Hydrologic Analysis of Upper Columbia Alternative Operations: Local Effects of Alternative Operations at Libby Dam

November 2002

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1.0 Introduction

1.1 Need for Study

Libby Dam is a multi-purpose storage project located on the Kootenai River in northwestern Montana (Figure 1). The project was built in 1973, and is operated to provide storage for local flood control in the Kootenai basin, storage for system flood control on the lower Columbia River, and hydroelectric power generation. Incidental purposes of the project are navigation and recreation.

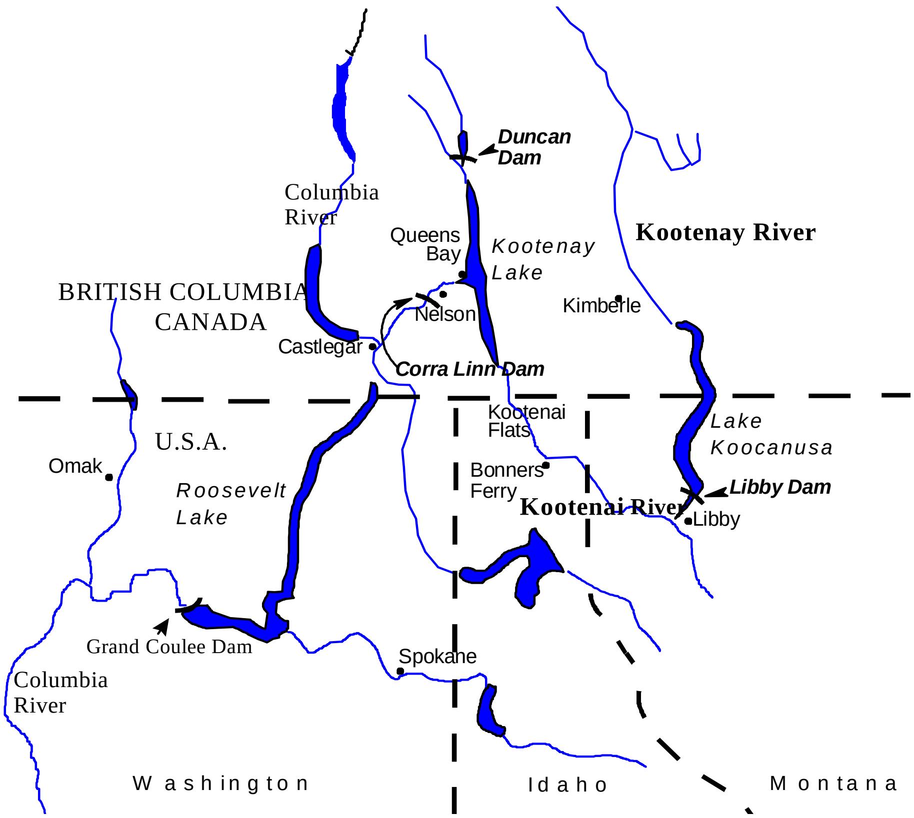


Figure 1. Kootenai River Basin Showing Canadian and U.S. Dams

Since 1973, several species in the Kootenai and Columbia Rivers have been listed for protection under the Endangered Species Act (ESA). In December 2000, the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) each issued a Biological Opinion (BiOp) outlining measures to protect the listed species. One measure, recommended by both the USFWS and NMFS, is to replace standard flood control (Standard FC) with an alternative procedure known as VARQ flood control (VARQ FC) at Libby Dam. VARQ FC is expected to improve refill reliability at Lake Koocanusa, thereby facilitating the flow augmentations requested by USFWS and NMFS for listed species downstream.

VARQ FC would result in a smaller flood control draft at Libby Dam in years when the water supply forecast ranges from low to average. In the years with large water supply forecasts (greater than 125% of average), there would not be any change to the flood control draft that is currently being used. The procedure currently used is referred to as

Standard FC, also called "BASE-CRT63". Before considering a switch in flood control procedures, the Corps must perform hydrologic modeling to evaluate potential impacts from implementation of VARQ FC.

1.2 Possible Interim Operation

In 2001, the Corps and the Bureau of Reclamation held public scoping meetings and began collecting information for an Environmental Impact Study (EIS) to document potential impacts from VARQ FC. The official title of that study is the "Upper Columbia Alternative Flood Control and Fish Operations EIS". The EIS is scheduled for completion in 2004, so that a final record of decision may be made in time for the flood control season of 2005.

The USFWS and NMFS BiOps called for the Corps and the Bureau to implement VARQ FC by the year 2001. Therefore, the scheduled EIS completion date in 2004 does not satisfy the Services' intent for VARQ to be implemented in a timely manner. The Services indicated that if the Corps holds off on an implementation decision until the EIS is complete, that this action could be considered as a take of listed species. In light of this, the Corps agreed to preparing this Environmental Assessment (EA) to make an interim decision on VARQ implementation at Libby while the EIS is being completed to address potential effects from long-term implementation.

1.3 Description of Flood Control Alternatives

The two methods of flood control compared in this hydrologic analysis are Standard flood control (Standard FC) and VARQ flood control (VARQ FC).

1.3.1 Standard FC

Standard FC is the method currently used, where Libby Dam is regulated according to the Columbia River Treaty Flood Operating Plan (Corps, 1972) as amended by the Review of Flood Control Columbia River Basin, Columbia River and Tributaries Study, CRT-63 (Corps, 1991). To determine the required flood control operation, a storage reservation diagram (SRD) specific to Libby Dam is used in combination with Libby's seasonal water supply forecasts to determine how much space is required for flood control (Figure 2). As the season progresses and the forecasts change, so do the storage requirements. Additional storage space associated with possible power drafts was not taken into consideration for Standard FC hydro-regulations.

1.3.2 VARQ Flood Control

VARQ is the flood control method being proposed for the future. Previous descriptions of VARQ FC have appeared in Status Report -- Work to Date on the Development of the VARQ Flood Control Operation at Libby Dam and Hungry Horse Dam (Corps, 1999), as well as Columbia River Basin System Flood Control Review – Preliminary Analysis Report (Corps, 1997). Like Standard FC, VARQ FC requires a storage reservation diagram in conjunction with water supply forecasts to determine the flood control space needed. As the season progresses and the forecasts change, so do the storage requirements. However, as compared with the Standard SRD, the VARQ SRD does not require as much flood control storage for years with low to medium water supply forecasts (Figure 3). The Standard FC SRDs are part of the 1972 Columbia River Treaty

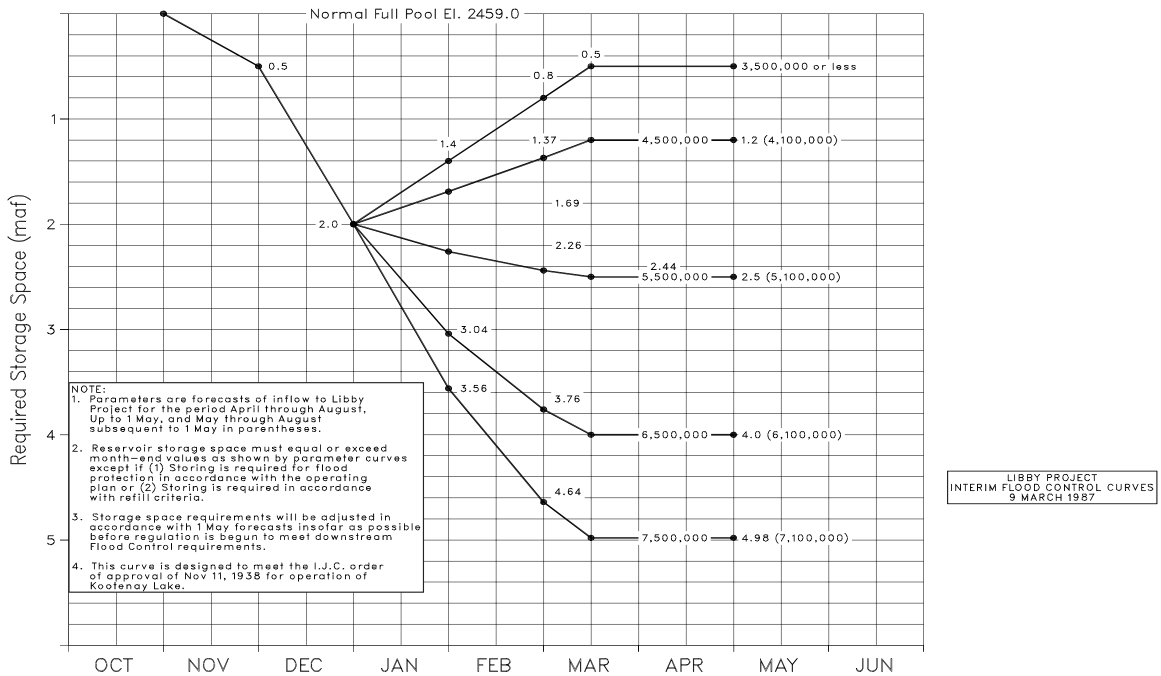


Figure 2. Columbia River Treaty Flood Control Operating Plan Storage Reservation Diagram at Libby Dam

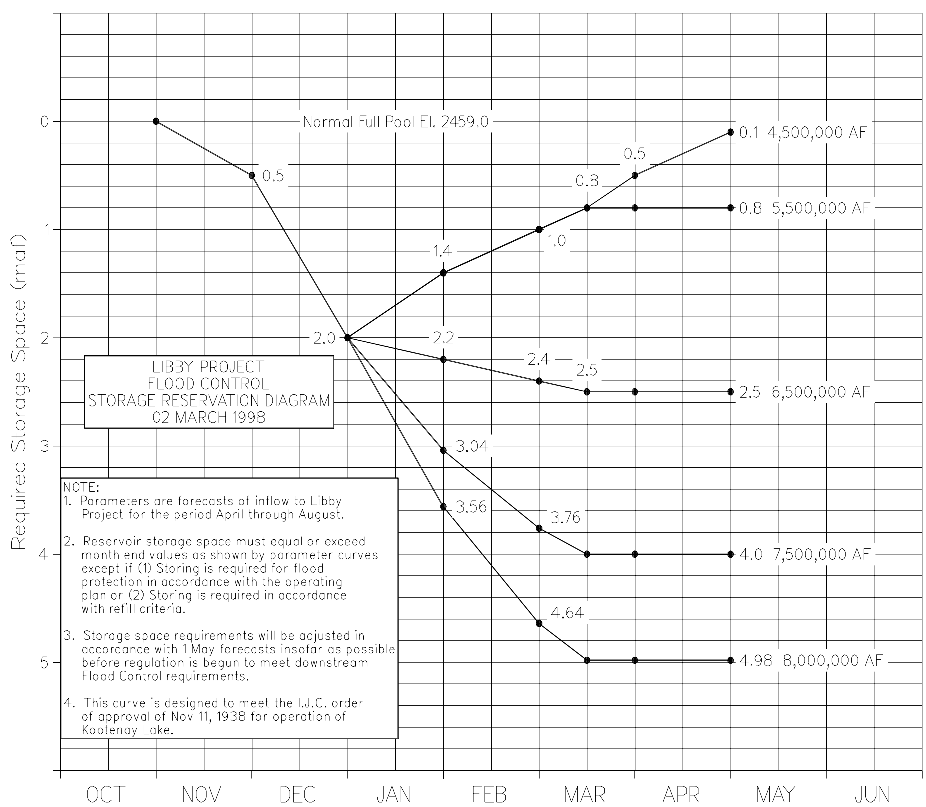


Figure 3. Draft VARQ Storage Reservation Diagram at Libby Dam

Flood Control Operating Plan (FCOP) and are based on the concept that outflows from Libby and Hungry Horse during the refill period are at their minimum level. On the other hand, the VARQ SRD is designed around the concept of allowing outflows to vary during refill based on the water supply forecast. VARQ is intended to improve refill reliability, thereby facilitating flow augmentations for fish. VARQ is intended to provide about the same level of flood protection as Standard FC. Additional storage space associated with possible power drafts was not taken into consideration for VARQ FC simulations.

1.4 Description of Fish Flows

In addition to pure flood control simulations, flow augmentations for listed fish species were modeled from both Libby Dam and Hungry Horse Dam for ten selected years. These flow augmentations are based on BiOp recommendations to help protect Kootenai River sturgeon, Columbia basin bull trout, and various stocks of Columbia basin salmon and steelhead. The ramping rates specified in the BiOps were used at both Libby Dam and Hungry Horse Dam for these simulations. The methodology used for modeling fish flows is explained in further detail later in this report, under Section 3.1.3.

2.0 Hydrologic Analysis of Flood Control Methods

2.1 Hydro-Regulations

To conduct this flood control study, simulated hydro-regulations were used in order to compare the differences between Standard FC and VARQ FC. The period of record, the assumed water supply forecasts, and the modeling procedure all affect the outcome of the hydro-regulations.

2.1.1 Introduction

As part of the technical studies conducted for the Upper Columbia EA, hydro-regulations were used to simulate flood control operation for the entire Columbia River system. This report focuses on the impact of flood control operation in the Kootenai River basin, which extends from Kootenay Lake in British Columbia up to the headwater projects of Libby Dam and Duncan Dam, located in Montana and British Columbia, respectively. The hydro-regulations are run for a fixed period of record, and show what “would have” happened if the Columbia River system dams had operated strictly according to the rules of Standard FC or VARQ FC.

The modeling of the reservoir system was conducted using the Corps SSARR and Autoreg programs. Autoreg follows the FCOP for developing the controlled flow targets at the Dalles and refilling Arrow (Hugh Keenleyside) and Grand Coulee, thereby providing a modeling process that limits subjectivity and the introduction of bias. The modeling was conducted using a daily time step, providing daily output of parameters such as reservoir elevation, project releases, and river flows

2.1.2 Period of Record for Flood Control Modeling

A 61-year record (1929-1989) was used in this study. This period of time encompasses a wide variety of water years, and therefore provides a good data set for testing the two different methods of flood control. However, the data set is still limited, as it is not large enough to produce a frequency curve that depicts the probability of extremely rare events of a frequency less than 1%. Previous studies have made use of a Libby Dam regulated 0.5% chance exceedance hypothetical flood (Merkle, Lawrence reference) in order to extrapolate frequency curves into this range. However, there are differences in modeling philosophy between this study's AUTOREG-defined operations and the prescribed operations used to regulate the hypothetical ½ percent chance exceedance flood. For example, the AUTOREG-defined operations for this study attempted to regulate Bonners Ferry to a stage of 1764 feet, whereas the hypothetical flood was regulated to a stage of 1770 feet at Bonners Ferry. In the interest of keeping the frequency curve data set as homogeneous as possible, the regulated hypothetical ½ percent chance exceedance flood has not been used to extrapolate frequency curves for this study.

2.1.3 Water Supply Forecasts

In the Columbia River Basin, the quantity of runoff from snowmelt is highly variable from one year to the next. Due to this variability, flood control operations at large storage projects like Libby Dam are guided by storage reservation diagrams (SRDs)(Figure 2, Figure 3). A SRD is used in combination with a seasonal water supply forecast to determine how much space is needed for flood control. The FCOP for Libby Project includes two phases, evacuation and refill. With Standard FC, the assumed release from Libby Dam during refill is the project's minimum outflow at 4,000 cfs. With VARQ FC, the minimum average release during refill is varied according to the graph shown in Figure 4 Hence, the name "VARQ", meaning "variable flow" ("Q" is shorthand for discharge).

