



Project Hydrology and Hydraulic Models Applied to the Hells Canyon Reach of the Snake River

Shaun K. Parkinson
Editor

**Technical Report
Appendix E.1-4**

Hells Canyon Complex
FERC No. 1971

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Hells Canyon Complex Operations Modeling

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Hydraulic Models Applied to the
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Snake River

Chapter 3

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1. INTRODUCTION

To accomplish Idaho Power Company's (IPC) integrated approach to resource evaluation, simulation of IPC's operation of the Hells Canyon Complex (HCC, FERC Project No. 1971) must be a component in the analyses. To simulate project operations, an operations model was developed for and configured to the HCC; this model uses a set of model input constraints to reflect real operating parameters. The operations model can produce output for several different probable project operations and link to other integrated models. By comparing these outputs, IPC can assess changes to resource conditions.

Hells Canyon, on the Oregon–Idaho border, is the deepest canyon in North America and home to IPC's largest hydroelectric generating complex, the HCC. This complex includes the Brownlee, Oxbow, and Hells Canyon dams, reservoirs, and power plants. Operations of the three projects of the complex are closely coordinated to generate electricity and serve many other public purposes.

IPC operates the complex to comply with the Federal Energy Regulatory Commission (FERC) license, as well as to accommodate other concerns, such as recreational use, environmental conditions, and voluntary arrangements. Among these arrangements are the 1980 *Hells Canyon Settlement Agreement*, the Fall Chinook Plan adopted in 1991, and, between 1995 and 2001, the cooperative arrangement that IPC had with federal interests in implementing portions of the Federal Columbia River Power System (FCRPS) biological opinion flow augmentation, which is intended to avoid jeopardy of the FCRPS operations below the HCC.

Brownlee Reservoir is the only one of the three HCC facilities—and IPC's only project—with significant storage. It has 101 vertical feet of active storage capacity, which equals approximately 1 million acre-feet of water. On the other hand, Oxbow and Hells Canyon reservoirs have significantly smaller active storage capacities—approximately 0.5 and 1.0% of Brownlee Reservoir's volume, respectively.

Brownlee Dam's hydraulic capacity is also the largest of the three projects. Its powerhouse capacity is approximately 35,000 cubic feet per second (cfs), while the Oxbow and Hells Canyon powerhouses have hydraulic capacities of 28,000 and 30,500 cfs, respectively.

Target elevations for Brownlee Reservoir define the flow through the HCC. However, when flows exceed powerhouse capacity for any of the projects, water is released over the spillways at those projects. When flows through the HCC are below hydraulic capacity, all three projects operate closely together to re-regulate flows through the Oxbow and Hells Canyon projects so that they remain within the 1-foot per hour ramp rate requirement (measured at Johnson Bar below Hells Canyon Dam) and meet daily peak load demands.

In addition to maintaining the ramp rate, IPC maintains minimum flow rates in the Snake River downstream of Hells Canyon Dam. These minimum flow rates are for navigation purposes and IPC's compliance with Article 43 of the existing license. Neither the Brownlee Project nor the Oxbow Project has a minimum flow requirement below its powerhouse. However, because of the Oxbow Project's unique configuration, a flow of 100 cfs is maintained through the bypassed reach of the Snake River below the dam (a segment called the Oxbow Bypass).

This interdependency between the projects links them in terms of operations modeling, in which the daily operation of one plant influences the daily operations of the other projects in the system. To analyze project interdependency, IPC chose the CHEOPS™ operations model. The model can simulate project operations in the HCC and help IPC assess the impacts of operations to resources (depending on the set of defined operational criteria).

2. CHEOPS PURPOSE AND ARCHITECTURE

CHEOPS, a simulation package for hydropower systems, was designed by Duke Engineering & Services (DE&S). The system evaluates physical and operational changes at multiple-development hydroelectric projects. CHEOPS is custom-configured for each application to ensure that the critical aspects of a project are accurately simulated. CHEOPS was designed to emphasize long-term simulations of project operations. Use of CHEOPS also emphasizes maintaining correct mass balances in reported flows and meeting all project-operating constraints in the simulations. IPC used CHEOPS Lower Snake Version 1.0 to calibrate historical operations and simulate operational scenarios. The CHEOPS Lower Snake configuration comprises Brownlee, Oxbow, and Hells Canyon projects for simulations of operations.

The physical configuration of the HCC allows the model to link the three projects together; it therefore preserves the coordination between each of the projects operations. Brownlee Project discharges and Wildhorse River flow become inflows to the Oxbow Project. Similarly, Oxbow project discharges, along with Oxbow Bypass flows and Pine Creek flow, become inflows to the Hells Canyon Project.

The CHEOPS modeling system comprises two separate, yet linked, modules: the Rule Curve module and the Energy module. The Rule Curve module uses daily average inflow, target elevations, plant capacity, and minimum flow requirements for the HCC to calculate daily average project outflows. These daily project outflow calculations are then input to the Energy module to produce the detailed 15-minute water releases within the defined operational constraints. Using a defined load shape, the Energy module shapes these daily flows. The load shape is used to define a typical daily response to energy load demand. Energy use is typically high during the day, which requires more generation at the projects and therefore greater water releases. Energy use is minimal during the late evening and early morning hours so less generation, or lower water releases, are required by the projects during these times. This general load shape used by the model to calculate water releases is presented in Figure 1. In addition to the operational constraints, such as ramp rate restrictions, the model is also configured to use the physical constraints for each project in the calculations. Examples of these physical constraints include reservoir storage curves, tailwater curves, and turbine curves.

It is important to note that the CHEOPS model does not attempt to quantify the “ancillary services” of hydroelectric plants. For example, system reliability and other benefits associated with plant capacity or reserves are not considered in the model logic or output.

3. MODEL CALIBRATION

Before the CHEOPS model can be used to represent project operations, it must be calibrated. The model uses historical data for boundary conditions in the calibration process. During calibration of CHEOPS, model-generated output are compared against historical data to determine whether modeled project discharges, reservoir elevations, and monthly generation values adequately represent historical conditions. However, historical day-to-day operations vary because of weather, load demands, and other system conditions, matching exact historical daily output with model-generated output is impossible.

The goal of the calibration process is to capture the range of historical operations. Once the model is calibrated, it can be used to compare the effects between the different operational scenarios on resource conditions. Therefore, matching exact historical daily output is not critical. The model-generated output will be ultimately used to compare scenarios relative to each other, rather than assessing absolute model-generated values.

3.1. Boundary Conditions

3.1.1. *Inflow Hydrology*

The input flow files are configured as daily average flows to the designated projects. The inflow to the Brownlee Project is a calculated flow. It is calculated beginning with the daily average discharge from Hells Canyon Dam, adding or subtracting flow based on the midnight-to-midnight change in storage in each reservoir and then subtracting inflows from the Wildhorse River and Pine Creek. For clarity, it should be noted that this final computed inflow to the Brownlee Project used in the model consists of the flow for the mainstem Snake River at Brownlee Reservoir. This computation accounts for the minor tributary and local inflows located downstream of gauging stations that influence flows to the project.

