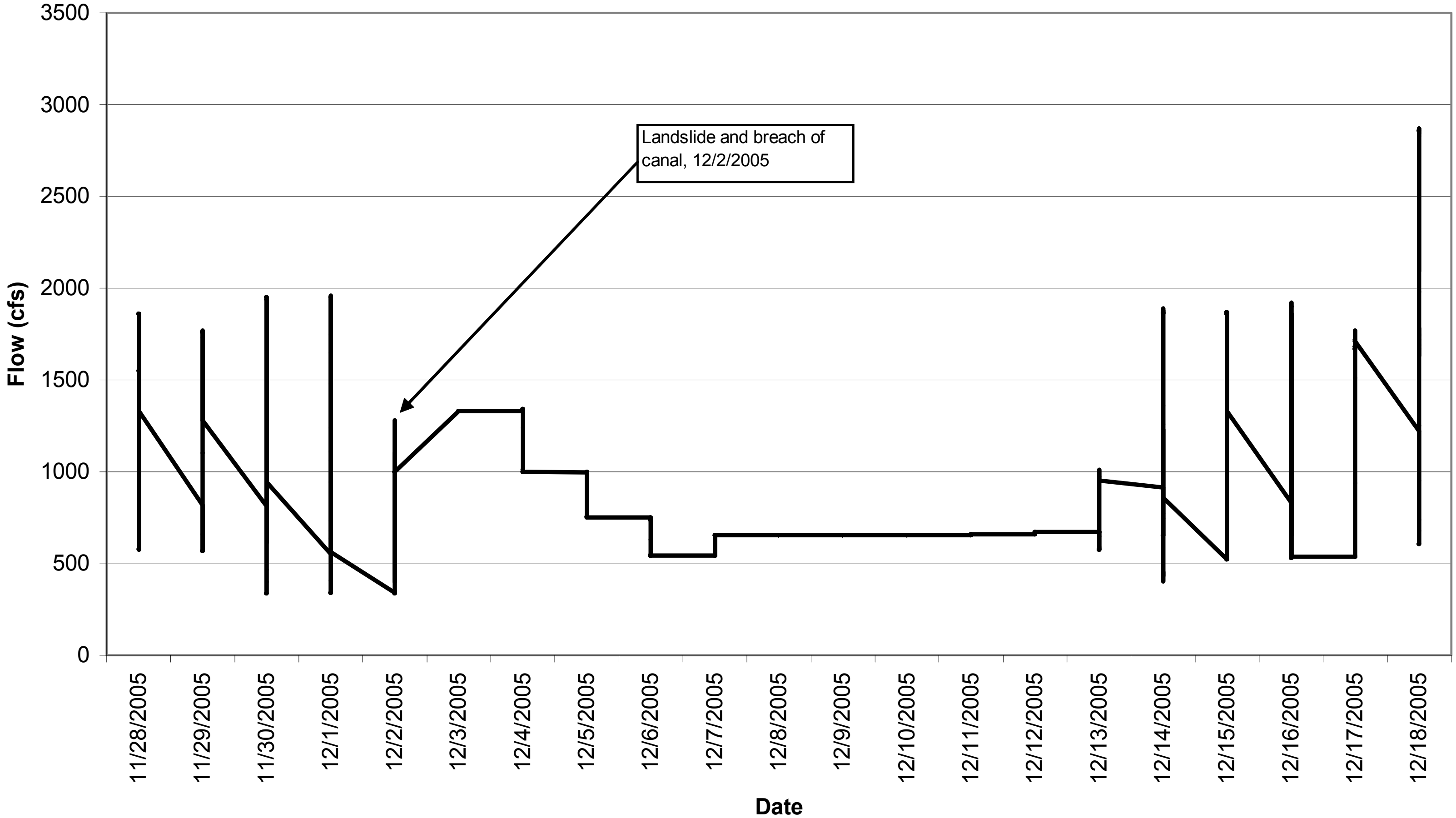


**Figure 13. Hourly Flow on the Klamath River below JC Boyle Powerplant, OR
12/15-12/16/2005
USGS 11510700**