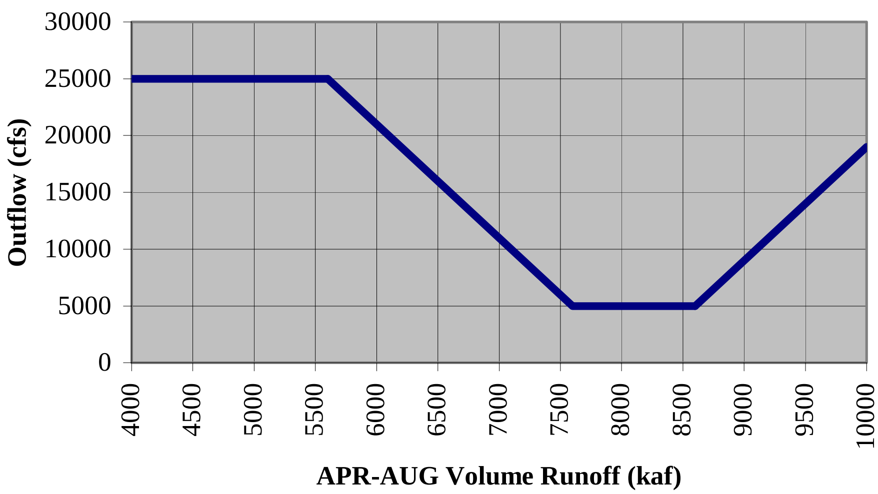


Figure 4. VARQ Minimum Average Outflows at Libby Dam

The use of forecast data in the hydro-regulations, as opposed to observed volumetric runoff, adds the element of uncertainty that is experienced in real-time water management and is a more rigorous test of the system flood control operation. The water supply forecasts used for this study are a combination of simulated and actual water supply volume forecasts for the 1929-1989 period. The forecasts did not change for system flood control or Upper Columbia River Alternative operations analyses.

The simulated forecasts developed in the late 1980's are called the Kuehl-Moffitt Simulated Runoff Forecasts (Kuehl and Moffit, 1986). These forecasts were used in the development of seasonal flood control requirements and system flood control analysis. The runoff forecasts were simulated using actual water supply forecasting procedures that are used in operational forecasting and were statistically corrected for long-term bias. The actual water supply forecasts were used for the final seven years of the study period (1983-1989). These forecasts are called the Wortman-Morrow Forecasts, and they have been used to predict inflow to Libby Dam for real-time operation since 1983.

Upper rule curves and reservoir draft points from January through April are all dependent on water supply forecasts. The operation of Libby Dan during this period may vary depending upon the statistical error that may be associated with any forecast. Flood Control Modeling Procedure

As a prerequisite to performing flood control simulations, Upper Rule Curves (URCs) that guide seasonal reservoir flood control operations were developed for storage projects on the Columbia River system. URCs are developed by using a project's SRD in conjunction with seasonal water supply forecasts for the project, on a month-by-month basis, to calculate the winter and early spring reservoir levels required to provide adequate flood control that year.

In the flood control simulations, Kootenay Lake, located in British Columbia at the lower end of the Kootenai basin, is regulated according rules defined by the International Joint Commission (IJC) Order of 1938. When a conflict existed in meeting the 1938 Order at Kootenay Lake, Duncan Reservoir was reduced to passing no more than inflow and Libby Dam was allowed to continue to draft if possible. At no time were Libby or Duncan Dams required to pass less than inflow. Libby and Duncan were operated so as not to drive Kootenay Lake above its allowable lake level during the period governed by the "lowering formula". Throughout the simulations, Corra Linn Dam at the outlet of Kootenay Lake operated according to its upper rule curve except during the "lowering" period, when it was releasing its hydraulic capacity.

The hydro-regulation model runs were performed with relatively strict modeling guidance and limited forecast approach. Although the actual hydrograph for each historic water year is known to modelers, operations were developed as if they had no for-knowledge of the weather and resultant hydrograph in any year.

In development of scenarios with fish flows a rigid operational template of outflow was developed. The increase of outflow from Libby Dam began on a fixed date, depending on the magnitude of the water year. In actual operations, adaptive management might cause fish flow operation that may begin earlier, or later, than those developed for the fish flow template. Real-time adaptive management allows for flexibility in the operation of Libby Dam to better meet multi-purpose needs.

Because of the short forward looking weather forecast and the rigid fish flow used by modelers, some of the model output results will be different than real-time operations, although the trends will be preserved. In real-time adaptive management some high flow may be somewhat reduced by use of operational flexibility that could not be injected into these scenarios.

2.2 Model Results

Output data from the flood control simulations were analyzed in order to quantitatively characterize the differences between Standard FC and VARQ FC at Libby Dam. Impacts to Lake Koocanusa and Libby Dam, Bonners Ferry, Kootenay Lake, and Duncan Dam are presented in the following sections.

2.2.1 Statistical Analysis

Potential impacts throughout the Kootenai basin as a result of VARQ FC can be characterized with flow/stage-frequency curves and flow/stage-duration curves at various locations. To illustrate the incremental difference between the two types of flood control, each figure has two curves plotted: one for Standard FC, and the other for VARQ FC. Procedures for graphing regulated hydrologic data are outlined in a Corps Engineer Manual entitled Hydrologic Frequency Analysis, EM 1110-2-1415.

2.2.2 Lake Koocanusa and Libby Dam

The BiOps call for implementation of VARQ at Libby Dam because it will improve the likelihood of refilling Lake Koocanusa. Historically, the Corps of Engineers has attempted to refill the project with a high degree of certainty. Model simulations for this study show that in the absence of power drafts or endangered species flows, it was possible to refill the reservoir within 5 feet of full before the end of July in 97% of the years, regardless of which flood control procedure is used. An elevation-frequency curve is provided in Figure 5. Both methods of flood control afford a high degree of refill probability.

When VARQ FC is being used, the reservoir is generally not drafted as deeply in the months of January through April as when Standard FC is used. In fact, with VARQ the reservoir is above elevation 2400 feet 60% of the time, as compared with Standard FC, when it is above that elevation only 25% of the time. This is shown in the elevation-duration graph given in Figure 6. Figure 7and Figure 8 show elevation-duration graphs for May and June, respectively. Again, VARQ FC leads to higher reservoir elevations than does Standard FC. By July, there is no significant difference in reservoir elevation. This is shown in Figure 9.

Besides reservoir elevation, the two methods of flood control also have an impact on outflow from Libby Dam. From a flood control perspective, the outflow during May, June, and July are of primary interest to downstream residents. A flow-frequency curve specific to those months is provided in Figure 10. At the onset of refill (usually sometime in April or May), the reservoir is generally higher with VARQ than it is with Standard FC. Therefore, the reservoir releases under VARQ are generally greater than those with Standard FC. For the high percent-chance-exceedance (low-runoff) events (on the left side of the graph), the VARQ outflows are consistently higher than Standard FC outflows. This holds true for releases up to about 15,000 cfs, where the curves begin to converge. Flows in this range are not known to pose any problems for downstream residents.

There are some differences in outflow from filling at low percent chance exceedance years. This divergence was not expected since VARQ FC and Standard FC were expected to be the same in these events. However, when very large water years are under-forecasted, it is possible for VARQ to provide less flood protection than Standard FC.   The highest data point for both curves in Figure 10 represents the modeled outflow from Libby Dam in 1948. The forecasts available in January, February, March, and April for the 1948 seasonal runoff volume were all under-forecasted by at least 1 million acre-feet. The divergence of the curves in Figure 10 is explained by the significant under-forecasting of seasonal runoff volume for 1948.

Figure 11 is similar to Figure 10, except that it depicts 7-day average flows rather daily flows. The curves in Figure 11 diverge similarly to the curves in Figure 10. Again, this is due to 1948 being significantly under-forecasted.

2.2.3 Trapped Storage

Sometimes because of hydraulic or regulatory restrictions on outflow, Lake Koocanusa cannot be drafted all the way down to the flood control elevations required by the storage reservation diagram. Any water remaining in a reservoir above the flood control rule curve is referred to as "trapped storage". Trapped storage can be caused by not drafting Libby because of a conflict with the 1938 IJC Order on Kootenay Lake. The 1938 IJC Order is discussed in further detail in Section 2.2.5. Trapped storage can also happen if one or more of the generating units at Libby Dam is out of service, such as when there is a mechanical breakdown. The hydro-regulation modeling for this EA assumed that all generating units at Libby Dam were available.

Table 1 compares the amount of trapped storage relative to each of the two flood control operations modeled. In years when the April-August inflow volume forecast is less than about 7.7 MAF, there is a tendency for more trapped storage under Standard FC than under VARQ FC. This is due to the simple fact that Standard FC drafts more than VARQ FC in these years, presenting a greater opportunity for trapped storage. Reference Libby Standard SRD and draft VARQ SRD shown respectively in Figure 2 and Figure 3, VARQ FC requires a greater inflow forecast (8.0 MAF versus 7.1 MAF) to reach full storage space of 4978 KAF. These cases are highlighted in bold in the last column of Table 1.

Figure 5. Elevation-Frequency Analysis: Lake Koocanusa Maximum Daily Elevation (June-July)

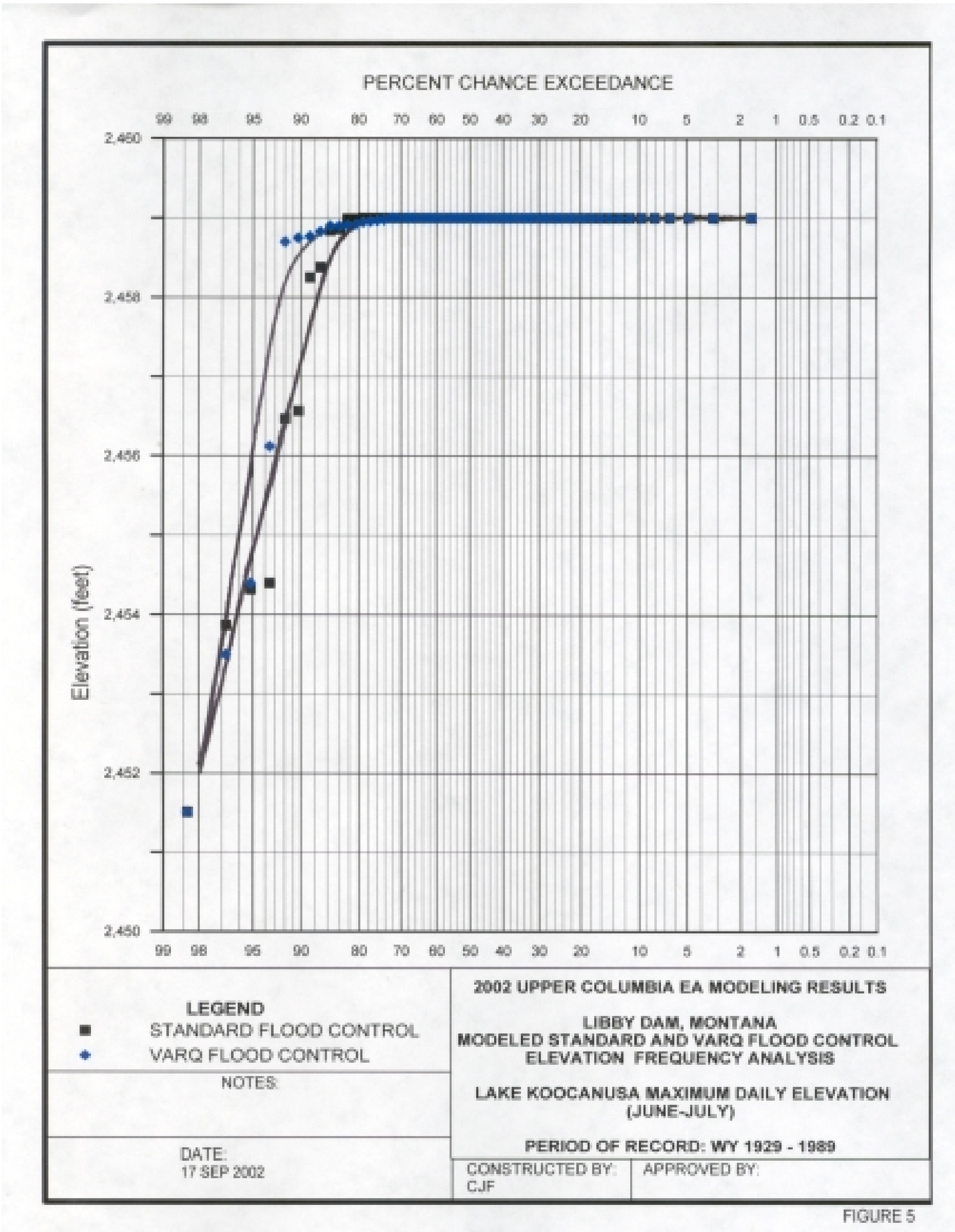


Figure 6. Elevation-Duration Analysis: Lake Koocanusa Daily Elevation (January-April)

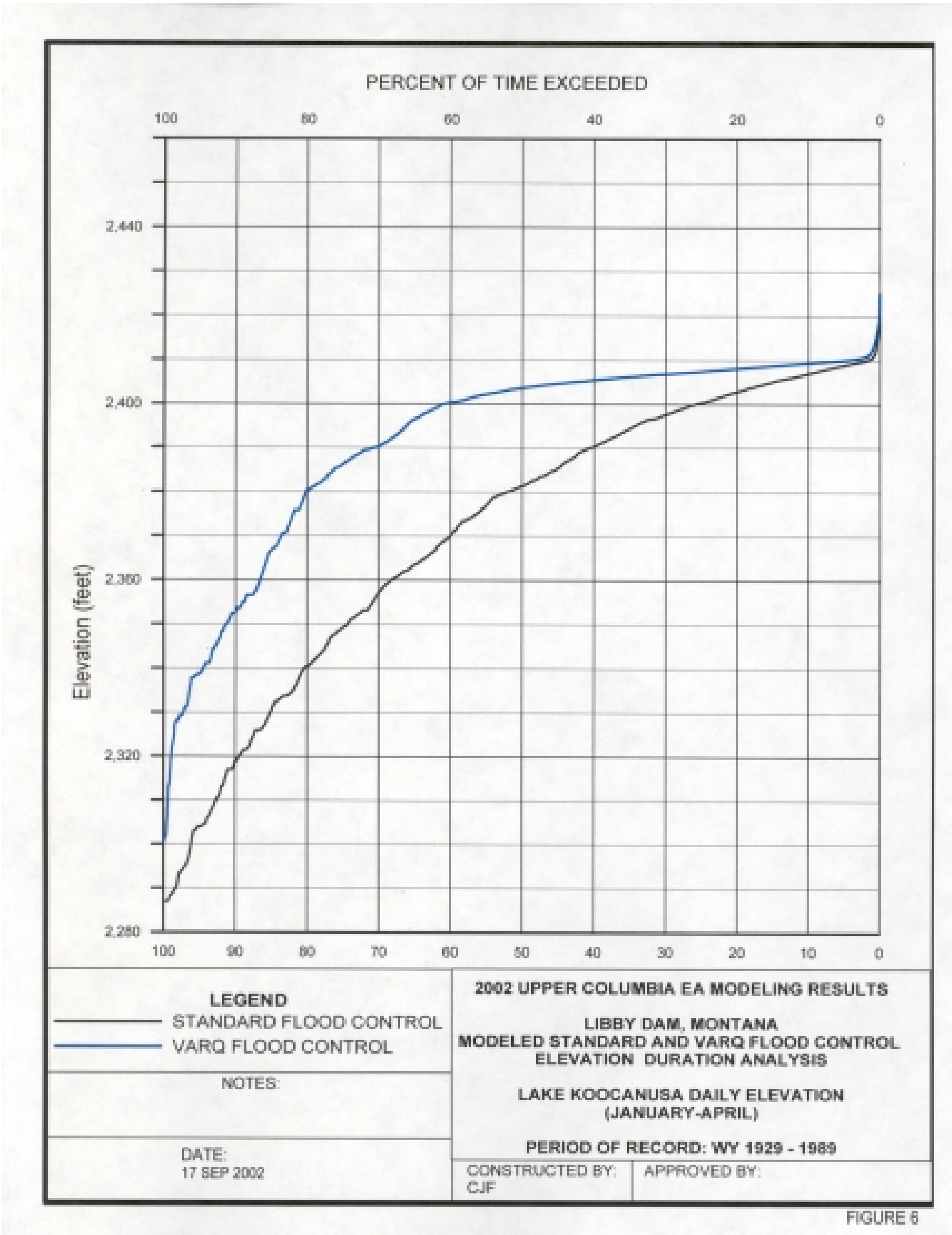


Figure 7. Elevation-Duration Analysis: Lake Koocanusa Daily Elevation (May)