Accretion flows to the complex, between Brownlee and Hells Canyon dams, include those from Wildhorse River and Pine Creek. Wildhorse River flows into the upper end of Oxbow Reservoir. Its contribution and Brownlee Dam discharges comprise the total flow into Oxbow Reservoir. Pine Creek also flows into the upper end of Hells Canyon Reservoir. Its contribution and Oxbow power plant discharges, bypass flow, and spillway comprise the total flow into Hells Canyon Reservoir. The U.S. Geological Survey (USGS) gauges we used to develop the daily average inflow file appear in Table 1.

As mentioned earlier, we used historical data to calibrate the model. Historical inflow data included representative low, average, and high water years. In selecting representative years for model comparisons, we chose years for which detailed historical data were available (Table 2). Although an extreme high water year occurred in 1997, we didn't use it in the calibration procedure because inflows exceeded hydraulic capacity for most of the year.

3.1.2. Project Description

The model's configuration represents the physical characteristics of the three-dam complex. The physical setting inputs to the model include the following:

- Reservoir curve
- Tailwater curve
- Spillway curve

The only ramp-rating curve specified in the model applies below Hells Canyon Dam. This curve keeps the simulated operation of Hells Canyon Dam within its specified ramp rate requirement. In addition, turbine and generator curves for each unit are specified in the model. Ultimately, the calculated amount of power that the entire complex generates is a function of reservoir and tailwater elevations and plant discharges.

3.1.3. Project Operating Constraints

Calibrating the CHEOPS model involves comparing model results against historical data so that we can assess how closely the model represents project operations. We apply historical boundary condition information to the model that matches historical operational constraints and limits. Then we compare the model's output with historical data. It is difficult to match the output and historical data exactly because load demand, emergency operations, weather, and day-to-day operational decisions can cause variations in the way the projects are operated. Because the model is consistent in applying a defined load shape to the calculated daily average outflow, it does not capture the day-to-day historical variations. This characteristic of the model can be seen later in this chapter in Section 3.2.3. on weekly comparisons.

We used the following historical data (specific to each year) for model boundary conditions:

- Brownlee Reservoir target elevations
- Unit maintenance for each project
- Fall chinook program discharge flows, including minimum spring flows below Hells Canyon Dam until fry emergence. (IPC instituted the fall chinook program in 1991 to protect spawning adults and emerging fry.)

The U.S. Army Corps of Engineers' (COE) North Pacific Division defines flood-control requirements and coordinates flood-control efforts with IPC. During the spring, IPC complies with Article 42 and responds to the COE request to lower the water level in Brownlee Reservoir. The lower water level provides space for excess spring runoff and helps prevent flooding, primarily on the lower Columbia and lower Snake rivers. Target elevations specified for Brownlee Reservoir in the spring are not calculated for the calibration exercise. However, the historical daily elevations are included as boundary conditions in the model, which contain the historical flood-control requirements and operations for that specific year.

Most operating constraint data, such as Oxbow Bypass flows, do not need to be adjusted for each year. Rather, the data specific to each year include Brownlee Reservoir elevations, minimum instantaneous flows below Hells Canyon Dam, fall chinook spawning period flows and duration period, and unit maintenance at each project. Enough Brownlee Reservoir historical target elevations had to be specified to capture the elevation changes during the year to represent the general annual shape of Brownlee Reservoir. However, for each year's calibration, each reservoir's level fluctuations, system load shape, and physical conditions remained unchanged.

The model always attempts to schedule the most efficient operation, given the available inflow and project constraints. As stated earlier, the load shape is used to define a typical daily response to energy load demand. Energy use is typically high during the day, which requires more generation at the projects and therefore greater water releases. Energy use is minimal during the late evening and early morning hours so less generation, or lower water releases, are required by the projects during these times. Load shape simply represents daily system demands for power. Defining a load shape enables the model to simulate the heavy-load and light-load periods encountered during a 24-hour cycle and thus to schedule the water released from each project accordingly. Figure 1 illustrates the load shapes used in the CHEOPS model. The model schedules the total daily water volume through the plant based on Brownlee Project inflow, Brownlee Reservoir target elevations, and Hells Canyon minimum flow requirements. Then it schedules the water to provide the maximum power generation possible during this defined, heavy-load demand period without violating any operational constraints. A midday secondary peak appearing during the six-month period between October and March (Figure 1) is considered part of the heavy-load demand period. It allows for reduced power generation at Brownlee and Oxbow powerhouses as long as no defined operational constraints are violated. This shape is based on typical historical system load demand seen for the colder months of the year.

The basic load shape in the CHEOPS operations model also includes a "super-peak" period, which better represents Hells Canyon Dam's peaking characteristics. This addition to the basic load shape comprises a brief four- or six-hour period that captures the peaking operations that have historically occurred below Hells Canyon Dam. This peak is defined in the model to occur in either the early morning between 6 A.M. and 12 P.M. or in the evening between 6 P.M. and 10 P.M. To simplify the model logic, one peak period is defined and located on either end of the heavy-load shoulder period. The season determines whether this peak period is placed at the morning or evening end of the heavy-load shoulder. This super-peak flow schedule occurs only on weekdays in the model. On weekends, Hells Canyon Dam's load shape matches the basic heavy-load period but does not schedule super-peak levels in the model. This super-peak period is not illustrated in Figure 1 but is identified in the label for each panel of the figure.

The CHEOPS Lower Snake model also allows a Saturday and Sunday weekend load shape to be defined. Based on general historical trends, this weekend load shape typically mimics the weekday load shape except that the peak period is reduced by one hour. However, for July through September, this heavy-load period appears to be typically two hours shorter, resulting in a 14-hour heavy-load period on weekends.

The load shape is the single most influential input parameter the model uses to calculate project discharge. The load shape defines the volume of water to be discharged through each project (once minimum flow requirements have been met). Therefore, if the heavy-load period of the day is 16 hours, then the model will schedule as much water through the plant during this period

as it can while still meeting defined operating constraints. If the heavy-load period is increased or decreased, then the same volume of water must be discharged under a longer or shorter time period. These situations result in different maximum project discharges and subsequently different peak project generation, as can generally be seen in the Figure 2 example. As a last resort, the model may also slightly reduce the duration of the heavy-load period to avoid violating a constraint such as reservoir level fluctuation limits.

Historically, the length or duration of the actual load shape on a given day adjusts to daily variations in system demand or conditions. The model cannot predict those changes. However, use of the general 16-hour heavy-load period load shapes (see Figure 2) provides excellent long-term calibration results.

3.2. Calibration Results

To calibrate the model, scheduling routines and load shapes were adjusted to those illustrated in Figure 1 to better simulate project operations. The calibration effort consisted of adjusting these parameters to assess model comparison with historical data.

