APPENDIX B

Libby Dam Hydro-Regulation Modeling Report

Hydrologic Analysis of Upper Columbia Alternative Operations: Local Effects of Alternative Flood Control and Fish Operations at Libby Dam

July 2004

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Errata Sheet—

Upper Columbia Alternative Flood Control (VARQ) and Fish Operations EIS –

Hydrologic Analysis of Upper Columbia Alternative Operations: Local Effects of Alternative Flood Control and Fish Operations at Libby Dam

Nomenclature Corrections

The following information should be used when reading the subject report.

Standard FC with fish flows at powerhouse capacity (Standard w/ FF @ powerhouse): corresponds to **Alternative LS1** in EIS

VARQ FC with fish flows at powerhouse capacity (VARQ w/ FF @ powerhouse): corresponds to **Alternative LV1** in EIS

Standard FC with fish flows at powerhouse plus 10 kcfs capacity (Standard w/ FF @ powerhouse +10 kcfs): corresponds to **Alternative LS2** in EIS

VARQ FC with fish flows at powerhouse plus 10 kcfs capacity (Standard w/ FF @ powerhouse+10 kcfs): corresponds to **Alternative LV2** in EIS

Standard FC benchmark: corresponds to **Benchmark Operation LS** in EIS

VARQ FC benchmark: corresponds to **Benchmark Operation LV** in EIS

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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). Construction of Libby Dam began in 1967, the structure was complete by 1973, and the project became fully operational in March, 1975. Libby Dam is operated to provide storage for system flood control on the lower Columbia River, storage for local flood control in the Kootenai basin, and hydroelectric power generation. Incidental purposes of the project are navigation and recreation.

Since the construction of Libby Dam, several populations of fish 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 NOAA Fisheries (NMFS) each issued a Biological Opinion outlining measures to protect the listed species. Among those measures is implementation of VARQ ("variable flow," with Q representing engineering shorthand for flow) alternative flood control at Libby and Hungry Horse dams in Montana. The intent of VARQ flood control (VARQ FC) is to better assure reservoir refill in years when flood control flexibility allows it. That in turn is intended to allow more assured provision of flows to benefit endangered Kootenai River white sturgeon, threatened bull trout in the Kootenai and Flathead rivers, and various listed stocks of salmon and steelhead in the Columbia. To allow a decision whether to implement VARQ on a long-term basis, and to address certain fish-flow related provisions in the Biological Opinions, an environmental impact statement (EIS) is being prepared. The official title of the EIS is the "Upper Columbia Alternative Flood Control and Fish Operations EIS" (UCEIS). The UCEIS updates previous modeling studies (Corps 1998; Corps 1999; Corps 2002).

It is important to note that the UCEIS addresses impacts of operational changes for Libby, Hungry Horse (on the South Fork Flathead River in Montana) and Grand Coulee (on the Columbia River in Washington) dams. However, because of the differences in how these three projects fit into the Federal Columbia River Power System, this report addresses VARQ FC only at Libby Dam. The US Bureau of Reclamation is providing separate analyses of the operation of Hungry Horse Dam. This analysis and that for Hungry Horse dam are informing a system hydropower modeling study, and that feeds into analysis for Grand Coulee Dam.

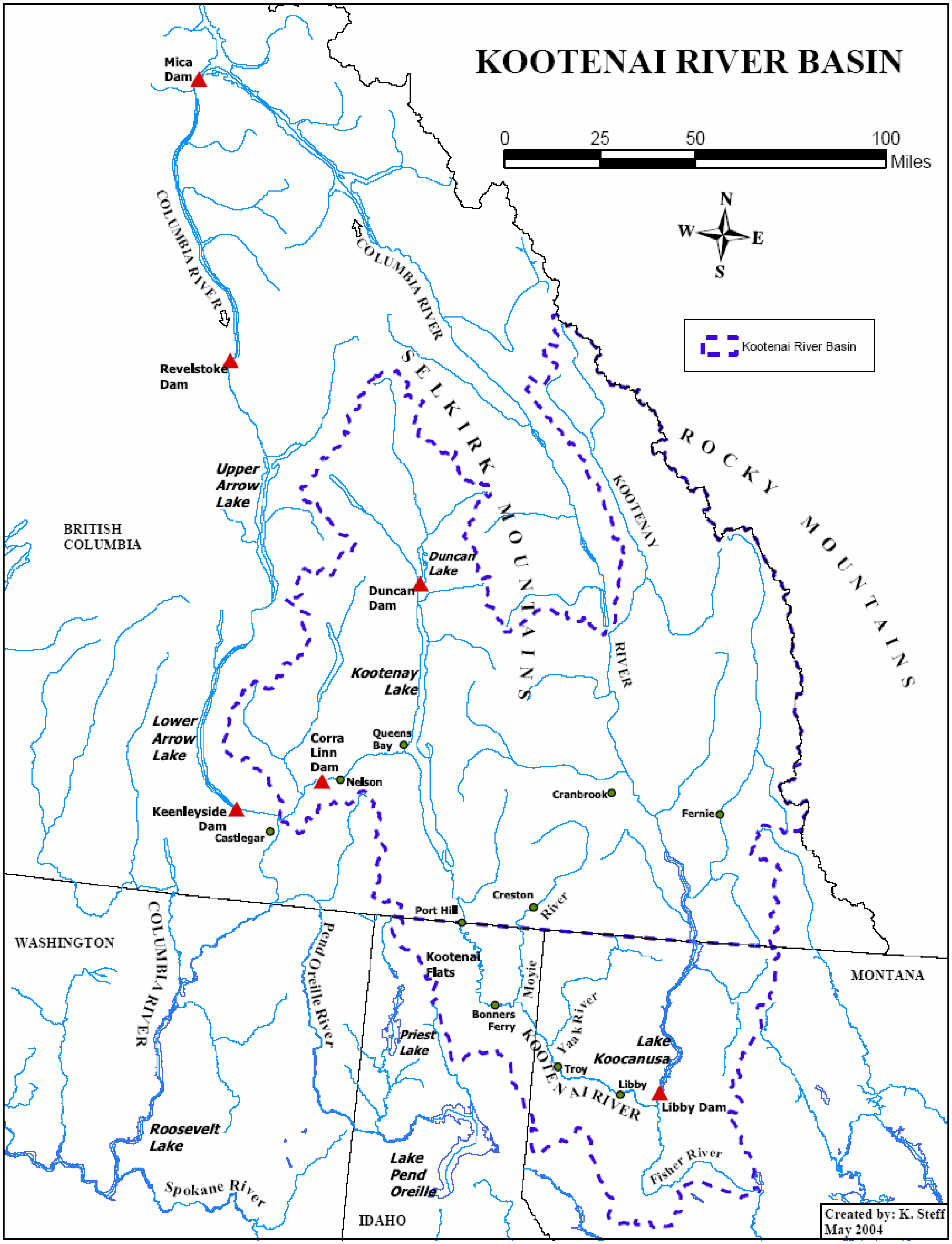

Figure 1. Kootenai River Basin Showing Canadian and U.S. Dams

The procedure currently authorized for long-term use is referred to as Standard FC, also called "BASE-CRT63". Before considering a permanent switch in flood control procedures, the Corps must perform hydrologic modeling to evaluate potential impacts from long-term implementation of VARQ FC. VARQ FC and Standard FC have the same reservoir draft *requirement* whenever the water supply forecast is greater than about 125% of normal[1]. In practice, the flood control draft *achieved* with VARQ FC would differ from the draft achieved with Standard FC only when the forecast falls between about 80%[2] and 120%[3] of normal. In other words, although the VARQ FC draft requirement differs from the Standard FC draft requirement whenever the forecast is less than 125% of normal, in practice there is a difference only when the forecast falls between about 80% and 120% of normal. A comparison of these two flood control methods is provided in Section 2.2 of this report. The VARQ FC procedure examined in this report is the same as that recommended in the USFWS and NMFS 2000 Biological Opinions.

The Biological Opinions also recommend flow augmentation (or "fish flows") for the benefit of listed species. Fish flows include: 1) sturgeon augmentation volumes which are provided in most years and vary based on the water supply forecast; 2) bull trout minimum flows which begin when sturgeon augmentation is over[4], and are also dependent on the water supply forecast; and 3) the salmon augmentation draft which begins sometime in either July or August and drafts Libby to an elevation of 2439 feet by the end of August (20 feet from full). The modeling of fish flows is described in Section 3.1.3 of this report.

1.2 Status of Study

In 2001, the Corps and the Bureau of Reclamation published a notice of intent to prepare an EIS and held public scoping meetings to begin collecting information on potential impacts from VARQ FC. The UCEIS is scheduled to be completed in 2005 in order to allow a record of decision in time to implement the selected alternative during the flood control season of 2006.

The Environmental Assessment (EA) for interim implementation of VARQ FC with fish flows (including sturgeon flows up to powerhouse capacity plus 1 kcfs spill) received a Finding of No Significant Impact in December 2003. Since then, the Corps of Engineers has been operating Libby Dam according to VARQ FC procedures and has continued to provide fish flows.

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[1] Forecast volumes expressed as "percent of normal" are based on the average observed runoff volume for the April-August period (POR: 1971 - 2000). This is the period of record used by the Northwest River Forecast Center to calculate average basin runoff volumes.

[2] For forecasts less than 80% of normal, the reservoir involuntarily drafts more water than is required by either VARQ FC or Standard FC. This is due to Libby's minimum outflow requirement of 4 kcfs.

[3] For forecasts greater than 120% of normal, Libby typically does not achieve the draft required by either VARQ FC or Standard FC. This occurs because Libby outflow must be reduced to comply with the 1938 IJC Order on Kootenay Lake.

[4] In years when sturgeon flow augmentation is not provided, a minimum bull trout flow is still required.

This report, entitled *Hydrologic Analysis of Upper Columbia Alternative Operations: Local Effects of Alternative Flood Control and Fish Operations at Libby Dam*, provides the technical analysis for the hydro-regulation model results for VARQ FC and Fish Flows at Libby Dam and is presented as an appendix to the UCEIS. Some information contained in this report is also used in further analyses such as those for economic, resident fish, and seepage impacts. Note that this report addresses results of the Kootenai basin flood control modeling alone. For a comprehensive evaluation of all possible impacts and benefits from the different dam operations investigated (including analysis of effects on agricultural seepage in the Kootenai Flats, hydropower, socioeconomics, resident fish, cultural resources, sediments, and other resources), please refer to the UCEIS main report.

1.3 Description of Modeled Simulations

All of the modeled simulations discussed in this report were developed using a numerical computer model. Simulations are also called "runs" and "hydro-regulations." A total of six different simulations were completed for this modeling report, as well as two sets of sensitivity runs (Table 1). It should be noted that all future operations will include some fish flows. Therefore, simulations 1 and 2, which do not include fish flows, are not considered "alternatives" under the UCEIS. Rather, they are "benchmark scenarios" used to assess differences between Standard FC and VARQ FC without the added impacts associated with fish flows, and to provide a basis to evaluate the effects of the fish flows.

Table 1. Simulation Runs.

Simulation 1	Standard FC Benchmark *[or LS in the EIS]*
Simulation 2	VARQ FC Benchmark *[or LV in the EIS]*
Simulation 3	Standard FC with fish flows at powerhouse capacity *[or LS1 in the EIS]*
Simulation 4	VARQ FC with fish flows at powerhouse capacity *[or LV1 in the EIS]*
Simulation 5	Standard FC with fish flows at powerhouse plus 10 kcfs capacity *[or LS2 in the EIS]*
Simulation 6	VARQ FC with fish flows at powerhouse plus 10 kcfs capacity *[or LV2 in the EIS]*
Sensitivity 1	Standard FC and VARQ FC with fish flows at powerhouse plus 10 kcfs capacity with conservative assumptions
Sensitivity 2	Standard FC and VARQ FC with fish flows at powerhouse plus 10 kcfs capacity with non-conservative assumptions

The Corps' Streamflow Synthesis and Reservoir Regulation computer model (SSARR) and the Autoreg pre/post-processing program were used to perform the model simulations for this study. Using historic unregulated streamflow records, reservoir storage-elevation relationships, rating curves for hydraulic capacity, and streamflow routing procedures, the operation of the Kootenai system was simulated according to user-defined rules. Typical rules include drafting a reservoir according to a specified rule curve, imposing maximum and/or minimum flow requirements, or providing an outflow over a specified period of time. The simulations were conducted using a daily time step, providing daily output values for reservoir elevation, project releases, and river flows and stages.

The results form these simulations are provided in three separate sections within this report: Hydrologic Analysis of Flood Control Alternatives (Section 2.0); Hydrologic Analysis of Flood Control Alternatives with Fish Flows (Section 3.0); and Hydrologic Analysis of Sensitivity Runs (Section 4.0).

1.3.1 Description of Flood Control

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

1.3.1.1 Standard FC Draft

Standard FC was the method used at Libby Dam prior to and through calendar year 2002. Under Standard FC, Libby Dam is regulated according to the *Columbia River Treaty Flood Control 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 in Libby needs to be made available by 15 March 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[5] was not taken into consideration for Standard FC hydro-regulations.

[5] In the flood control simulations, all prescribed drafts at storage projects are made for flood control purposes, not for power generation. In the fish flow simulations, prescribed drafts also occur for the purpose of benefiting downstream fish (i.e., the 20 ft salmon draft in July-August), but again, drafting for the purpose of power generation is not included. A power modeling report is attached as a separate appendix to the UCEIS. This report discusses modeling and modeling results that have been completed to analyze the impacts from flood control, fish flows, and power operations.

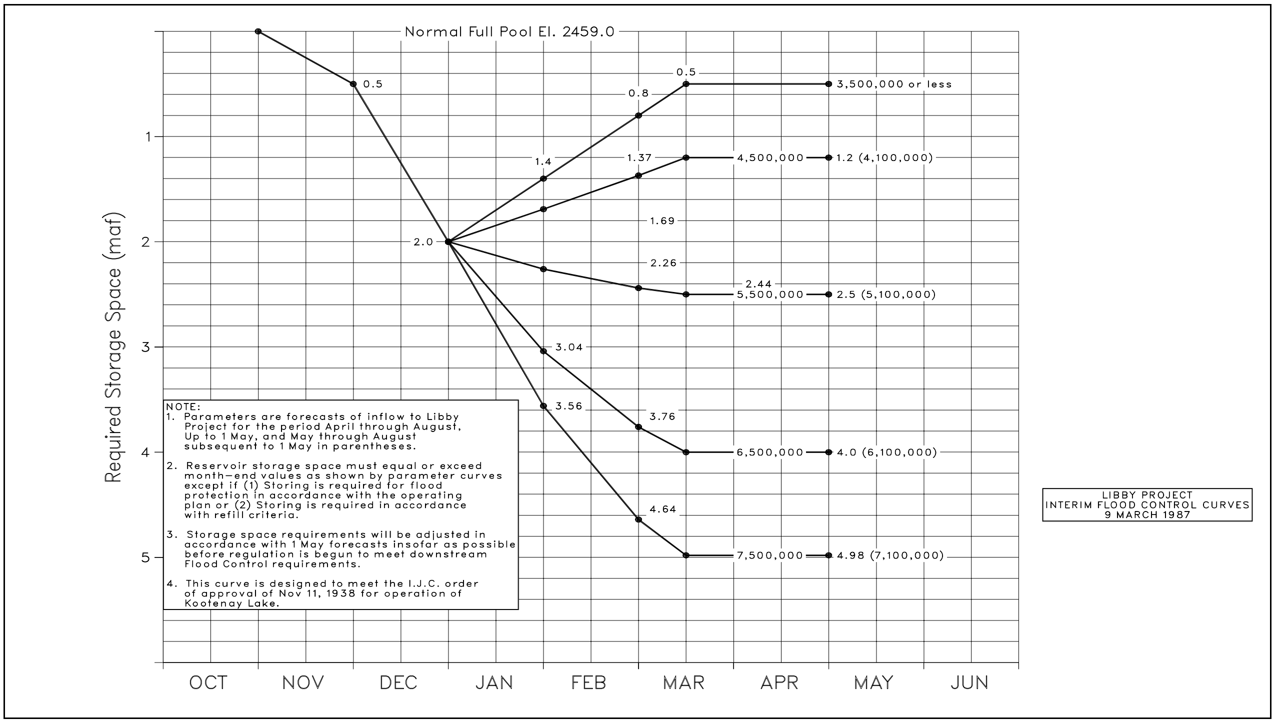

Figure 2. Columbia River Treaty Flood Control Operating Plan Storage Reservation Diagram (SRD) at Libby Dam

1.3.1.2 VARQ FC Draft

VARQ FC is the flood control method being used on an interim basis at Libby Dam, and recommended for long-term implementation in both of the Biological Opinions. 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). Most recently, VARQ FC was described in the *Upper Columbia Alternative Flood Control and Fish Operations Interim Implementation Environmental Assessment* (Corps 2002), previously mentioned in Section 1.2 of this report. Like Standard FC, VARQ FC requires a storage reservation diagram in conjunction with the water supply forecast 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 FC SRD, the VARQ SRD generally requires less flood control space (Figure 3). Consistent with the Standard FC simulations, additional storage space associated with possible power drafts was not taken into consideration for VARQ FC hydro-regulations.

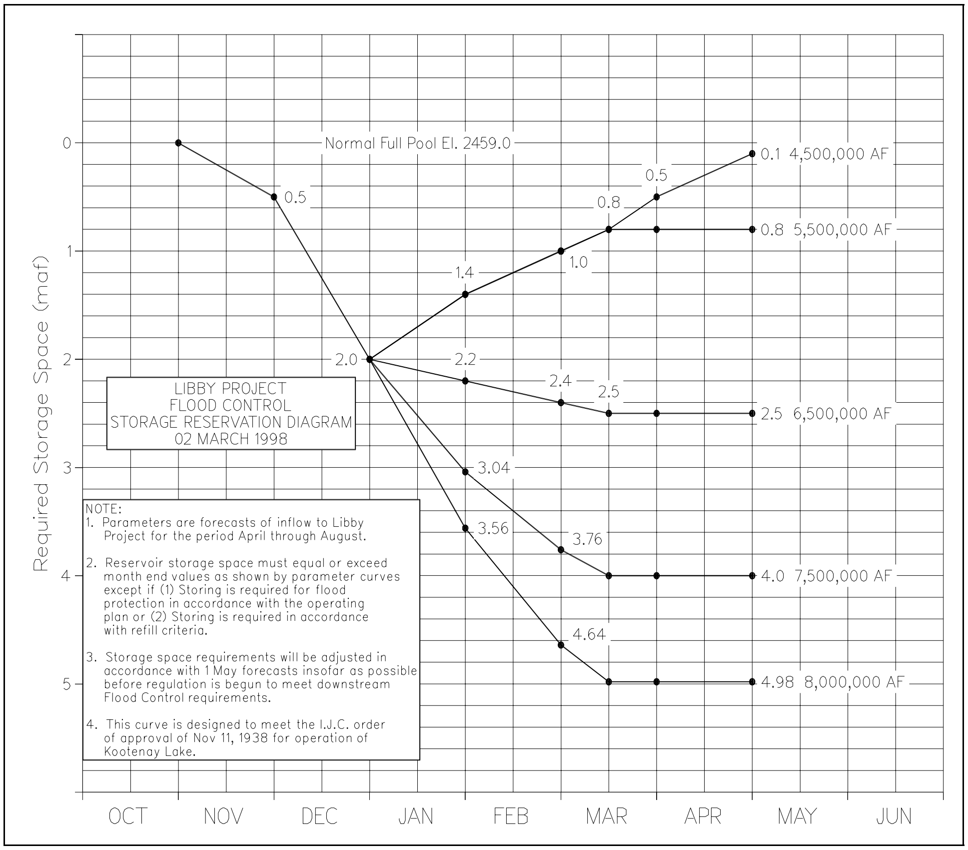

Figure 3. VARQ Storage Reservation Diagram (SRD) at Libby Dam

1.3.1.3 Standard FC and VARQ FC Refill

The Standard FC SRD for Libby Dam is part of the 1972 Columbia River Treaty Flood Control Operating Plan (FCOP), as amended, and is based on the concept that outflow from Libby Dam during the refill period will be held constant at the minimum outflow requirement of 4 kcfs. Unlike Standard FC, the VARQ SRD was developed with the assumption that outflow from Libby Dam during the refill period would vary based on the reservoir level and water supply forecast. VARQ FC is intended to improve refill reliability, thereby facilitating flow augmentations for fish. VARQ FC is intended to provide the same level of system and local flood protection as Standard FC as prescribed in the Libby Project authorizing document.

1.3.2 Description of Fish Flows

The USFWS and NMFS 2000 Biological Opinions recommended several fish flow operations to help protect Kootenai River sturgeon, Columbia basin bull trout, and various stocks of Columbia basin salmon and steelhead. The first requirement is to provide a tiered volume of water during the spring freshet for sturgeon spawning and recruitment[6], followed by a tiered minimum bull trout flow during July and August.

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[6] The volume of water for sturgeon can either be released at powerhouse capacity, or at powerhouse capacity plus some additional flow capacity up to 10 kcfs. The additional flow capacity of 10 kcfs is

Finally, through July and August Libby drafts to elevation 2439 feet, 20 feet from full, for salmon flow augmentation. The ramping rates specified in the Biological Opinions were used for these simulations. Actual fish flow operations will look different than those for this model study. In real-time they are managed to address differing conditions each year, including calls from the USFWS and NMFS for specific fish flows. In contrast, evaluations based on model studies must use a consistent set of provisions in order to make valid comparisons. The rules and assumptions used for modeling fish flows are explained in further detail later in this report, under Section 3.1.3.

1.3.3 Use of Sensitivity Runs

Risk-Based Analysis for Flood Damage Reduction Studies, EM 1110-2-1619 (Corps 1996), stipulates that risk and uncertainty should be characterized, when possible, to describe the uncertainty in choice of the hydrologic, hydraulic, and economic functions, to describe parameter uncertainty, and to describe explicitly the uncertainty in results.

The team members for this study, in conjunction with community members participating in the Kootenai Valley Resources Initiative (KVRI), identified uncertain model parameter combinations to define an upper-bound scenario and a lower-bound scenario for river stage at Bonners Ferry. The rules used for sensitivity runs are explained in further detail later in this report, under Section 4.0.

1.3.4 Statistical Analysis

Potential impacts throughout the Kootenai basin as a result of VARQ FC and/or fish flows can be characterized with flow/stage-frequency curves and flow/stage-duration curves at various locations. Procedures for graphing regulated hydrologic data are outlined in a Corps Engineer Manual entitled *Hydrologic Frequency Analysis*, EM 1110-2-1415 (Corps 1993). As stipulated in the manual, frequency curves for regulated systems (like the Kootenai) are better calculated by graphical methods ("hand-fit") than by pure statistical methods. In some cases, known information outside of the modeling was used to help define specific regions of frequency curves, as will be discussed in subsequent sections (Sections 2.2.3, 2.2.6, and 2.2.7).

1.3.5 Transmission Limitations

In recent years, there has been a transmission restriction in Western Montana which has limited combined generation at Libby and Hungry Horse dams to 900 MW. Current generation capacity is 600 MW for Libby and 428 MW for Hungry Horse for a total of 1028 MW. The limit will be raised from 900 MW to at least 944 MW by the summer of 2005. Even with this increase in transmission capacity, there will still be limitations that will prevent Libby and Hungry Horse from generating at full capacity at the same time. The modeling for this report assumes that Libby is able to use its full powerhouse capacity whenever needed, and that any necessary reductions in generation are assumed by Hungry Horse Dam. This is discussed in further detail in the *Hydrologic Analysis of the VARQ Flood Control Plan at Hungry Horse Dam, Montana*, a report prepared by the

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stipulated in the 2000 USFWS Biological Opinion. The means of providing the additional flow capacity is not identified in this report, or in the UCEIS itself.

Bureau of Reclamation and included as a separate appendix to the UCEIS (Reclamation 2004).