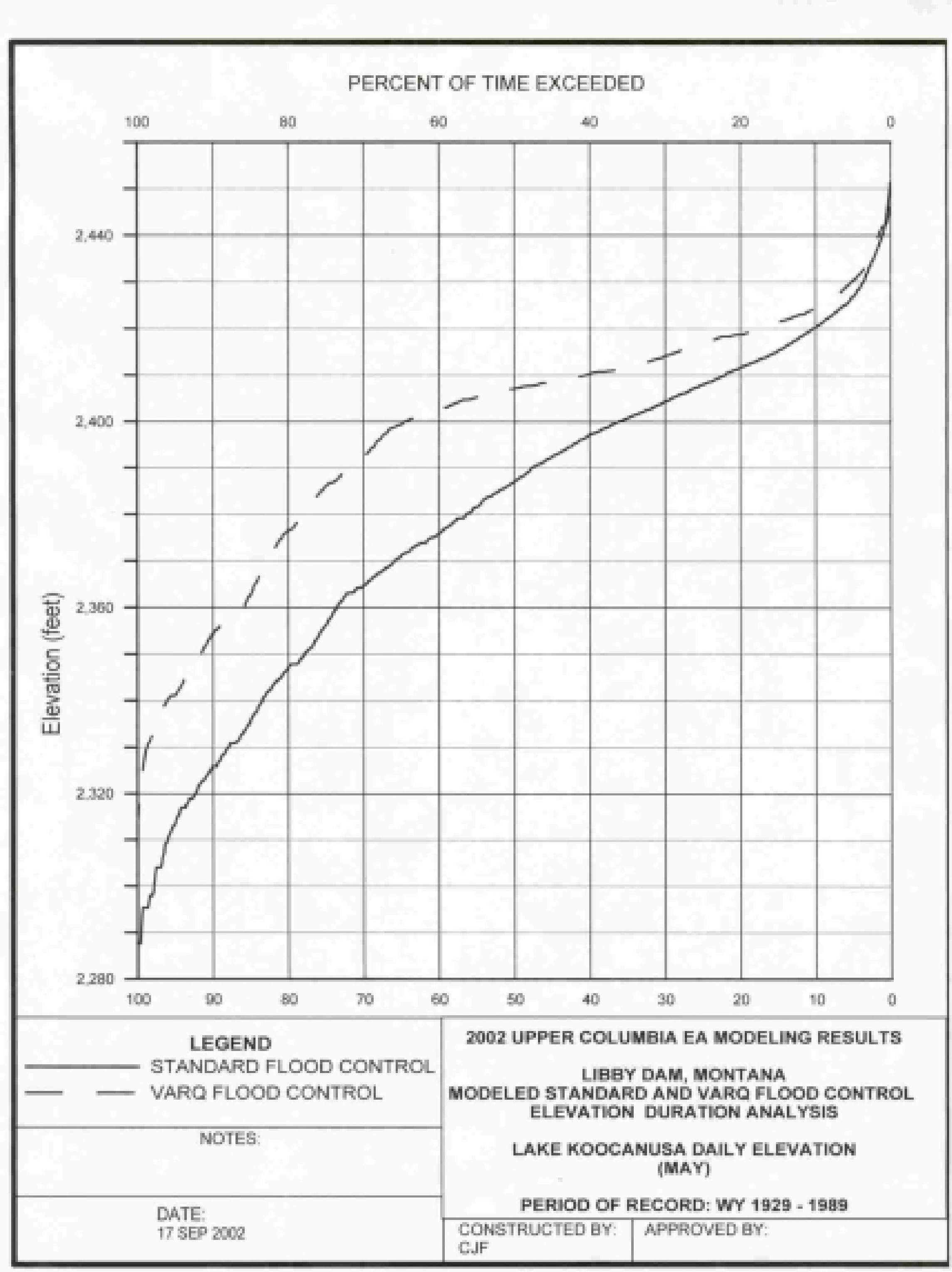


Figure 8. Elevation-Duration Analysis: Lake Koocanusa Daily Elevation (June)

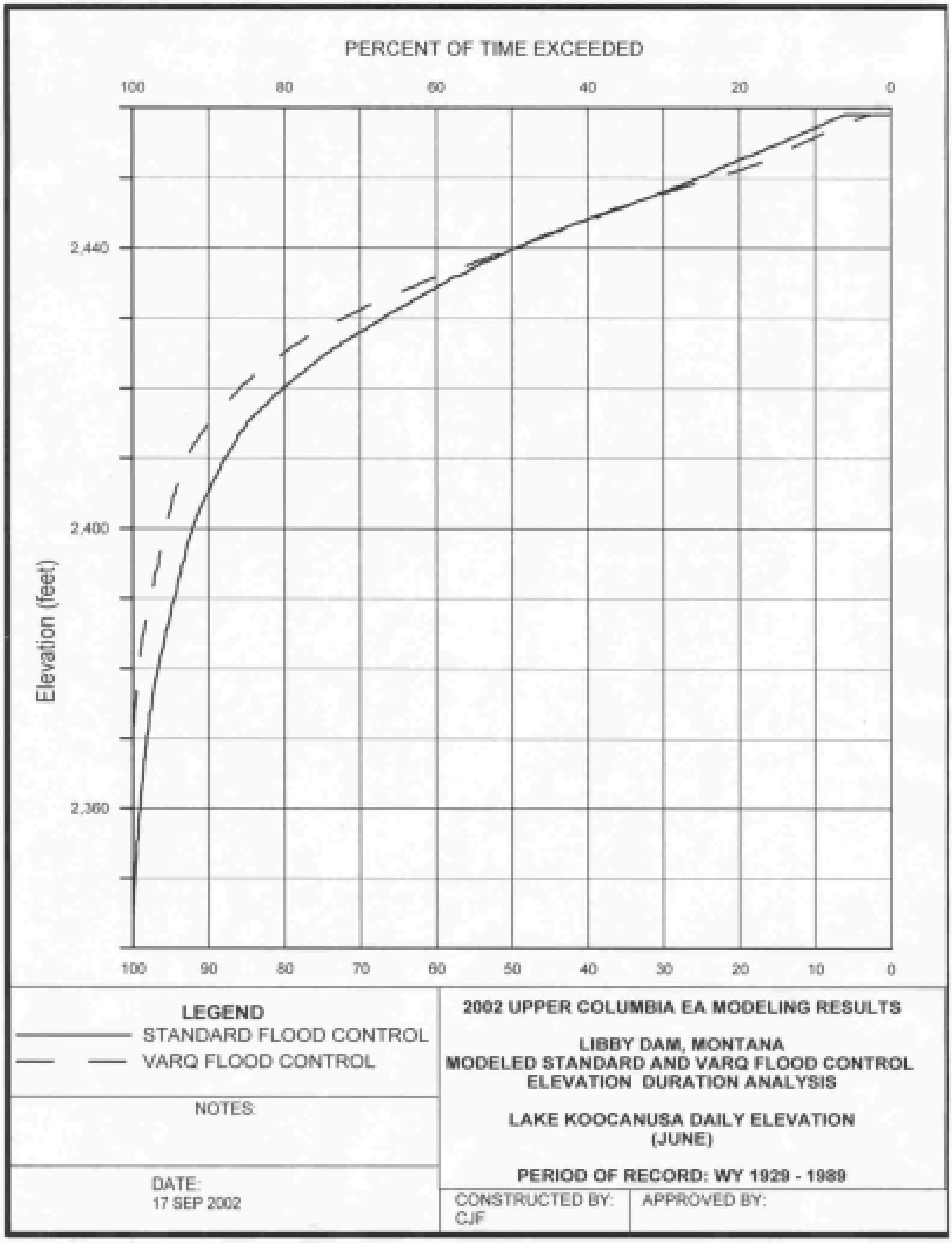


Figure 9. Elevation-Duration Analysis: Lake Koocanusa Daily Elevation (July)

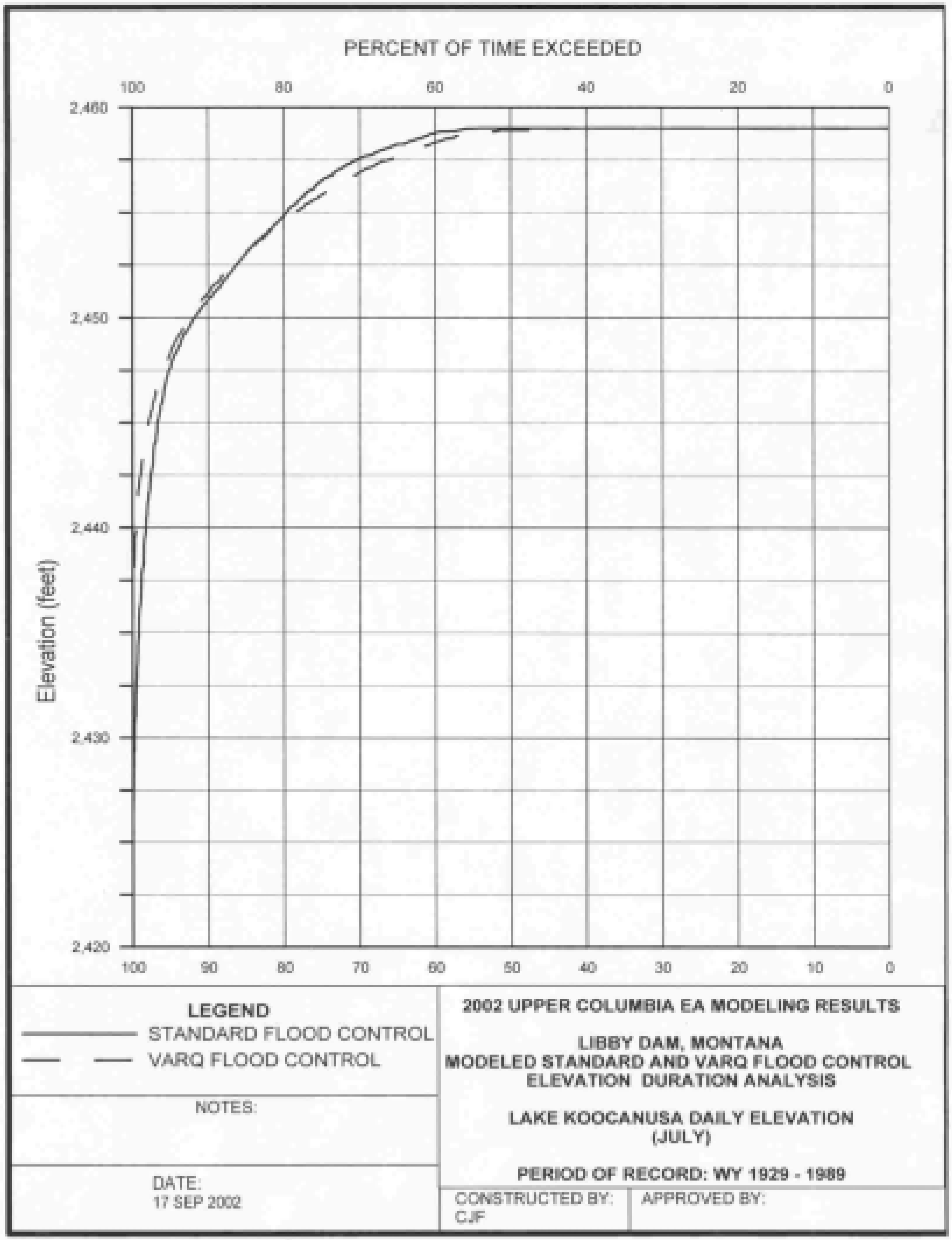


Figure 10. Flow-Frequency Analysis: Libby Dam Maximum Daily Outflow (May-July)

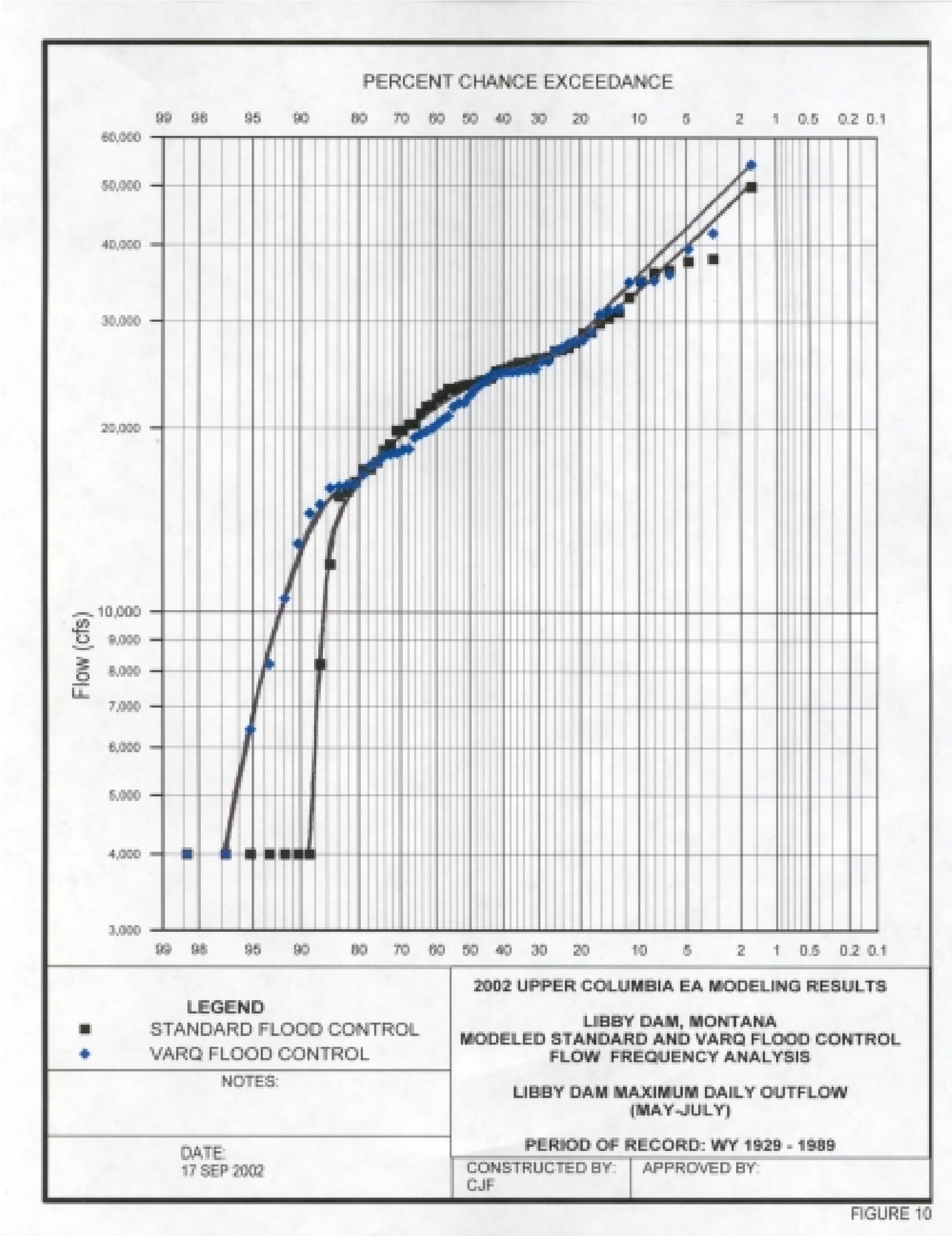


Figure 11. Flow-Frequency Analysis: Libby Dam Maximum 7-day Average Outflow (May-July)