3.2.1. Generation

To help IPC understand how historical data compared with model output, we looked at differences between the projects' actual and model-generated results for 1994, 1995, and 1996 (Tables 3, 4, and 5). Positive values indicate that actual historical generation was higher than modeled generation, while negative values indicate that actual historical generation was less than modeled generation. More values are negative than positive and can be attributed to historical variations in daily load shape caused by emergency operations, weather, and other daily factors, which can in turn result in less efficient use of the daily average project discharge. Still, given the variability of day-to-day operations, the tables illustrate that the annual generation comparisons are within 5%. This small difference is considered good for operations calibration, given the complexity of the HCC operations. Other discrepancies in generation, particularly when comparing months, are attributable to differences between historical and modeled Brownlee Reservoir elevations. Such discrepancies are also apparent when comparing Oxbow and Hells Canyon reservoirs, which are presented in Section 3.2.2. As mentioned previously, the CHEOPS model does not attempt to quantify the ancillary benefits of hydroelectric plants. For example, benefits associated with system stability or reserves are not considered in the model logic or output. But these ancillary services do influence the difference between historical and modeled monthly generation values.

We also compared actual and modeled power generation for calendar years 1992 and 1997, which were extreme low and extreme high water years, respectively (Table 6). The differences between actual and modeled power generation for each project are very small considering the real-time variability of operations.

Figures 3 through 5 compare model-generated values with historical daily averages (during 1994, 1995, and 1996) for Brownlee Reservoir elevations and Hells Canyon Dam discharges.

Absolute mean error (AME) was also used as a quantitative means of evaluating the calibration. The equation for AME can be described as

$$AME = \frac{\sum |X_M - X_D|}{N}$$

where X_M = Modeled value

X_D = Measured value

N = Number of data pairs

AME calculations were performed for Brownlee Reservoir elevation comparisons and Hells Canyon Dam discharges. Table 7 presents the results. Again, the model does not capture daily average reservoir elevations for Brownlee every day. This is because the target elevations are not specified for every day of the year, as discussed earlier. Small changes in Brownlee Reservoir elevation can significantly influence project discharges because of the reservoir's large total volume. Therefore, the small variation between modeled daily average reservoir elevation and historical daily average elevation for Brownlee is influencing the project discharge below Hells Canyon Dam. Discrepancies may also be attributable to the fact that the Brownlee inflows are also calculated values and ultimately influence the comparison between modeled project flows and historical project flows.

3.2.2. Project Flow Discharges

To further compare modeled and actual project outflows, IPC developed duration curves for discharge from Hells Canyon Dam (Figures 6 through 8). The duration curves are created from 15-minute historical data and 15-minute model output data for comparison purposes. As the duration curves show, the model captures the range of plant discharge flows and forms a basis against which to compare other operational scenarios.

To compare modeled and historical headwater results, we created reservoir elevation duration curves for Oxbow (Figures 9 through 11) and Hells Canyon (Figures 12 through 14) reservoirs. We used hourly historical data and hourly model output data to create the curves. These plots illustrate the model's capability to represent typical historical elevations: generally the curves have the same shape. However, the differences between historical and simulated operations are attributable to several factors. The model reaches the flood elevation before spill occurs, whereas, at times, actual spill occurs at the projects at lower than flood elevations. (Spill typically occurs during average to high water years.) Figures 9 through 14 also show why the annual trend of modeled monthly generation in megawatt hours (MWh) was greater than historical generation because the modeled reservoir elevations were generally higher. In addition, the variability in Brownlee Reservoir elevation and Hells Canyon Dam discharge comparisons presented in Table 7 also illustrates the differences. Small changes in Brownlee Reservoir elevation amount to significant changes in water volume, particularly at elevations closer to full. However, these curves still demonstrate the model's capability to represent historical conditions.

3.2.3. Weekly Comparisons

The weeks presented in Figures 15 through 17 show how modeled and actual operations compared on a weekly basis. The figures illustrate the model's ability to replicate the historical mode of operation. Figure 16 shows the model's attempt to capture the short peak period that is pronounced in the morning hours. The model output captures the general daily minimum and maximum flows.

The first and last days on the charts (Figures 15 through 17) are weekends, so the model does not show the short spike in Hells Canyon Dam's discharge. Figure 17 also illustrates the historical variability of the daily load shape from day to day and even from the previous week, as shown in Figure 16. It is important to note that the ending and beginning modeled flows are discontinuous between days. This discontinuity is visible between December 18 and 19 in Figure 16. Because the model creates a detailed schedule based on the calculated daily average flow discharged for each day (developed by the model's Rule Curve module), any daily analysis of modeled project operations is limited to a 24-hour period. This limitation helps prevent overstating impacts in flow or reservoir changes between 11:45 P.M. and midnight (hour zero) the following day.

Figure 18 illustrates the variability of historical 15-minute data below Hells Canyon Dam. This variability also influences the historical flow duration curves that were presented earlier in this chapter (see Figures 6 through 8). Because only the daily average inflow is used as model input, the CHEOPS model is limited to using these data to produce 15-minute project output. In this particular case (shown in Figure 18), flows exceed Hells Canyon Dam's hydraulic capacity. The model is programmed to pass the daily average inflow through the powerhouse and spillway, maintaining a full pool in the reservoir. But the project's actual inflows vary over the course of the day, a situation that ultimately influences comparisons between project discharge and headwater elevations for modeled and historical data.

The model is also programmed to follow load (or load-follow) every day, shaping the water passing through the project based on the defined load shape and operational constraints. This feature causes the model to simulate a more aggressive operation of the complex than it has historically operated. Figure 19 depicts historical daily load shapes as irregular and shows load shapes passing inflow for the last two days of that week. The model, however, continues to load-follow every day. Figure 20 illustrates that, for a low-flow period, the model reduces the 16-hour heavy-load period scheduled for the Hells Canyon Complex and tries to shape as much water into the shorter duration peak period to avoid exceeding reservoir elevation limits at Hells Canyon Reservoir. This algorithm also appears to replicate the historical mode of operation.

Duration curves in Figures 21 through 23 illustrate the daily comparisons between modeled and historical operations below Hells Canyon Dam. These figures show historical and modeled daily maximum flows, daily minimum flows, and daily flow changes for each of the three calibration years. As shown in these graphs, replicating daily project operations exactly is impossible; however, the model represents the historical trends and captures the range of conditions that exist below the Hells Canyon Project. Due to the 15-minute variation in flows below Hells Canyon Dam (as illustrated in Figure 18), the daily change in project outflows are only represented for flows lower than the hydraulic capacity of the Hells Canyon Powerhouse.

3.3. Conclusions

Calibration results presented in this chapter reveal that the CHEOPS model produces output that represents HCC project operations. It is also apparent that matching the output of the CHEOPS model exactly to historical operations is difficult or impossible. However, the model can represent 1) typical daily outflow below the project on a 15-minute basis and 2) reservoir elevations for the each of the three projects within the complex.

The calibration and verification of the operations model is complete. Results show that this model has been successfully calibrated for the purposes of comparing various operational scenarios against a baseline condition. Therefore, the model can be used to compare operational scenarios used for resource evaluations, as presented in Section 4.

4. RELICENSING OPERATIONAL SCENARIOS

The integrated modeling approach is designed to use a common and consistent flow-based data set throughout the study area (reach) for use in resource evaluations. The CHEOPS operations model is an integral piece of the modeling effort and these evaluations. A wide array of potential scenarios can be simulated using this integrated modeling approach. The two scenarios used for relicensing the HCC are described below.