2.0 Hydrologic Analysis of Flood Control Methods

2.1 Hydro-Regulations

To evaluate flood control methods for this study, simulated hydro-regulations were used in order to compare the differences between Standard FC and VARQ FC. As stated in section 1.3, these simulations were performed to provide a comparison between the two flood control procedures without the influence of fish flows. The flood-control-only runs also serve as a basis to evaluate how the fish flows affect the basin hydrology.

The outcome of the hydro-regulations can be affected by many factors, including (but not limited to): the period of record used for modeling, the assumed water supply forecasts, and the rules used to trigger operational changes. To minimize bias, a consistent set of rules regarding flood control drafts, residual volume tracking, and foresight were applied in all model simulations. Factors affecting the hydro-regulations are discussed in greater detail later in this report.

Modeling of the Kootenai River basin was conducted using the Corps SSARR and Autoreg computer programs. The modeling was conducted using a daily time step, providing daily output of parameters such as reservoir elevation, project releases, and river flows.

2.1.1 Period of Record for Flood Control Modeling

A 52-year record (1948-1999) 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 having less than a 1% chance exceedance.[7] This study makes use of a Libby Dam regulated 0.5%-chance-exceedance[8] hypothetical flood, based on the flood event of 1894, in order to extrapolate frequency curves into this range.

2.1.2 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 SRDs (Figure 2, Figure 3). An SRD is used in combination with a seasonal water supply forecast to determine how much space is needed for flood control. 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 a flood control operation. The water supply forecasts used for this study are a combination of derived and actual water

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[7] A 1%-chance-exceedance flood has a 1 in 100 chance of being equaled or exceeded in any given year. It is sometimes called a “100-year flood.”

[8] A 0.5%-chance-exceedance flood has a 1 in 200 chance of being equaled or exceeded in any given year. It is sometimes called a “200-year flood.”

supply volume forecasts for the 1948-1999 period. The forecasts used are the Wortman-Morrow Forecasts, which have been used to predict the inflow volume to Libby Dam for real-time operation since 1986. Historic snowpack, precipitation and temperature data were used to derive the Wortman-Morrow Forecasts from 1948-1985.

2.1.3 Upper Rule Curves

As a prerequisite to performing flood control simulations for the Kootenai basin, Upper Rule Curves (URCs) that guide seasonal reservoir flood control operations during the evacuation period were developed for storage projects in the basin. 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 a truly single-purpose flood control simulation, Libby would operate to its URC and would deviate from it only due to a minimum flow requirement, a flood emergency requiring temporary impoundment of water above the URC, or to prevent an IJC violation at Kootenay Lake (see Section 2.1.5). However, this flood control modeling was conducted with the additional assumption that Libby may also be above its URC if it would otherwise have to spill to reach its flood control draft targets. This modeling used a fixed end-of-December target elevation of 2411 feet.[9] In the simulations, Libby tends to be slightly above elevation 2411 ft at the end of December, due to the no-spill assumption, avoidance of an IJC violation, or a combination of the two. This is a conservative assumption from a flood control standpoint, because it puts an additional strain on achieving adequate flood control space in subsequent months.

2.1.4 Powerhouse Capacity

This modeling assumed a powerhouse capacity ranging from 19 kcfs to 27.6 kcfs, depending on reservoir pool elevation (head). The powerhouse capacity-head relationship used for modeling is based on historic data from the project. This was deemed to be the most realistic choice for estimating powerhouse capacity, rather than assuming a full wicket gate opening where the maximum powerhouse capacity was as high as 29 kcfs.

The hydro-regulation modeling for this EIS assumed that all five generating units at Libby Dam were available, and that Libby would not exceed its powerhouse capacity (i.e., Libby would not spill) in order to reach its flood control targets.

2.1.5 The 1938 IJC Order on Kootenay Lake

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 release 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 by this order. Throughout the simulations, Corra Linn Dam at the outlet of Kootenay Lake operated according to its

[9] For a discussion of the variable end-of-December draft at Libby, which was implemented after the modeling for the EIS was completed, refer to Section 1.6.1 of the DEIS or, for more details, Appendix M.

upper rule curve, unless the outflow required by the rule curve exceeded the hydraulic capacity at Grohman Narrows. Grohman Narrows is a natural constriction in the channel located upstream of Corra Linn Dam. At this location, the channel has a relatively small cross-sectional area, creating a “pinch point” that physically limits outflow to the hydraulic capacity of the opening. Once the spring rise of Kootenay Lake has commenced, the rule curve is no longer fixed and is instead determined by a “lowering” formula. During this “lowering” period, the modeled results for Kootenay Lake are based on the hydraulic capacity of Grohman Narrows.

2.1.6 Initialization

For the simulations comparing Standard FC benchmark and VARQ FC benchmark, all reservoirs in the basin were re-initialized at full pool at the beginning of each water year. (A water year begins on 1 October and ends on 30 September.) Flood control simulations are re-initialized each year, rather than run in a continuous mode, so that one year’s flood control operation is independent of conditions in the previous year. From a flood control standpoint, initializing reservoirs at full pool is a conservative assumption that will provide the most rigorous test of whether adequate flood control space can be achieved at a project.

2.1.7 Local Flood Control and Refill

The assumed Bonners Ferry flood stage used in this modeling is elevation 1764 ft, which was established by the National Weather Service in 1997. Flood stage is defined as the level or stage at which a stream overflows its banks or the stage at which the overflow of a stream begins to cause damage. In all simulations, Libby was regulated to keep the stage at Bonners Ferry below elevation 1764 insofar as possible.

Operation of Libby Dam includes an evacuation phase and a refill phase. With Standard FC, the assumed release from Libby Dam during refill is the project’s minimum outflow of 4 kcfs. With VARQ FC, the release during refill varies according to the graph shown in Figure 4, and is further refined depending on reservoir elevation. Hence, the name “VARQ”, meaning “variable flow” (“Q” is shorthand for flow).

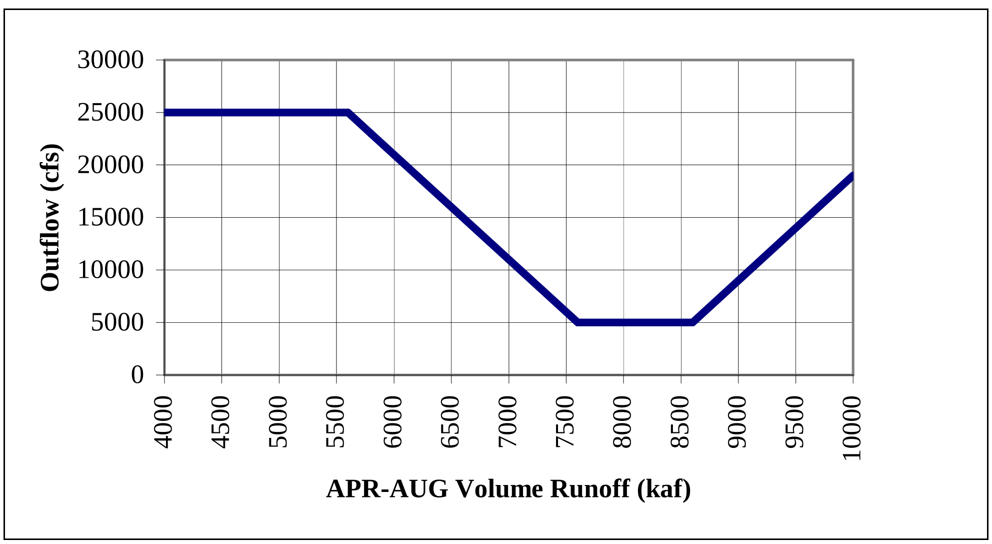


Figure 4. VARQ Outflows at Libby Dam

Refill for the standard flood control simulations began 10 days before the forecasted exceedance of the Initial Controlled Flow (ICF) at The Dales. The outflow during refill was set to the minimum flow of 4 kcfs unless the Libby reservoir elevation was significantly above the URC on the date that refill began. If this occurred, outflow from Libby was increased relative to the volume of water stored above the flood control rule curve.

Refill for the VARQ flood control simulations also began 10 days before the forecasted exceedance of the Initial Controlled Flow (ICF) at The Dalles. The VARQ outflow during refill was determined according to Appendix A: VARQ Operating Procedures, from the status report entitled *Work to Date on the Development of the VARQ Flood Control Operation at Libby Dam and Hungry Horse Dam* (Corps 1999). An abbreviated version of the rules governing VARQ FC and outflow during refill is provided at the end of this report.

The hydro-regulation model runs were performed with consistent modeling rules. Although the actual hydrograph for each historic water year is known to modelers, the modeling was conducted with limited foresight, assuming regulators would make decisions based on a 10-day streamflow forecast, and no greater. Libby outflows during refill were increased (no higher than powerhouse capacity) ten days prior to when the reservoir would otherwise fill and spill. If it appeared that Libby was not going to refill, outflows were decreased (no lower than minimum outflow) ten days before inflows dropped below powerhouse capacity. In some years, it was necessary to spill water from Libby during the late stages of refill in order to preserve flood control space. The first spill increment (2 kcfs) was used no more than five days prior to the date when the reservoir would otherwise fill and spill. If necessary, the spill was adjusted upward in a step-wise fashion using no more than three days of foresight.

In addition to the streamflow forecast foresight discussed above, adjustments were made based on volume forecasts as well. Residual volume of forecasted runoff provided an objective tool to guide the timing and magnitude of reservoir outflow adjustments. Seasonal water supply forecasts, observed runoff to date, and planned reservoir releases were used to determine whether the amount of space remaining in the reservoir was adequate to store the forecasted remaining water volume. When the residual volume ratio reached a value of two (meaning that there is twice as much water that needs to be stored as there is storage space), outflow from Libby Dam was increased in order to preserve space. This concept of residual volume tracking is also used during actual refill operations to make real-time decisions for outflow adjustments. Overall, the refill-season operations simulated for this study do a very good job of representing the actual level of skill with which reservoir refill is conducted.

2.2 Model Results

Output data from the flood control simulations were analyzed in order to quantitatively characterize the differences between the Standard FC benchmark and VARQ FC benchmark 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 Analysis of Results

Potential impacts from 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 the Standard FC benchmark and one with the VARQ FC benchmark. Procedures for graphing regulated hydrologic data are outlined in a Corps Engineer Manual entitled *Hydrologic Frequency Analysis*, EM 1110-2-1415 (Corps 1993).

2.2.2 Lake Koocanusa

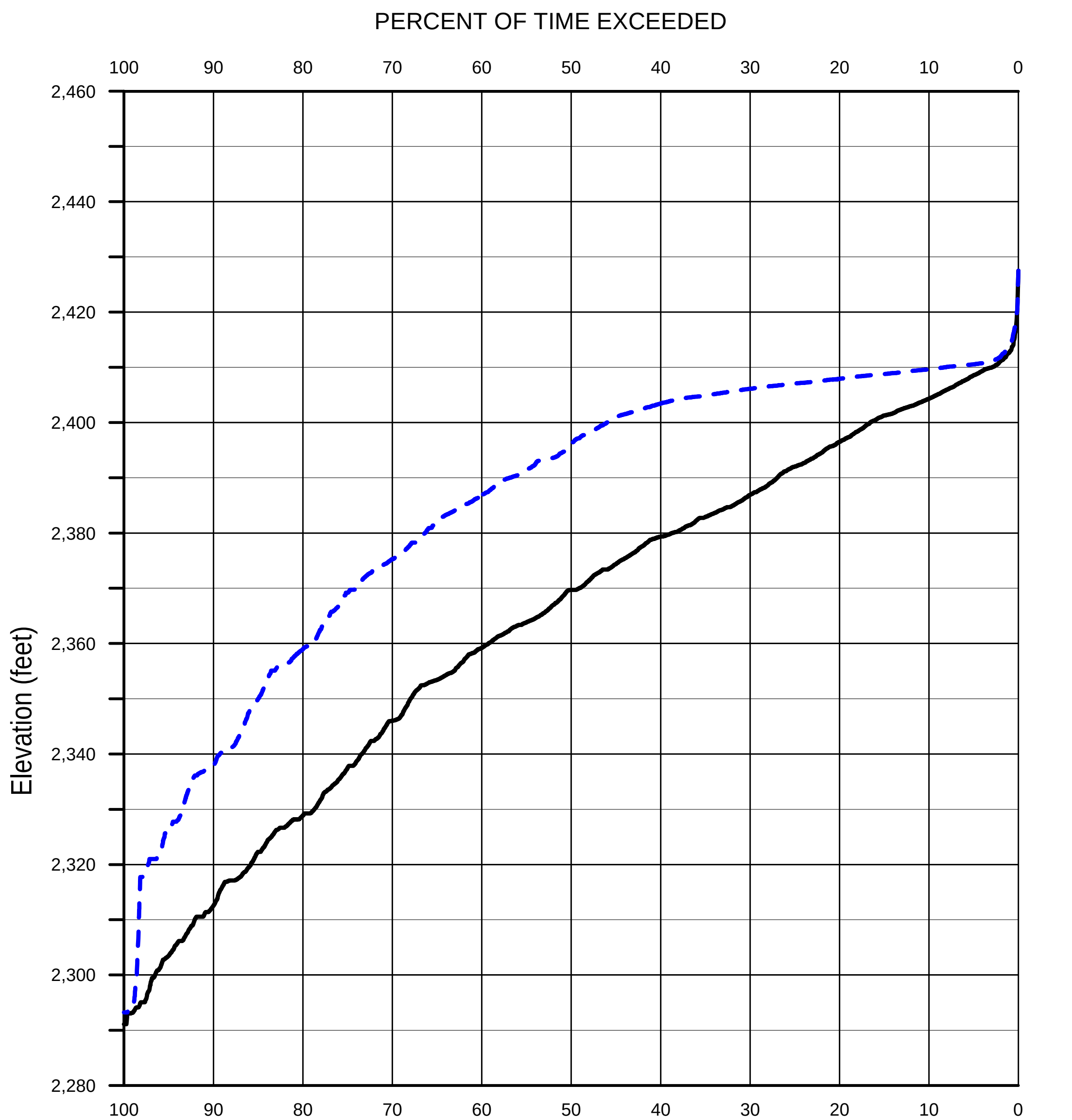
Historically, the Corps of Engineers has attempted to refill Lake Koocanusa (the reservoir behind Libby Dam) with a high degree of certainty. Model simulations for this study show that in the absence of power drafts or fish flows, it was possible to refill the reservoir within 1 foot of full before the end of July in 92% of the years, regardless of which flood control procedure is used, and within 5 feet of full before the end of July in 98% of the years, regardless of which flood control procedure is used. The simulated 31 July reservoir elevations are shown in Table 2.

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 the VARQ FC benchmark, the reservoir is above elevation 2400 feet 46% of the time, as compared with the Standard FC benchmark, when it is above that elevation only 17% of the time (Figure 5). Again, in May (Figure 6) and June (Figure 7), the VARQ FC benchmark leads to higher reservoir elevations than does the Standard FC benchmark. By July, reservoir elevations are essentially equivalent (Figure 8).

Table 2: Simulated Reservoir Elevation on 31 July (Flood Control only)

Water Year	Standard FC benchmark-->LS	VARQ FC benchmark-->LV	Water Year	Standard FC benchmark-->LS	VARQ FC benchmark-->LV
1948	2459.0	2459.0	1974	2459.0	2459.0
1949	2459.0	2459.0	1975	2458.3	2459.0
1950	2459.0	2459.0	1976	2459.0	2459.0
1951	2459.0	2459.0	1977	2451.8	2453.3
1952	2458.9	2459.0	1978	2459.0	2459.0
1953	2459.0	2459.0	1979	2456.5	2456.5
1954	2459.0	2459.0	1980	2459.0	2459.0
1955	2459.0	2459.0	1981	2459.0	2459.0
1956	2459.0	2459.0	1982	2459.0	2459.0
1957	2459.0	2459.0	1983	2459.0	2459.0
1958	2459.0	2459.0	1984	2459.0	2459.0
1959	2459.0	2459.0	1985	2456.5	2459.0
1960	2459.0	2459.0	1986	2459.0	2459.0
1961	2459.0	2459.0	1987	2459.0	2459.0
1962	2459.0	2459.0	1988	2459.0	2459.0
1963	2459.0	2459.0	1989	2459.0	2459.0
1964	2459.0	2459.0	1990	2459.0	2459.0
1965	2458.9	2459.0	1991	2459.0	2459.0
1966	2459.0	2459.0	1992	2455.4	2458.5
1967	2459.0	2459.0	1993	2459.0	2459.0
1968	2459.0	2459.0	1994	2459.0	2459.0
1969	2459.0	2459.0	1995	2459.0	2459.0
1970	2459.0	2459.0	1996	2459.0	2459.0
1971	2459.0	2459.0	1997	2459.0	2459.0
1972	2459.0	2459.0	1998	2459.0	2459.0
1973	2459.0	2459.0	1999	2459.0	2459.0

Figure 5. Elevation-Duration Analysis: Lake Koocanusa Daily Elevation (January-April), Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND

Standard FC
VARQ FC

2004 UPPER COLUMBIA EIS MODELING RESULTS

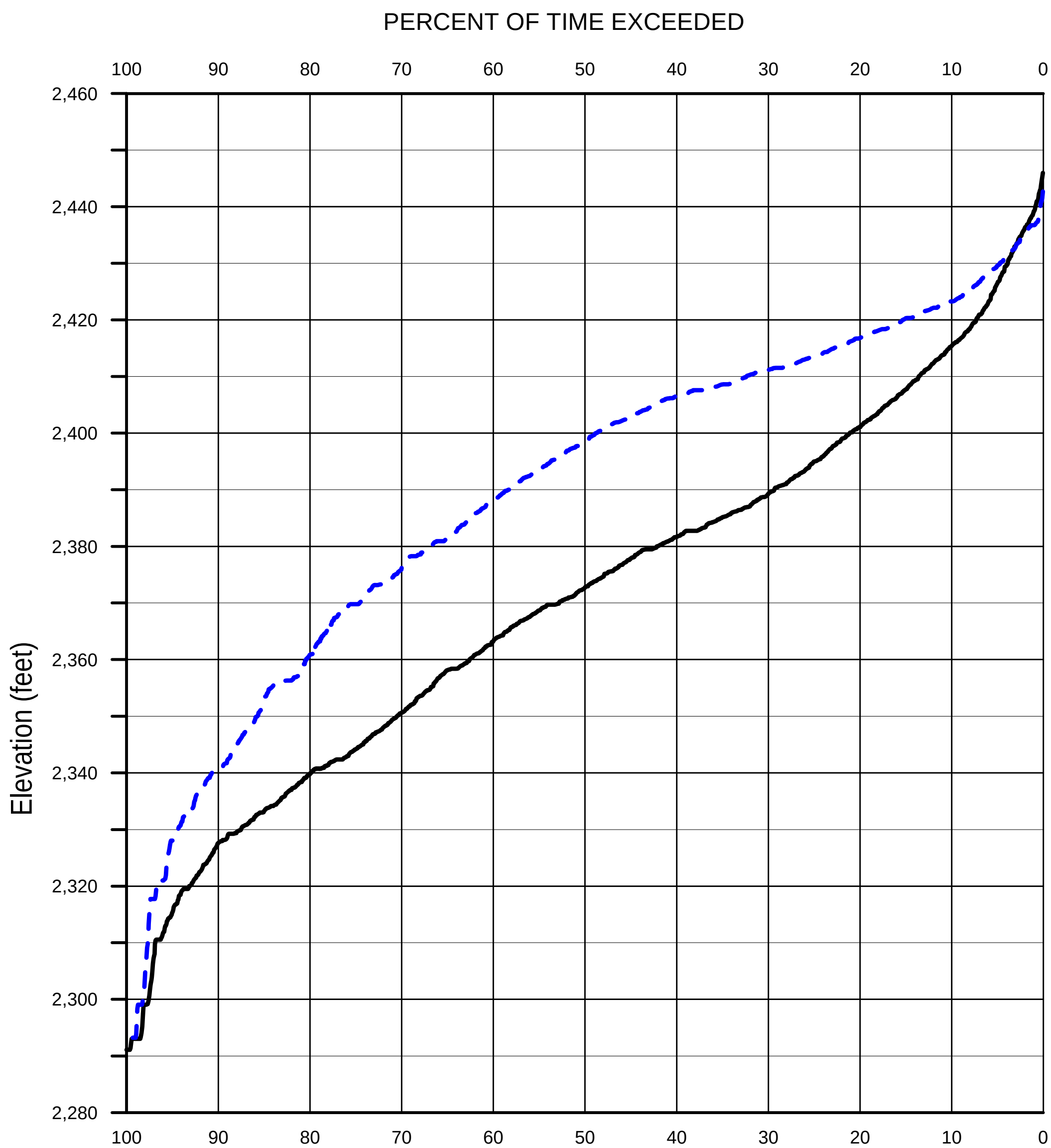
LIBBY DAM
MODELED STANDARD AND VARQ FLOOD CONTROL STAGE DURATION ANALYSIS

LIBBY DAM DAILY ELEVATION (JAN-APR)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 12 APR 2004 | CONSTRUCTED BY: CJF | APPROVED BY:

Figure 6. Elevation-Duration Analysis: Lake Koocanusa Daily Elevation (May), Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND

Standard FC

VARQ FC

2004 UPPER COLUMBIA EIS MODELING RESULTS

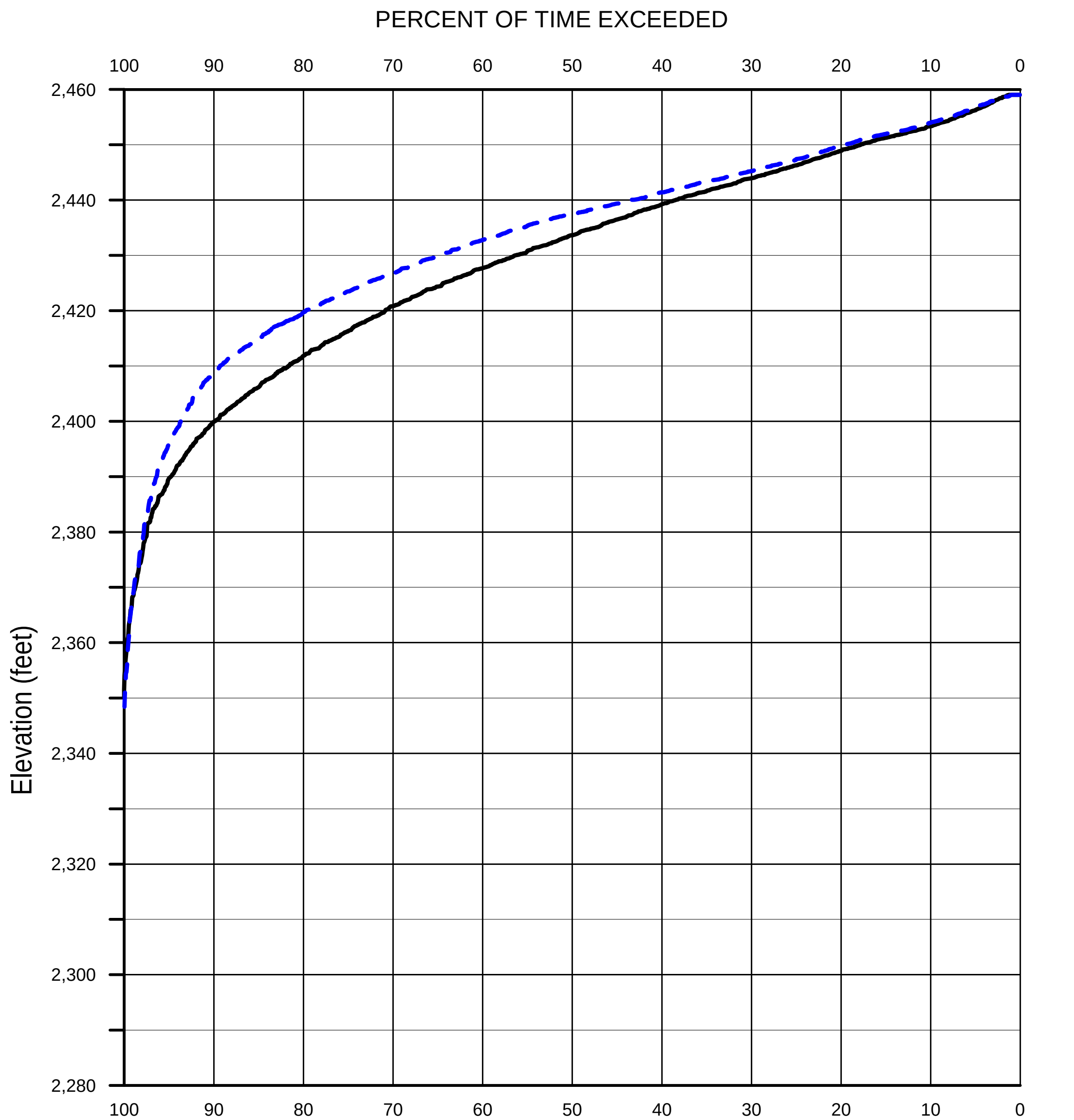
LIBBY DAM
MODELED STANDARD AND VARQ FLOOD CONTROL
STAGE DURATION ANALYSIS

LIBBY DAM DAILY ELEVATION
(MAY)