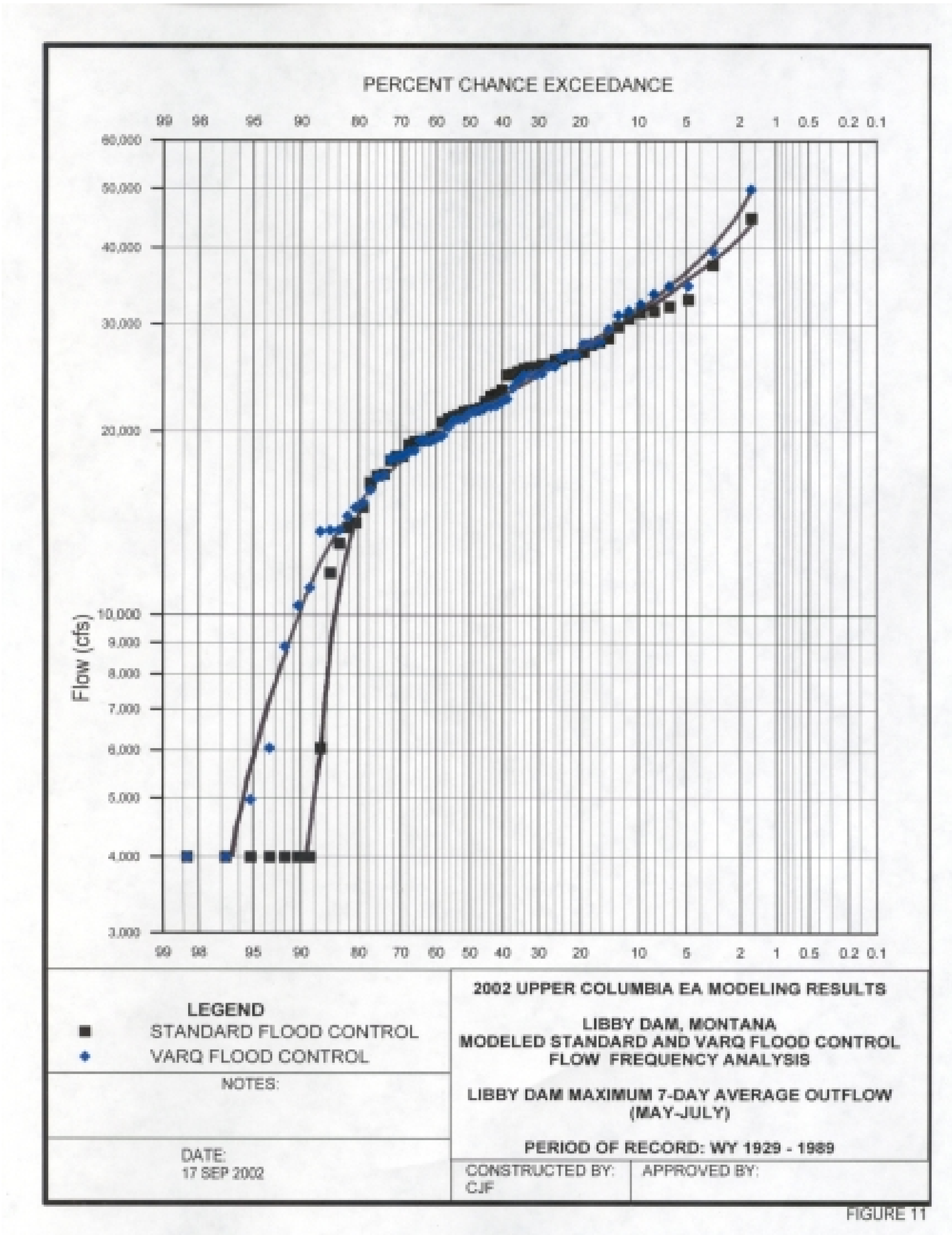


Table 1. Trapped storage at Libby Dam as a result of Standard FC and VARQ

YEAR	STANDARD FC				VARQ FC				Difference in Trapped Storage* (STANDARD - VARQ) (KAF)
	Draft Required (KAF)	Targeted Flood Control Elev. (feet)	Simulated Minimum Elev. (feet)	Trapped Storage (KAF)	Draft Required (KAF)	Targeted Flood Control Elev. (feet)	Simulated Minimum Elev. (feet)	Trapped Storage (KAF)	
1929	1091	2434	2398	0	192	2455	2400	0	0
1930	2212	2405	2392	0	731	2443	2402	0	0
1931	805	2441	2400	0	141	2456	2400	0	0
1932	4207	2330	2340	227	2815	2386	2390	122	105
1933	4978	2287	2287	0	4978	2287	2313	442	-442
1934	4978	2287	2353	1296	4978	2287	2352	1277	19
1935	4662	2306	2303	0	4203	2330	2338	174	-174
1936	1865	2415	2399	0	582	2446	2399	0	0
1937	2050	2410	2385	0	625	2445	2398	0	0
1938	4881	2293	2288	0	4341	2323	2331	153	-153
1939	2500	2396	2379	0	801	2441	2403	0	0
1940	2553	2395	2389	0	870	2440	2404	0	0
1941	1783	2417	2396	0	634	2445	2403	0	0
1942	2694	2390	2358	0	1041	2435	2388	0	0
1943	4085	2336	2332	0	2628	2392	2380	0	0
1944	498	2448	2400	0	178	2455	2400	0	0
1945	1441	2426	2399	0	306	2452	2399	0	0
1946	4127	2334	2332	0	2694	2390	2389	0	0
1947	4545	2313	2313	8	3335	2367	2366	0	8
1948	3395	2365	2351	0	1969	2412	2400	0	0
1949	3778	2349	2362	313	2264	2403	2401	0	313
1950	4978	2287	2304	274	4573	2311	2341	609	-335
1951	4978	2287	2334	851	4978	2287	2354	1308	-457
1952	3742	2351	2333	0	2202	2405	2381	0	0
1953	3320	2368	2360	0	1846	2415	2396	0	0
1954	3384	2365	2319	0	4637	2308	2348	841	-841
1955	2444	2398	2390	0	788	2441	2405	0	0
1956	4978	2287	2287	0	4232	2329	2327	0	0
1957	3387	2365	2366	36	2119	2408	2404	0	36
1958	2746	2388	2387	0	1075	2435	2403	0	0
1959	4900	2292	2293	19	3923	2343	2339	0	19
1960	4335	2324	2320	0	3016	2379	2367	0	0
1961	4930	2290	2326	640	3925	2343	2376	823	-183

YEAR	STANDARD FC Draft Required (KAF)	STANDARD FC Targeted Flood Control Elev. (feet)	STANDARD FC Simulated Minimum Elev. (feet)	STANDARD FC Trapped Storage (KAF)	VARQ FC Draft Required (KAF)	VARQ FC Targeted Flood Control Elev. (feet)	VARQ FC Simulated Minimum Elev. (feet)	VARQ FC Trapped Storage (KAF)	Difference in Trapped Storage* (STANDARD - VARQ) (KAF)
1962	2340	2401	2379	0	757	2442	2406	0	0
1963	3082	2376	2368	0	1457	2425	2406	0	0
1964	3289	2369	2340	0	1738	2418	2390	0	0
1965	4865	2294	2288	0	4752	2301	2300	0	0
1966	4429	2319	2310	0	3156	2374	2350	0	0
1967	4939	2290	2293	54	4455	2318	2338	416	-362
1968	2257	2404	2397	0	713	2443	2407	0	0
1969	4710	2304	2303	0	3591	2357	2344	0	0
1970	1398	2427	2398	0	228	2454	2402	0	0
1971	3807	2348	2347	0	2512	2396	2384	0	0
1972	4918	2291	2317	451	4429	2319	2357	830	-379
1973	2185	2406	2384	0	674	2444	2406	0	0
1974	4978	2287	2321	596	4978	2287	2329	758	-162
1975	4474	2317	2306	0	3925	2343	2357	326	-326
1976	4272	2327	2326	0	2917	2382	2382	0	0
1977	498	2448	2404	0	392	2450	2404	0	0
1978	3469	2362	2343	0	1898	2414	2393	0	0
1979	1790	2417	2406	0	555	2447	2406	0	0
1980	2637	2392	2392	0	945	2438	2403	0	0
1981	3789	2349	2349	0	2769	2387	2385	0	0
1982	3803	2348	2374	652	2763	2388	2405	547	105
1983	3715	2352	2351	0	2340	2401	2401	0	0
1984	1884	2414	2379	0	568	2446	2407	0	0
1985	2862	2384	2359	0	1208	2431	2385	0	0
1986	3255	2370	2374	93	1734	2418	2404	0	93
1987	2853	2385	2379	0	1390	2427	2407	0	0
1988	1116	2434	2402	0	468	2449	2402	0	0
1989	3003	2379	2363	0	1433	2426	2405	0	0

*Note: values highlighted if VARQ causes more trapped storage than Standard FC

2.2.4 Bonners Ferry

As a secondary benefit to providing system flood control for the Lower Columbia River, Libby Dam also provides local flood control for the Kootenai basin. The control point used for local flood control is the USGS gage in Bonners Ferry, Idaho. When Libby Dam was completed in 1973, flood stage was estimated to occur at about 1770 feet at Bonners Ferry. Since then, the estimate for flood stage at Bonners Ferry has been reduced twice, and is presently estimated at 1764 feet.

The Corps of Engineers operates Libby Dam to minimize downstream flood impacts without compromising the local flood control objective of providing flood protection from the 0.5% chance-exceedance flood to the Bonners Ferry area from river stages greater than 1770 feet (COE, 1992) (National Geodetic Vertical Datum 1929, or NGVD 29). Since NWS presently estimates flood stage at 1764 feet for Bonners Ferry, the hydro-regulation modeling performed for this study also attempted to limit river stages to 1764 feet at Bonners Ferry.

The highest river stages at Bonners Ferry generally occur during the months of May, June, and July. A daily stage-frequency curve and 7-day average stage frequency curve specific to those months are provided in Figure 12 and Figure 13, respectively. Overall, the VARQ FC results in higher river stages at Bonners Ferry than the Standard FC procedure. As was the case with the Libby Dam outflow frequency curves discussed in Section 2.2.2, the under-forecasting of 1948 resulted in VARQ showing higher stage at Bonners Ferry than Standard FC.

A stage-duration curve specific to the months of May through July was also developed for Bonners Ferry, and is shown in Figure 14. As one would expect, the stage at Bonners Ferry is higher for a longer duration under VARQ FC when compared with Standard FC. However, for river stages above elevation 1764 feet, this effect diminishes and there is almost no perceptible difference between the two flood control methods.

2.2.5 Kootenay Lake

Corra Linn Dam controls the level of Kootenay Lake during the majority of the year when low runoff and base flow conditions exist. There can be periods of high flow when the lake level is controlled by the natural constriction through Grohman Narrows located upstream of Corra Linn Dam in the west arm of Kootenay Lake. The International Joint Commission (IJC) Order of 1938 on Kootenay Lake established rules governing the lake's maximum allowable level. These rules are still used today.

There are two hydropower facilities at the outlet of Kootenay Lake: Corra Linn Dam and the Kootenay Canal Plant with several other hydroelectric dams immediately downstream. In the modeling done for this study, they were collectively modeled as one dam. All hydro-regulations for this study met the requirements of the 1938 IJC Order. Kootenay Lake was drafted to its flood control rule curve as required. When a conflict existed in meeting the 1938 IJC Order, outflow from Duncan Dam was reduced to passing no more than inflow and Libby Dam was allowed to continue drafting if allowable. Both projects were operated so as not to drive Kootenay Lake above its allowable lake level in the period of the "lowering formula".

Figure 12. Stage-Frequency Analysis: Bonners Ferry Maximum Daily Elevation (May-July)

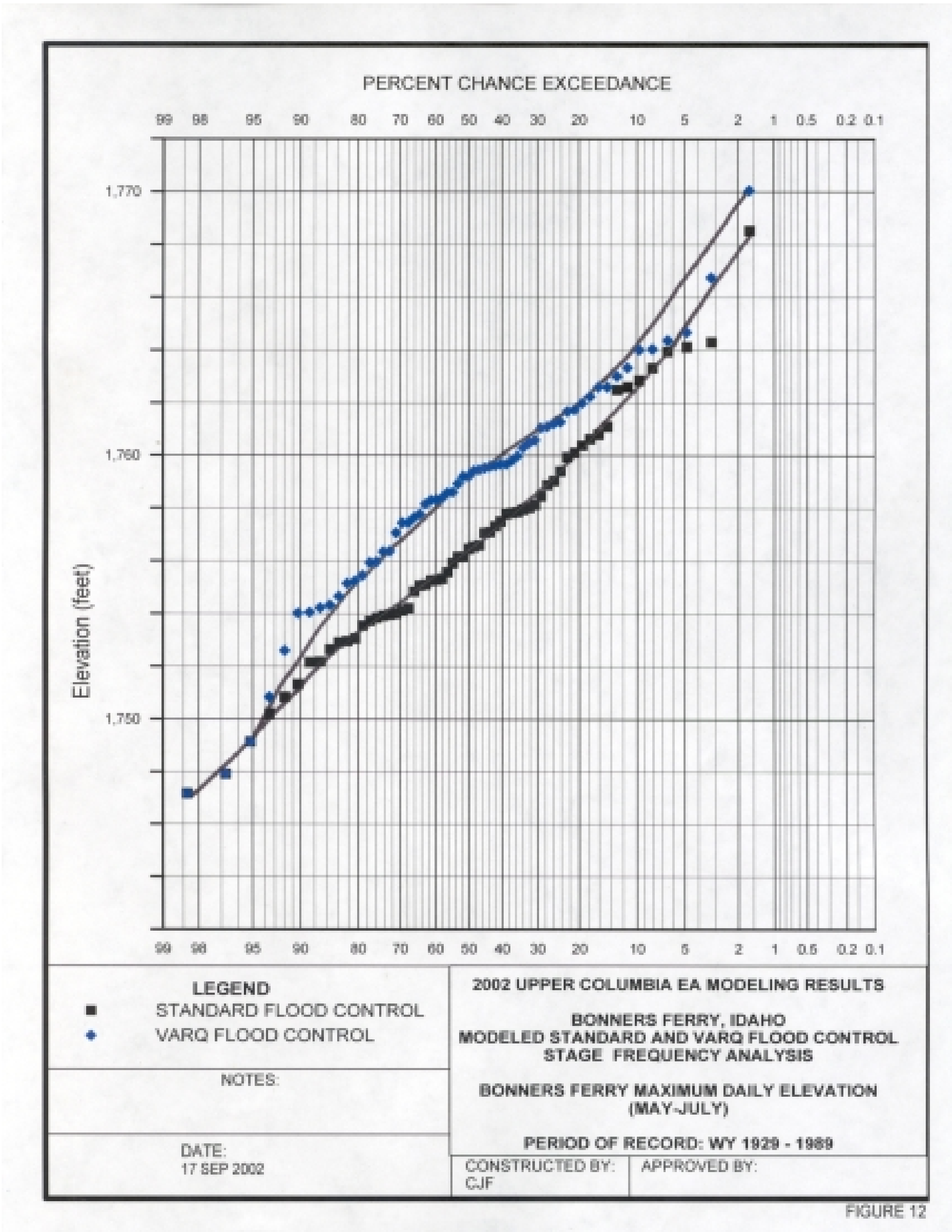


Figure 13. Stage-Frequency Analysis: Bonners Ferry Maximum 7-day Average Elevation (May-July)