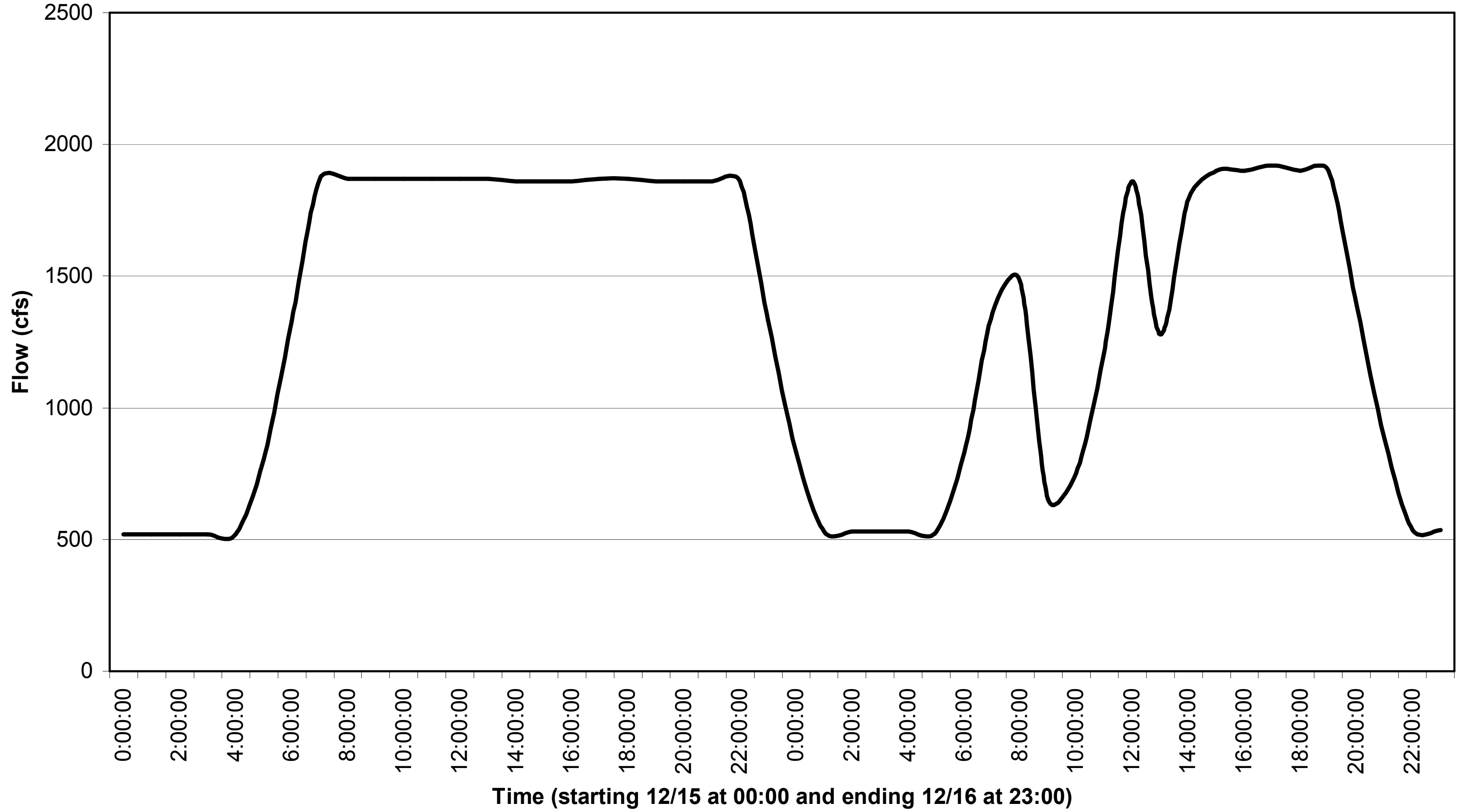


Figure 14. Hourly flow in Klamath River at JC Boyle Gauge and Suspected flow in Klamath River bypass of JC Boyle Canal, 1/1/06 to 4/20/06