4.1. Definition of Operations

Two operational scenarios are modeled for the license application. Operational analyses use the *proposed operations* scenario of the HCC as the base case scenario. This scenario defines the operational parameters under which the complex would typically operate as a point of comparison with other operational scenarios. The other operational scenario analyzed is the *full pool run-of-river scenario*.

4.1.1. Proposed Operations

Varying hydrologic conditions and numerous other factors influence the way hydropower projects operate. Because daily operations are influenced by many factors, which may include project inflow, energy demand, market conditions, or emergency situations, they are difficult to predict on a long-term basis with any certainty. In addition, flood-control requirements, navigation, recreation, and biological needs can influence real-time daily operations as well. Therefore, for the purposes of the relicensing studies, *operations* is defined in general terms. In addition, IPC's definition of proposed project operations looks forward into the new license term and provides a general point of comparison for other potential operating scenarios.

It is important to note that, if the output of IPC's operations model were compared with historical conditions, differences would be apparent. That is, parameters of the proposed operating scenario for the HCC differ considerably from the operating parameters of the original license. The reason for these differences is that over time, energy and environmental conditions have altered how the HCC is operated. For example, when fall chinook salmon were designated as threatened under

the Endangered Species Act, IPC modified its operations. In the fall of 1991, IPC started a program to protect spawning adults and emerging fry. IPC's proposed operations continue this special program.

To capture the types of hydrology entering the project, the proposed operations scenario has also been defined in terms of low, medium, and high water years. These distinctions are made to reflect variations in operations based on inflowing water conditions.

4.1.2. Full Pool Run-Of-River Operations

Full pool run-of-river is the operational scenario IPC will compare with the base case scenario (proposed operations) to determine project impacts. Full pool run-of-river establishes a scenario where inflows to the HCC, including tributary inflows, equal outflows from the HCC. This scenario does not necessarily reflect conditions that would be most beneficial to environmental resources. Rather, it reflects conditions under which IPC could analyze impacts with the project in place but without project operations influencing the outflow hydrograph.

4.2. Boundary Conditions

4.2.1. Inflow Hydrology

4.2.1.1. Long-Term Hydrology

The flow input file, comprising 72 years of daily average inflows, was developed for use in studies requiring a long-term hydrologic record. Details on the development of this hydrologic record are described in Chapter 2 (Simons et al. 2001).

We categorized each year modeled into low, medium, or high water years and applied the appropriate operational constraints in the model runs. We also paid particular attention to high water years that preceded low water years so that we could establish spawning flow requirements for the fall chinook program that could be met the following spring. Output from the operations model consisted of daily average discharge and reservoir elevations of each project for further analysis.

4.2.1.2. Short-Term Hydrology

Studies requiring more detailed flow information than is provided in the long-term hydrology use results from five representative years of inflow hydrology. The five representative years selected for input to the CHEOPS model are also described in Chapter 2 (Simons et al. 2001). These representative years are, from low to high, 1992, 1994, 1995, 1999, 1997. The output from each project is produced in 15-minute increments. We categorized each year by low, medium, or high water year and applied the appropriate operational constraints to each discrete year used in the model runs. Delineating how a particular year's classification followed or preceded a different year's classification was not relevant for this modeling purpose.

4.2.2. Physical Settings

The model's configuration represents the physical characteristics of the three-dam complex. The physical setting inputs to the model include the following:

- Reservoir curve
- Tailwater curve
- Spillway curve

We integrated the CHEOPS operations model with a separate water quality model, CE-QUAL-W2. As part of the integration, we made slight adjustments to the CHEOPS reservoir curves for each project so that the volume interpolation in CHEOPS mimicked, as closely as possible, the reservoir volume calculation by the water quality model. The water quality model uses a two-dimensional laterally averaged rectangular grid developed from surveyed reservoir bathymetry (Butler 2002) to calculate water volumes in the reservoir, whereas the CHEOPS model uses a reservoir volume curve.

The only ramp-rating curve specified in the model applies below Hells Canyon Dam. This curve keeps the simulated operation of Hells Canyon Dam within its specified ramp rate requirement. In addition, turbine and generator curves for each unit are specified in the model. Ultimately, the calculated amount of power that the entire project generates is a function of reservoir and tailwater elevations and plant discharges.

4.2.3. Operating Constraints

In this section, we discuss and present load-shape configuration as an operating constraint for the relicensing scenarios. For these scenarios, we used the same load-shape configuration as for the model calibration procedure (see Section 3.1.3.).

4.2.3.1. Proposed Operations

As mentioned in Section 3.1.3., the COE's North Pacific Division defines flood-control requirements and coordinates flood-control efforts with IPC. During the spring, IPC complies with Article 42 and responds to the COE request to lower the water level in Brownlee Reservoir. The lower water level provides space for excess spring runoff and helps prevent flooding, primarily on the lower Columbia and lower Snake rivers.

The CHEOPS model uses the latest 1998 rule curve formulas to calculate the target elevations for Brownlee Reservoir based on observed flows at Brownlee and The Dalles projects. For each year, the model begins drafting Brownlee Reservoir after January 7 for each year. This drafting simulates IPC's flood-control requirements by reaching calculated target elevations for February 28, March 31, April 15, and April 30 again, based on the observed flows. Then the model begins refilling Brownlee Reservoir after the calculated April 30 target. The refill target is 2,069 ft above mean sea level (msl) or higher by the first week in June and full by the latter part of June. Meeting this target ensures that enough water is stored in the reservoir to meet peak summer electricity demands, provide suitable spawning habitat for resident fish, and offer

optimal recreational opportunities, particularly through the Fourth of July holiday. After the Fourth of July holiday, the model again drafts the reservoir beginning July 5 each year to simulate IPC customers' power needs during the summer months. The amount of draft varies according to the type of water year and the target elevation specified for August 31 (Table 8).

Historically and in the future, Brownlee Reservoir elevations may be higher or lower than those specified in the model constraints. The elevations used in the model are considered "typical" and actual reservoir elevations by August 31 are a function of IPC's system or load needs and water conditions.

During the fall, Brownlee Reservoir is operated largely to benefit the fall chinook below the HCC. To maintain stable spawning conditions for fall chinook, water is released from Brownlee Reservoir before the spawning period to allow the reservoir to capture fall inflows and maintain a constant flow below Hells Canyon Dam.

To calculate the target elevation for Brownlee Reservoir, the model calculates the difference between the total inflow volume during the spawning season and the constant set spawning flow released during the fall chinook program. The model is configured to begin drafting Brownlee Reservoir around September 9 (sometime after Labor Day weekend for each year so that recreationists have access to boat ramps before the fall chinook program begins) to capture the inflow volume. The type of water year determines the spawning flow released below the HCC in the model. The spawning season is defined in the model as October 21 through December 11 for each year. After the spawning season is complete, the minimum instantaneous flow volume below Hells Canyon Dam is reduced slightly below the fall spawning flow so that water is maintained over the shallow-most redd through fry emergence in the spring. After fry emergence, or June 1 in the model, the minimum instantaneous flow below Hells Canyon Dam is reduced to 6,500 cfs, or such inflows that Brownlee Reservoir is not drafted to meet the minimum flow requirement. Table 9 summarizes the minimum instantaneous flows below Hells Canyon Dam for three time periods.