PERIOD OF RECORD: WY 1948 - 1999

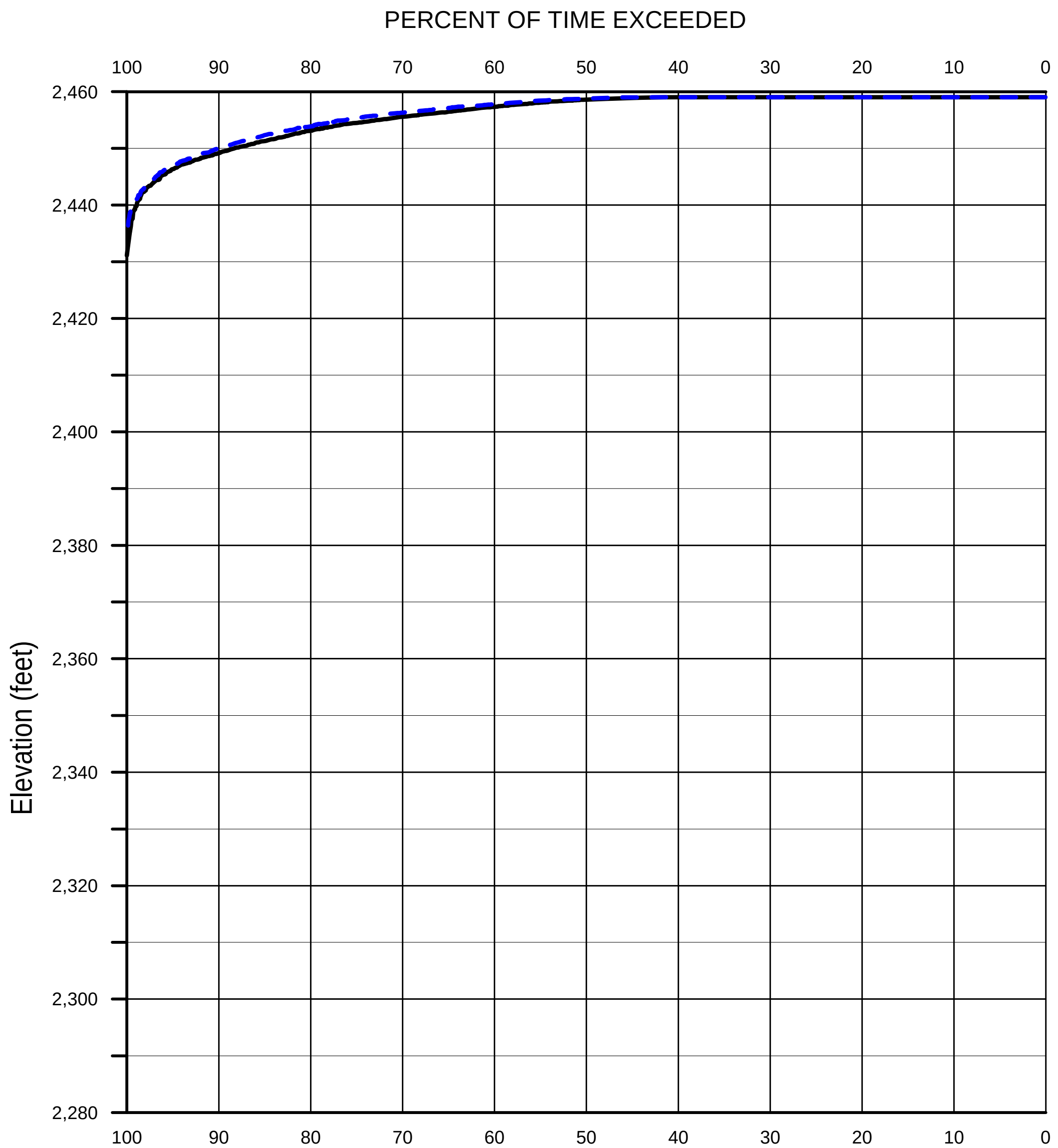
DATE: 12 APR 2004	CONSTRUCTED BY: CJF	APPROVED BY:

Figure 7. Elevation-Duration Analysis: Lake Koocanusa Daily Elevation (June), Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND	2004 UPPER COLUMBIA EIS MODELING RESULTS
Standard FC VARQ FC	LIBBY DAM MODELED STANDARD AND VARQ FLOOD CONTROL STAGE DURATION ANALYSIS LIBBY DAM DAILY ELEVATION (JUNE) PERIOD OF RECORD: WY 1948 - 1999
DATE: 12 APR 2004	CONSTRUCTED BY: CJF / APPROVED BY:

Figure 8. Elevation-Duration Analysis: Lake Koocanusa Daily Elevation (July), Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND

Standard FC

VARQ FC

2004 UPPER COLUMBIA EIS MODELING RESULTS

LIBBY DAM
MODELED STANDARD AND VARQ FLOOD CONTROL
STAGE DURATION ANALYSIS

LIBBY DAM DAILY ELEVATION
(JULY)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 12 APR 2004	CONSTRUCTED BY: CJF	APPROVED BY:

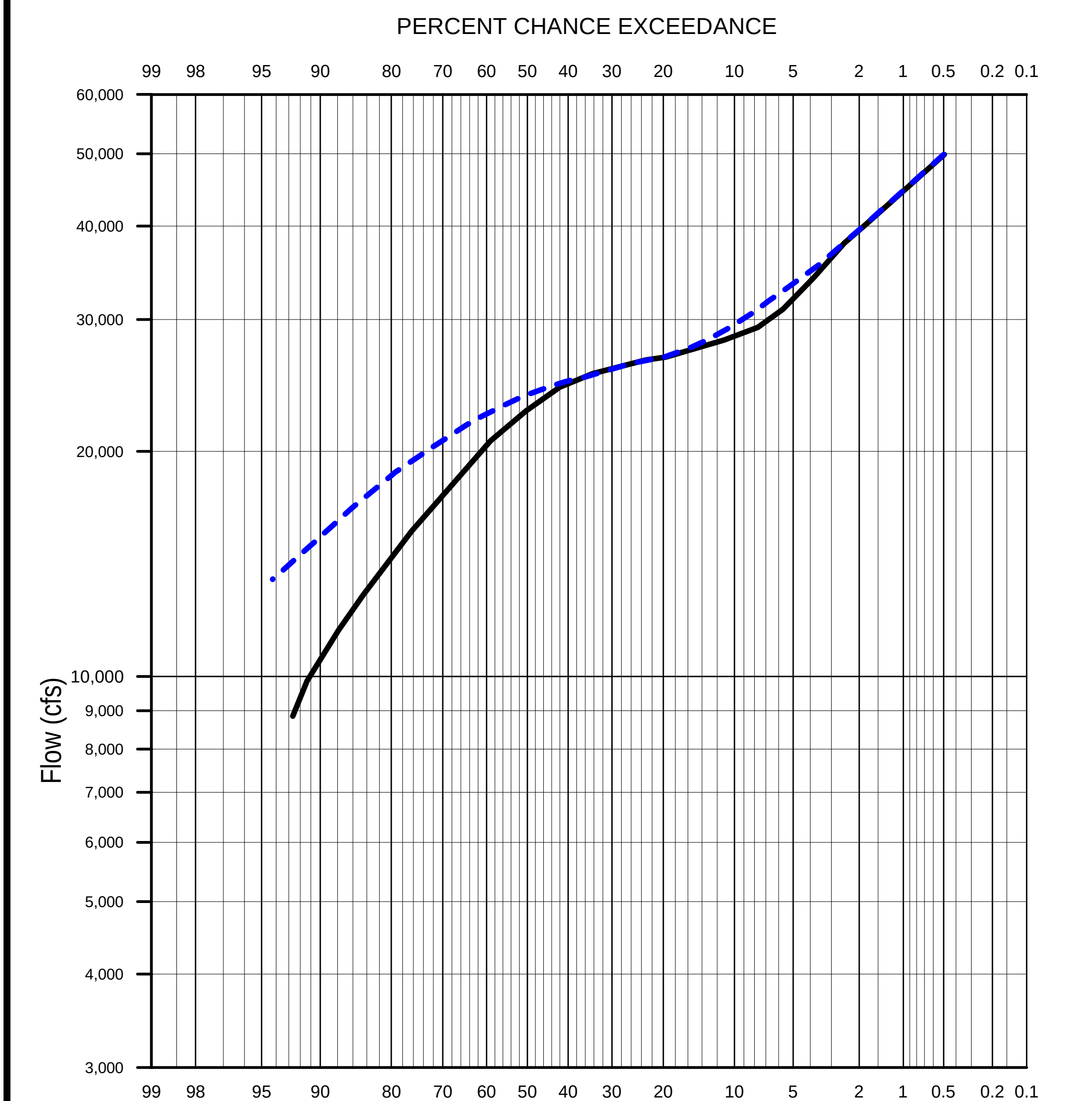
2.2.3 Libby Dam Outflow

Besides reservoir elevation, the two methods of flood control also have an impact on one-day peak outflow from Libby Dam. From a flood control perspective, the outflows during May, June, and July are of primary interest to downstream residents. A flow-frequency curve specific to those months is provided in

Figure 9[10]. At the onset of refill (usually sometime in April or May), the reservoir is generally higher with the VARQ FC benchmark than it is with the Standard FC benchmark. As a result, the Libby Dam outflows during refill are generally greater with the VARQ FC benchmark than they are with the Standard FC benchmark. For the high percent-chance-exceedance (low runoff) events (on the left side of the figure), the VARQ benchmark outflows are consistently higher than Standard FC benchmark outflows. As outflows approach the powerhouse capacity (about 25 kcfs), the two curves converge. This convergence occurs because of the modeling assumption that Libby would not exceed powerhouse capacity during refill until it was evident that spill was required to preserve flood control space. The decision to spill was made no more than five days prior to the date when the reservoir would otherwise fill and spill. For outflows just above the powerhouse capacity, the VARQ FC benchmark curve is again higher than the Standard FC benchmark curve, meaning that spilling to preserve flood control space is slightly more likely with the VARQ FC benchmark than with Standard FC benchmark. However, for the very low percent-chance-exceedance events (on the far right side of the figure), the two curves once again converge. This is because very high runoff years (April-August Libby volume inflow of 8 million acre-feet [MAF] or higher) have the exact same draft requirement for the Standard FC and VARQ FC benchmarks. In all simulations, the maximum outflow from Libby Dam remained below 40 kcfs.

[10] A regulated outflow of 50 kcfs from the hypothetical 0.5%-chance-exceedance event was used to help define the upper end of this frequency curve.

Figure 9. Flow-Frequency Analysis: Libby Dam Maximum Daily Outflow (May-July), Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND

Standard FC

VARQ FC

NOTE: A regulated outflow of 50,000 cfs from the hypothetical 0.5%-chance-exceedance event was used to help define the upper end of this frequency curve.

DATE: 27 JULY 2004

2004 UPPER COLUMBIA EIS MODELING RESULTS

LIBBY DAM, MONTANA
MODELED STANDARD AND VARQ FLOOD CONTROL
FLOW FREQUENCY ANALYSIS

LIBBY DAM MAXIMUM DAILY OUTFLOW
(MAY-JULY)

PERIOD OF RECORD: WY 1948 - 1999

CONSTRUCTED BY: CJF

APPROVED BY:

2.2.4 Water Quality

When the existing spillway at Libby Dam must be used for flood control, there is an increase in total dissolved gas (TDG) saturation downstream. In 2002, TDG data and spill amounts from Libby Dam that occurred in June and July were used to develop a relationship between spill and TDG saturation just downstream of the dam (ERDC 2003). Using this relationship, expected TDG levels greater than 100% were tabulated for the simulated Libby outflows (Table 3). The water quality standard for TDG established by the state of Montana is 110%, maximum. This110% standard was exceeded for one or more days in 11 out of 52 years modeled using the Standard FC benchmark, and 13 out of 52 years modeled using the VARQ FC benchmark. Based on all 52 years modeled, the Standard FC benchmark had 102 days in excess of the 110% standard, and the VARQ FC benchmark had 137 days in excess of the 110% standard.

Table 3. Modeled TDG Exceedance, Flood Control Simulations

Threshold TDG saturation immed. below Libby Dam	Number of years with TDG greater than threshold (Standard FC benchmark)	Number of years with TDG greater than threshold (VARQ FC benchmark)	Number of days with TDG greater than threshold (Standard FC benchmark)	Number of days with TDG greater than threshold (VARQ FC benchmark)
100%	11	13	108	142
105%	11	13	107	141
110%	11	13	102	137
115%	8	8	61	92
120%	6	7	43	79
125%	6	7	41	78
130%	3	5	27	54

2.2.5 Storage Above the URC

There are some cases when Libby, Duncan, or both, cannot be drafted in accordance with their Storage Reservation Diagram, because doing so would violate the 1938 IJC Order on Kootenay Lake. (The 1938 IJC Order is discussed in further detail in Section 2.1.5.) When this condition occurs, the reservoir (Libby, Duncan, or both) is said to have “trapped storage.” The amount of trapped storage is the volume of water stored above the URC at the time that refill begins. Storage above the URC can also happen for other reasons, such as when one or more of the generating units at Libby Dam is out of service, and/or there is a decision to maintain water quality by storing water rather than spilling it. The hydro-regulation modeling for this EA assumed that all generating units at Libby Dam were available, and that Libby would not exceed its powerhouse capacity (i.e., Libby would not spill) in order to reach its flood control targets.

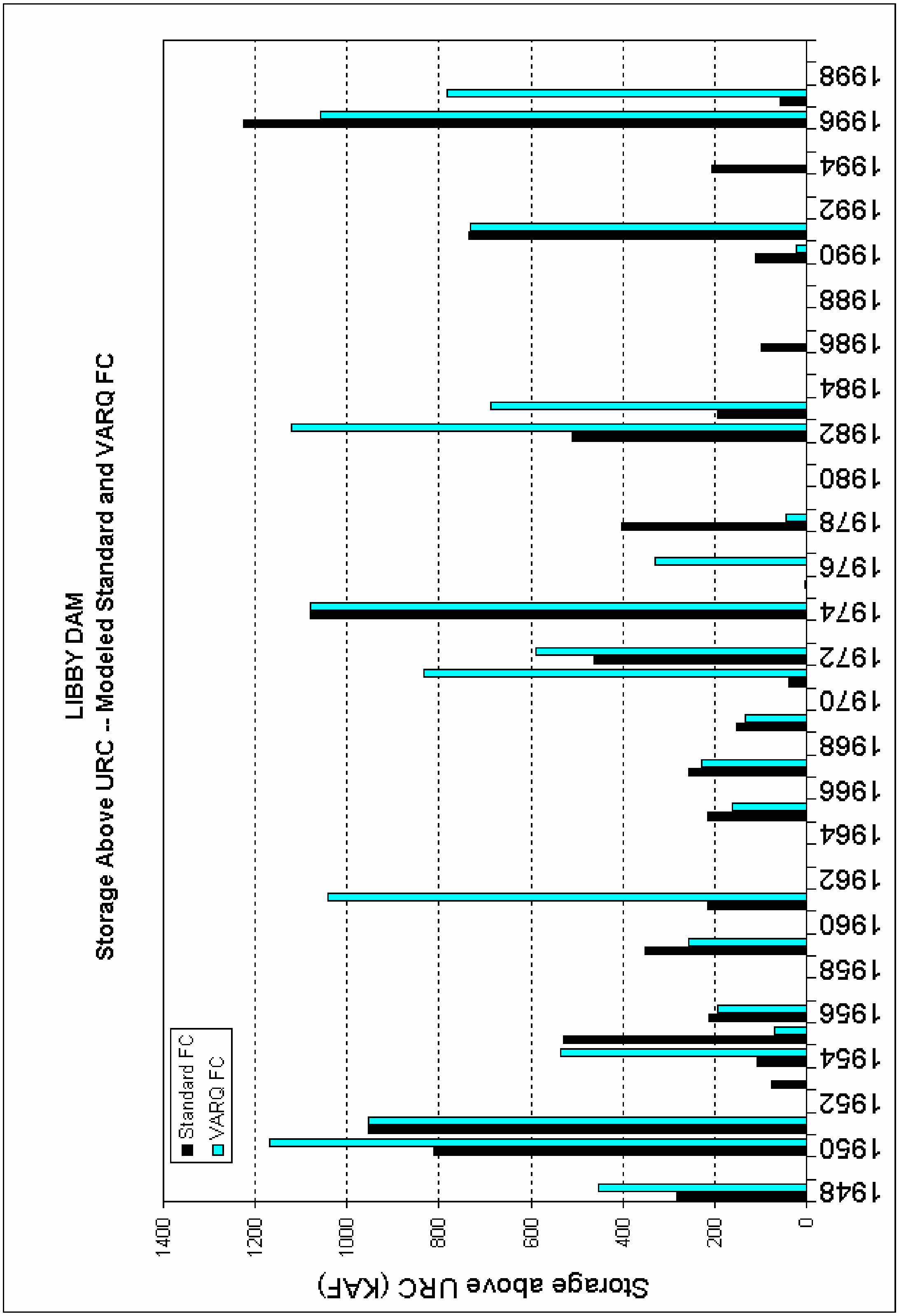
Technically, any water stored above the URC for reasons other than the IJC order on Kootenay Lake should not be called “trapped storage.” It is more appropriate to call it “undesired storage”, since the strict definition of trapped storage includes only the IJC Order on Kootenay Lake and mentions nothing of storage induced by other reasons (e.g., unit outages, water quality). In practice, any water stored above the URC is a concern, regardless of the reason why it is there. For this analysis, “trapped storage” and “undesired storage” are collectively referred to as “storage above the URC.” Figure 10 compares the amount of storage above the URC relative to each of the two flood control operations modeled. In about half of the years modeled, some amount of storage above the URC was associated with the Standard FC benchmark, VARQ FC benchmark, or both. These years fall into three general categories: 1) years when the Standard FC and VARQ FC benchmarks both have equal storage above the URC; 2) years where the VARQ FC benchmark has more storage above the URC than the Standard FC benchmark; and 3) years where the VARQ FC benchmark has less storage above the URC than the Standard FC benchmark.

The first category, where both flood control procedures have the same storage above the URC, occurs when the seasonal volume forecasts are consistently high (greater than 8 MAF) throughout the flood control draft period. The years 1951, 1974, and 1991 fall into this category. Examination of historic operations at Libby Dam confirms the tendency to be above the URC in years with very large forecasts. This is primarily due to the draft restrictions associated with the IJC Order on Kootenay Lake.

The second category describes years where the VARQ FC benchmark has more storage above the URC than the Standard FC benchmark. This occurs when the seasonal volume forecasts later in the season (in April or May) are higher than the forecasts issued earlier in the season (Jan, Feb, or March). Due to the changing nature of the forecast, the VARQ FC benchmark ends up with more storage above the URC because the draft requirement early in the season turned out to be too small. Years such as 1954, 1961, 1971, and 1982 fall into this category.

The third category describes years where the VARQ FC benchmark has less storage above the URC than the Standard FC benchmark. This is due to the simple fact that the Standard FC benchmark requires a significantly greater draft than the VARQ FC benchmark in these years, presenting a greater opportunity for having storage above the URC. Years such as 1955, 1959, 1978, and 1994 fall into this category.

Figure 10. Storage above the URC at Libby Dam as a result of Standard FC and VARQ FC Benchmarks



2.2.6 Bonners Ferry

As well as 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 #12310100 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. Flood stage is defined as the level or stage at which a stream overflows its banks or the stage at which overflow from a stream begins to cause damage.

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[11] to the Bonners Ferry area from river stages greater than 1770 feet (Corps 1992) (National Geodetic Vertical Datum 1929, or NGVD 29). Since the National Weather Service presently estimates flood stage at 1764 feet for Bonners Ferry, the hydro-regulation modeling performed for this study attempted to limit river stages to 1764 feet at Bonners Ferry insofar as possible.

The highest river stages at Bonners Ferry generally occur during the months of May, June, and July. A stage-frequency curve specific to those months is provided in Figure 11[12]. In general, the VARQ FC benchmark results in higher river stages in non-flood years at Bonners Ferry than the Standard FC benchmark. However, this effect diminishes for the lower percent-chance-exceedance events (right side of graph), and both curves temporarily plateau near elevation 1764 feet. This plateau occurs because of the modeling objective to try to limit Bonners Ferry stage to that level. Beyond the elevation 1764 feet plateau, the two curves diverge a very small amount before converging again, at which point both Standard FC and VARQ FC benchmarks provide the same level of protection. This occurs around elevation 1765 feet, which is approximately a 2%-chance-exceedance event.[13]

A stage-duration curve specific to the months of May through July was also developed for Bonners Ferry, and is shown in Figure 12. As one would expect, the stage at Bonners Ferry is higher a greater percentage of time under the VARQ FC benchmark than it is with the Standard FC benchmark. This effect diminishes as the stage increases, and there is little perceptible difference between the two flood control methods as the stage approaches elevation 1764 feet. Thus, the modeling results indicate that the VARQ FC benchmark provides comparable flood protection to the Standard FC benchmark at Bonners Ferry.