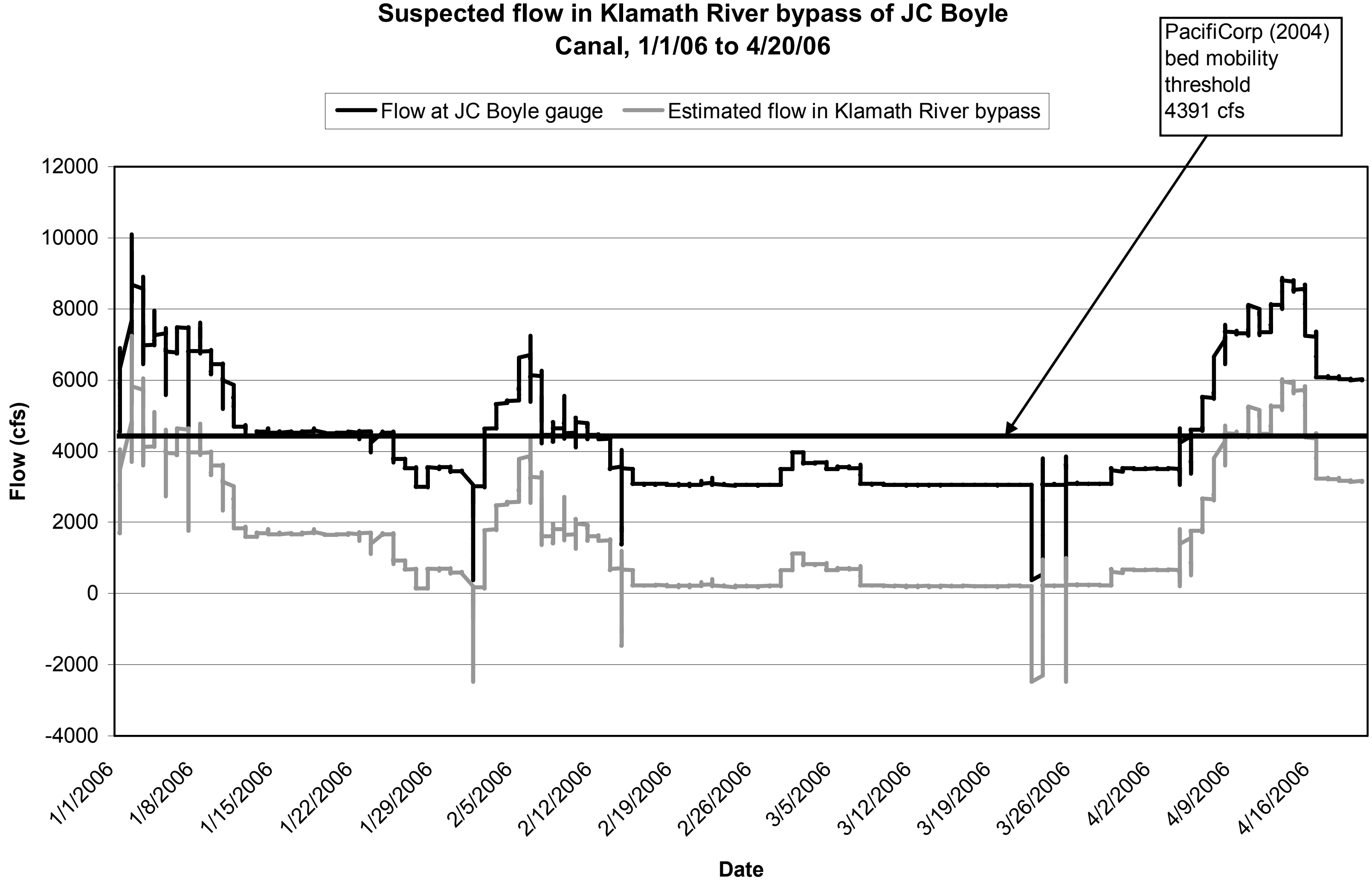


Table 1. Flood Frequencies for the Link River, Keno, JC Boyle, and Iron Gate Gauges