Certainly the spawning season and associated minimum flows vary among all years. However, the minimum instantaneous flows listed in are considered typical for modeling purposes. For example, the constant spawning flow for fall chinook beginning in October 2001 was 8,000 cfs.

A minimum flow of 6,500 cfs below Hells Canyon Dam is modeled by CHEOPS to represent the agreement between IPC and the COE initially dated September 1988. This agreement was entered into to maintain navigation flows below the project. However, IPC's license stipulates a minimum flow of 5,000 cfs below Hells Canyon Dam at Johnson Bar. Depending on water conditions, flows below 6,500 cfs may be released below Hells Canyon Dam if 13,000 cfs is maintained at Lime Point.

Other operational constraints that apply to the operations model include reservoir elevation limits (Table 10) and reservoir-level fluctuation limits (Table 11). These constraints define the typical operational scheme for HCC model simulations.

Because of its unique configuration, only the Oxbow Project has a minimum bypass flow requirement in the existing license (Table 12). This minimum bypass flow is released from the dam and discharged into the bypassed reach. Flows exceeding powerhouse capacity are also discharged into the Oxbow Bypass.

Only the Hells Canyon Project has a license-restricted ramping rate. Its compliance is measured at Johnson Bar, located approximately 17.6 river miles downstream of the dam. Those restrictions are shown in Table 13.

During the recreation months, the daily fluctuation below Hells Canyon Dam is typically limited to 10,000 cfs and used in the model simulations. Again, this daily limit is used to represent typical operations between June 1 and September 30 because historically, 80% of the time, daily fluctuations below Hells Canyon were 10,000 cfs or less during this time period. Therefore, the remaining 20% of the time, the daily fluctuation exceeds 10,000 cfs and is not modeled by CHEOPS during this period.

4.2.3.2. Full Pool Run-of-River Operations

IPC uses the full pool run-of-river operational scenario to evaluate HCC project impacts. The full pool run-of-river operational scenario represents the HCC in place without the influence of operations. Within the scenario and for all types of water years, Brownlee Reservoir is maintained at 2,077 ft above msl for the entire year. Similarly, Oxbow and Hells Canyon reservoirs are held at 1,805 ft and 1,688 ft, respectively. Spill occurs at any of the projects when the hydraulic capacity is exceeded. Inflow to the projects is the same as for proposed operations on a daily average basis. Because the projects pass a constant daily average inflow, ramp rate restrictions below Hells Canyon Dam are not applicable. Also, flood control and the fall chinook program are not simulated in this scenario. Tables 14 through 18 illustrate the model settings or boundary conditions for the full pool run-of-river scenario.

In the full pool run-of-river scenario, each reservoir is held at maximum pool elevation and passes daily average inflow. Load-following does not occur at any of the projects because that operation would cause reservoir level and project discharges to fluctuate over the course of the day.

Again, only the Oxbow Project has a minimum bypass flow requirement in the existing license. This scenario also maintains the bypass flow released from the dam and discharged into the bypassed reach (Table 17). Flows exceeding powerhouse capacity are discharged into the Oxbow Bypass.

As mentioned previously, the ramp rate restriction below Hells Canyon Dam does not apply within the run-of-river scenario. A constant daily average inflow is passed through the project without operations influencing the hydrograph.

5. MODEL RESULTS

5.1. Long-Term Hydrology

CHEOPS presents results from the long-term hydrology files as daily average flows for use in resource evaluations. Further evaluation and representation of the CHEOPS model output are described below.

To help analyze CHEOPS model output for the Snake River below the Hells Canyon Dam, we used the Indicators of Hydrologic Alteration (IHA) software, a statistical tool. The Nature Conservancy with Smythe Scientific Software developed the software. This tool helped us calculate hydrologic regime characteristics and analyze changes in those characteristics over time or between data sets. IHA statistically characterizes resulting flow regimes from project operations and presents the frequency, magnitude, and duration of flow events for scenario comparison. All data entered into IHA were daily average discharges (cfs) from Hells Canyon Dam, so we did not perform daily analyses.

We used the IHA software to compare the two operational scenarios for calendar years 1928 through 1999: 1) proposed operations and 2) full pool run-of-river operations. These two data sets contained daily average discharge flow from Hells Canyon Dam (Table 19 and Figure 24).

5.2. Short-Term Hydrology

Samples of the 15-minute detailed output presented in Figures 25 through 26 illustrate the operation of and coordination between each project in the complex. The figures show average water year output results under the proposed operational scenario. Figure 25 illustrates the secondary load shape tier both Brownlee and Oxbow reservoirs use in scheduling water through the projects. These figures also depict the projects' re-regulating effect as the flow discharged from Brownlee Reservoir is ultimately dampened when it is finally discharged below Hells Canyon Dam.

Figure 26 illustrates project discharge characteristics when inflows exceed plant capacity. The added flows between projects result from Wildhorse River and Pine Creek discharges to the HCC.

Figures 27 through 32 present detailed results of typical summer operations, fall chinook program operations, and winter operations of the projects, as well as full pool run-of-river operations for comparison. Subsequently, we used these detailed output data in various resource models to compare effects to the resources from the two operational scenarios.

For comparisons of relicensing scenarios, the daily average flows and reservoir elevations presented in Figures 33 through 42 illustrate how operations influence the daily outflow hydrology when compared with Brownlee Reservoir inflow. Appendix 1 contains additional CHEOPS model output for each of the five representative years. Data compare Hells Canyon Dam outflow for proposed operations with the full pool run-of-river scenario. The data presented are 15-minute data for each month and each representative year.

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Butler, M., editor. 2002. Topographic integration for the Hells Canyon studies. In: Technical appendices for Hells Canyon Complex Hydroelectric Project. Idaho Power, Boise, ID. Technical Report E.1-3.

Settlement Agreement. 1980. Agreement dated February 14, 1980, among Idaho Power Company, Idaho Fish and Game Commission, Idaho Department of Fish and Game, Oregon Fish and Wildlife Commission, Oregon Department of Fish and Wildlife, Washington Department of Game, Washington Department of Fisheries, and National Marine Fisheries Service, 17 p.

Simons, R. K., B. Lane, J. Salas, J. Braatne, S. Rood, C. Blair, and C. Johnson. 2001. Development of inflow hydrology for Hells Canyon Complex studies. In: S. K. Parkinson, editor. Chapter 2. Project hydrology and hydraulic models applied to the Hells Canyon reach of the Snake River. Technical appendices for new license application: Hells Canyon Hydroelectric Project. Technical Report E.1-4.

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Table 1. Projects and their associated USGS gauges.

Inflow	USGS Gauge
Hells Canyon Dam	Snake River at Hells Canyon Dam 13290450
Wildhorse River	Wildhorse River at Brownlee Dam 13289960
Pine Creek	Pine Creek near Oxbow, OR 13290190

Table 2. Inflow years chosen to represent categories of flow.

Year	Category
1994	Low
1995	Medium
1996	High

Table 3. Comparisons of actual and modeled results for power generated in 1994 by month, done as part of the calibration process. Positive values indicate that actual power generation was higher than modeled generation, while negative values indicate that actual power generation was lower.