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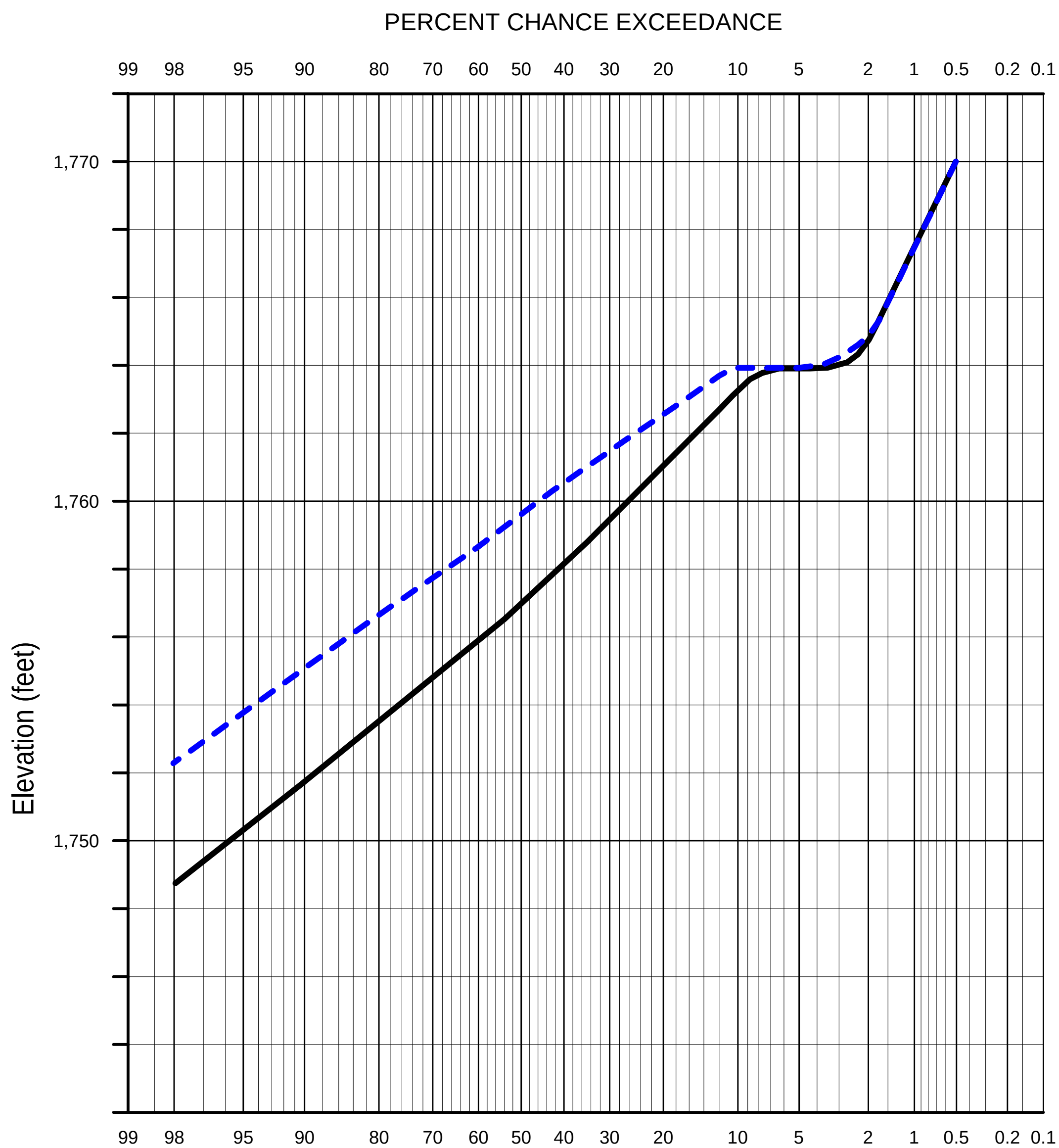
[11] A 0.5%-chance-exceedance flood has a 1 in 200 chance of being equaled or exceeded in any given year. It is sometimes called a "200-year flood."

[12] A regulated stage of 1770 feet for the 0.5%-chance-exceedance event was used to help define the upper end of this frequency curve.

[13] A 2%-chance-exceedance flood has a 1 in 50 chance of being equaled or exceeded in any given year. It is sometimes called a "50-year flood."

Figure 11. Stage-Frequency Analysis: Bonners Ferry Maximum Daily Elevation (May-July), Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND

Standard FC

VARQ FC

2004 UPPER COLUMBIA EIS MODELING RESULTS

BONNERS FERRY, IDAHO
MODELED STANDARD AND VARQ FLOOD CONTROL
STAGE FREQUENCY ANALYSIS

BONNERS FERRY MAXIMUM DAILY ELEVATION
(MAY-JULY)

PERIOD OF RECORD: WY 1948 - 1999

NOTE: A regulated stage of 1770 feet for the 0.5%-chance-exceedance event was used to help define the upper end of this frequency curve.

DATE: 27 JULY 2004

CONSTRUCTED BY: CJF

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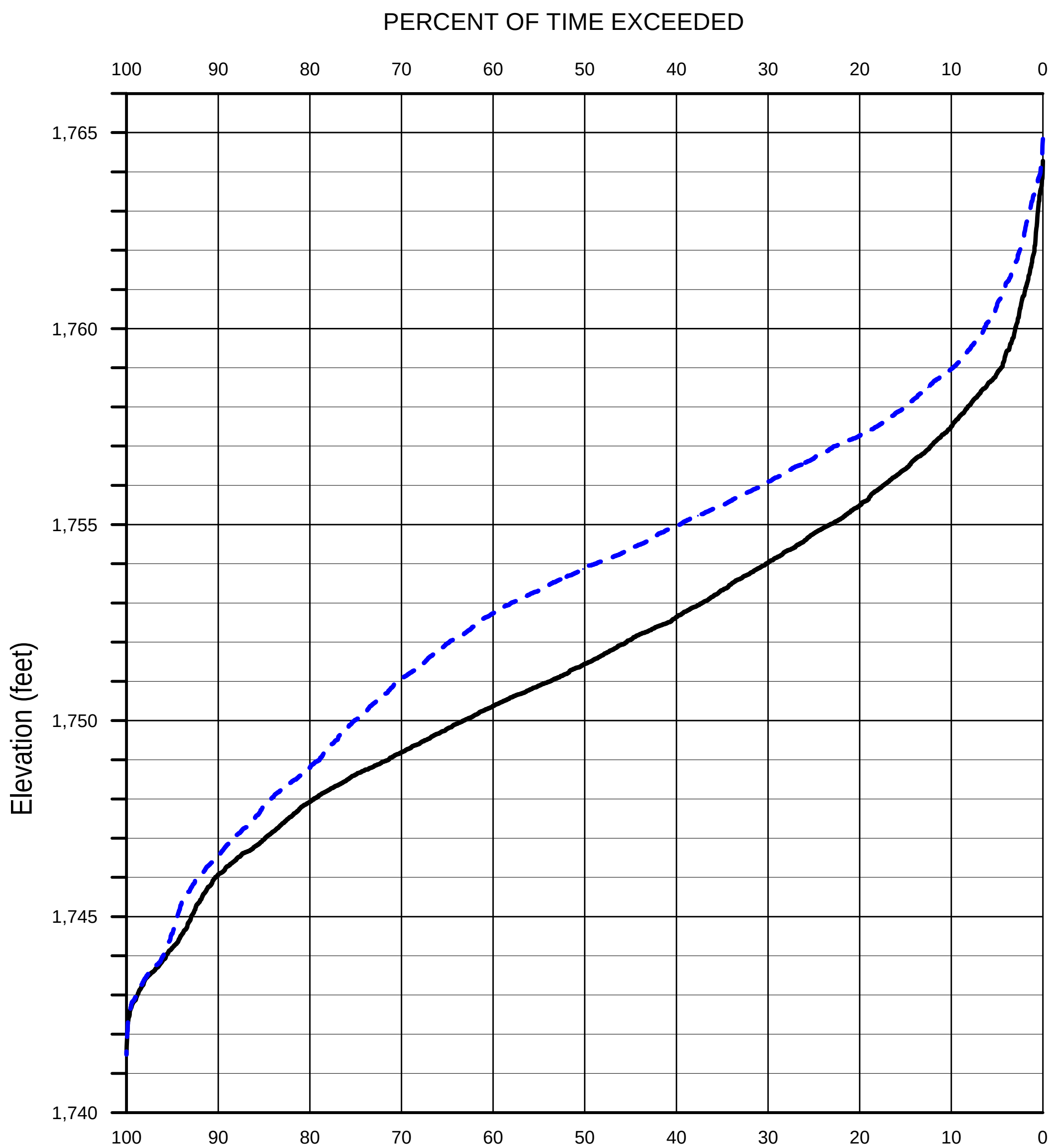
Figure 12. Stage-Duration Analysis: Bonners Ferry Daily Elevation (May-July), Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND

Standard FC
VARQ FC

2004 UPPER COLUMBIA EIS MODELING RESULTS

BONNERS FERRY, IDAHO
MODELED STANDARD AND VARQ FLOOD CONTROL
STAGE DURATION ANALYSIS

BONNERS FERRY DAILY ELEVATION
(MAY-JULY)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 12 APR 2004	CONSTRUCTED BY: CJF	APPROVED BY:

2.2.7 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.

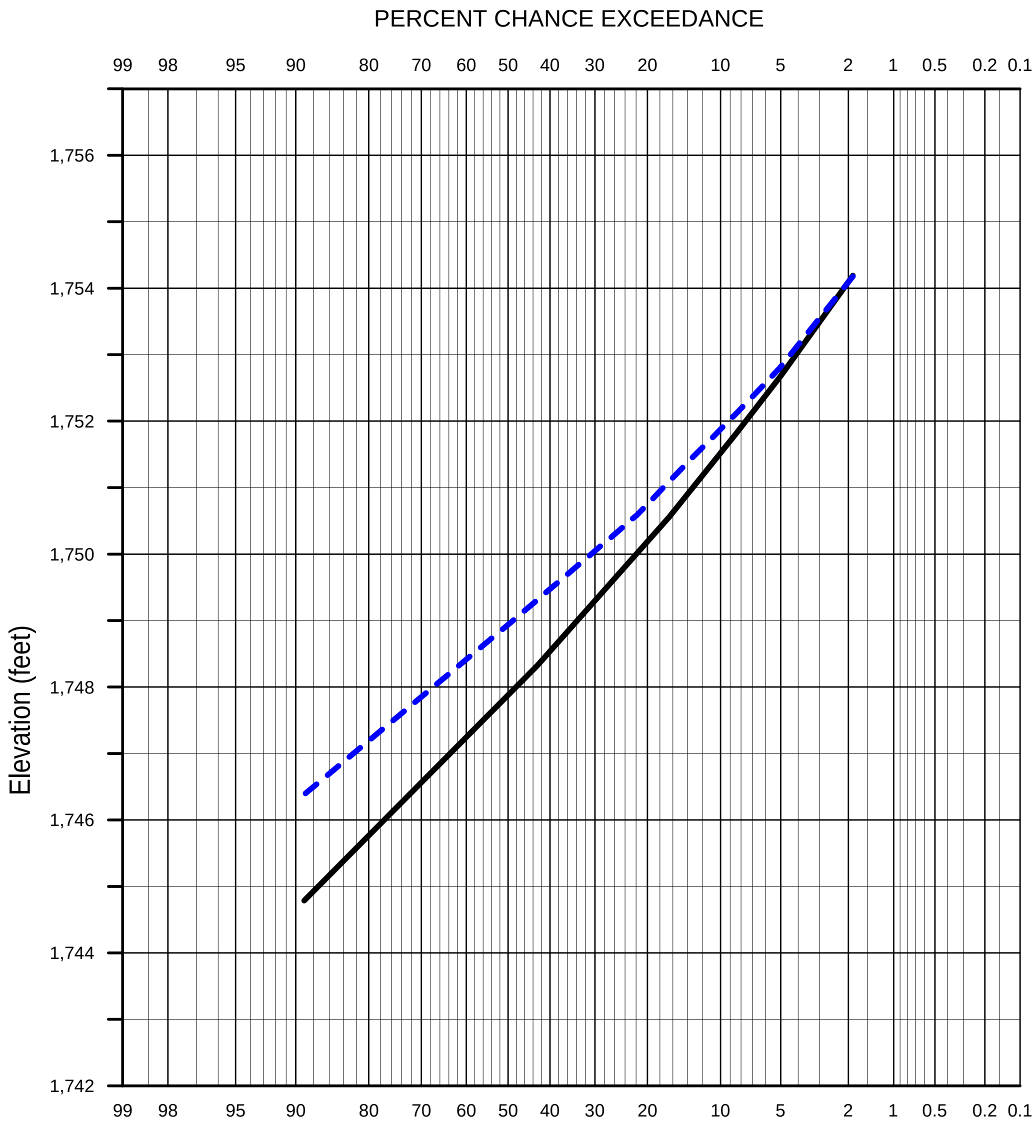
There are two hydropower facilities at the outlet of Kootenay Lake: Corra Linn Dam and the Kootenay Canal Plant with several other hydroelectric dams immediately downstream. In the modeling done for this study, they were collectively modeled as one dam. All hydro-regulations for this study met the requirements of the 1938 IJC Order. 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.

From a flood control perspective, the impacts of VARQ FC on the level of Kootenay Lake are of greatest importance in May, June, and July. An elevation-frequency curve specific to those months is provided in Figure 13[14]. The frequency curve shows that for the high percent-chance-exceedance (low runoff) events (on the left side of the graph), the Kootenay Lake levels associated with the VARQ FC benchmark are consistently higher than those under the Standard FC benchmark. This effect diminishes as one moves toward the low percent-chance-exceedance events (on the right side of the graph), and the two curves eventually converge near elevation 1754 feet. In all simulations, the maximum stage at Kootenay Lake remained below elevation 1755 feet, regardless of which flood control procedure was used. 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" (Corps 1972). Since 1972, substantial encroachment around Kootenay Lake has occurred, and it is probable that damage now commences below elevation 1755 feet. The Canadian entity is endeavoring to create an updated stage-damage relationship at Kootenay Lake.

Elevation-duration curves for Kootenay Lake were developed for the months of May, June, and July. These are shown in Figure 14, Figure 15, and Figure 16, respectively. During May and June, the VARQ FC benchmark leads to higher Kootenay Lake elevations than does the Standard FC benchmark. This is also true for the month of July, but to a lesser degree.

[14] 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).

Figure 13. Elevation-Frequency Analysis: Kootenay Lake Maximum Daily Elevation (May-July), Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND

— Standard FC

- - - VARQ FC

NOTE: 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 figure).

2004 UPPER COLUMBIA EIS MODELING RESULTS

KOOTENAY LAKE, CANADA
MODELED STANDARD AND VARQ FLOOD CONTROL
ELEVATION FREQUENCY ANALYSIS

KOOTENAY LAKE MAXIMUM DAILY ELEVATION
(MAY-JULY)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 27 JULY 2004	CONSTRUCTED BY: CJF	APPROVED BY:

Figure 14. Elevation-Duration Analysis: Kootenay Lake Daily Elevation (May), Flood Control Simulations - Standard FC and VARQ FC Benchmarks

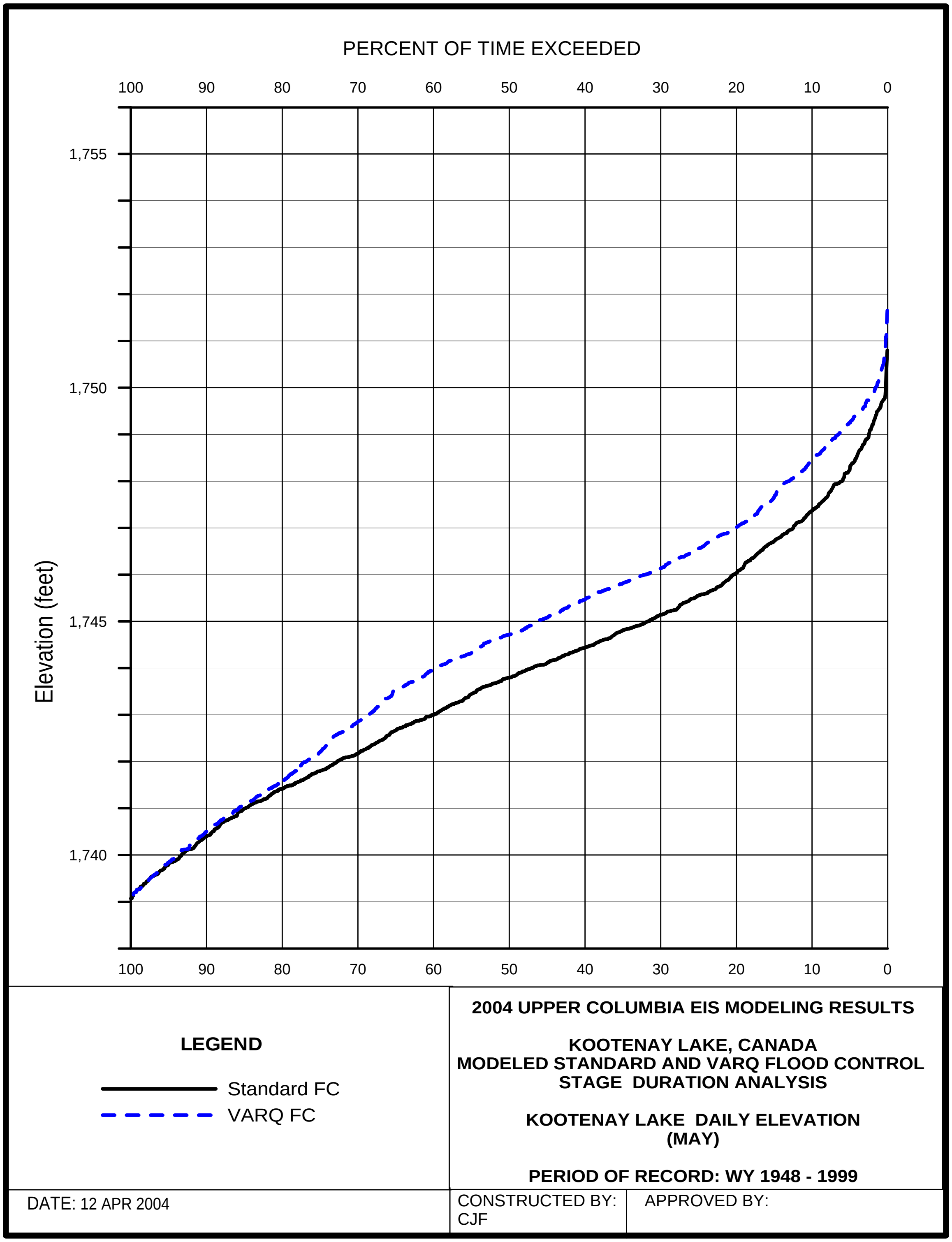
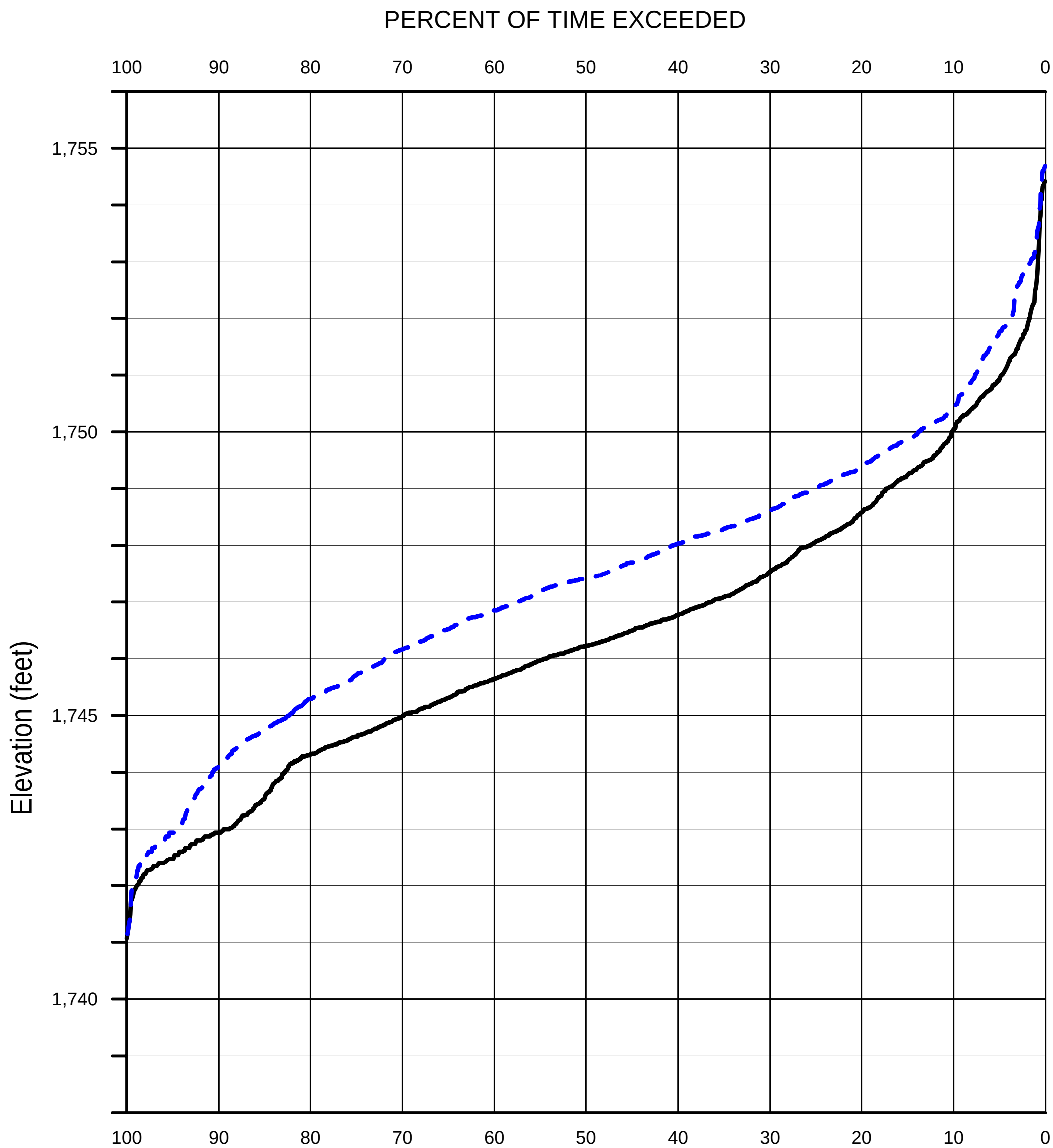


Figure 15. Elevation-Duration Analysis: Kootenay Lake Daily Elevation (June) , Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND

Standard FC

VARQ FC

2004 UPPER COLUMBIA EIS MODELING RESULTS

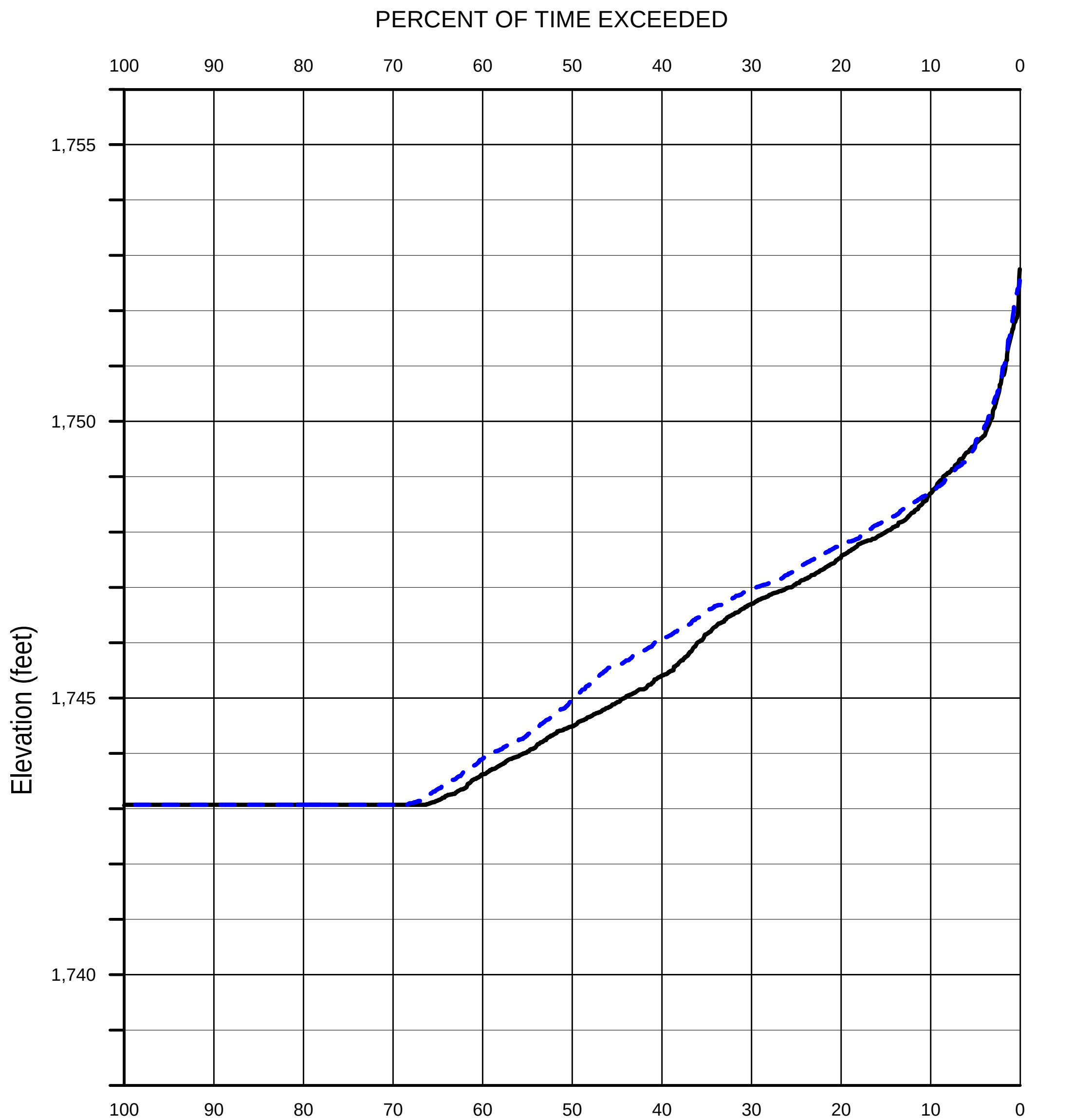
KOOTENAY LAKE, CANADA
MODELED STANDARD AND VARQ FLOOD CONTROL
STAGE DURATION ANALYSIS

KOOTENAY LAKE DAILY ELEVATION
(JUNE)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 12 APR 2004	CONSTRUCTED BY: CJF	APPROVED BY:

Figure 16. Elevation-Duration Analysis: Kootenay Lake Daily Elevation (July), Flood Control Simulations - Standard FC and VARQ FC Benchmarks



LEGEND	2004 UPPER COLUMBIA EIS MODELING RESULTS KOOTENAY LAKE, CANADA MODELED STANDARD AND VARQ FLOOD CONTROL STAGE DURATION ANALYSIS KOOTENAY LAKE DAILY ELEVATION (JULY) PERIOD OF RECORD: WY 1948 - 1999	
Standard FC (solid line) VARQ FC (dashed line)		
DATE: 12 APR 2004	CONSTRUCTED BY: CJF	APPROVED BY:

2.2.8 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, and the Kootenay River flows into the south arm of Kootenay Lake. Depending on the forecasted volume runoff, Duncan 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 outflows and reservoir elevations at Duncan Dam are essentially equivalent with the Standard FC or VARQ FC benchmarks.