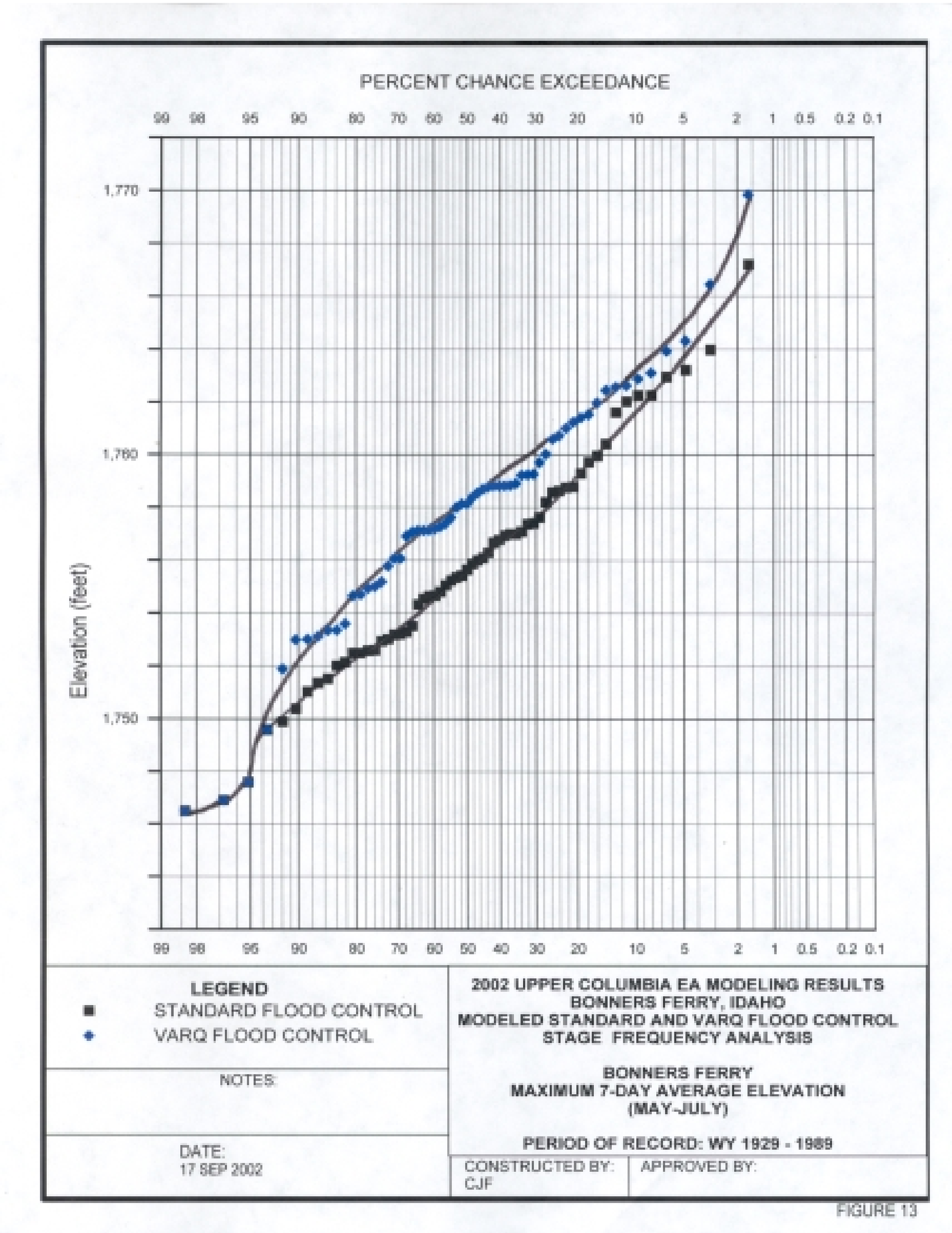
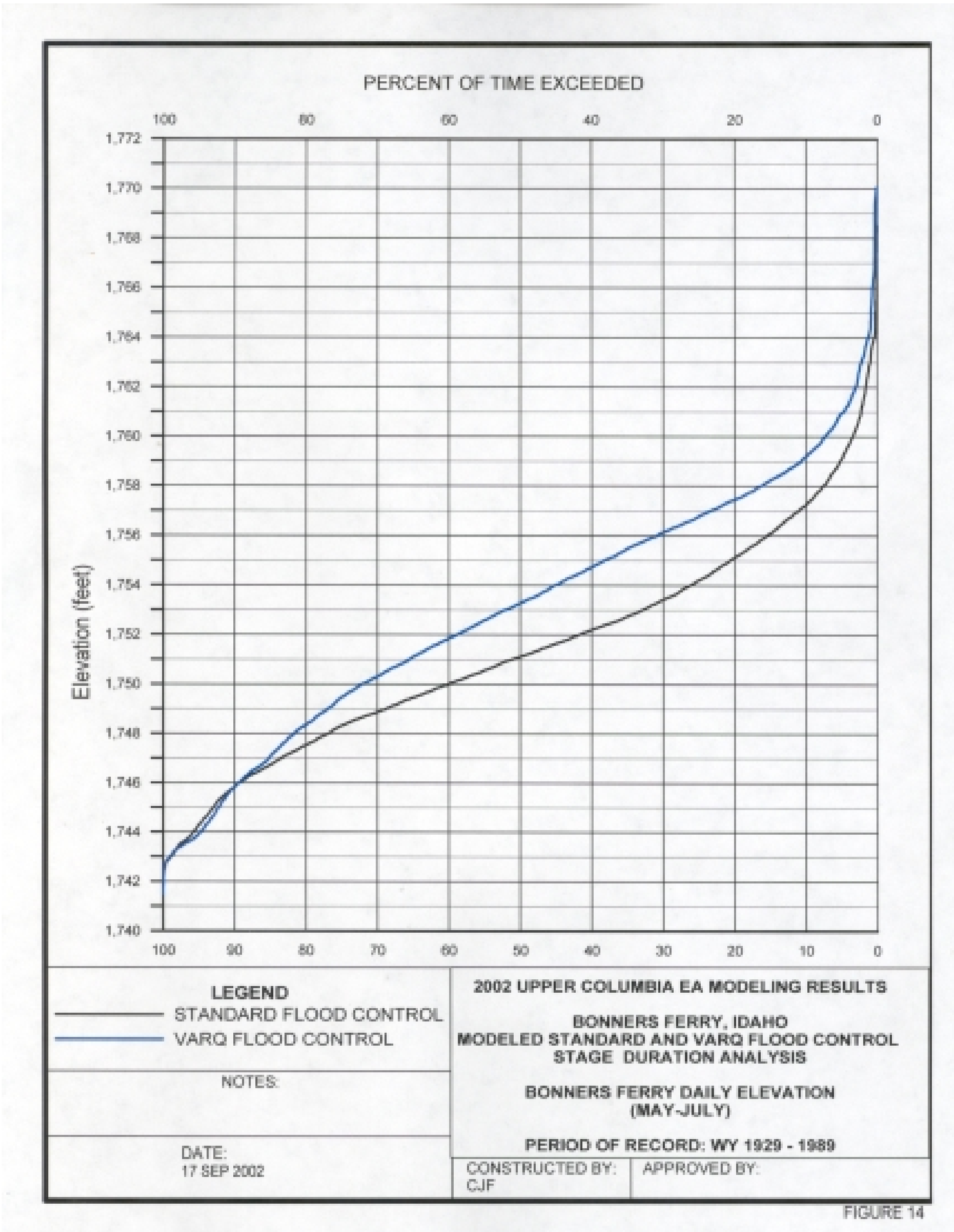


Figure 14. Stage-Duration Analysis: Bonners Ferry Daily Elevation (May-July)



From a flood control perspective, the impacts of VARQ on the level of Kootenay Lake are of greatest importance in May, June, and July. A daily elevation-frequency curve specific to those months is provided in Figure 15. The frequency curve shows that when VARQ FC is used, the level increases for Kootenay Lake. The two curves appear to converge around elevation 1751 feet, but then split from each other again for the low percent-chance-exceedance events (on the right side of the graph). As was the case with other locations in the Kootenai basin, the under-forecasting of some large years caused the flows and elevations from the model simulations to be higher than expected.

The two highest points for both curves represent the years 1948 and 1974. In both of these years, the raw data from model results indicate that there is a risk of higher stages at Kootenay Lake if VARQ FC is followed. The 7-day average elevation-frequency curve, shown on Figure 15 shows similar results.

Libby Dam became fully operation in 1973. Therefore, the observed elevation of 1754.23 feet at Kootenay Lake in 1974 was used to help weight the placement of the Standard FC frequency curve for the low percent-chance-exceedance events (on the right side of the graph).

An elevation-duration curve specific to the months of April through August was also developed for Kootenay Lake, and is shown in Figure 17. There is no significant difference between VARQ and Standard FC for lake levels below 1743 feet. However, lake levels between 1743 feet and 1750 feet are exceeded more with VARQ than with Standard FC.

The 1972 Columbia River Treaty Flood Control Operating Plan (FCOP) states that "damage commences at Nelson when Kootenay Lake reaches elevation 1755 feet and major damage stage is elevation 1759 feet" (COE, 1972). The stage-frequency curves shown in Figure 15 and Figure 16 show that, when VARQ FC is used, Kootenay Lake levels are somewhat higher. The VARQ and Standard FC curves appear to converge around elevation 1751 feet, but the split from each other again for the low percent-exceedance events, with the simulated VARQ FC elevation always higher than the simulated Standard FC elevation. However, Figure 17 shows that there is almost no difference between the two flood control procedures in influencing the duration of lake levels at high elevations.

2.2.6 Duncan Dam

Duncan Dam is located upstream of Kootenay Lake on the Duncan River in southern British Columbia (Figure 1). The Duncan River flows into the north arm of Kootenay Lake, as opposed to the Kootenay River, which flows into the south arm of Kootenay Lake. Depending on the forecasted volume runoff, it can provide up to 1.27 MAF of flood control storage space (versus up to 5 MAF for Lake Koocanusa). When conflicts developed in complying with the 1938 IJC Order on Kootenay Lake in the model simulations, Libby was given priority to draft before Duncan.

The flood control simulations show that VARQ has no real impact on either the maximum daily outflow or the maximum reservoir elevation at Duncan Dam. This is shown in Figure 18 and Figure 19, respectively.

Figure 15. Elevation-Frequency Analysis: Kootenay Lake Maximum Daily Elevation (May-July)

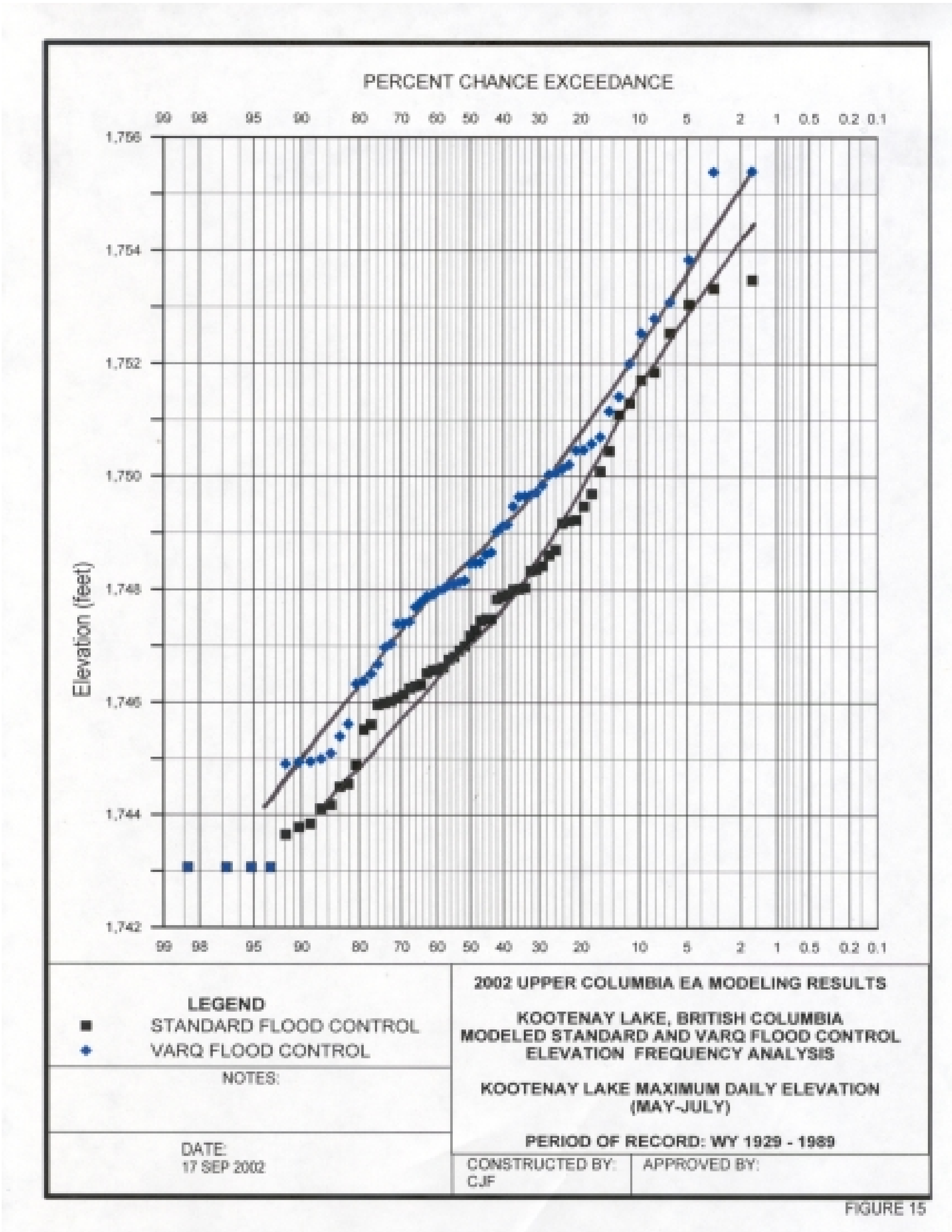


Figure 16. Elevation-Frequency Analysis: Kootenay Lake Maximum 7-day Average Elevation (May-July)