Return Period (years)	Exceedance Probability (%)	PACIFICORP Estimated Flow (cfs) HEC-FFA	FAHEY Estimated Flow (cfs) Calculation only	FAHEY Estimated Flow (cfs) Plot with trendline
LINK RIVER				
100	1	11,000	9,300	9,800
50	2	9,740	8,900	8,800
20	5	8,130	7,400	7,400
10	10	6,920	6,990	6,400
5	20	5,690	6,220	5,300
2	50	3,890	3,850	3,650
1.25	80	2,630	2,400	2,550
KENO				
100	1	14,800	NA	12,800
50	2	12,900	10,210	11,200
20	5	10,500	9,800	9,400
10	10	8,710	9,000	8,200
5	20	6,920	7,860	6,700
2	50	4,380	4,190	4,600
1.25	80	2,700	2,670	3,200
JC BOYLE				
100	1	19,600	NA	21,200
50	2	16,800	11,600	18,000
20	5	13,400	11,200	13,800
10	10	10,900	10,300	11,200
5	20	8,640	9,480	8,500
2	50	5,530	5,650	5,100
1.25	80	3,540	2,980	2,900
IRON GATE				
100	1	38,200	NA	36,000
50	2	31,100	NA	29,000
20	5	23,000	19,700	21,000
10	10	17,600	17,400	16,500
5	20	12,700	11,800	12,000
2	50	6,830	7,500	6,200
1.25	80	3,600	3,340	3,400

NA—I was not able to calculate these values due to the short period of record for the gauge.

Table 2. Flood Frequency Analysis for WY 1959-2001

Return Period (years)	Exceedance Probability (%)	PACIFICORP Estimated Flow (cfs) HEC-FFA	Fahey estimated flow (cfs) Calculated
JC BOYLE			
100	1	19,600	NA
50	2	16,800	NA
20	5	13,400	11,300
10	10	10,900	10,500
5	20	8,640	9,480
2	50	5,530	5,690
1.25	80	3,540	2,980

NA—I was not able to calculate these values due to the short period of record for the gauge.

Table 3. Bed Mobility Threshold Flow Return Intervals and Exceedance Percentage

		PACIFICORP	FAHEY
	PacifiCorp Estimated Flow at Threshold of Bed Mobility (cfs)	Approximate Return Interval (yr)	Updated Approximate Return Interval (yr)
LINK RIVER	1,268	0.7	1
KENO	3,747	2	1.8
JC BOYLE	4,391	1.8	1.6
IRON GATE	14,942	8.7	7.8

		PACIFICORP	FAHEY
	PacifiCorp Estimated Flow at Threshold of Bed Mobility (cfs)	Percent of Flows Exceeding Threshold of Mobility, WY1968-2001 (%)	Percent of Flows Exceeding Threshold of Mobility, 10/1/2003 to 4/20/2006 (%)
LINK RIVER	1,268	33	24.4
KENO	3,747	9	11.7
JC BOYLE	4,391	7	11.1
IRON GATE	14,942	0.3	0

Table 4. Sediment Size Range

	Size Range (mm)
Clay	Smaller than 0.0039
Silt	0.0039-0.0625
Sand	0.0625-2.0
Gravel	2.0-64.0
Cobble	64.0-256.0
Boulder	256.0-4096.0

Reprinted from Dunne and Leopold (1978), p. 665

Appendix 1. Recurrence Interval and Probability of Occurrence at Gauge at Link River at Klamath Falls, OR
USGS 11507500