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 Dam were added to 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 Biological Opinions call for augmented flows from Libby Dam to benefit several listed fish populations 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, the following simulations were completed for water years 1948-1999:

- Standard FC with fish flows (including sturgeon flows to outflow capacity at powerhouse) *[or LS1 in the EIS]*
- VARQ FC with fish flows (including sturgeon flows to outflow capacity at powerhouse) *[or LV1 in the EIS]*
- Standard FC with fish flows (including sturgeon flows to outflow capacity at powerhouse plus 10 kcfs)[15] *[or LS2 in the EIS]*
- VARQ FC with fish flows (including sturgeon flows to outflow capacity at powerhouse plus 10 kcfs) *[or LV2 in the EIS]*

[15] The maximum sturgeon outflow called for in the U.S. Fish and Wildlife Service (USFWS) 2000 Biological Opinion is the current powerhouse capacity + 10 kcfs.

3.1.2 Initialization

For the fish flow simulations, the reservoir elevation at Libby Dam was re-initialized at elevation 2439 feet (20 feet below the full pool elevation of 2459 feet) at the beginning of each water year to depict a realistic starting condition caused by the previous year's salmon draft. The other reservoirs in the Kootenai basin were re-initialized at full pool.

3.1.3 Description of "Fish Flow" Template

The following paragraphs describe the fish flow operations and assumptions used in this modeling effort. Actual operations will look different because they must be managed to address differing conditions each year, including calls from the USFWS and NMFS for specific fish flows. Dam discharges will be "shaped" in real time to address requirements for fish and to meet flood control constraints. In contrast, an evaluation like the one documented below must use a consistent set of provisions in order to make valid comparisons.

In general for this evaluation, between October and April, Libby Dam operates the same in the fish flow simulations as it did in the flood-control-only simulations. Special operation of Libby Dam to provide fish flows for ESA-listed fish populations downstream is not required until the late spring and summer. In May and/or 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 ranging from 6 to 9 kcfs 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.

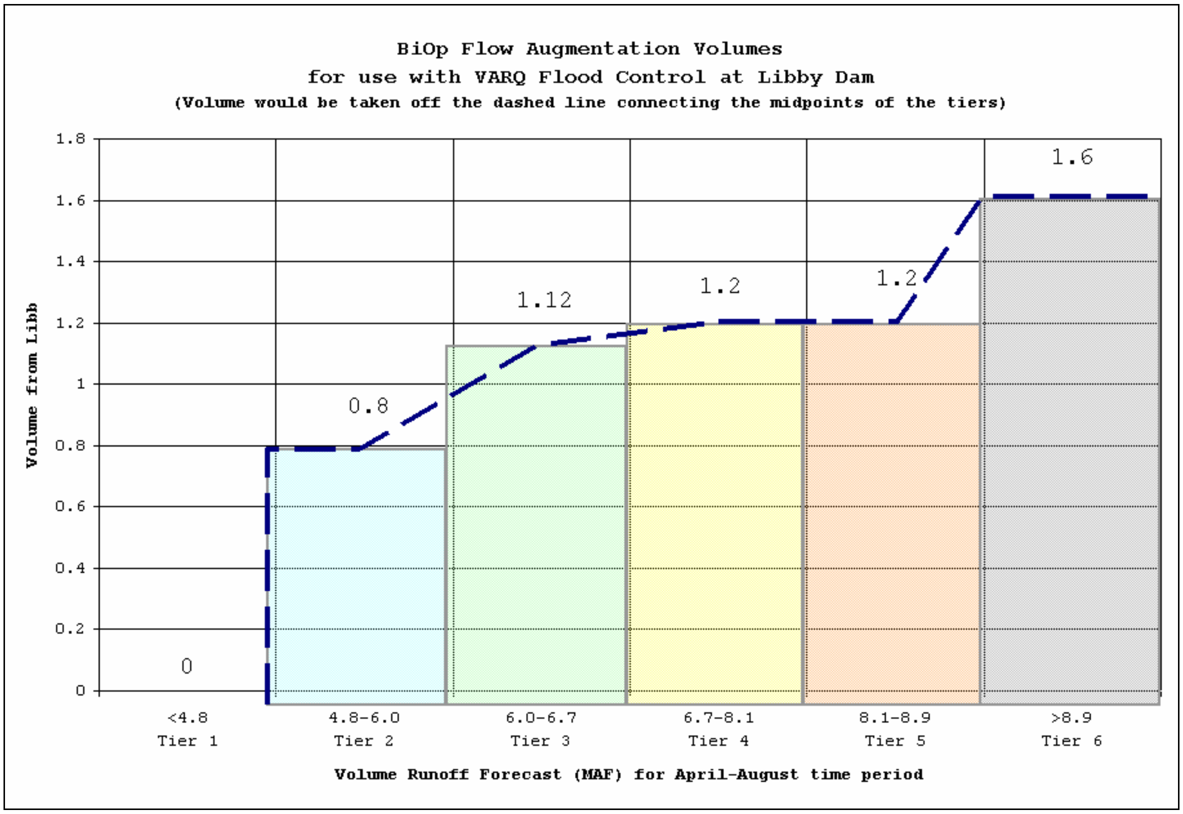
3.1.3.1 Sturgeon Operation

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 will be measured at Libby Dam. This facilitates volume accounting and greatly simplifies the modeling process. It was further decided that the augmentation volume should be interpolated according to the runoff forecast, as shown below in Figure 17.

A fish flow template was also developed to define the timing and shaping of fish flows for modeling purposes. The sturgeon volumes as measured at Libby Dam and the fish flow template to be used for the EIS modeling were memorialized at the executive level in August 2002.

The aforementioned method for measuring and delivering sturgeon water was used to perform the fish flow simulations. If the seasonal water supply forecast was less than 4.8 MAF no sturgeon water was provided. If the forecast was greater than 8.9 MAF, the amount of water provided for sturgeon was capped at 1.6 MAF.[16] The minimum release of 4 kcfs from Libby Dam is not included in the accounting of sturgeon water.

Figure 17. Sturgeon water volumes to be provided from Libby Dam



[16] In assessing the effects of future sturgeon operations, reliant upon water stored under VarQ flood control procedures, it should be noted that sturgeon augmentation flows are not expected to occur annually in the long-term.
The Kootenai River White Sturgeon Recovery Plan indicates that the species could be downlisted to threatened status when: 1) successful natural recruitment can be documented in at least three years out of a 10 year period; 2) the population is stable or increasing; and 3) a management strategy is in place which describes the environmental conditions necessary for this natural recruitment with emphasis on its repeatability.

Successful natural recruitment is defined in the recovery plan as the documentation of at least 20 individuals reaching age one or more from a given year class. However, in spite of the remarkably high fecundity, no year class since 1974 is known to have fulfilled even this minimal success threshold. Until the required conditions to downlist the sturgeon are met, flow augmentation for the species can be expected to occur regularly.

In practice, the timing and shaping of these volumes are based on seasonal requests from the USFWS. However, for modeling purposes, the following guidelines from the fish flow template 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
- 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 the maximum sturgeon flow of either powerhouse capacity or powerhouse capacity plus 10 kcfs according to Biological Opinion ramp rates. Then, the outflow was held constant at either powerhouse capacity or powerhouse capacity plus 10 kcfs 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 (by holding the river below flood stage) and sturgeon augmentation water from Libby Dam, local flood control operations took precedence.

At the present time, it is not possible to discharge anything higher than full powerhouse capacity plus 1-2 kcfs via the spillway without exceeding Montana state water quality limits of 110% for total dissolved gas (TDG) in parts of the river just downstream of the dam (ERDC 2003). Nonetheless, the powerhouse capacity plus 10 kcfs sturgeon flows were modeled to address the flow recommendations listed under RPA 8.2 in the USFWS 2000 Biological Opinion. The model simulations assume that it would be possible to discharge powerhouse capacity plus 10 kcfs from Libby Dam for sturgeon flow augmentation, regardless of reservoir elevation. In other words, it was not necessary for the simulated reservoir elevation to be above the spillway crest to discharge more than the powerhouse capacity. No assumption was made concerning which outlets were used for this release. This is an important point, because the mechanism for implementation of additional flow capacity has not been determined, and may ultimately involve spill. For this analysis, no mechanism could be assumed. Further analysis and documentation will occur as necessary if and when a mechanism is developed.

3.1.3.2 Bull Trout Operation

Immediately following ramp-down from the sturgeon flow augmentation, the model required Libby Dam to release the minimum bull trout outflow ranging from 6 to 9 kcfs until at least the end of June. In years where sturgeon augmentation was not required due to a low runoff forecast, the bull trout flow began on 1 July. The bull trout flow requirement is based on the April-August forecast (issued in June), as shown in Table 4.

Table 4. Minimum bull trout flows to be provided from Libby Dam

April-August forecast (MAF) issued in June	Minimum bull trout flow to be provided (cfs)
Less than 4.8	6,000
4.8 – 6.0	7,000
6.0-6.7	8,000
Greater than 6.7	9,000

3.1.3.3 Salmon Operation

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, as stipulated in RPA 19 of the NMFS 2000 Biological Opinion. A steady outflow operation over the months of July and August was modeled to avoid the “double-peak” that can occur if salmon water is released solely in the month of August. In that scenario, a drop in outflows following sturgeon operations reduces the wetted perimeter of the river channel and impacts aquatic invertebrates and juvenile fish, and is then followed by a rewatering. It is better to maintain flows sufficient to keep the river margins submerged. 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. This modeling approach was discussed and approved by NMFS on August 28, 2003.

In some years, the modeled sturgeon flow augmentation ended during the last week of June. Rather than providing the minimum bull trout flow for one week (or less) and then increasing to a steady salmon flow beginning on 1 July, an immediate transition from sturgeon flows to salmon flows was made. By transitioning in this manner, a double-peak operation was avoided. In all cases, the outflow from Libby Dam following the sturgeon operation was greater than or equal to the minimum bull trout flow required.

3.1.3.4 Fish Flow Template vs. Actual Operations

In development of scenarios with fish flows, a template of outflow was developed for use in all fish flow model runs. The increase of outflow from Libby Dam began on a fixed date, depending on the magnitude of the water year. In actual operations, the fish flow operation may begin earlier or later than the dates specified in the fish flow template.

Because of the short forward-looking weather forecast and the rigid fish flow template used by modelers, the model output results will be different than real-time operations, although the trends will be preserved. Real-time adaptive management allows for flexibility in the operation of Libby Dam to better meet multi-purpose needs. 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.

3.2 Model Results

Output data from period-of-record flood control simulations with fish flows are presented in the following sections, which depict impacts to Lake Koocanusa and Libby Dam, Bonners Ferry, Kootenay Lake, and Duncan Dam.

3.2.1 Analysis of Results

Potential impacts from fish flows can be characterized with flow/stage-frequency curves and flow/stage-duration curves at various locations throughout the Kootenai basin. To illustrate the differences between Standard FC and VARQ FC when fish flows are introduced, each figure has four curves plotted:

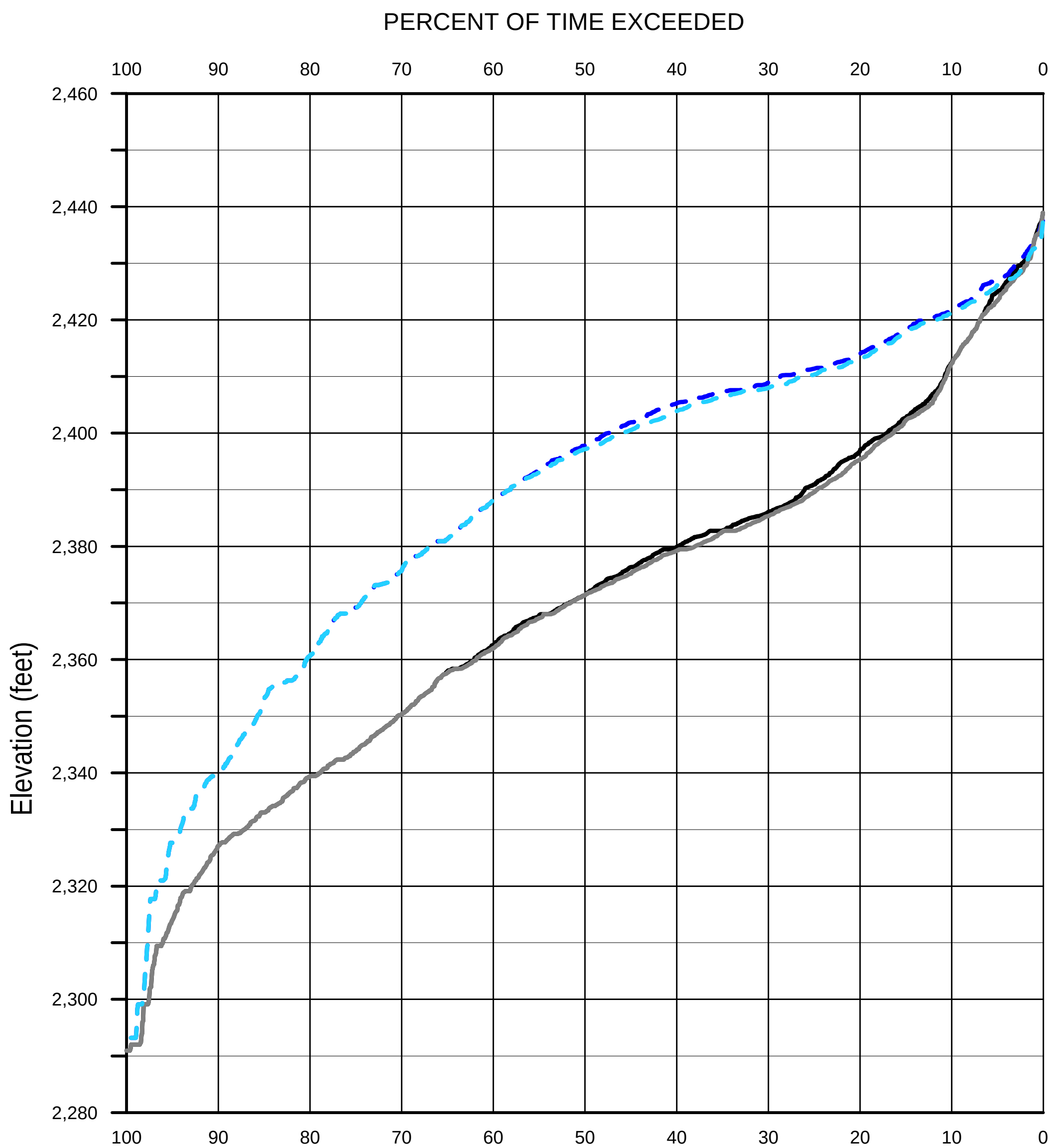
- Standard FC with fish flows at powerhouse capacity *[or LS1 in the EIS]*
- VARQ FC with fish flows at powerhouse capacity *[or LV1 in the EIS]*
- Standard FC with fish flows at powerhouse capacity plus 10 kcfs *[or LS2 in the EIS]*
- VARQ FC with fish flows at powerhouse capacity plus 10 kcfs *[or LV2 in the EIS]*

Procedures for graphing regulated hydrologic data are outlined in a Corps Engineer Manual entitled *Hydrologic Frequency Analysis*, EM 1110-2-1415 (Corps 1993).

3.2.2 Lake Koocanusa

Model simulations for this study show that when fish flows are included in the operation of Libby Dam, it is no longer possible to refill the reservoir with the same degree of certainty as was possible with the flood-control-only scenarios. Elevation-duration curves for the months of May, June, and July are shown in Figure 18, Figure 19, and Figure 20, respectively. In all cases, reservoir elevations for the fish flow simulations are higher when VARQ FC is used instead of Standard FC, as expected. Also, the reservoir elevations in the fish flow scenarios are all depressed from those in the flood-control-only scenarios (refer to Section 2.2.2).

Figure 18. Elevation-Duration Analysis: Libby Dam Daily Elevation (May), Fish Flow Simulations



LEGEND

- Standard w/FF @ powerhouse
- VARQ w/FF @ powerhouse
- Standard w/FF @ pwrhs+10 kcfs
- VARQ w/FF @ pwrhs+10 kcfs

2004 UPPER COLUMBIA EIS MODELING RESULTS

LIBBY DAM
MODELED STANDARD & VARQ FC WITH FISH FLOWS
STAGE DURATION ANALYSIS

LIBBY DAM DAILY ELEVATION (MAY)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 16 APR 2004	CONSTRUCTED BY: CJF	APPROVED BY:

Figure 19. Elevation-Duration Analysis: Libby Dam Daily Elevation (June), Fish Flow Simulations

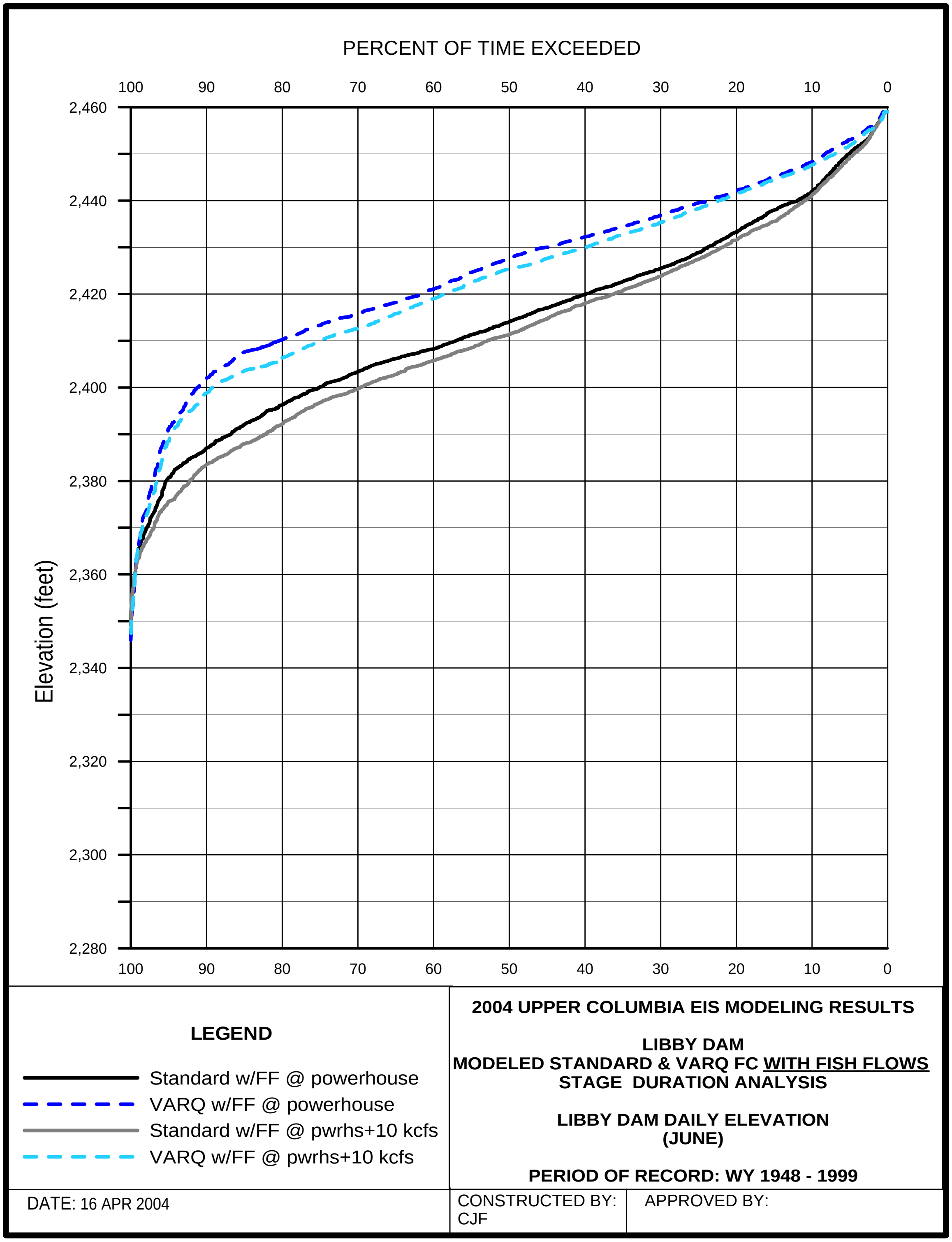
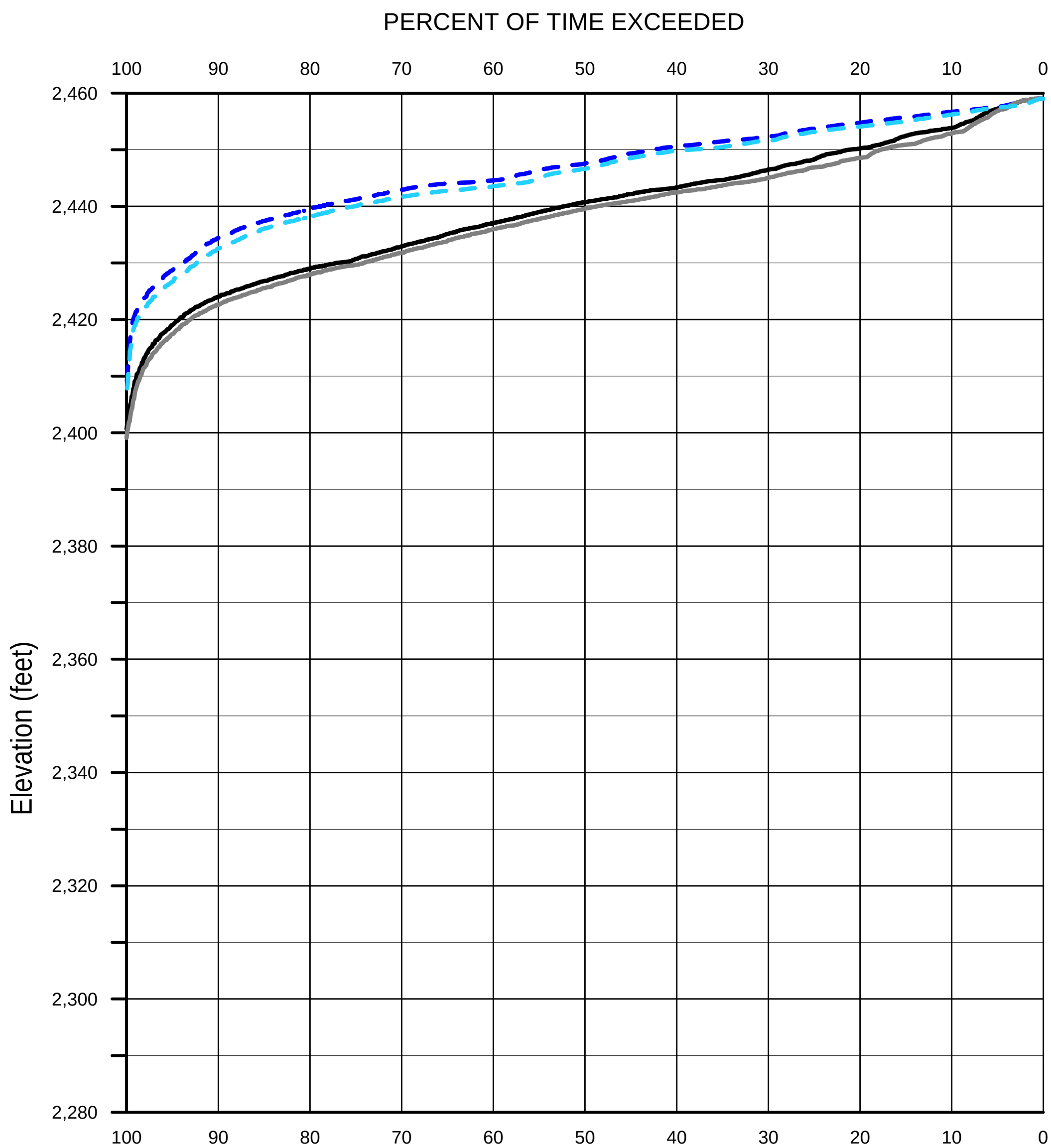


Figure 20. Elevation-Duration Analysis: Libby Dam Daily Elevation (July), Fish Flow Simulations



LEGEND

- Standard w/FF @ powerhouse
- VARQ w/FF @ powerhouse
- Standard w/FF @ pwrhs+10 kcfs
- VARQ w/FF @ pwrhs+10 kcfs

2004 UPPER COLUMBIA EIS MODELING RESULTS

LIBBY DAM
MODELED STANDARD & VARQ FC WITH FISH FLOWS
STAGE DURATION ANALYSIS

LIBBY DAM DAILY ELEVATION
(JULY)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 16 APR 2004	CONSTRUCTED BY: CJF	APPROVED BY:

3.2.3 Libby Dam Outflow

Besides reservoir elevation, the introduction of fish flows will obviously have an impact on outflow from Libby Dam. A flow-frequency curve based on the maximum outflow between May and July is provided in Figure 21. To model the sturgeon operation, the outflow was ramped up to either powerhouse capacity or powerhouse capacity plus 10 kcfs according to Biological Opinion ramping rates. The outflow was then held constant at either powerhouse capacity or powerhouse capacity plus 10 kcfs for whatever duration was necessary so that the full sturgeon volume was delivered before the end of the ramp-down to bull trout flows. Therefore, the first two curves in Figure 21 are relatively flat in the vicinity of 25-28 kcfs (powerhouse flow) and the next two curves are relatively flat in the vicinity of 35-38 kcfs (powerhouse plus 10 kcfs). The VARQ FC with fish flow curves plot slightly above the Standard FC with fish flow curves for the high percent-chance-exceedance events (at the left side of the graph). Moving to the right, the lines begin to converge, and there is no difference between Standard and VARQ FC for the low percent-chance-exceedance events when fish flows are introduced.