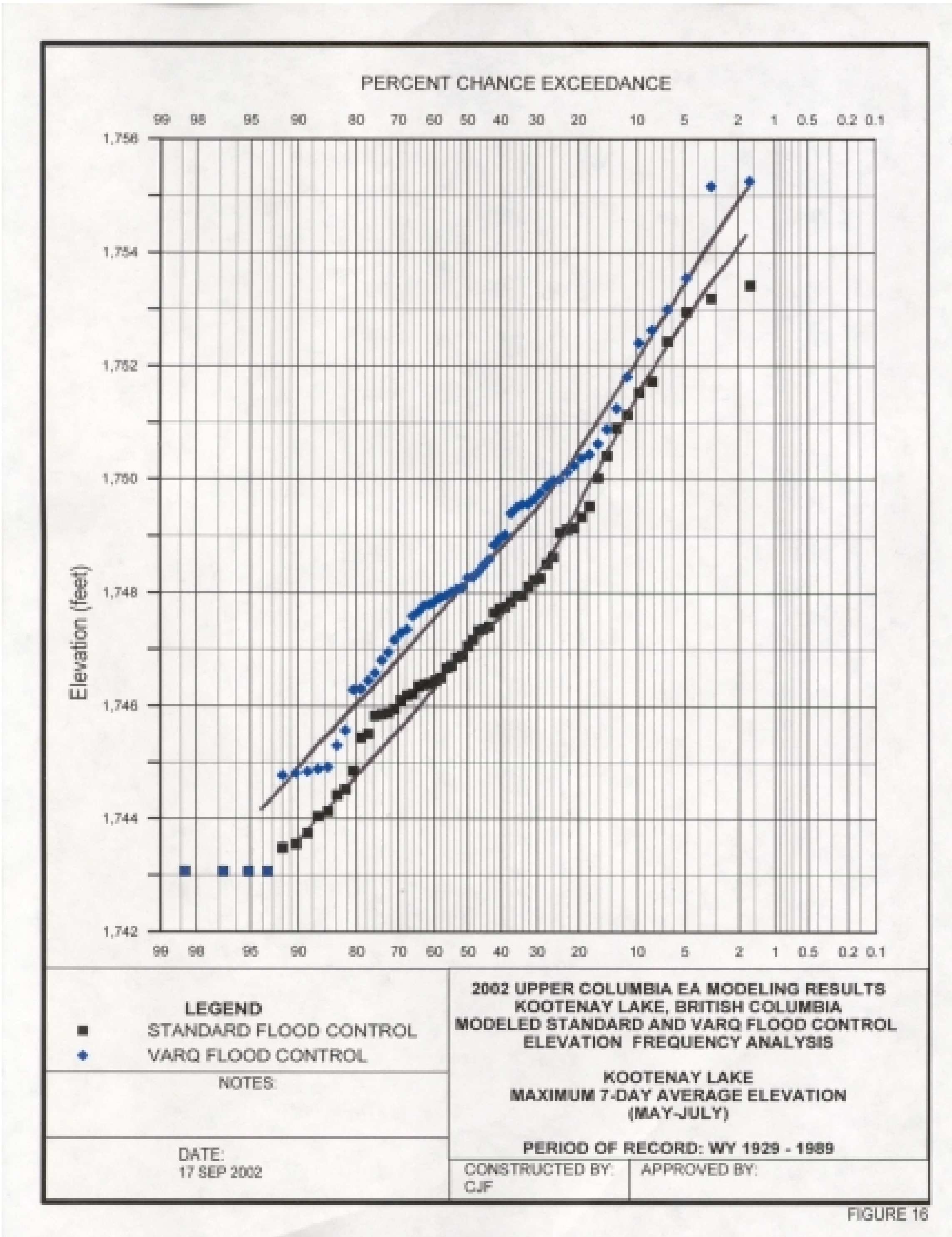


Figure 17. Elevation-Duration Analysis: Kootenay Lake Daily Elevation (April-August)

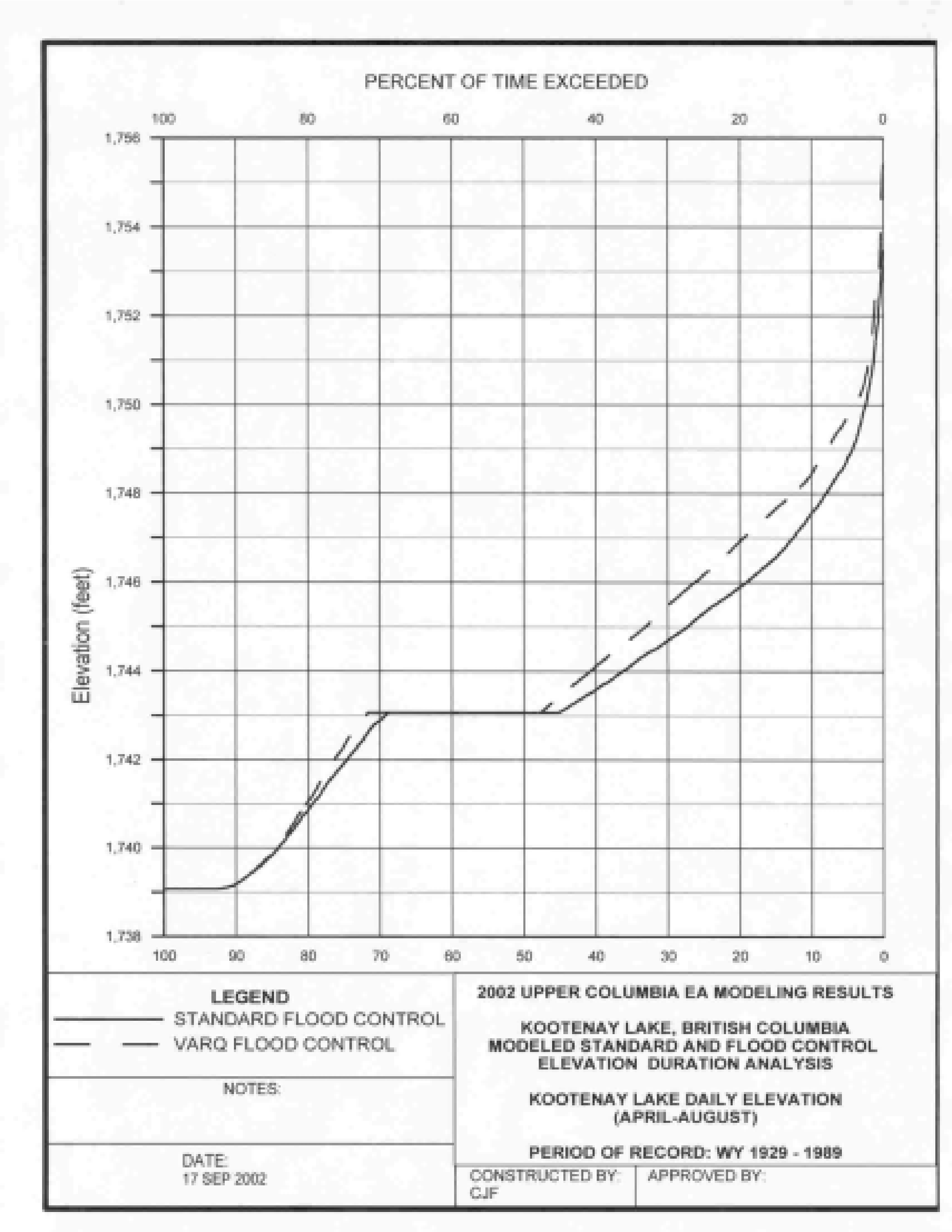


Figure 18. Flow-Frequency Analysis: Duncan Dam Maximum Daily Outflow (April-August)

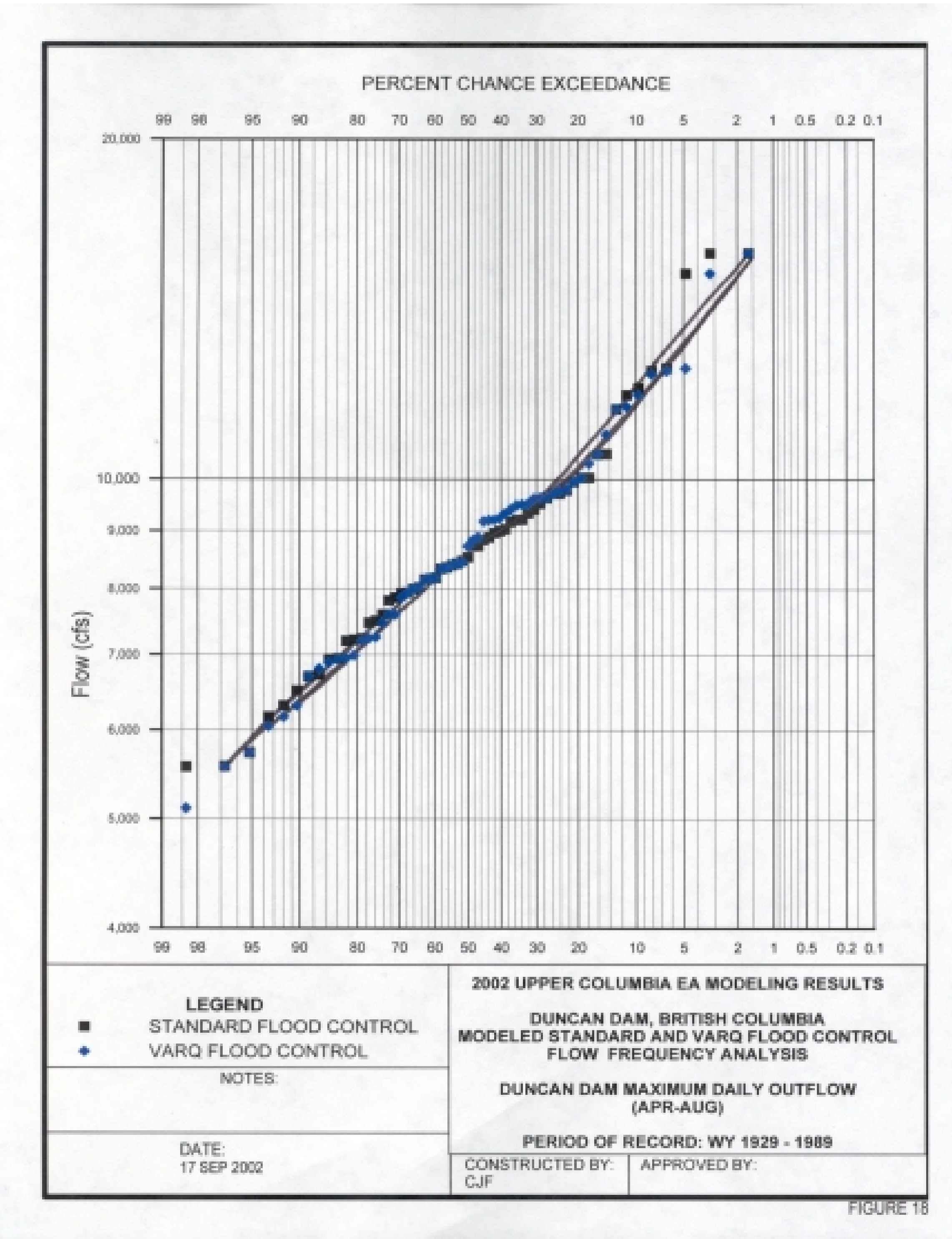
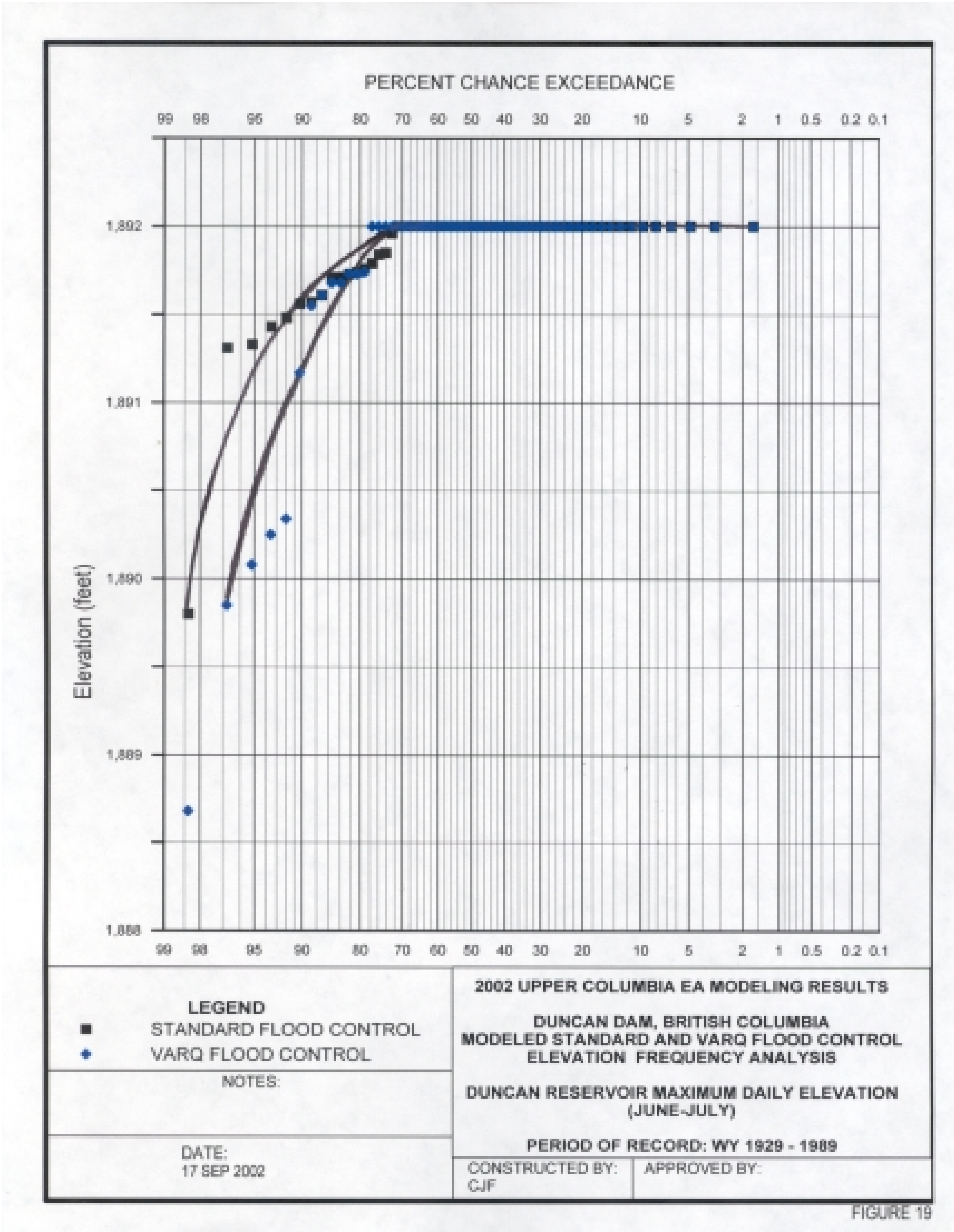


Figure 19. Elevation-Frequency Analysis: Duncan Reservoir Maximum Daily Elevation (June-July)



3.0 Hydrologic Analysis of Flood Control Methods Combined with Fish Flows

3.1 Hydro-Regulations

For this part of the study, fish flows from Libby Project were included in the flood control hydro-regulations. The results from the simulations are used to compare the differences between Standard FC and VARQ FC when fish flows from Libby Dam are introduced.

3.1.1 Background on Fish Flow Simulations

The 2000 BiOps call for augmented flows from Libby Dam to benefit several listed species downstream from the project. While the flood control simulations described in Section 2.0 of this report are useful in assessing incremental differences between Standard FC and VARQ FC, the added complexity of providing fish flows from Libby Dam must also be assessed. To do this, ten years were selected according to specific criteria (described in Section 3.1.2) and the BiOp flow recommendations for sturgeon, bull trout, and salmon were included in flood control model runs.

3.1.2 Selection of Years to Model

The ten years selected for system flood control modeling were chosen based on their potential to influence stages at Bonners Ferry or flood control draft at Grand Coulee Dam. In addition to this, understanding how forecast error or early/delayed spring freshets might compound effects at Bonners Ferry or Grand Coulee was also important. To address these issues, the criteria below were developed to select the ten years.

Each of the ten years met all of the following three criteria:

1. VARQ FC draft points had to be different from the Standard FC draft points. During high forecast years (greater than 125%) the VARQ and Standard FC draft targets are identical for the months of January through April. Therefore, the April-August Libby inflow forecast volumes (issued in May) needed to be less than 8.0 MAF.
2. The volume forecast had to be large enough so that sturgeon volumes would be provided. Therefore, the April – August Libby inflow forecast volumes (issued in May) needed to be greater than 4.8 MAF.
3. The maximum stage at Bonners Ferry for the VARQ flood-control only simulations had to be between 1757 and 1765 feet. The low end of this range was selected as 1757 feet because agricultural impacts begin to occur at that river stage. The high end of 1765 feet was selected because previous modeling suggested that the VARQ and Standard FC frequency curves converge for large water years when the stage at Bonners Ferry exceeds 1764 feet.

Each of the ten years also met at least one of the following criteria:

4. The forecast representing the April – August Libby inflow volume (as issued in May) had to be over-forecasted by at least 1 MAF or under-forecasted by at

least 1 million acre-feet (MAF). This way, the impact of a mis-forecast could be assessed.