DATE	FLOW (cfs)	New Peak	Rank	Recurrence Interval (yr)	Exceedance Probability (%)
5/12/1904	9400		1	104.00	0.96
3/4/1982	8960		2	52.00	1.92
3/18/1972	8590		3	34.67	2.88
3/7/1986	7500		4	26.00	3.85
4/5/1974	7460		5	20.80	4.81
3/20/1984	7280		6	17.33	5.77
1/31/1970	7270		7	14.86	6.73
1/12/1997	7200		8	13.00	7.69
4/13/2006	**7020**	**Yes (Provisional)**	9	11.56	8.65
3/31/1993	6990		10	10.40	9.62
5/5/1969	6980		11	9.45	10.58
1/2/1965	6940		12	8.67	11.54
4/18/1952	6870		13	8.00	12.50
3/30/1971	6810		14	7.43	13.46
3/5/1958	6690		15	6.93	14.42
3/9/1957	6660		16	6.50	15.38
4/30/1938	6440		17	6.12	16.35
3/31/1940	6260		18	5.78	17.31
4/17/1956	6260		19	5.47	18.27
4/29/1911	6220		20	5.20	19.23
4/11/1985	6220		21	4.95	20.19
3/18/1983	6190		22	4.73	21.15
5/27/1953	6180		23	4.52	22.12
2/23/1996	6160		24	4.33	23.08
3/6/1999	6130		25	4.16	24.04
5/4/1943	5910		26	4.00	25.00
3/16/1954	5870		27	3.85	25.96
4/4/1907	5790		28	3.71	26.92
4/2/1910	5710		29	3.59	27.88
3/17/1995	5700		30	3.47	28.85
5/13/1967	5320		31	3.35	29.81
3/25/1998	5280		32	3.25	30.77
4/23/1963	5040		33	3.15	31.73
4/4/1921	5000		34	3.06	32.69
2/20/1909	4990		35	2.97	33.65
3/25/1989	4920		36	2.89	34.62
4/20/1914	4900		37	2.81	35.58
3/27/2003	**4850**	**Yes**	38	2.74	36.54
3/28/1975	4830		39	2.67	37.50
4/18/1912	4810		40	2.60	38.46
12/17/1977	4810		41	2.54	39.42
12/7/1975	4730		42	2.48	40.38
5/8/1951	4620		43	2.42	41.35

4/26/1913	4570		44	2.36	42.31
4/28/1906	4440		45	2.31	43.27
5/9/1917	4330		46	2.26	44.23
11/5/1965	4250		47	2.21	45.19
4/10/1916	4170		48	2.17	46.15
4/16/1935	4030		49	2.12	47.12
3/8/2000	4010		50	2.08	48.08
4/29/1915	3960		51	2.04	49.04
5/9/1922	3850		52	2.00	50.00
5/5/2005	**3810**	**Yes**	53	1.96	50.96
2/23/1980	3770		54	1.93	51.92
3/7/1946	3700		55	1.89	52.88
12/28/1972	3640		56	1.86	53.85
4/7/1908	3540		57	1.82	54.81
4/17/1942	3450		58	1.79	55.77
4/7/1919	3430		59	1.76	56.73
3/29/1905	3400		60	1.73	57.69
3/25/1968	3360		61	1.70	58.65
4/1/1918	3350		62	1.68	59.62
1/5/1959	3320		63	1.65	60.58
1/16/1923	3250		64	1.63	61.54
11/17/1976	3240		65	1.60	62.50
3/30/1934	3200		66	1.58	63.46
5/5/1936	3100		67	1.55	64.42
12/18/1925	3090		68	1.53	65.38
3/17/1927	3030		69	1.51	66.35
4/3/1928	3020		70	1.49	67.31
11/16/1946	2990		71	1.46	68.27
4/8/1979	2980		72	1.44	69.23
2/2/1964	2880		73	1.42	70.19
4/11/1962	2870		74	1.41	71.15
1/15/1924	2820		75	1.39	72.12
5/3/1932	2770		76	1.37	73.08
4/10/1960	2640		77	1.35	74.04
12/14/1948	2560		78	1.33	75.00
3/20/1955	2560		79	1.32	75.96
8/9/2001	2500		80	1.30	76.92
5/12/1933	2450		81	1.28	77.88
4/20/1981	2420		82	1.27	78.85
6/18/1948	2410		83	1.25	79.81
1/30/1925	2350		84	1.24	80.77
12/16/1949	2340		85	1.22	81.73
12/21/1990	2330		86	1.21	82.69
8/9/1941	2300		87	1.20	83.65
11/6/1936	2270		88	1.18	84.62
8/19/1945	2260		89	1.17	85.58
6/16/1961	2230		90	1.16	86.54
3/31/1987	2220		91	1.14	87.50
4/23/1990	2200		92	1.13	88.46
10/4/1943	2180		93	1.12	89.42