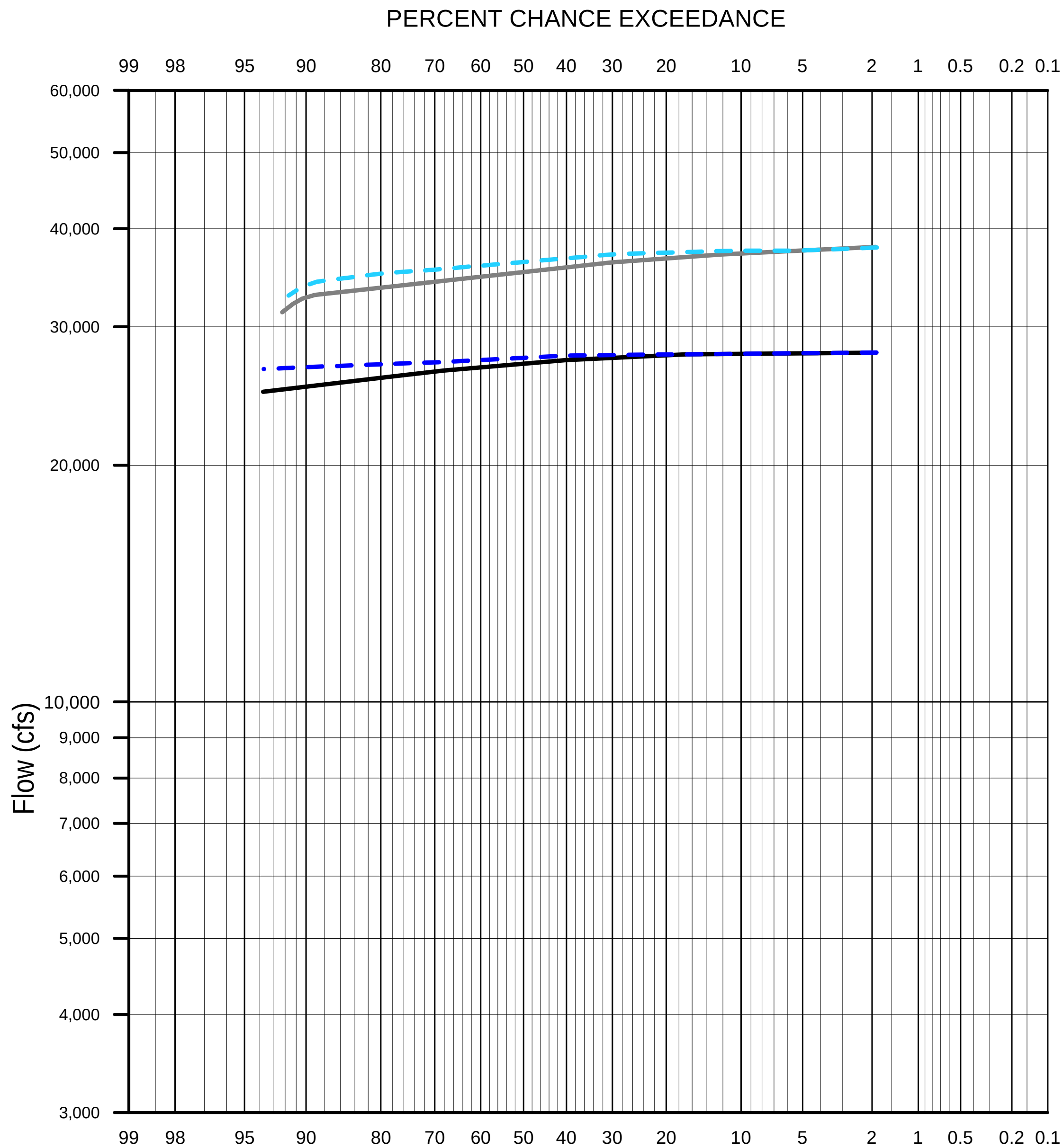
In reality, the sturgeon operations called for by USFWS have not always been at full powerhouse capacity. For instance, in 1995, 1998, and 2003, the maximum flow provided for sturgeon ranged between 20 kcfs and 22 kcfs. Thus, the model results tend to over-predict outflow from Libby Dam and river stages at Bonners Ferry when compared with the flows and stages that have actually occurred.

Due to the timing of the fish flows, the fish flow scenarios tend to increase outflow from Libby Dam between May and August. This is shown in Table 5, which also includes results from the flood control only simulations for comparison purposes. During May and June, the fish flow scenarios show high outflow because sturgeon flows are being provided. During the month of July, there is not much of a difference between the flood control only outflows and the fish flow outflows. This is because the sturgeon volume provided in the fish flow scenarios serves to preserve flood control space, reducing the required outflow in July. During the month of August, the fish flow scenarios show high outflows because the reservoir is being drafted to elevation 2439 feet by the end of the month.

Table 5. Monthly Average Outflow from Libby Dam (kcfs) – all scenarios

Month	Standard FC benchmark	VARQ FC benchmark	Standard FC w/ fish flows (powerhouse)	VARQ FC w/ fish flows (powerhouse)	Standard FC w/ fish flows (powerhouse +10 kcfs)	VARQ FC w/ fish flows (powerhouse +10 kcfs)
January	20.9	13.7	20.5	13.2	20.5	13.2
February	14.7	10.8	14.7	10.8	14.7	10.8
March	7.5	6.4	7.5	6.4	7.5	6.4
April	5.7	6.4	5.7	6.4	5.7	6.4
May	6.0	12.1	9.8	14.3	10.9	15.3
June	9.2	13.8	18.0	18.3	17.9	18.3
July	14.9	15.4	14.1	17.0	13.7	16.5
August	9.7	9.8	13.6	16.1	13.2	15.7

Figure 21. Flow-Frequency Analysis: Libby Dam Maximum Daily Outflow (May-July), Fish Flow Simulations



LEGEND

- **Standard w/FF @ powerhouse**
- **VARQ w/FF @ powerhouse**
- **Standard w/FF @ powerhouse+10 kcfs**
- **VARQ w/FF @ powerhouse+10 kcfs**

2004 UPPER COLUMBIA EIS MODELING RESULTS

LIBBY DAM, MONTANA
MODELED STANDARD & VARQ FC WITH FISH FLOWS
FLOW FREQUENCY ANALYSIS

LIBBY DAM MAXIMUM DAILY OUTFLOW
(MAY-JULY)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 27 JULY 2004	CONSTRUCTED BY: CJF	APPROVED BY:

3.2.4 Water Quality

When fish flows are introduced to the flood control simulations, spillway use at Libby Dam for flood control becomes less frequent. The first two fish flow scenarios assume the maximum outflow from Libby Dam (for fish purposes) would be limited to the powerhouse capacity, whereas the last two fish flow scenarios assume an outflow of powerhouse plus 10 kcfs as the maximum fish flow. As stated previously, this modeling did not consider the mechanism by which the additional 10 kcfs would be released, so there is no relationship to assume regarding flow and TDG for the last two scenarios. In other words, it was assumed that the additional 10 kcfs could be released from Libby Dam even if the modeled pool elevation was below the spillway crest.[17] Therefore, a TDG analysis has been performed only for the first two fish flow scenarios, where fish flows are limited to the powerhouse capacity. Any spill associated with these first two fish flow scenarios is done for flood control purposes, not as flow augmentation for fish. A summary of the TDG exceedance for the first two fish flow scenarios is provided in Table 6. The TDG values used to develop this table come from the derived relationship between spill and TDG saturation downstream of the dam (ERDC 2003). The Montana water quality standard of 110% was exceeded in 1 out of 52 years for Standard FC with fish flows at powerhouse, and 3 out of 52 years for VARQ FC with fish flows at powerhouse. Based on all 52 years modeled, Standard FC with fish flows at powerhouse had 2 days in excess of the 110% standard, and VARQ FC with fish flows at powerhouse had 31 days in excess of the 110% standard. Comparing Table 6 with Table 3 (see Section 2.2.4), one sees that by introducing fish flows into to the simulations, the amount of spill needed to preserve flood control space is reduced. While this reduction in spill is beneficial from a water quality point of view, it comes at a price – namely, depressed elevations for Lake Koocanusa in the late spring and summer (see Section 3.2.2).

[17] Although the mechanism for providing the additional 10 kcfs was not considered, modeled reservoir elevations indicate that the spillway would not be available to provide this additional flow in several years, as the pool elevation at the time of the sturgeon flow augmentation (according to the fish flow template) would be below the spillway crest. For the Standard FC with fish flows at powerhouse + 10 kcfs scenario, the spillway would only be available for use in 12 out of the 49 years when sturgeon flows are provided (based on the timing in the fish flow template). For the VARQ FC with fish flows at powerhouse + 10 kcfs scenario, the spillway would be available for use in 26 out of the 49 years when sturgeon flows are provided (based on the timing in the fish flow template) – significantly more often than the previous scenario.

Table 6. Modeled TDG Exceedance, Flood Control with Fish Flows at Powerhouse Capacity Simulations

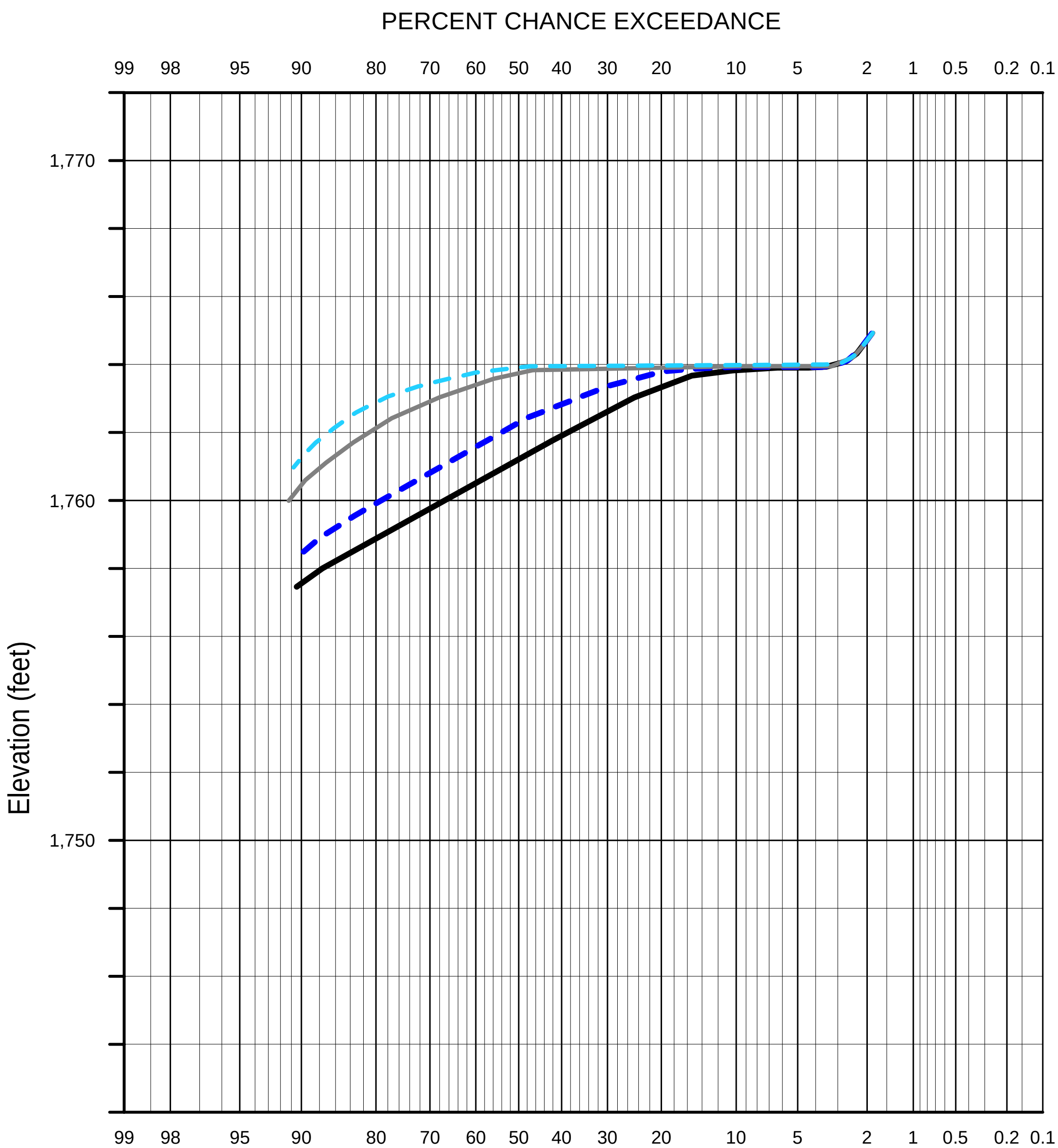
Threshold TDG saturation immed. below Libby Dam	Number of years with TDG greater than threshold Standard FC	Number of years with TDG greater than threshold VARQ FC	Number of days with TDG greater than threshold Standard FC	Number of days with TDG greater than threshold VARQ FC
100%	1	3	3	31
105%	1	3	3	31
110%	1	3	2	31
115%	0	2	0	25
120%	0	2	0	25
125%	0	2	0	24
130%	0	1	0	12

3.2.5 Bonners Ferry

The highest river stages at Bonners Ferry generally occur during the months of May, June, and July. A stage-frequency curve for the fish flow scenarios specific to those months is provided in Figure 22. For the high percent-chance-exceedance events (on the left side of the graph), the VARQ FC with fish flows curves plot above the Standard FC with fish flows curves, as expected. As was the case with the flood control only benchmark scenarios (refer to Section 2.2.6), this effect diminishes as one moves to the right toward the lower percent-chance-exceedance events. All four curves plateau at elevation 1764 feet. This plateau occurs because of the modeling objective to try to limit Bonners Ferry stage to that level. At the far right side of the graph, there is no perceptible difference between any of the fish flow scenarios. Note that peak stages above about 1758 feet occur much more frequently when fish flows are introduced than they do in the flood-control-only scenarios (refer to Section 2.2.6).

A stage-duration curve for the fish flow scenarios, covering the months of May through July, was also developed for Bonners Ferry, and is shown in Figure 23. As one would expect, the stage at Bonners Ferry is higher more often for the VARQ FC with fish flow scenarios than the Standard FC with fish flow scenarios. Also, stages of 1759 feet and above are more likely to occur when the fish flows are provided at powerhouse + 10 kcfs than they are when just the powerhouse is used.

Figure 22. Stage-Frequency Analysis: Bonners Ferry Maximum Daily Elevation (May-July), Fish Flow Simulations



LEGEND

- **Standard w/FF @ powerhouse**
- **VARQ w/FF @ powerhouse**
- **Standard w/FF @ powerhouse+10 kcfs**
- **VARQ w/FF @ powerhouse+10 kcfs**

2004 UPPER COLUMBIA EIS MODELING RESULTS

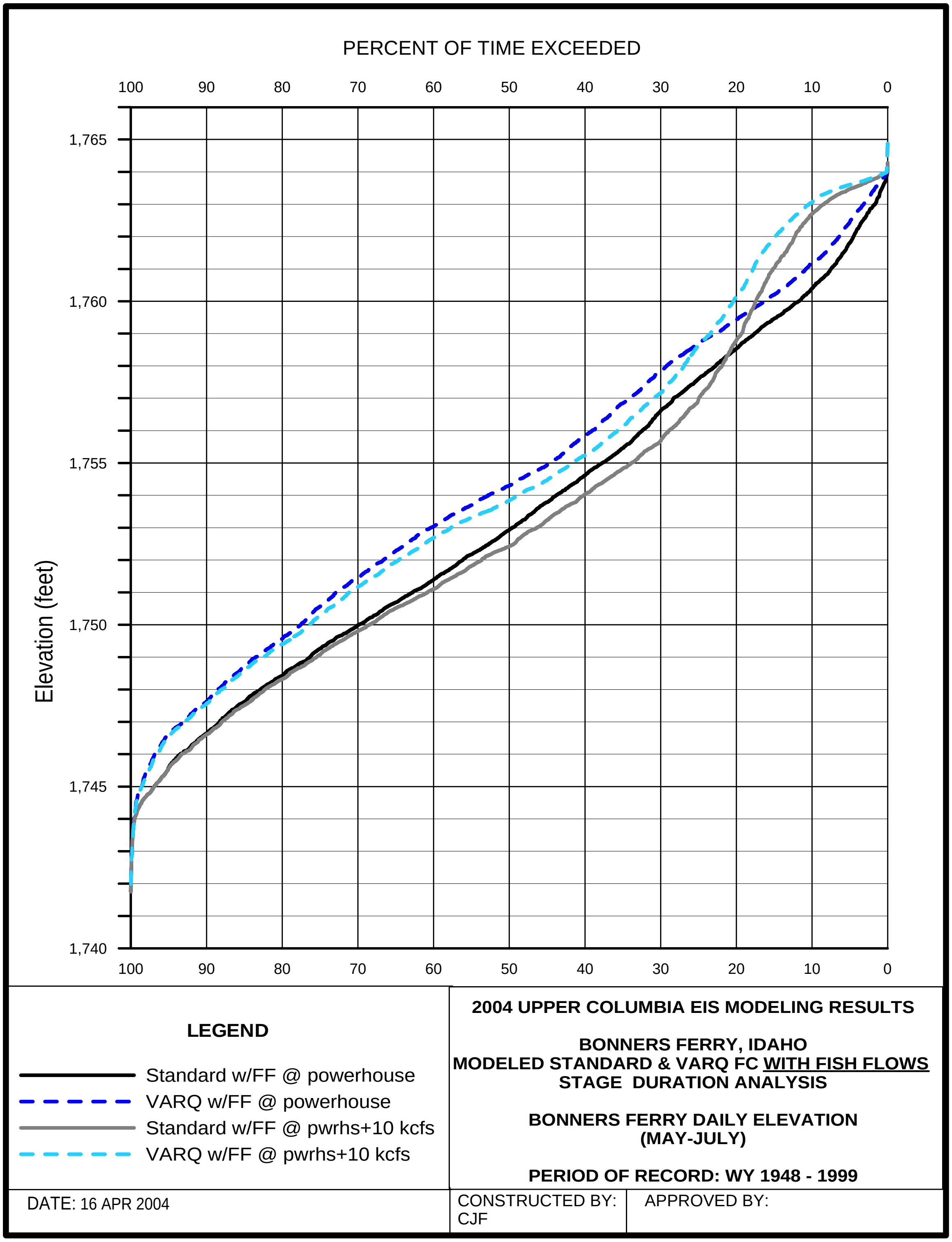
BONNERS FERRY, IDAHO
MODELED STANDARD & VARQ FC WITH FISH FLOWS
STAGE FREQUENCY ANALYSIS

BONNERS FERRY MAXIMUM DAILY ELEVATION
(MAY-JULY)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 27 JULY 2004	CONSTRUCTED BY: CJF	APPROVED BY:

Figure 23. Stage-Duration Analysis: Bonners Ferry Daily Elevation (May-July) , Fish Flow Simulations

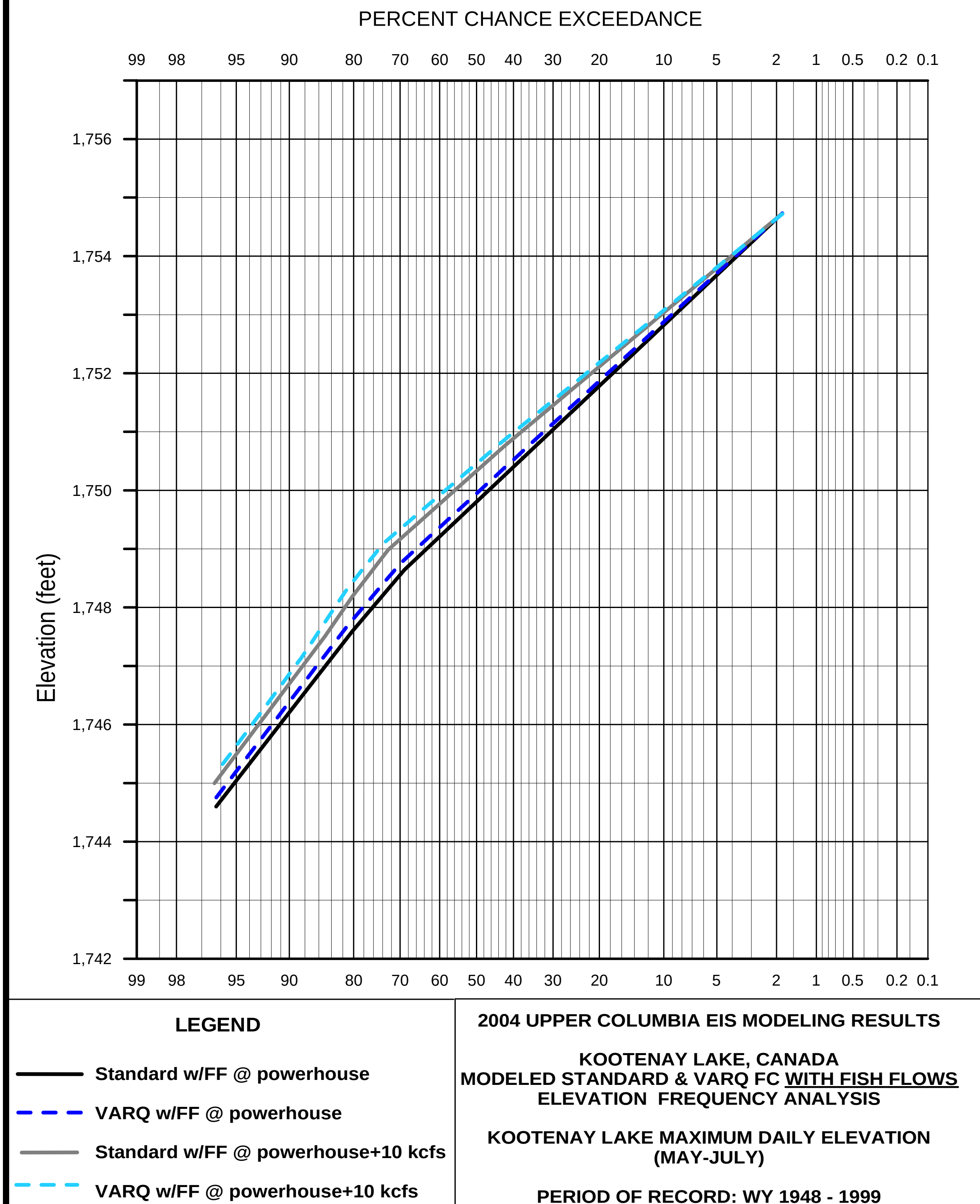


3.2.6 Kootenay Lake

From a flood control perspective, the impacts of fish flows on the level of Kootenay Lake are of greatest importance in May, June, and July. An elevation-frequency curve specific to those months is provided in Figure 24. For the high percent-chance-exceedance events (on the left side of the graph), the VARQ FC with fish flows curves plot above the corresponding Standard FC with fish flows curves, as expected. Also as expected, the scenarios where fish flows are provided at powerhouse capacity plus 10 kcfs result in a higher Kootenay Lake stage than the scenarios where fish flows are limited to powerhouse capacity. As was the case with the flood control only scenarios (refer to Section 2.2.7), the curves converge as one moves to the right toward the lower percent-chance-exceedance events. In all of the fish flow simulations, the maximum stage at Kootenay Lake remained below elevation 1755 feet.