Month	Brownlee Dam	Oxbow Dam	Hells Canyon Dam
January	-3%	+5%	-4%
February	-2%	+2%	-6%
March	-1%	+2%	-5%
April	-3%	-4%	-3%
May	+2%	+3%	-1%
June	-6%	-7%	-5%
July	-3%	+5%	-4%
August	-5%	-6%	-7%
September	-3%	-7%	-7%
October	+4%	+1%	-2%
November	-3%	-4%	+1%
December	-3%	-4%	+2%
Annual	-2%	-1%	-3%

Table 4. Comparisons of actual and modeled results for power generated in 1995 by month, done as part of the calibration process. Positive values indicate that actual power generation was higher than modeled generation, while negative values indicate that actual power generation was lower.

Month	Brownlee Dam	Oxbow Dam	Hells Canyon Dam
January	-4%	+2%	-5%
February	0%	+1%	-4%
March	0%	+2%	-4%
April	-5%	0%	-4%
May	-3%	+1%	+2%
June	-4%	+1%	+1%
July	-3%	+1%	-3%
August	-6%	-1%	-6%
September	-2%	+5%	-5%
October	+3%	+3%	-4%
November	-2%	+5%	+2%
December	+2%	+1%	-2%
Annual	-2%	+1%	-3%

Table 5. Comparison of actual and modeled results for power generated in 1996 by month, done as part of the calibration process. Positive values indicate that actual generation was higher than modeled generation, while negative values indicate that actual generation was lower.

Month	Brownlee Dam	Oxbow Dam	Hells Canyon Dam
January	+5%	+3%	-4%
February	-9%	-1%	-6%
March	-7%	-3%	-5%
April	-12%	-5%	-3%
May	-8%	0%	-1%
June	-6%	-3%	-5%
July	-3%	-3%	-4%
August	-1%	-4%	-7%
September	+6%	0%	-7%
October	+4%	+7%	-2%
November	-3%	+9%	+1%
December	-4%	0%	+2%
Annual	-5%	-1%	-3%

Table 6. Comparison of generation calibration (modeled and actual) by year. Positive values indicate that actual generation was higher than modeled generation, while negative values indicate that actual generation was lower.

Year	Brownlee Dam	Oxbow Dam	Hells Canyon Dam
1992	-2%	-1%	-3%
1997	-7%	-4%	-3%

Table 7. AME comparison of calibration (model and actual) by year.

AME	1994	1995	1996
Brownlee Reservoir Elevation (ft)	0.63	0.43	0.62
Hells Canyon Discharge (cfs)	1,411	1,177	1,835

Table 8. Modeled target elevations for power needs (proposed operations).

Type of Water Year	Brownlee Target Elevation for August 31
Low	2,072 ft
Medium	2,069 ft
High	2,059 ft

Table 9. Modeled minimum instantaneous flows below Hells Canyon Dam for three time periods (proposed operations).

Time Period	Type of Water Year	Minimum Instantaneous Flow
December 12 through June 1	Low	8,500 cfs
	Medium	10,500 cfs
	High	12,000 cfs
June 2 through October 20	Low	6,500 cfs
	Medium	6,500 cfs
	High	6,500 cfs
October 21 through December 11	Low	9,000 cfs
	Medium	11,500 cfs
	High	13,000 cfs

Table 10. Modeled reservoir elevation limits (proposed operations).

Project	Maximum Elevation	Minimum Elevation
Brownlee Reservoir	2,077 ft above msl	1,976 ft above msl
Oxbow Reservoir	1,805 ft above msl	1,800 ft above msl
Hells Canyon Reservoir	1,688 ft above msl	1,683 ft above msl

Table 11. Modeled reservoir-level fluctuation limits (proposed operations).

Project and Time Period	Daily Fluctuation Limits
Brownlee Reservoir	
January 1 through May 20	3 ft per day
May 21 through June 21	1 ft per day for resident fish spawning
June 21 through December 31	3 ft per day
Oxbow Reservoir	
January 1 through December 31	5 ft per day
Hells Canyon Reservoir	
January 1 through December 31	5 ft per day

Table 12. Modeled bypass flows at the Oxbow Project (proposed operations).

Project	Minimum Bypass Flow
Oxbow Reservoir	100 cfs continuously

Table 13. Modeled ramping rate restrictions (proposed operations).

Project and Conditions	Ramping Rate Limits
Hells Canyon	
Ramp rate restrictions	
Ramping rate up	1 ft per hour
Ramping rate down	1 ft per hour
Daily limit between minimum and maximum flows	
June 1 through September 30	10,000 cfs per day
October 21 through December 11	No load-following during fall chinook program

Table 14. Modeled minimum instantaneous flows below Hells Canyon Dam (full pool run-of-river).

January 1 through December 31	
Type of Water Year	Minimum Instantaneous Flow
Low	Not Applicable
Medium	Not Applicable
High	Not Applicable

Table 15. Modeled reservoir elevation limits (full pool run-of-river).

Project	Maximum Elevation	Minimum Elevation
Brownlee Reservoir	2,077 ft above msl	2,077 ft above msl
Oxbow Reservoir	1,805 ft above msl	1,805 ft above msl
Hells Canyon Reservoir	1,688 ft above msl	1,688 ft above msl

Table 16. Modeled reservoir-level fluctuation limits (full pool run-of-river).

Project and Time Periods	Daily Fluctuation Limits
Brownlee Reservoir	
January 1 through December 31	0 ft per day
Oxbow Reservoir	
January 1 through December 31	0 ft per day
Hells Canyon Reservoir	
January 1 through December 31	0 ft per day

Table 17. Modeled bypass flows (full pool run-of-river).

Project	Minimum Bypass Flow
Oxbow Reservoir	100 cfs continuously

Table 18. Modeled ramping rate restrictions (full pool run-of-river).

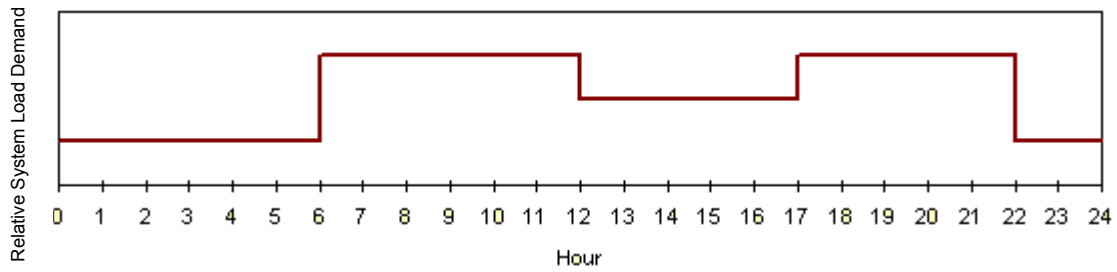
Project	Ramping Rate Limits
Hells Canyon	
Ramp rate restrictions	
Ramping rate up	Not applicable
Ramping rate down	Not applicable
Daily limit between minimum and maximum flow	
June 1 through September 30	Not applicable
October 21 through December 11	Not applicable

Table 19. Results from the IHA for Hells Canyon Dam discharge evaluation, 1928–1999.