10/9/1928	2110		94	1.11	90.38
3/29/2004	**2070**	**Yes**	95	1.09	91.35
2/23/1988	2060		96	1.08	92.31
4/21/1939	2020		97	1.07	93.27
12/25/1919	2000		98	1.06	94.23
2/25/2002	1940		99	1.05	95.19
1/9/1930	1750		100	1.04	96.15
12/10/1930	1750		101	1.03	97.12
6/16/1994	1340		102	1.02	98.08
6/11/1992	1270		103	1.01	99.04

Appendix 2. Recurrence Interval and Probability of Occurrence at Gauge on Klamath River at Keno, OR
USGS 11509500

DATE	FLOW (cfs)	New Peak	Rank	Recurrence Interval (yr)	Exceedance Probability (%)
2/28/1986	10300		1	87.00	1.15
2/24/1982	10200		2	43.50	2.30
3/5/1972	10100		3	29.00	3.45
1/3/1997	9870		4	21.75	4.60
2/22/1996	9520		5	17.40	5.75
4/2/1974	9300		6	14.50	6.90
12/16/1983	9150		7	12.43	8.05
3/14/1983	9100		8	10.88	9.20
1/2/2006	**8940**	**Yes (provisional)**	9	9.67	10.34
1/29/1970	8920		10	8.70	11.49
3/23/1993	8920		11	7.91	12.64
3/6/1999	8820		12	7.25	13.79
3/27/1971	8560		13	6.69	14.94
2/1/1965	8480		14	6.21	16.09
3/11/1989	7910		15	5.80	17.24
3/16/1995	7890		16	5.44	18.39
4/4/1969	7880		17	5.12	19.54
3/25/1998	7820		18	4.83	20.69
3/3/1958	7470		19	4.58	21.84
3/18/1957	7210		20	4.35	22.99
1/25/1956	7150		21	4.14	24.14
5/1/1938	6830		22	3.95	25.29
4/10/1985	6740		23	3.78	26.44
4/19/1952	6590		24	3.63	27.59
4/5/1940	6540		25	3.48	28.74
5/7/1943	6440		26	3.35	29.89
5/28/1953	6350		27	3.22	31.03
3/26/1975	6200		28	3.11	32.18
1/18/1978	6140		29	3.00	33.33
5/14/1967	6070		30	2.90	34.48
3/24/1954	5810		31	2.81	35.63
5/17/2005	**5530**	**Yes**	32	2.72	36.78
4/24/1963	5490		33	2.64	37.93
2/24/1980	5290		34	2.56	39.08
4/19/1907	5220		35	2.49	40.23
12/4/1975	4870		36	2.42	41.38
4/30/1951	4690		37	2.35	42.53
4/21/1935	4470		38	2.29	43.68
3/23/1946	4430		39	2.23	44.83
11/5/1965	4270		40	2.18	45.98
11/30/1976	4250		41	2.12	47.13
3/10/2000	4220		42	2.07	48.28
4/6/1910	4190		43	2.02	49.43
3/24/1908	4080		44	1.98	50.57