Elevation-duration curves for Kootenay Lake for the fish flow scenarios were developed for the months of May, June, and July. These are shown in Figure 25, Figure 26, and Figure 27, respectively. During May, VARQ FC with fish flows leads to higher Kootenay Lake elevations than does Standard FC with fish flows. This is also true for the months of June and July, but to a lesser degree. Overall, the fish flow scenarios all lead to higher spring and summer time elevations at Kootenay Lake than would with a pure flood control operation (refer to Section 2.2.7).

Figure 24. Elevation-Frequency Analysis: Kootenay Lake Maximum Daily Elevation (May-July), Fish Flow Simulations



2004 UPPER COLUMBIA EIS MODELING RESULTS

KOOTENAY LAKE, CANADA
MODELED STANDARD & VARQ FC WITH FISH FLOWS
ELEVATION FREQUENCY ANALYSIS

KOOTENAY LAKE MAXIMUM DAILY ELEVATION (MAY-JULY)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 27 JULY 2004	CONSTRUCTED BY: CJF	APPROVED BY:

Figure 25. Elevation-Duration Analysis: Kootenay Lake Daily Elevation (May) , Fish Flow Simulations

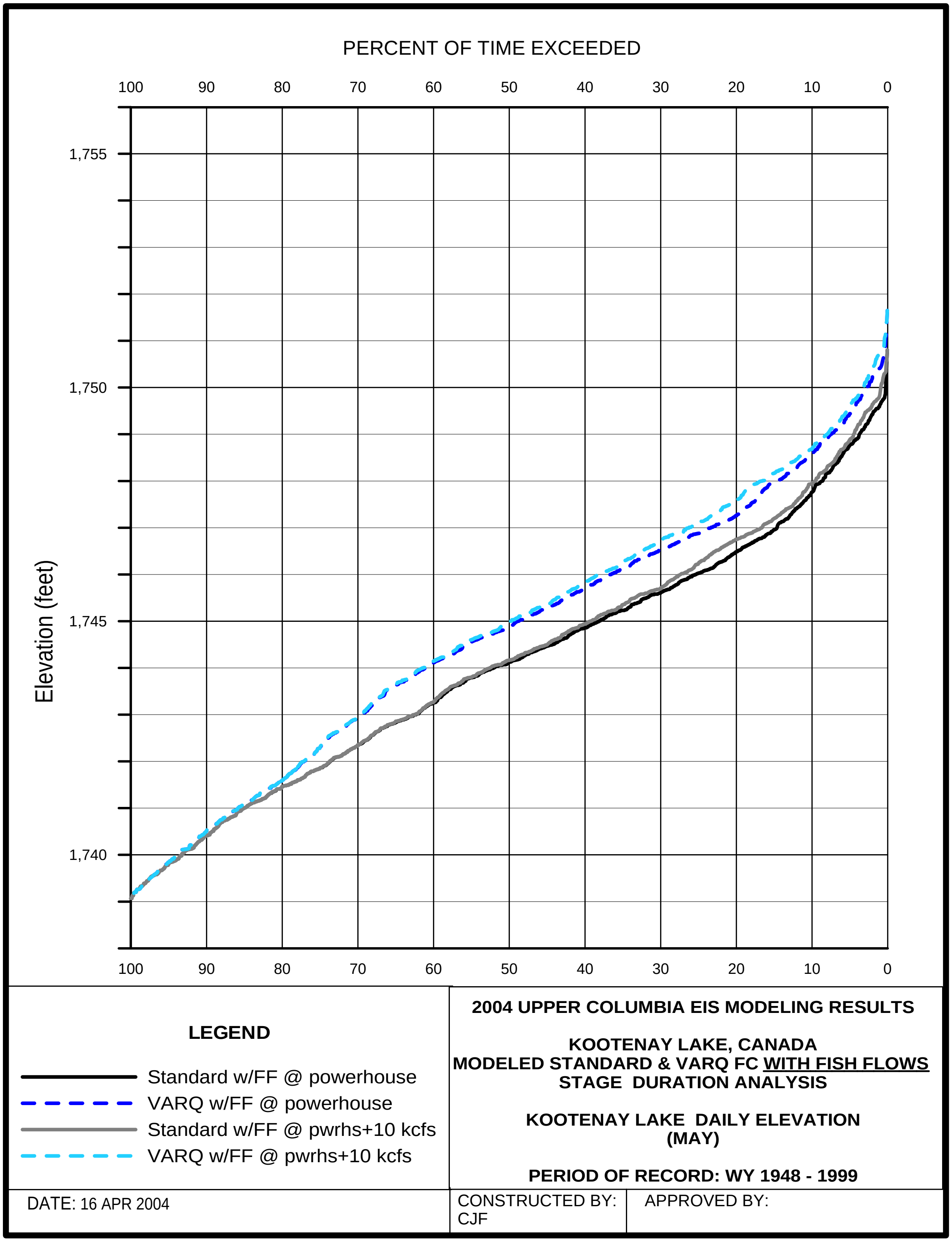
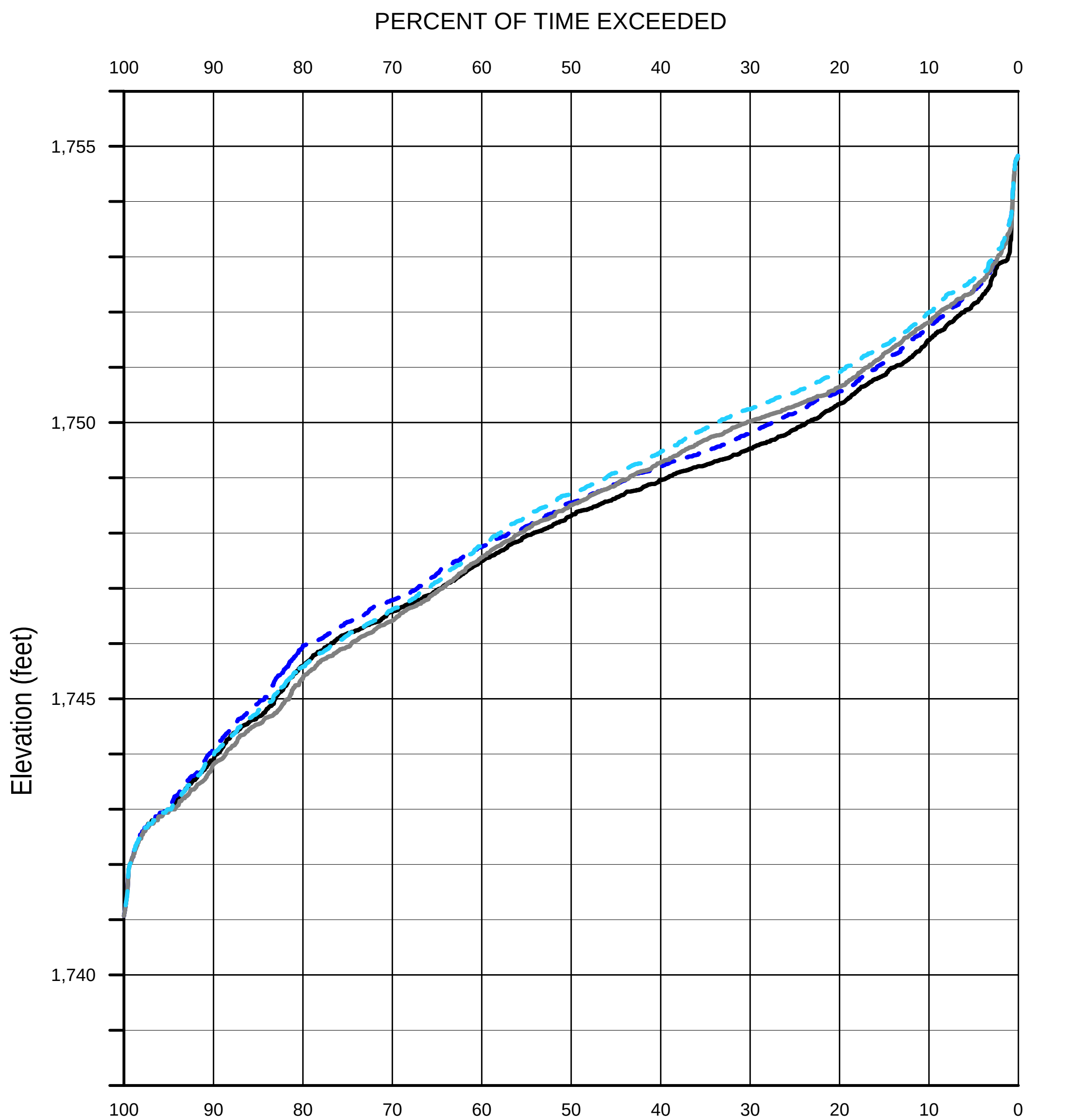


Figure 26. Elevation-Duration Analysis: Kootenay Lake Daily Elevation (June) , Fish Flow Simulations



LEGEND

- Standard w/FF @ powerhouse
- VARQ w/FF @ powerhouse
- Standard w/FF @ pwrhs+10 kcfs
- VARQ w/FF @ pwrhs+10 kcfs

2004 UPPER COLUMBIA EIS MODELING RESULTS

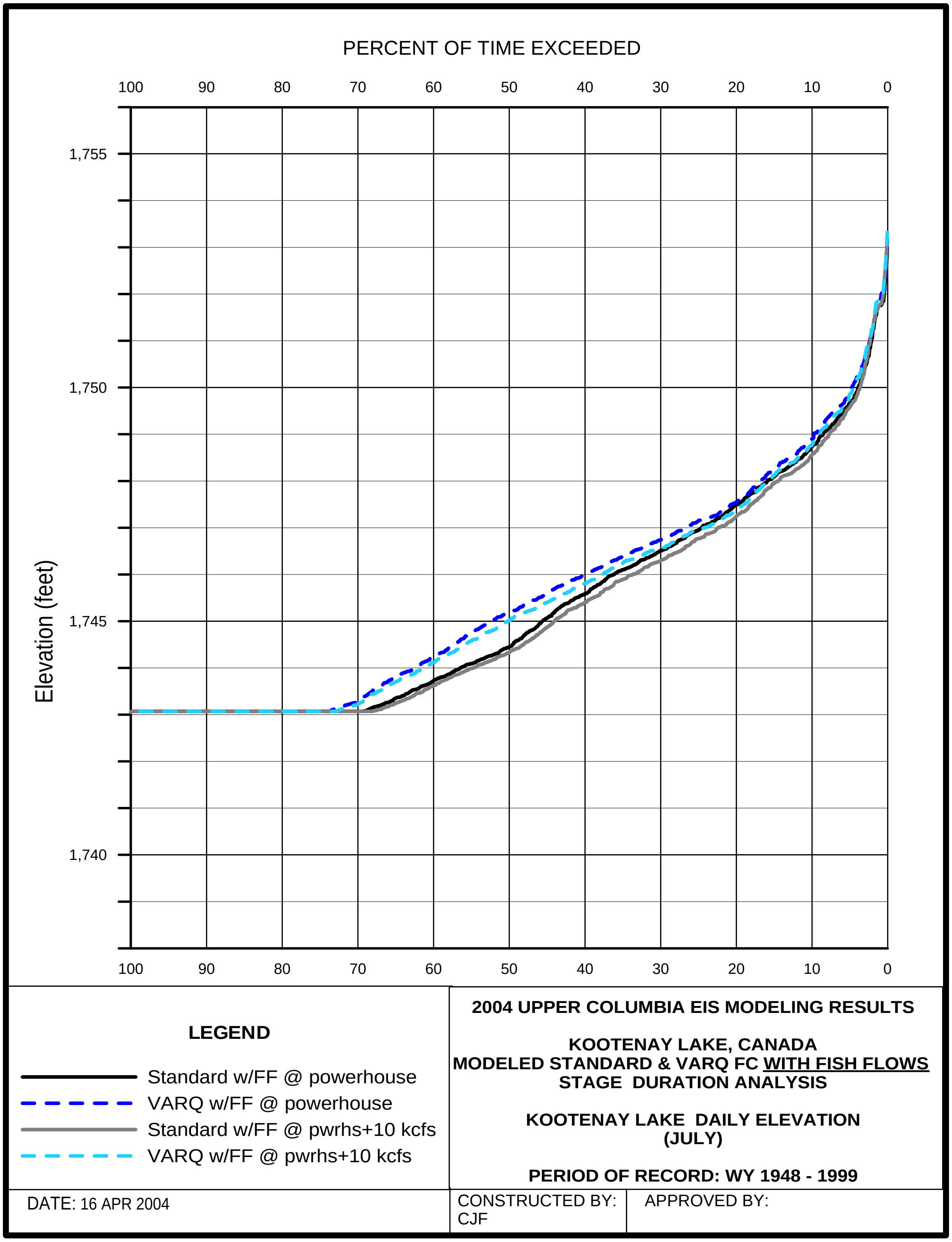
KOOTENAY LAKE, CANADA
MODELED STANDARD & VARQ FC WITH FISH FLOWS
STAGE DURATION ANALYSIS

KOOTENAY LAKE DAILY ELEVATION
(JUNE)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 16 APR 2004	CONSTRUCTED BY: CJF	APPROVED BY:

Figure 27. Elevation-Duration Analysis: Kootenay Lake Daily Elevation (July) , Fish Flow Simulations



3.2.7 Duncan Dam

The scenarios with fish flows have the exact same operations at Duncan Dam as the flood control-only scenarios (refer to Section 2.2.8). There is no significant change in either the maximum daily outflow or the maximum daily lake elevation.

4.0 Sensitivity Analysis

4.1 Hydro-Regulations

For this part of the study, twenty years were simulated to characterize the sensitivity of model results when certain modeling assumptions are modified. These sensitivity simulations are in accordance with guidelines set forth in *Risk-Based Analysis for Flood Damage Reduction Studies*, EM 1110-2-1619 (Corps 1996).

4.1.1 Background on Sensitivity Simulations

The team members for this study, in conjunction with USFWS, NMFS, and community members participating in the Kootenai Valley Resources Initiative (KVRI) in Boundary County, Idaho, identified uncertain model parameter combinations to define an upper-bound scenario and a lower-bound scenario for certain model runs. These upper- and lower-bound combinations were each applied to the following two simulations: Standard FC with Fish Flows at powerhouse capacity plus 10 kcfs and VARQ FC with Fish Flows at powerhouse capacity plus 10 kcfs. The intent of the sensitivity analysis is to show how much the river stage at Bonners Ferry can vary depending on the modeling assumptions that are used. The assumed start date and discharge pattern of sturgeon flows are of particular importance, because in real life these are in-season management decisions, and can be quite different from the fish flow template discussed in Section 3.1.3. The sensitivity runs performed are listed below:

- Standard FC, fish flows (including sturgeon flows to outflow capacity of powerhouse + 10 kcfs), and upper-bound assumptions
- VARQ FC, fish flows (including sturgeon flows to outflow capacity of powerhouse + 10 kcfs), and upper-bound assumptions
- Standard FC, fish flows (including sturgeon flows to outflow capacity of powerhouse + 10 kcfs), and lower-bound assumptions
- VARQ FC, fish flows (including sturgeon flows to outflow capacity of powerhouse + 10 kcfs), and lower-bound assumptions

4.1.2 Description Sensitivity Scenarios

The uncertain model parameters used to define upper- and lower-bound sensitivity runs are shown in Table 7. The model parameters were selected through a collaborative process between the team members for this study, USFWS, NMFS, and KVRI to ensure that community concerns regarding the modeling were addressed. To select the twenty years, model output from the flood control with fish flows at powerhouse capacity plus 10 kcfs scenarios was used. The years were ranked according to their maximum 15-day average stage at Bonners Ferry, and the top twenty years were chosen for sensitivity modeling. One should note that in all cases, the full volume of water allocated to sturgeon was delivered in the simulations. In practice, the augmentation volume for sturgeon may actually be less than what is shown in Table 7 (see Section 3.1.3.1). The reservoir re-initialization procedures used for the fish flow scenarios (see Section 3.1.2) were also used in the sensitivity scenarios.

Table 7. Uncertain Parameters Modeled in Sensitivity Analysis.

Parameter	Lower Bound Value (tends to decrease stage below dam)	Value Used for full period of record modeling	Upper Bound Value (tends to increase stage below dam)
Residual Volume trigger[18]	1.5 times residual volume	2.0 times residual volume	2.5 times residual volume
Streamflow forecast assumed foresight[19]	15-days	10-days	5-days
Allowable spill for flood control[20]	5 kcfs	2 kcfs	0 kcfs
Sturgeon flows start date[21]	Start sturgeon flows 9 days earlier than template	Tier 2 = 16 May Tier 3 = 23 May Tier 4-6=01 Jun	Start sturgeon flows 15 days later than template
Shape of sturgeon flows[22]	3-day pulse when IJC allows, then QPHC +10 kcfs per template	Powerhouse +10 kcfs Per template	Highest flow that can be sustained for at least 21 days per template
Managing Salmon Flow Augmentation[23]	Forecast to avoid double peak, draft to 2449' (swap with Canadian Storage)	Forecast to avoid double peak, be at 2439' by Aug 31	Pass inflow if <2439 on 1 Jul; otherwise forecast to avoid double peak, be at 2439' by Aug 31

[18]Once each month the Reservoir Control Center (RCC) gets an April – August *volume* forecast. The residual volume is the amount of water, based on the forecast that needs to be stored (forecast seasonal runoff volume – inflow volume to date – projected outflow volume). A factor of 2 means that the residual volume is twice as large as the volume of storage remaining. Operational changes are made when the parameter exceeds the values in the table.

[19] During real-time reservoir control, RCC gets long-lead *streamflow* forecasts once a week and 10-day forecasts 3 times per week. This parameter defines the lead time used to make decisions. For instance, if the model shows that the reservoir fills and starts spilling on 20 June, then an operational change will be made based on an assumed streamflow forecast either 15 days, 10 days, or 5 days before 20 June.

[20] For the full period of record modeling, the reservoir will preemptively begin spilling 2 kcfs five days prior to a forecasted fill and spill. By changing the pre-emptive spill amount to a *larger* value (5 kcfs), more storage space is preserved in the reservoir, reducing the likelihood of the reservoir filling while inflows greatly exceed powerhouse capacity (resulting in involuntary spill).

[21] For the full period of record modeling, sturgeon flow start dates ("the template") were determined in a meeting with USFWS, State of Montana, and the Corps in March, 2002. This parameter defines the start date for the main sturgeon flow augmentation.

[22] For the full period of record modeling, the sturgeon volume is delivered as quickly as possible with an outflow of powerhouse + 10 kcfs. For the lower-bound, some of the sturgeon volume will be used for a "pulse" early in the season, and the remaining volume will be delivered as quickly as possible with an outflow of powerhouse + 10kcfs. For the upper-bound, the sturgeon volume will be delivered such that there will be at least 21 days of sustained high flows, not to exceed powerhouse +10 kcfs.

[23] From p. 9-63 in the Biological Opinion: "If Libby is below elevation 2,439 feet on July 1, the Action Agencies shall provide the USFWS bull trout minimum flow or inflow during the July and August salmon flow season. If this operation results in Libby storing above elevation 2,439 feet in July or August, that storage may be used for salmon flow augmentation before August 31. Instead of "passing inflow or bull trout flows", the period of record modeling forecasts a constant outflow. This modeling approach was coordinated with NMFS via phone and email in August, 2003.

Also in the Biological Opinion: "…Libby may be operated in a manner that reduces impacts to other listed species, while releasing water to meet salmon flow objectives. Reduction in a second peak operation can be achieved by implementation of a Canadian storage/Libby exchange of water or by releasing water earlier…" So lower bound includes a Libby-Canada storage swap.

4.2 Model Results

Impacts to the river stage at Bonners Ferry are the focus of this sensitivity analysis. Output data from the twenty years of sensitivity runs are presented in the following sections.