5. The Initial Controlled Flow at The Dalles had to be reached early enough so that refill was initiated in April (considered early), or late enough so that refill did not begin until after 15 May (considered normal to later than normal).
6. The average June flows at The Dalles had to be greater than 625 kcfs – thereby indicating a large, late freshet.
7. In the flood control-only simulations, the draft at Grand Coulee Dam had to be at least four feet deeper with VARQ FC than with Standard FC.

Sixty-one years (1929-1989) have been narrowed down to ten by using the above criteria. However, even though 1942 met the screening criteria, it was not chosen because it was a low volume year with minimal flood control draft at Grand Coulee Dam and an initial control flow less than 220 kcfs. The criteria and the actual years selected are summarized in Table 2:

Table 2. Years to be modeled for flood control simulations with fish flows

Criteria	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Forecast* less than 8.0 MAF	x	x	x	x	x	x	x	x	x	x
Forecast* greater than 4.8 MAF	x	x	x	x	x	x	x	x	x	x
Bonners Ferry stage 1757-1765 ft	x	x	x	x	x	x	x	x	x	x
Forecast* at least 1 MAF lower than obs.		x			x	x		x		
Forecast* at least 1 MAF higher than obs.			x				x			
Refill begins before 1May			x							x
Refill begins after 15May	x			x					x	
June flow at the Dalles > 625kcfs	x	x				x				
Difference in GCL draft at least 4 feet			x	x				x	x	x
* Volume forecast for Libby Dam issued in month of May										

3.1.3 Description of "Fish Flow" Template

Special operation of Libby Dam is required in the late spring and summer because of ESA-listed fish species downstream. In May and June, discharge from the project is increased for the benefit of sturgeon downstream in the Bonners Ferry reach of the river. Immediately following the sturgeon flow augmentation, minimum flows from 6,000 to 9,000 cfs are required for bull trout. Then, before August 31, a portion of the water stored behind Libby Dam must be released for the benefit of salmon in the lower Columbia.

On March 25 and 26, 2002, representatives from the Corps of Engineers and the USFWS met to discuss measurement and delivery of augmented water volumes for sturgeon. It was decided that augmentation volumes should be measured at Libby Dam rather than Bonners Ferry. This facilitates volume accounting and greatly simplifies the modeling process. It was further decided that the augmentation volume should be interpolated according to the forecast runoff, as shown below in Table 3. A discharge of 35,000 cfs is the maximum outflow called for n the U.S. Fish and Wildlife Service (USFWS) 2000 BiOp. This sturgeon volume release measured at Libby Dam was memorialized at the executive level in August 2002. Then, the outflow was held constant at either 25,000 cfs or 35,000 cfs for whatever duration was necessary so that the full sturgeon volume was delivered before the end of the ramp-down to bull trout flows. In cases where there was a conflict between providing flood control at Bonners Ferry and releasing 25,000 cfs (or 35,000 Cfs) from Libby Dam, local flood control operations took precedence.

If the forecast is less than 4.8 MAF no sturgeon water is provided. If the forecast is greater than 8.9 MAF the amount of water provided for sturgeon is capped at 1.6 MAF. The minimum release of 4,000 cfs from Libby Dam is not included in the accounting of sturgeon water.

Table 3. Sturgeon water volumes to be provided from Libby Dam

April-August Forecast (MAF) issued in May	Sturgeon Volume to be provided (MAF)
4.80	0.80
5.40	0.80
6.35	1.12
7.40	1.20
8.50	1.20
8.90	1.60

In practice, the timing and shaping of these volumes would be based on seasonal requests from the USFWS. However, for modeling purposes, the following guidelines were used: for years when the April-August forecast (issued in May) was between 4.8 and 6.0 MAF, ramp-up for the sturgeon flows began on 16 May; for years when the April-August forecast (issued in May) was between 6.0 and 6.7 MAF, the ramp-up for sturgeon flows began on 23 May; and finally, for years when the April-August forecast (issued in May) was greater than 6.7 MAF, the ramp-up for sturgeon flows began on 1 June. For modeling, the outflow was ramped up to either 25,000 cfs or 35,000 cfs as rapidly as permitted by the BiOp.

Because maximum outflows of both 25,000 cfs and 35,000 cfs were considered, the fish flow simulations were done twice for each of the ten years. First, Libby's maximum sturgeon outflow was limited to 25,000 cfs, which is approximately equal to the powerhouse capacity. Then, the maximum sturgeon outflow was limited to 35,000 cfs (USFWS, 2000). At the present time, it is not possible to discharge anything higher than full powerhouse capacity plus some limited spill via the spillway without exceeding Montana state water quality limits of 110% for total dissolved gas (TDG) in the unmixed zone. The exact amount is still in debate but is likely less than 1500 cfs. Nonetheless, the 35,000 cfs sturgeon flows were modeled because of the recommendations in the USFWS 2002 BiOp. A release of this magnitude may require installation of additional generating unit(s).

Immediately following ramp-down from the sturgeon flow augmentation, Libby Dam released a minimum bull trout outflow ranging from 6,000 to 9,000 cfs until at least the end of June. For years when the April-August forecast (issued in June) was less than 4.8 MAF, the minimum bull trout flow was 6,000 cfs and did not commence until 1 July. For years when the April-August forecast (issued in June) was between 4.8 and 6.0 MAF, the minimum bull trout flow was 7,000 cfs. For years when the April-August forecast (issued in June) was between 6.0 and 6.7 MAF, the minimum bull trout flow was 8,000 cfs. For years when the April-August forecast (issued in June) was greater than 6.7 MAF, the minimum bull trout flow was 9,000 cfs.

For the months of July and August, an attempt was made to provide steady outflow from Libby Dam such that the reservoir would be drafted to elevation 2439 feet by the end of August. The steady outflow operation over the months of July and August was done to avoid the "double-peak" that can occur if salmon water is released solely in the month of August. In cases where the steady outflow operation called for a lower discharge than the minimum bull trout flow, the minimum bull trout flow was provided.

3.2 Model Results

Output data from the ten years of flood control simulations with fish flows are presented in the following sections. Impacts to Lake Koocanusa and Libby Dam, Bonners Ferry, Kootenay Lake, and Duncan Dam are presented in the following sections.

3.2.1 Analysis of Results

The flood control-only simulations in Section 2.0 of this report were conducted for a 61-year period of record (1929-1989), enabling a quantitative comparison between Standard FC and VARQ FC using frequency and duration curves. Due to complexity in the modeling effort, ten years were chosen for modeling with fish flows. Therefore, the results from these ten years are presented in tabular form rather than with frequency curves.

3.2.2 Lake Koocanusa and Libby Dam

Table 4, Table 5 and Table 6 show the simulated maximum daily elevation, simulated maximum daily outflow, and simulated maximum 7-day average outflow from Libby Dam, respectively. For the flood control-only scenarios, the reservoir is able to fill every year. However, once the fish flows are added to Standard FC, the reservoir fails to fill within the top five feet in 6 of the 10 years. When fish flows are added to VARQ FC, 4 of the 10 years fail to get within the top five feet. In years when the reservoir fails to refill because of fish flows, the simulated VARQ elevation is always higher than the simulated Standard FC elevation – sometimes by as much as 18 feet (1949 and 1975).

Table 4. Maximum daily elevation (feet) of Lake Koocanusa

	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Standard FC only	2459	2459	2459	2459	2459	2459	2454	2459	2459	2459
VARQ FC only	2459	2459	2459	2459	2459	2459	2459	2459	2459	2459
Standard FC with fish flows (max. Libby outflow 25 kcfs)	2432	2459	2424	2459	2459	2459	2419	2449	2445	2435
VARQ FC with fish flows (max. Libby outflow 25 kcfs)	2440	2459	2441	2459	2459	2459	2437	2457	2459	2446
Standard FC with fish flows (max. Libby outflow 35 kcfs)	2431	2459	2423	2459	2459	2459	2417	2446	2445	2434
VARQ FC with fish flows (max. Libby outflow 35 kcfs)	2440	2459	2441	2459	2459	2459	2435	2459	2459	2445

Table 4, Table 5 and Table 6 show that the scenarios with fish flows can cause both higher and lower peak outflows from Libby Dam when compared against the flood control-only scenarios. For most cases, the fish flows increase the peak outflow from Libby Dam, especially the scenarios that call for 35 kcfs to be released for sturgeon. However, there are also cases (such as 1948, 1955, and 1971) when the fish flows actually resulted in a reduced peak outflow from Libby Dam. In these cases, the fish flows serve the secondary purpose of drafting additional flood control space in Libby's reservoir. This additional storage is sometimes significant enough to prevent a very large outflow that would have otherwise occurred later in the runoff season.

3.2.3 Spill from Libby Dam

In June and July of 2002, a series of water quality sensors in the Kootenai River measured total dissolved gas (TDG) levels while the spillway was in use. Discussion in this section is limited to spill and TDG levels as they pertain to the hydrologic modeling that was done for both methods of flood control with fish flows.

The relationship between spill and TDG saturation is characterized in Table 7 and Table 8. Table 7 shows the relationship between project outflow and TDG levels immediately downstream of the spillway. Table 8 shows the same relationship, except that TDG values have been averaged across the river cross-section. In other words, Table 8 shows the effective dilution on TDG levels when the powerhouse discharge is taken into account. Data for spill in excess of 15 kcfs is extrapolated – it was not observed data.

Table 5. Maximum daily outflow (kcfs) from Libby Dam

	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Standard FC only	23.4	49.8	4.0	34.9	36.0	28.7	4.0	26.1	25.7	16.3
VARQ FC only	18.5	54.2	18.2	30.8	27.1	39.4	16.1	27.6	22.0	21.0
Standard FC with fish flows (max. Libby outflow 25 kcfs)	25.0	30.8	25.0	25.0	29.0	25.9	25.0	25.0	25.0	25
VARQ FC with fish flows (max. Libby outflow 25 kcfs)	25.0	54.2	25.0	30.3	27.2	29.3	25.0	25.0	25.0	25
Standard FC with fish flows (max. Libby outflow 35 kcfs)	35.0	32.0	35.0	30.0	35.0	35.0	35.0	35.0	35.0	35
VARQ FC with fish flows (max. Libby outflow 35 kcfs)	35.0	54.2	35.0	30.0	35.0	35.0	35.0	35.0	35.0	35

Table 6. Maximum 7-day average outflow (kcfs) from Libby Dam

	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Standard FC only	20.7	44.8	4.0	32.1	32.9	28.5	4.0	25.6	22.4	15.0
VARQ FC only	18.5	49.9	18.2	28.1	26.7	33.6	8.9	25.6	20.8	21.0
Standard FC with fish flows (max. Libby outflow 25 kcfs)	25.0	29.9	25.0	25.0	26.3	25.1	25.0	25.0	25.0	25.0
VARQ FC with fish flows (max. Libby outflow 25 kcfs)	25.0	49.8	25.0	29.2	25.6	29.2	25.0	25.0	25.0	25.0
Standard FC with fish flows (max. Libby outflow 35 kcfs)	29.3	29.9	35.0	29.0	34.3	35.0	33.4	35.0	34.4	34.9
VARQ FC with fish flows (max. Libby outflow 35 kcfs)	28.7	49.8	35.0	28.9	35.0	35.0	33.6	35.0	34.4	34.6

Table 7. Relationship between Libby Dam discharge and TDG levels (immediately downstream of spillway)

Total discharge from Libby Dam (kcfs)	Powerhouse Discharge (kcfs)	Discharge via spillway (kcfs)	TDG saturation immediately downstream of spillway
25	25	0	100.00
26	25	1	108.32
27	25	2	115.96
28	25	3	123.60
29	25	4	127.22
30	25	5	129.21
31	25	6	130.49
32	25	7	131.31
33	25	8	131.84
34	25	9	132.17
35	25	10	132.39
36	25	11	132.53
37	25	12	132.62
38	25	13	132.68
39	25	14	132.71
40	25	15	132.74
42	25	17	132.75
44	25	19	132.75
46	25	21	133.00
48	25	23	133.00
50	25	25	133.00
52	25	27	133.00
54	25	29	133.00
56	25	31	133.00

Table 8. Relationship between Libby Dam discharge and TDG levels (cross-section averaged value)

Total discharge from Libby Dam (kcfs)	Powerhouse Discharge (kcfs)	Spillway Discharge (kcfs)	TDG % saturation immediately downstream of powerhouse	TDG % saturation immediately downstream of spillway	TDG % saturation (cross-section averaged value)
25	25	0	100	100.00	100.00
26	25	1	100	108.32	100.32
27	25	2	100	115.96	101.18
28	25	3	100	123.60	102.53
29	25	4	100	127.22	103.75
30	25	5	100	129.21	104.87
31	25	6	100	130.49	105.90
32	25	7	100	131.31	106.85
33	25	8	100	131.84	107.72
34	25	9	100	132.17	108.52
35	25	10	100	132.39	109.25
36	25	11	100	132.53	109.94
37	25	12	100	132.62	110.58
38	25	13	100	132.68	111.18
39	25	14	100	132.71	111.74
40	25	15	100	132.74	112.28
42	25	17	100	132.75	113.26
44	25	19	100	132.75	114.14
46	25	21	100	133	115.07
48	25	23	100	133	115.81
50	25	25	100	133	116.50
52	25	27	100	133	117.13
54	25	29	100	133	117.72
56	25	31	100	133	118.27

The information shown in Table 7 and Table 8 was combined with simulated Libby outflow data in order to model the amount of TDG downstream of Libby Dam. The scenarios where flood control is combined with fish flows (targeting 25 kcfs outflow for sturgeon) were used for the analysis. For the ten years that were modeled, the earliest any spill occurred was in late May, and it was always done before the end of July. Therefore, this analysis is limited to the time period from16 May through 31 July for each of the ten years modeled.

TDG saturation-duration curves were developed in order to compare TDG immediately downstream of Libby Dam with Standard FC and VARQ FC. Figure 20 shows the percent of time that dissolved gas levels achieved at this location This assessment measured at a site where TDG levels had not yet been diluted by powerhouse flow. The dashed line in the figure shows that 3.7% of the days in the data set (between 16 May and 31 July, for ten years only) in the Standard FC simulations had TDG levels greater than 110%. The solid line in the figure shows that 11.2% of the days in the data set had TDG levels greater than 110% with the modeled VARQ operation.

Figure 21 shows the percent of time that dissolved gas levels were achieved at this location, assuming that TDG values have been averaged across the river cross-section. The solid line in the figure shows that 3.7% of the days in the data set had TDG levels greater than 110% with the modeled VARQ FC operation, versus 0% in the case of Standard FC.

3.2.4 Bonners Ferry

Table 9 and Table 10 show that the scenarios with fish flows increase the peak stage at Bonners Ferry when compared against the flood control-only scenarios. The simulations show that in some years, the stage can increase by as much as six feet. However, for the scenarios where 25 kcfs is provided for sturgeon, the stage does not exceed elevation 1764 feet except in 1948. For 1948, the stage at Bonners Ferry exceeded 1764 feet even for the scenarios where no fish flows were provided. For the scenarios where 35 kcfs is provided for sturgeon, the peak stage for all ten years is near or above 1764 feet.