12/23/1972	4030		45	1.93	51.72
5/4/1906	3960		46	1.89	52.87
3/28/2003	**3890**	**Yes**	47	1.85	54.02
5/25/1942	3670		48	1.81	55.17
5/4/1911	3660		49	1.78	56.32
4/24/1913	3660		50	1.74	57.47
3/21/1941	3650		51	1.71	58.62
6/4/1909	3450		52	1.67	59.77
4/4/1964	3410		53	1.64	60.92
3/30/1962	3350		54	1.61	62.07
11/5/1954	3330		55	1.58	63.22
3/28/1905	3300		56	1.55	64.37
12/22/1958	3160		57	1.53	65.52
3/10/1979	3030		58	1.50	66.67
4/17/1981	3020		59	1.47	67.82
12/19/1967	2900		60	1.45	68.97
3/3/1961	2880		61	1.43	70.11
3/15/1912	2870		62	1.40	71.26
5/1/1936	2770		63	1.38	72.41
4/20/1990	2770		64	1.36	73.56
3/17/1950	2760		65	1.34	74.71
3/31/1934	2700		66	1.32	75.86
6/20/1948	2700		67	1.30	77.01
5/24/1949	2690		68	1.28	78.16
1/7/1937	2670		69	1.26	79.31
12/20/1990	2670		70	1.24	80.46
3/20/1987	2620		71	1.23	81.61
2/23/1988	2520		72	1.21	82.76
4/8/1960	2510		73	1.19	83.91
5/4/1932	2460		74	1.18	85.06
2/18/2004	**2450**	**Yes**	75	1.16	86.21
3/4/2002	2430		76	1.14	87.36
10/4/1943	2410		77	1.13	88.51
5/10/1933	2380		78	1.12	89.66
3/23/1939	2310		79	1.10	90.80
8/19/1945	2280		80	1.09	91.95
11/18/1946	2190		81	1.07	93.10
6/6/2001	1860		82	1.06	94.25
1/29/1930	1700		83	1.05	95.40
12/12/1930	1610		84	1.04	96.55
10/4/1993	1270		85	1.02	97.70
11/21/1991	851		86	1.01	98.85

Appendix 3. Recurrence Interval and Probability of Occurrence at Gauge on the Klamath River Below John C. Boyle Powerplant, Near Keno, OR
USGS 115107000

DATE	FLOW (cfs)	New Peak	RANK	Recurrence Interval (yr)	Exceedance Probability (%)
2/21/1996	11600		1	49.00	2.04
1/3/1997	11400		2	24.50	4.08
3/5/1972	11000		3	16.33	6.12
2/23/1982	10600		4	12.25	8.16
3/8/1986	10300		5	9.80	10.20
1/2/2006	**10100**	**Yes (provisional)**	6	8.17	12.24
3/25/1993	9820		7	7.00	14.29
3/14/1983	9640		8	6.13	16.33
1/27/1970	9480		9	5.44	18.37
4/1/1974	9480		10	4.90	20.41
12/16/1983	9340		11	4.45	22.45
3/27/1971	9270		12	4.08	24.49
3/7/1999	9010		13	3.77	26.53
2/1/1965	8830		14	3.50	28.57
3/11/1989	8500		15	3.27	30.61
3/16/1995	8240		16	3.06	32.65
4/3/1969	8180		17	2.88	34.69
3/26/1998	8080		18	2.72	36.73
4/10/1985	7320		19	2.58	38.78
1/18/1978	6620		20	2.45	40.82
5/13/1967	6270		21	2.33	42.86
5/13/1987	6270		22	2.23	44.90
3/26/1975	6120		23	2.13	46.94
5/17/2005	**5690**	**Yes**	24	2.04	48.98
4/24/1963	5420		25	1.96	51.02
3/9/2000	5100		26	1.88	53.06
12/5/1975	5000		27	1.81	55.10
1/16/1980	4880		28	1.75	57.14
12/23/1972	4700		29	1.69	59.18
11/5/1965	4330		30	1.63	61.22
3/28/2003	**4010**	**Yes**	31	1.58	63.27
11/29/2001	**3780**	**Yes**	32	1.53	65.31
2/18/2004	**3570**	**Yes**	33	1.48	67.35
4/25/1961	3320		34	1.44	69.39
1/1/1959	3300		35	1.40	71.43
11/7/2000	3120		36	1.36	73.47
12/6/1961	3080		37	1.32	75.51
12/22/1990	3020		38	1.29	77.55
10/16/1959	2980		39	1.26	79.59
3/31/1990	2980		40	1.23	81.63
1/20/1964	2960		41	1.20	83.67
11/22/1991	2920		42	1.17	85.71
10/20/1993	2890		43	1.14	87.76
2/13/1988	2880		44	1.11	89.80