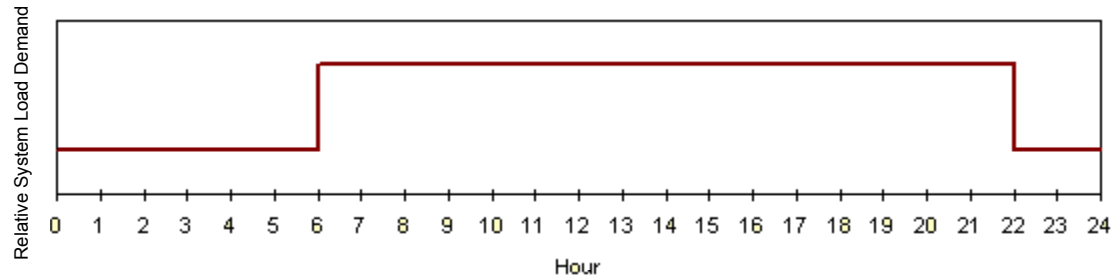
Area of River Basin (mi ²)	Scenario	
	Proposed	Run of River
	72590	72590
	Mean Discharge (cfs)	Mean Discharge (cfs)
January	20,835	18,465
February	23,947	21,250
March	25,829	24,996
April	31,911	31,202
May	23,613	30,010
June	24,841	24,847
July	13,987	13,096
August	12,679	11,645
September	17,692	13,408
October	16,638	15,724
November	11,234	16,417
December	16,179	17,940
	Daily Discharge Value	Daily Discharge Value
1-day minimum	9,527	8,476
3-day minimum	9,635	8,998
7-day minimum	9,750	9,333
30-day minimum	10,119	10,328
90-day minimum	12,311	11,664
1-day maximum	49,256	48,612
3-day maximum	47,447	46,960
7-day maximum	45,018	44,304
30-day maximum	37,870	37,511
90-day maximum	32,020	32,440
	Date of Annual Extreme	Date of Annual Extreme
Minimum	September 19	August 3
Maximum	May 12	April 16

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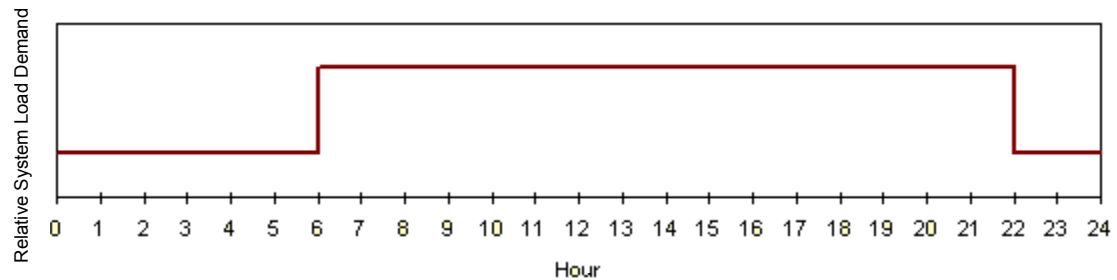
HCC January, February, and March load shape: Hells Canyon super-peak period is 6 A.M. to 10 A.M.



HCC April, May, and June load shape: Hells Canyon super-peak period is 6 A.M. to 12 P.M.



HCC July, August, and September load shape: Hells Canyon super-peak period is 6 P.M. to 10 P.M.



HCC October, November, and December load shape: Hells Canyon super-peak period is 6 A.M. to 10 A.M.

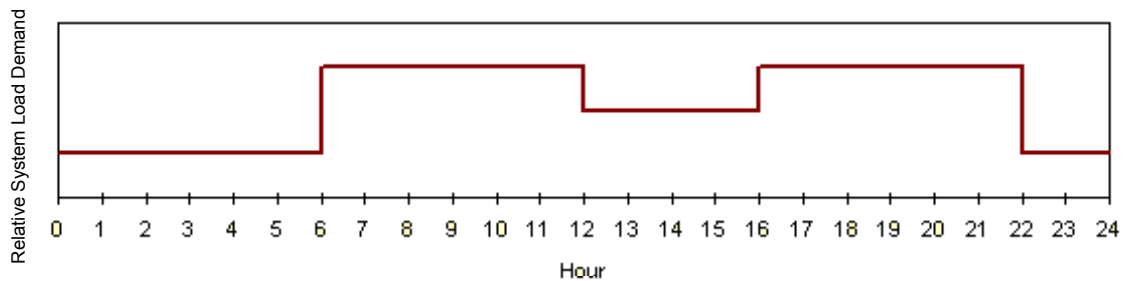


Figure 1. Model weekday load shapes for Brownlee, Oxbow, and Hells Canyon projects.

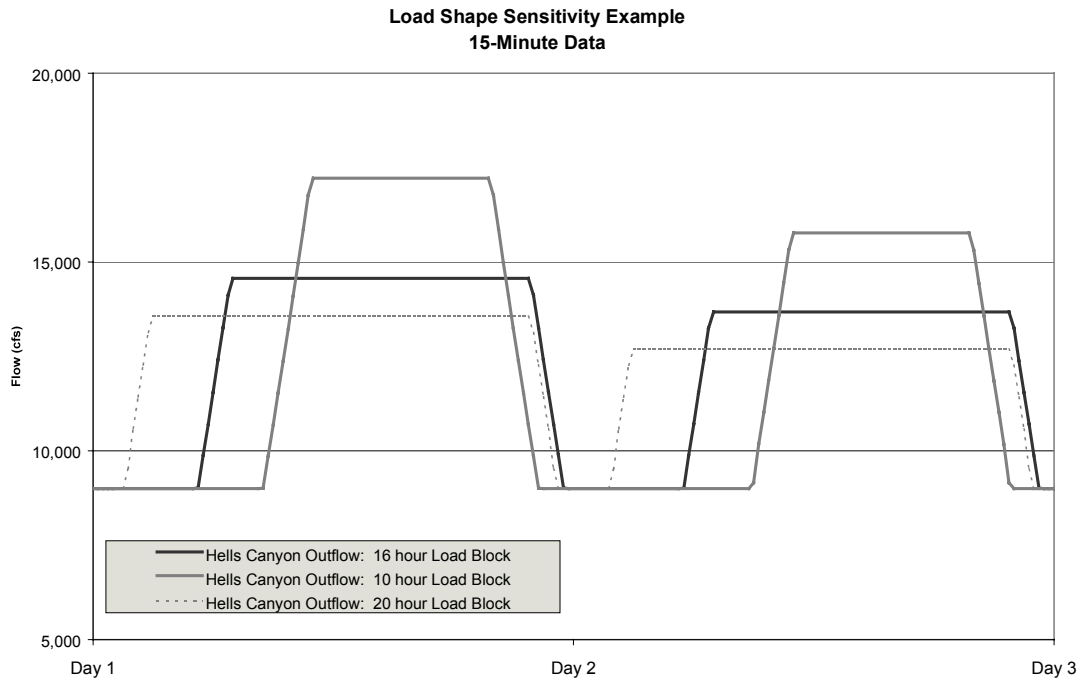


Figure 2. Sensitivity of Hells Canyon Dam discharge to general load shape without super-peak period.