4.2.1 Analysis of Results

The sensitivity of model results is characterized with stage-frequency curves for Bonners Ferry. Because prolonged high river stages are of concern to the downstream community, the maximum 15-day average stage at Bonners Ferry is analyzed in addition to the maximum daily stage. To compare the upper- and lower-bound sensitivity runs with the actual flood control with fish flow simulations, six curves are presented on each frequency curve:

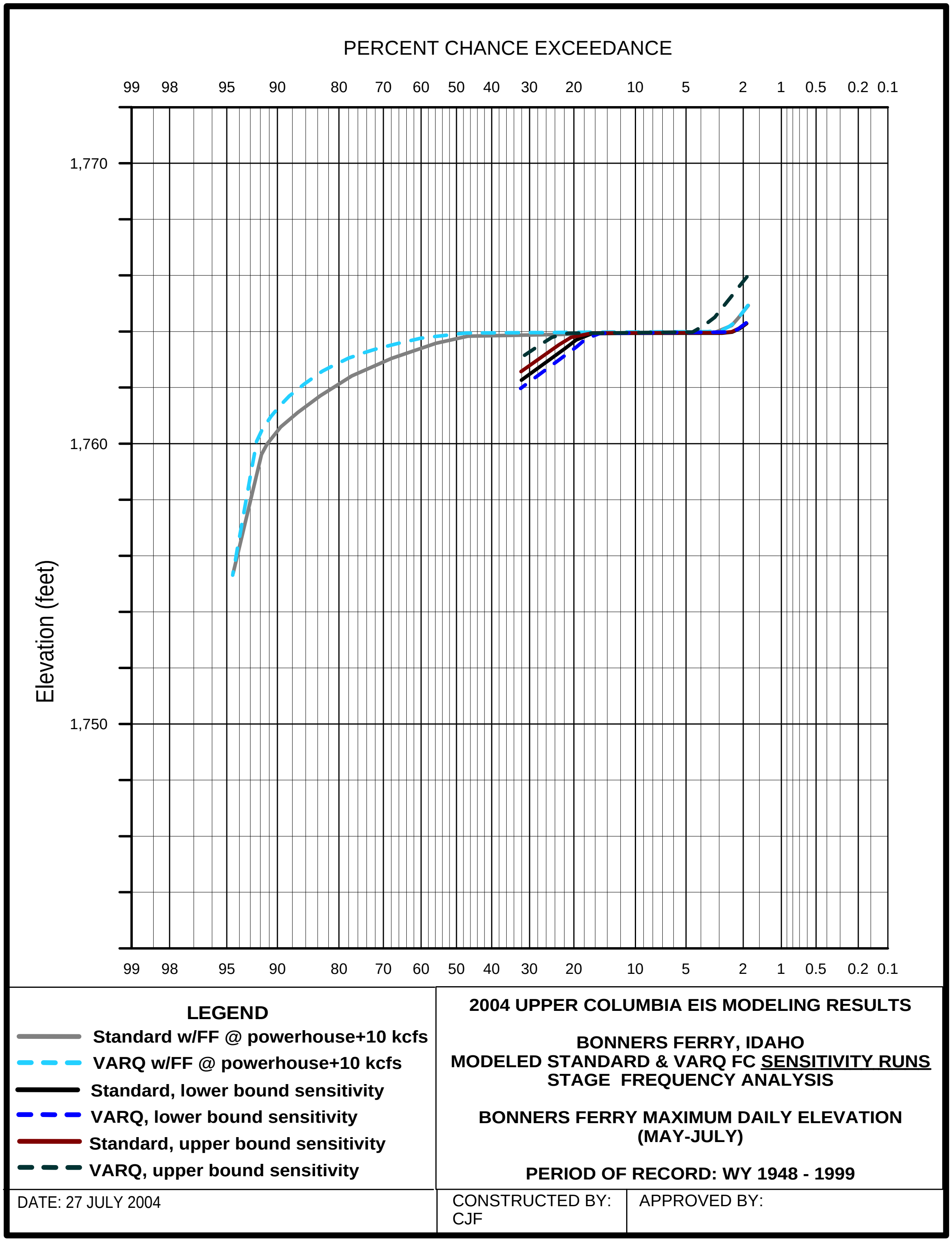
- Standard FC with fish flows with outflow capacity at powerhouse plus 10 kcfs
- VARQ FC with fish flows with outflow capacity at powerhouse plus 10 kcfs
- Standard FC, fish flows with outflow capacity of powerhouse plus 10 kcfs, and upper-bound assumptions
- VARQ FC, fish flows with outflow capacity of powerhouse plus 10 kcfs, and upper-bound assumptions
- Standard FC, fish flows with outflow capacity of powerhouse plus 10 kcfs, and lower-bound assumptions
- VARQ FC, fish flows with outflow capacity of powerhouse plus 10 kcfs, and lower-bound assumptions

Procedures for graphing regulated hydrologic data are outlined in a Corps Engineer Manual entitled *Hydrologic Frequency Analysis*, EM 1110-2-1415 (Corps 1993).

4.2.2 Bonners Ferry Peak 1-day Stage

The highest river stages at Bonners Ferry generally occur during the months of May, June, and July. A stage-frequency curve specific to those months is provided in Figure 28. The most significant feature of the frequency curve is that all six curves plateau near elevation 1764 feet. Despite the assumptions expected to create an upper- and lower-bound, the modeling assumption that Bonners Ferry will be regulated to 1764 feet to the extent possible is the most dominant feature. On the far right hand side of the graph, one sees that there is about a two foot range between the upper- and lower-bound curves for the VARQ FC scenario. Moving to the left, the upper- and lower-bound curves for both the Standard FC and VARQ FC scenarios all plot below the respective Standard FC or VARQ FC with Fish Flows curves, suggesting that the approach described in Section 3.0 of this report is already quite conservative from a flood control perspective. In other words, the modeling rules used in Section 3.0 present the highest river stages at Bonners Ferry that would result from the alternatives.

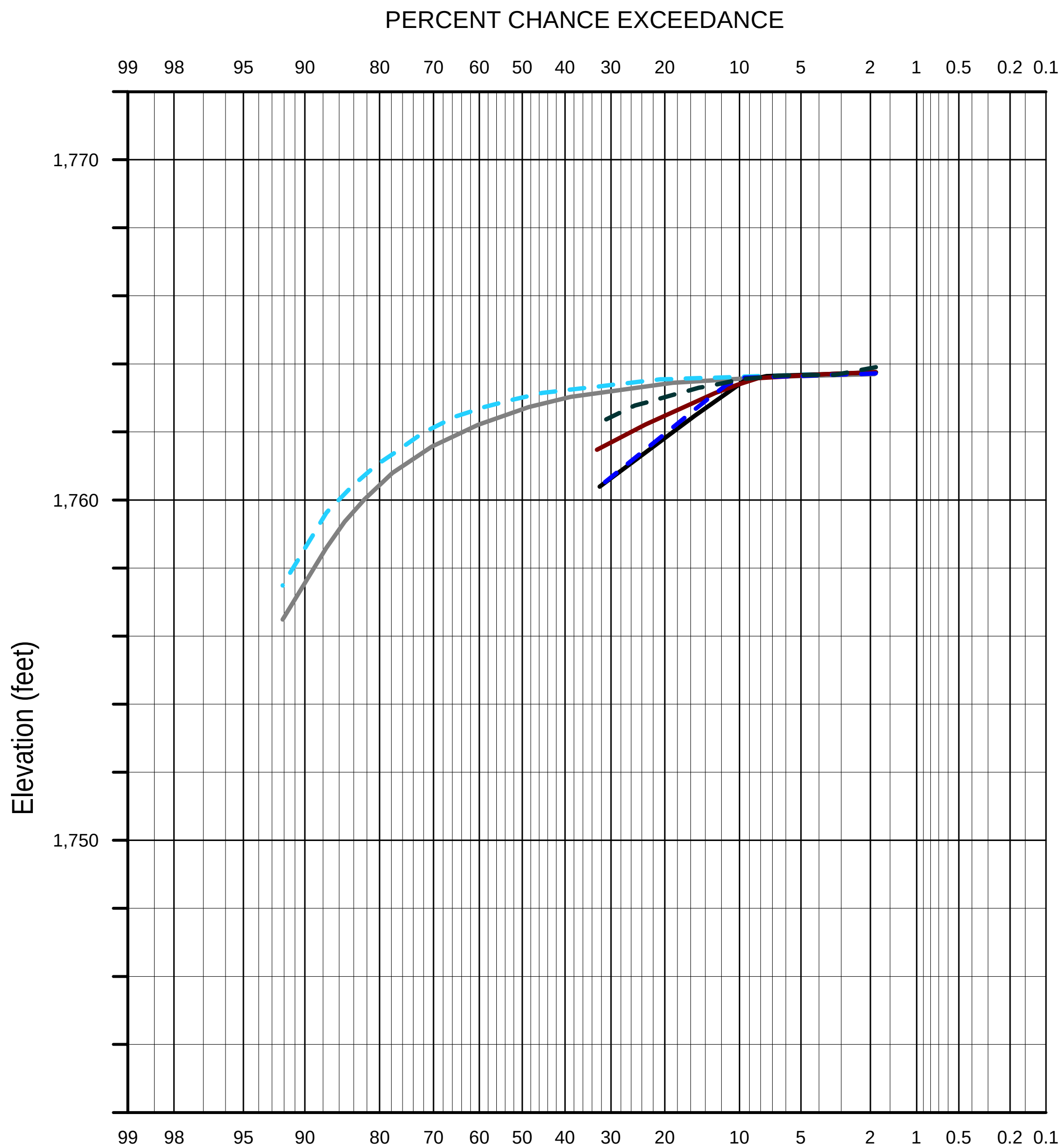
Figure 28. Stage-Frequency Analysis: Bonners Ferry Maximum Daily Elevation (May-July), Sensitivity Simulations



4.2.3 Bonners Ferry Maximum 15-day Average Stage

In addition to peak 1-day water levels at Bonners Ferry, the local community is also concerned with sustained high flows at Bonners Ferry. Therefore, a stage-frequency curve for the maximum 15-day average stage was prepared. This curve covers the period from May through July, and is provided in Figure 29. Figure 29 is very similar to Figure 28, except that all of the curves are shifted downward, as would be expected with the 15-day average. All six curves plateau just under elevation 1764 feet, again from the assumption that Bonners Ferry will be regulated to the current flood stage of 1764 feet to the extent possible. For both the Standard FC with Fish Flows and VARQ FC with Fish Flows scenarios, the assumptions for creating upper and lower bounds all led to lower stages at Bonners Ferry, again suggesting that the modeling assumptions described in Section 3.0 are very conservative from a flood control perspective. In other words, the modeling rules used in Section 3.0 present the highest river stages at Bonners Ferry that would result from the alternatives.

Figure 29. Stage-Frequency Analysis: Bonners Ferry Maximum 15-Day Average Elevation (May-July), Sensitivity Simulations



LEGEND
- Standard w/FF @ powerhouse+10 kcfs
- VARQ w/FF @ powerhouse+10 kcfs
- Standard, lower bound sensitivity
- VARQ, lower bound sensitivity
- Standard, upper bound sensitivity
- VARQ, upper bound sensitivity

2004 UPPER COLUMBIA EIS MODELING RESULTS

BONNERS FERRY, IDAHO
MODELED STANDARD & VARQ FC SENSITIVITY RUNS
STAGE FREQUENCY ANALYSIS

BONNERS FERRY MAX. 15-DAY AVERAGE ELEVATION (MAY-JULY)

PERIOD OF RECORD: WY 1948 - 1999

DATE: 27 JULY 2004

CONSTRUCTED BY: CJF

APPROVED BY:

5.0 Conclusions

The hydrologic modeling described in this report was performed in order to evaluate potential impacts in the Kootenai basin from VARQ FC and fish flows. 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 FC, but that this effect diminishes for lower percent-chance exceedance events. Beyond the 2%-chance-exceedance event (sometimes referred to as the "50-year flood"), the lines on the frequency curves converge, demonstrating that the two flood control procedures provide the same level of local flood protection. At Bonners Ferry, the two flood control operations are essentially equivalent for events where the river is at or above flood stage. Previous studies (Corps 2002) have demonstrated that the two flood control procedures provide the same level of system flood protection to the Portland-Vancouver area.

The simulations discussed in Section 3.0 show that Libby Dam outflow, Bonners Ferry stage, and Kootenay Lake elevation tend to increase when fish flows are modeled in addition to flood control. Additionally, Lake Koocanusa has a lower chance of refilling when fish flows are provided from Libby Dam. VARQ FC with fish flows does a better job of getting the reservoir close to full than Standard FC with fish flows. In general, the maximum outflow from Libby Dam increases as a result of fish flows, particularly for the scenarios where flows of powerhouse capacity plus 10 kcfs are provided for sturgeon. River levels below flood stage at Bonners Ferry increase almost without exception when compared to the flood-control-only scenarios, again with the sturgeon flows at powerhouse capacity plus 10 kcfs having the greatest impact. 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 powerhouse capacity or powerhouse capacity plus 10 kcfs from Libby Dam).

The sensitivity modeling described in Section 4.0 shows that the assumptions used in the Section 3.0 modeling are very conservative from a flood control standpoint. In nearly all cases, the modeled stages at Bonners Ferry from the sensitivity runs produced lower stages than what was modeled in Section 3.0 – even the simulations expected to establish an upper bound! The only exception to this is for the very rare events where VARQ FC with Fish Flows is used. For the 2%-chance-exceedance event using VARQ FC with Fish Flows, the sensitivity runs showed that there is about a two foot range between the upper- and lower-bound curves.

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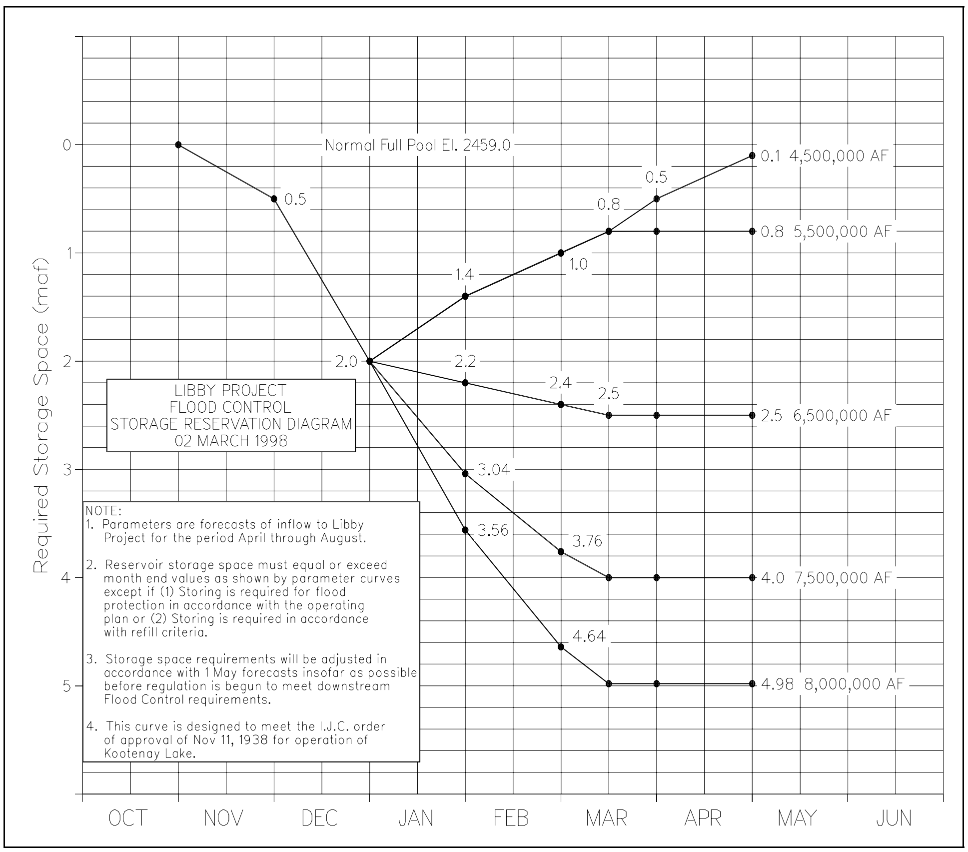
VARQ Operating Procedures at Libby Dam

INTRODUCTION. The following pages contain a description of the rules that govern the VARQ FC procedure at Libby Dam. The general rules are listed below.

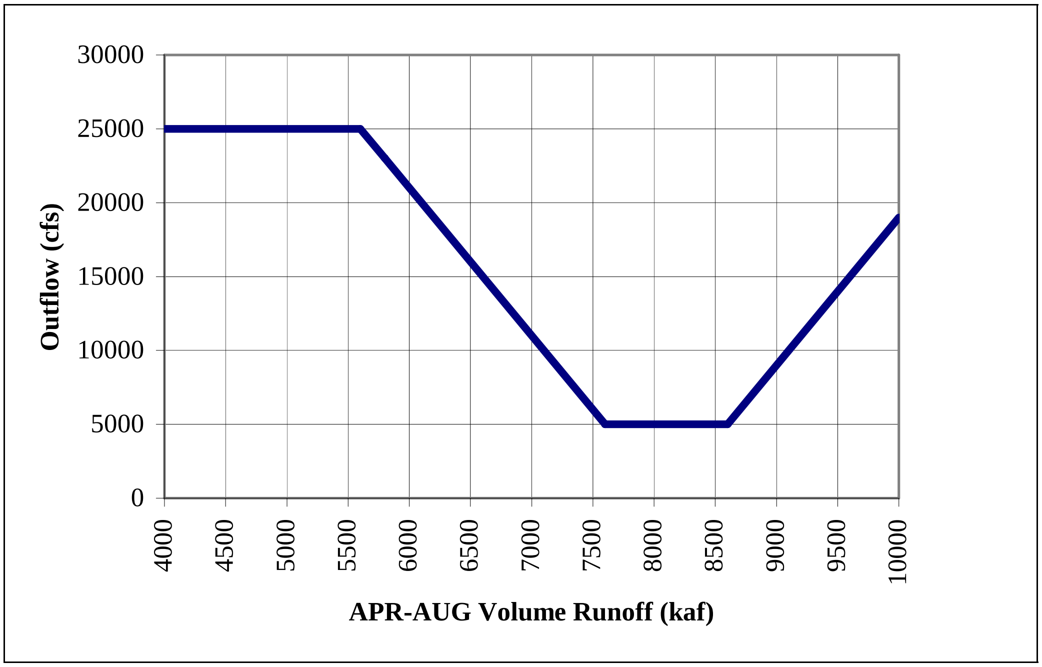
Rule 1. Storage Reservation Diagram. A storage reservation diagram (SRD) for Libby Dam (see figure below) guides the evacuation of space for flood control. Required space is a function of the April-August runoff volume forecast at Libby Dam. Following the evacuation period, the project is required to maintain this space until the initiation of refill. During evacuation and up until the initiation of refill, outflows should be limited to hydraulic capacity of the powerhouse to the best extent possible. However, situations such as the loss of hydraulic capacity or rapidly changing forecasts may require spill to meet flood control requirements.



VARQ Storage Reservation Diagram for Libby Dam

Rule 2. Initiation of Refill. Initiation of refill is determined by the operating procedures for system flood control on the lower Columbia River. These procedures are described in *Columbia River Treaty, Flood Control Operating Plan, October 1972.* At Libby Dam, refill is initiated approximately ten days prior to when streamflow forecasts of unregulated flow are projected to exceed the Initial Controlled Flow (ICF) at The Dalles, Oregon. This criterion applies most of the time: however, if the reservoir intersects with its flood control refill curve (FCRC) prior to ICF being reached, then refill is initiated at that time. The FCRC is a refill curve that fills the reservoir with 95 percent confidence at minimum outflow.

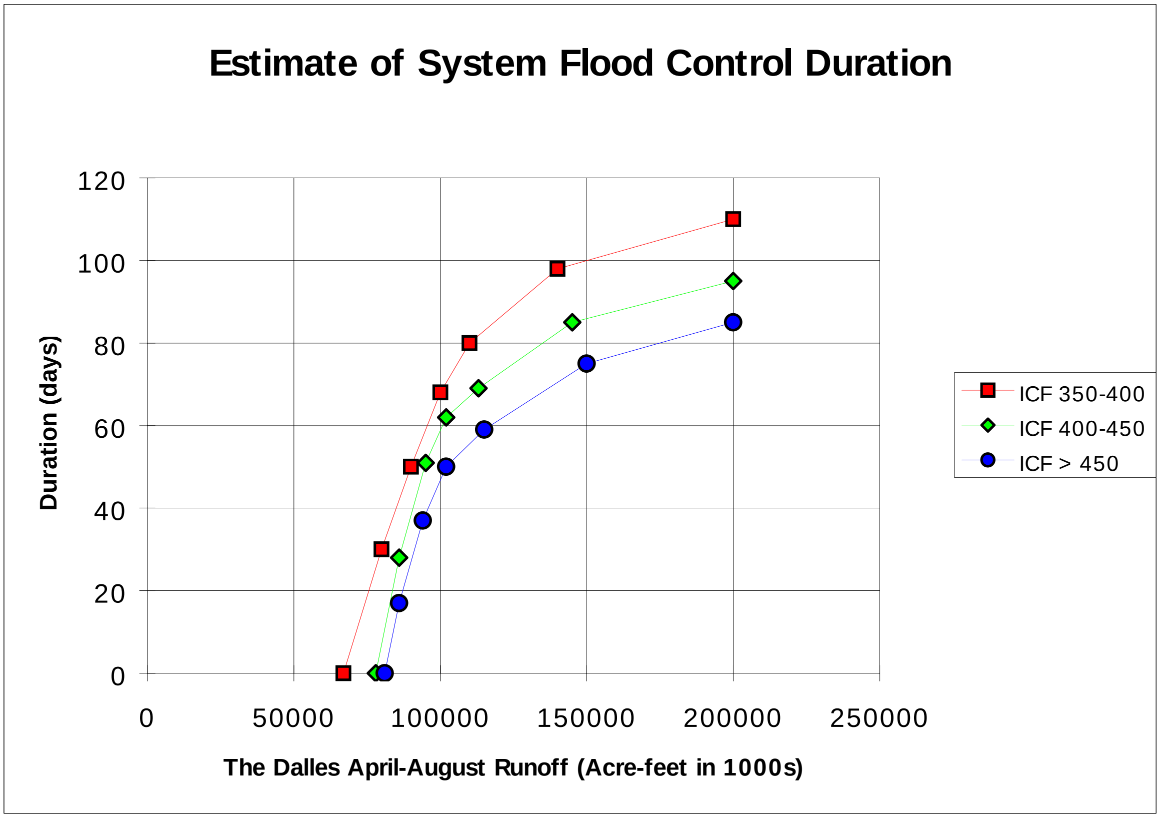
Rule 3. Initial VARQ Outflow. Use the figure below to determine an initial VARQ outflow for Libby Dam.



VARQ Outflows at Libby Dam

Rule 4. Adjusting VARQ Outflows for Delta Storage. Adjust the initial VARQ outflow, if necessary, to compensate for any storage difference between the actual reservoir level and the space required for flood control. This difference can reflect under or over-drafted conditions (Delta). This is done in the following manner:

- Estimate the duration of the system flood control operation (Duration) using the figure below. Select the appropriate curve based on the level of the latest projected control flow at The Dalles (ICF).



Estimate of System Flood Control Duration

- From the selected curve determine the flood control duration using the April-August runoff forecast for The Dalles.
- Compute the VARQ storage adjustment:

ADJSTO = [Delta(kaf) x 0.5(ksfd/kaf)] / Duration(days)

- Compute the new VARQ outflow:

VARQ(new) = VARQ(initial) + ADJSTO

If the runoff forecast at The Dalles is less than 85 million acre-feet, it is likely that system flood control of any significant duration will not be necessary for the lower Columbia River. Use streamflow forecasts to adjust VARQ outflows, if necessary, to compensate for any storage difference between the actual reservoir level and the space required for flood control. Reduce the VARQ outflows as necessary to provide protection against local flooding and to improve the likelihood of refill.

Rule 5. Adjusting VARQ Outflows for Prior VARQ Releases. VARQ releases are seasonal in nature, generated using seasonal runoff forecasts.

- This rule accounts for the difference in outflows released since the initiation of refill and the new VARQ outflows developed using the updated runoff forecast:

  ADJDUR = [VARQ(new) – VARQ(prior)] x [Prior Release(days) / [New Duration(days) – Prior Release(days)]]

- Compute final VARQ outflow:

  VARQ(final) = VARQ(new) + ADJDUR

Rule 6. Inflows Less than VARQ Outflows. At the initiation of refill, if inflows are less than the VARQ outflow, pass inflow until inflows rise to the VARQ level. Thereafter, if inflows drop below the VARQ outflow, pass inflow until they rise again to the VARQ level.

Rule 7. Updating VARQ Outflows During Refill Season. Update VARQ outflows throughout the refill season as new runoff forecasts are developed. Use streamflow forecasts to evaluate the performance of the VARQ outflows in meeting system and local flood control objectives. Reduce VARQ outflows if necessary to provide protection from local flooding. Return to VARQ outflows once local flooding is over.

Rule 8. Final Stages of Refill. Increase outflows during the final stages of refill to avoid overfilling and unwanted spill. Likewise, decrease outflows during the final stages of refill if the present outflow would otherwise not fill the reservoir. Use streamflow forecasts and engineering judgment to select the appropriate outflows.