3/30/1981	2850	45	1.09	91.84
11/3/1976	2840	46	1.07	93.88
11/17/1978	2840	47	1.04	95.92
3/22/1968	2760	48	1.02	97.96

Appendix 4. Recurrence Interval and Probability of Occurrence at Gauge on Klamath River Below Iron Gate Dam, CA
USGS 11516530

DATE	FLOW (cfs)	New Peak	Rank	Recurrence Interval (yr)	Exceedance Probability (%)
12/22/1964	29400		1	47.00	2.13
1/1/1997	20500		2	23.50	4.26
1/16/1974	18700		3	15.67	6.38
2/21/1982	18700		4	11.75	8.51
3/3/1972	17000		5	9.40	10.64
1/26/1970	14900		6	7.83	12.77
2/19/1986	13900		7	6.71	14.89
2/22/1996	12600		8	5.88	17.02
12/30/2005	**12400**	**YES (provisional)**	9	5.22	19.15
3/24/1993	11100		10	4.70	21.28
12/17/1983	10900		11	4.27	23.40
3/28/1971	10800		12	3.92	25.53
3/15/1983	10800		13	3.62	27.66
12/2/1962	10600		14	3.36	29.79
3/11/1989	10200		15	3.13	31.91
3/18/1995	9380		16	2.94	34.04
3/20/1999	9220		17	2.76	36.17
4/4/1969	9090		18	2.61	38.30
3/25/1998	8770		19	2.47	40.43
1/13/1980	8580		20	2.35	42.55
3/18/1975	8260		21	2.24	44.68
4/11/1985	7970		22	2.14	46.81
12/14/1977	7580		23	2.04	48.94
5/14/1967	6890		24	1.96	51.06
12/1/1960	6030		25	1.88	53.19
12/5/1975	5900		26	1.81	55.32
5/18/2005	**5520**	**YES (provisional)**	27	1.74	57.45
3/7/2000	5190		28	1.68	59.57
11/16/1965	4940		29	1.62	61.70
1/20/1964	4850		30	1.57	63.83
12/24/1972	4790		31	1.52	65.96
3/28/2003	**4410**	**YES**	32	1.47	68.09
2/18/2004	**4380**	**YES**	33	1.42	70.21
4/7/1962	3710		34	1.38	72.34
2/23/1968	3470		35	1.34	74.47
1/9/1990	3360		36	1.31	76.60
3/18/1987	3350		37	1.27	78.72
1/2/1979	3320		38	1.24	80.85
11/14/1976	3120		39	1.21	82.98
3/31/1981	3120		40	1.18	85.11
2/28/2002	3110		41	1.15	87.23
2/28/1988	2890		42	1.12	89.36
12/28/1990	2430		43	1.09	91.49

5/18/2001	2280	44	1.07	93.62
11/1/1993	2150	45	1.04	95.74
12/2/1991	1000	46	1.02	97.87