Table 9. Maximum daily stage (feet) at Bonners Ferry

	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Standard FC only	1757.9	1768.5	1757.8	1762.6	1759.4	1759.9	1756.6	1757.8	1753.9	1755.3
VARQ FC only	1758.6	1770.1	1762.6	1761.3	1757.4	1763.4	1758.6	1759.2	1759.2	1760.6
Standard FC with fish flows (max. Libby outflow 25 kcfs)	1763.9	1764.0	1760.5	1763.3	1759.9	1760.3	1763.2	1761.2	1760.7	1759.2
VARQ FC with fish flows (max. Libby outflow 25 kcfs)	1764.0	1770.1	1762.6	1763.4	1760.2	1763.3	1763.5	1762.2	1760.9	1760.6
Standard FC with fish flows (max. Libby outflow 35 kcfs)	1764.0	1764.0	1763.5	1763.8	1762.8	1763.4	1764.0	1763.9	1763.8	1762.4
VARQ FC with fish flows (max. Libby outflow 35 kcfs)	1764.2	1770.1	1764.2	1764.0	1763.1	1763.8	1764.0	1764.0	1763.9	1762.7

3.2.5 Kootenay Lake

At Kootenay Lake, the scenarios with fish flows tend to increase the lake elevation. For the scenarios where 25 kcfs is provided for sturgeon, the increase in lake elevation is less than one foot for most years, with years 1933, 1975, and 1986 being the exceptions. In those years, the increase in lake level is closer to two feet. For the scenarios where 35 kcfs is provided for sturgeon, the lake level increases still more, though typically in the range of another six inches to one foot. This is shown in Table 11 and Table 12 below.

Figure 20. TDG Saturation Duration Analysis: Immediately Downstream of Libby Dam Spillway

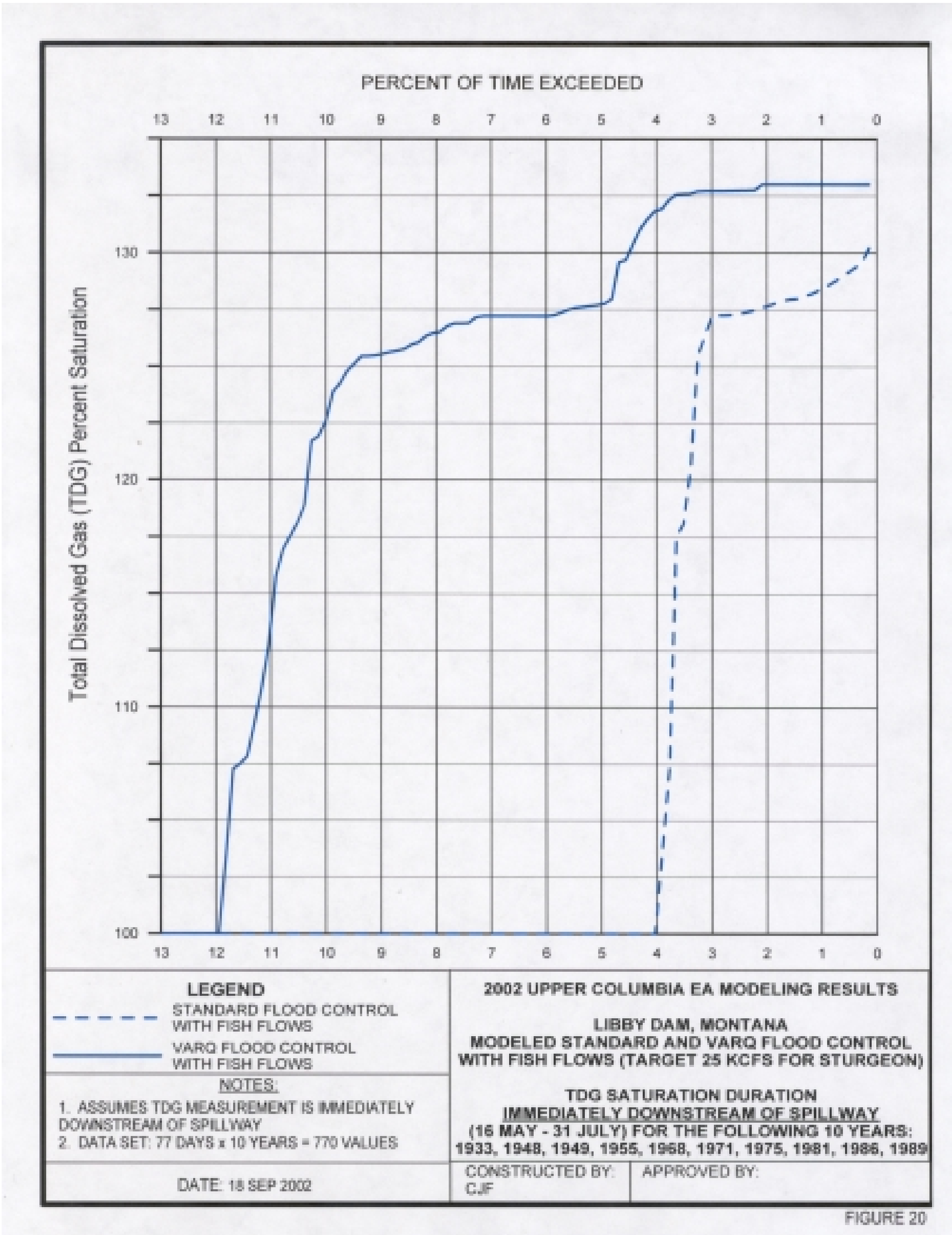


Figure 21. TDG Saturation Duration Analysis: Cross-Section Averaged Value Downstream of Libby Dam

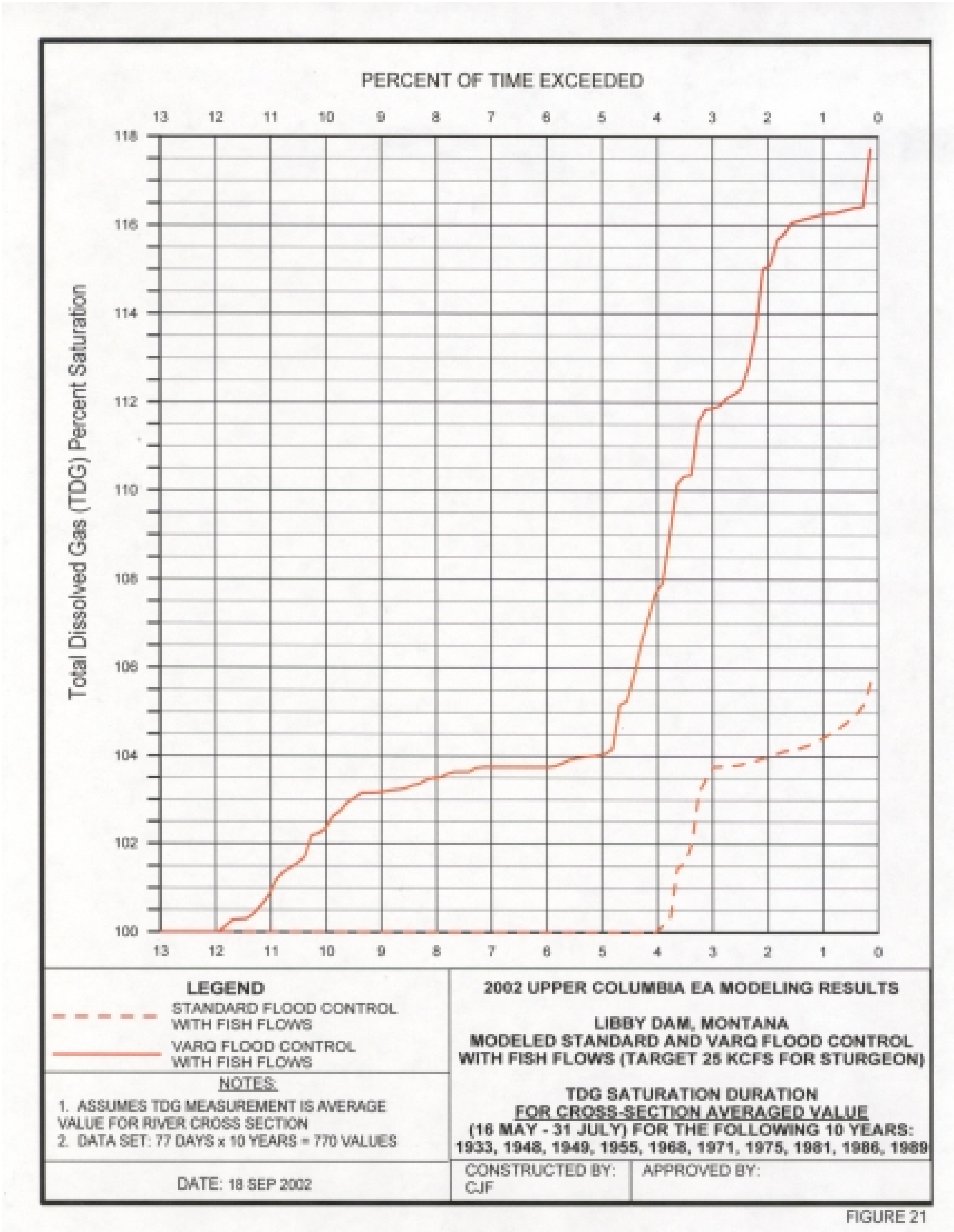


Table 10. Maximum 7-day average stage (feet) at Bonners Ferry

	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Standard FC only	1757.6	1767.2	1757.0	1761.6	1758.6	1759.7	1756.0	1757.4	1752.6	1754.6
VARQ FC only	1757.1	1769.8	1762.0	1760.7	1757.3	1762.6	1758.0	1758.6	1758.8	1759.7
Standard FC with fish flows (max. Libby outflow 25 kcfs)	1763.1	1763.5	1759.8	1762.8	1759.6	1759.9	1762.5	1760.5	1760.4	1758.9
VARQ FC with fish flows (max. Libby outflow 25 kcfs)	1763.2	1769.9	1762.0	1762.9	1759.9	1762.6	1763.0	1761.4	1760.5	1759.7
Standard FC with fish flows (max. Libby outflow 35 kcfs)	1763.7	1763.9	1762.9	1763.7	1762.4	1763.1	1763.8	1763.4	1763.3	1762.1
VARQ FC with fish flows (max. Libby outflow 35 kcfs)	1763.9	1769.9	1763.7	1763.8	1762.9	1763.5	1763.8	1763.9	1763.3	1762.3

Table 11. Maximum daily elevation (feet) of Kootenay Lake

	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Standard FC only	1749.2	1753.3	1747.9	1751.9	1748.6	1749.7	1747.2	1748.0	1747.8	1746.1
VARQ FC only	1749.6	1755.4	1749.7	1751.4	1749.0	1750.2	1748.0	1749.2	1750.1	1748.1
Standard FC with fish flows (max. Libby outflow 25 kcfs)	1751.9	1752.9	1748.6	1751.1	1749.5	1749.8	1749.8	1749.3	1750.6	1748.5
VARQ FC with fish flows (max. Libby outflow 25 kcfs)	1752.3	1755.4	1749.7	1751.1	1749.7	1750.5	1750.0	1750.0	1750.7	1748.7
Standard FC with fish flows (max. Libby outflow 35 kcfs)	1752.4	1753.1	1749.6	1751.3	1749.4	1750.9	1750.5	1750.3	1751.4	1749.0
VARQ FC with fish flows (max. Libby outflow 35 kcfs)	1752.7	1755.4	1750.4	1751.3	1749.7	1751.3	1750.7	1750.9	1751.5	1749.2

Table 12. Maximum 7-day average elevation (feet) of Kootenay Lake

	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Standard FC only	1749.1	1753.2	1747.7	1751.7	1748.5	1749.5	1747.1	1747.8	1747.7	1745.9
VARQ FC only	1749.6	1755.3	1749.6	1751.3	1748.8	1750.1	1747.9	1749.0	1750.0	1747.9
Standard FC with fish flows (max. Libby outflow 25 kcfs)	1751.9	1752.8	1748.5	1750.9	1749.4	1749.8	1749.7	1749.2	1750.5	1748.2
VARQ FC with fish flows (max. Libby outflow 25 kcfs)	1752.3	1755.3	1749.6	1751.0	1749.5	1750.4	1749.8	1749.9	1750.6	1748.5
Standard FC with fish flows (max. Libby outflow 35 kcfs)	1752.2	1753.0	1749.5	1751.1	1749.1	1750.7	1750.5	1750.2	1751.1	1748.9
VARQ FC with fish flows (max. Libby outflow 35 kcfs)	1752.6	1755.3	1750.3	1751.1	1749.5	1751.3	1750.6	1750.8	1751.2	1749.2

3.2.6 Duncan Dam

At Duncan Dam, the scenarios with fish flows have very similar results to the flood control-only scenarios. There is no significant change in either the maximum daily outflow or the maximum daily lake elevation. This is shown in Table 13 and Table 14 below.

Table 13. Maximum daily outflow (kcfs) from Duncan Dam

	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Standard FC only	12.1	8.5	7.2	8.8	10.5	12.6	9.2	10.0	8.0	8.2
VARQ FC only	11.6	7.6	7.2	8.8	10.5	12.6	9.2	10.0	8.0	8.2
Standard FC with fish flows (max. Libby outflow 25 kcfs)	12.1	8.5	7.2	8.8	10.5	12.6	9.2	10.0	8.0	8.2
VARQ FC with fish flows (max. Libby outflow 25 kcfs)	11.6	7.6	7.2	8.8	10.5	12.6	9.2	10.0	8.0	8.2
Standard FC with fish flows (max. Libby outflow 35 kcfs)	12.1	8.5	7.2	8.8	10.5	12.6	9.2	10.0	8.0	8.2
VARQ FC with fish flows (max. Libby outflow 35 kcfs)	11.6	7.6	7.2	8.8	10.5	12.6	9.2	10.0	8.0	8.2

Table 14. Maximum daily elevation (feet) of Duncan Dam Reservoir

	1933	1948	1949	1955	1968	1971	1975	1981	1986	1989
Standard FC only	1892.0	1892.0	1889.8	1891.6	1892.0	1891.7	1892.0	1891.5	1892.0	1892.0
VARQ FC only	1891.7	1892.0	1889.9	1891.6	1892.0	1892.0	1892.0	1891.6	1892.0	1892.0
Standard FC with fish flows (max. Libby outflow 25 kcfs)	1892.0	1892.0	1889.8	1891.6	1892.0	1891.7	1891.6	1891.5	1892.0	1892.0
VARQ FC with fish flows (max. Libby outflow 25 kcfs)	1891.7	1892.0	1889.9	1891.6	1892.0	1892.0	1892.0	1891.6	1892.0	1892.0
Standard FC with fish flows (max. Libby outflow 35 kcfs)	1892.0	1892.0	1889.8	1891.6	1892.0	1891.7	1891.6	1891.5	1892.0	1892.0
VARQ FC with fish flows (max. Libby outflow 35 kcfs)	1891.7	1892.0	1889.9	1891.6	1892.0	1892.0	1892.0	1891.6	1892.0	1892.0

4.0 Conclusions

The hydrologic modeling described in this report was performed in order to evaluate potential impacts in the Kootenai basin from VARQ FC. The flood-control-only simulations discussed in Section 2.0 show that both methods of flood control have a high probability of reservoir refill in the absence of power drafts and flow augmentation for listed species. The simulations also show that the outflow from Libby Dam, the river stage at Bonners Ferry, and the elevation of Kootenay Lake all tend to increase in the late spring/early summer under VARQ.

The simulations discussed in Section 3.0 show that there may be impacts at Libby Dam, Bonners Ferry, and Kootenay Lake when fish flows are modeled in addition to flood-control. Generally, Lake Koocanusa has a lower chance of refilling when fish flows are provided from Libby Dam. VARQ with fish flows does a better job of getting the reservoir close to full than Standard FC with fish flows. In most cases, the maximum outflow from Libby Dam increases as a result of fish flows. There are some years, however, when the opposite is also true. Stages at Bonners Ferry increase almost without exception. Many of these increases still keep the water level below the current estimate for flood stage at 1764 feet, the official flood stage at the present time. The level of Kootenay Lake is also likely to increase when fish flows are introduced. The typical increase is between 1 and 3 feet, depending on the flood control method (standard or VARQ) and type of fish flows provided (limited to 25 kcfs or 35 kcfs from Libby Dam).

5.0 References

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