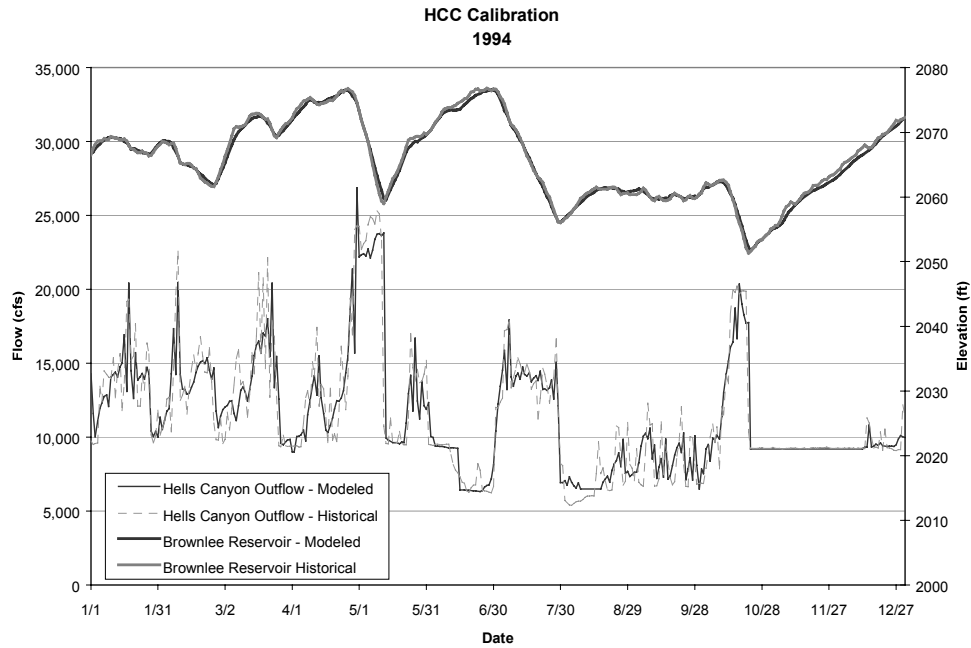


Figure 3. Daily average comparisons of modeled values with actual Brownlee Reservoir elevations and Hells Canyon Dam discharges in 1994.

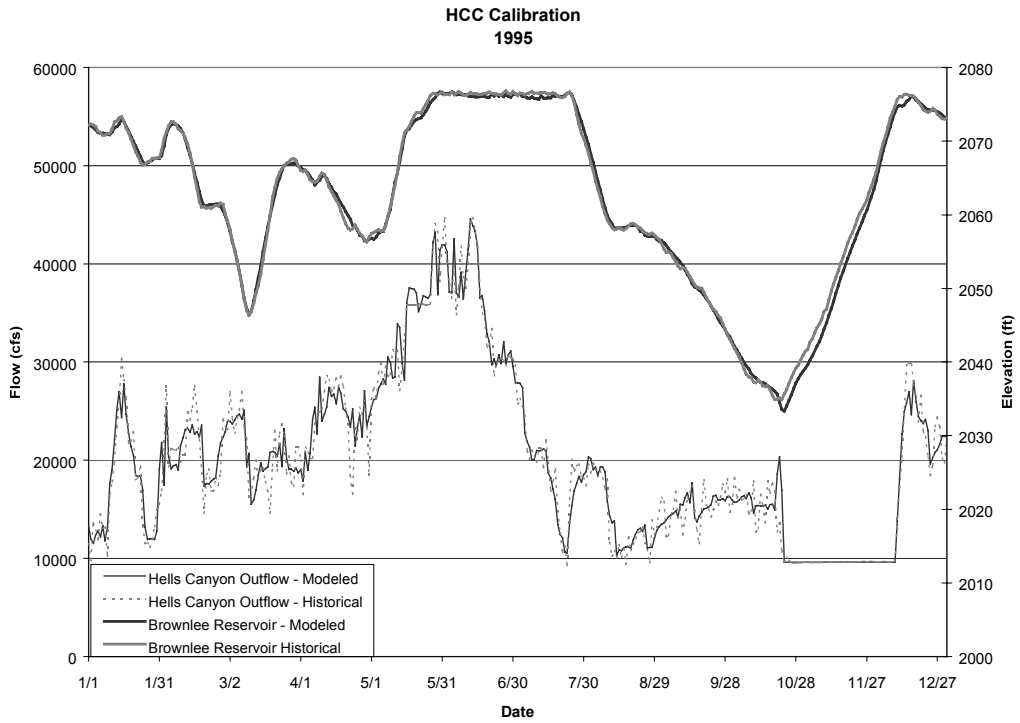


Figure 4. Daily average comparisons of modeled values with actual Brownlee Reservoir elevations and Hells Canyon Dam discharges in 1995.

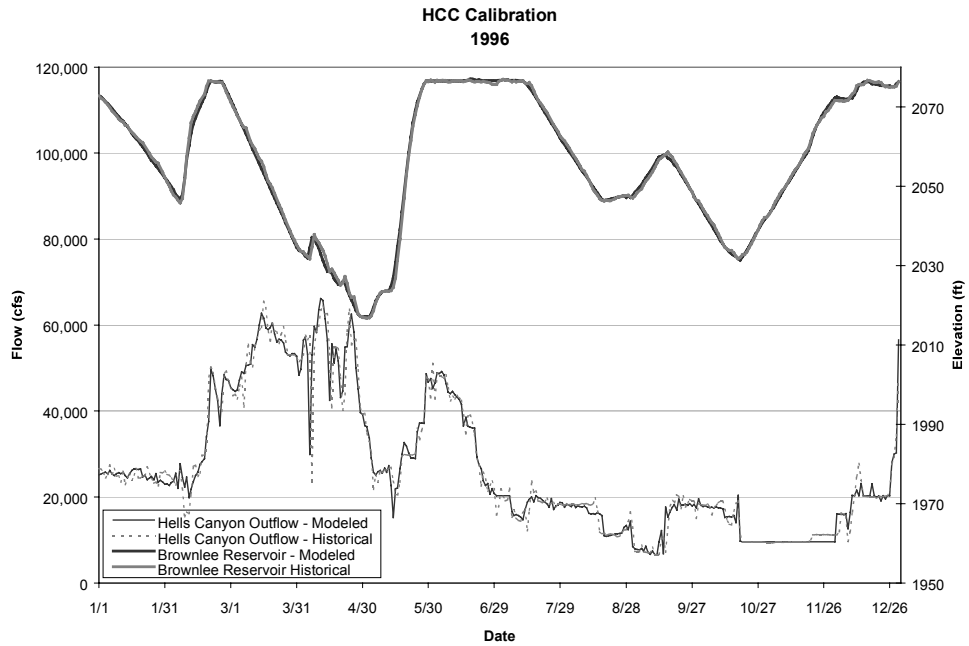


Figure 5. Daily average comparisons of modeled values with actual Brownlee Reservoir elevations and Hells Canyon Dam discharges in 1996.

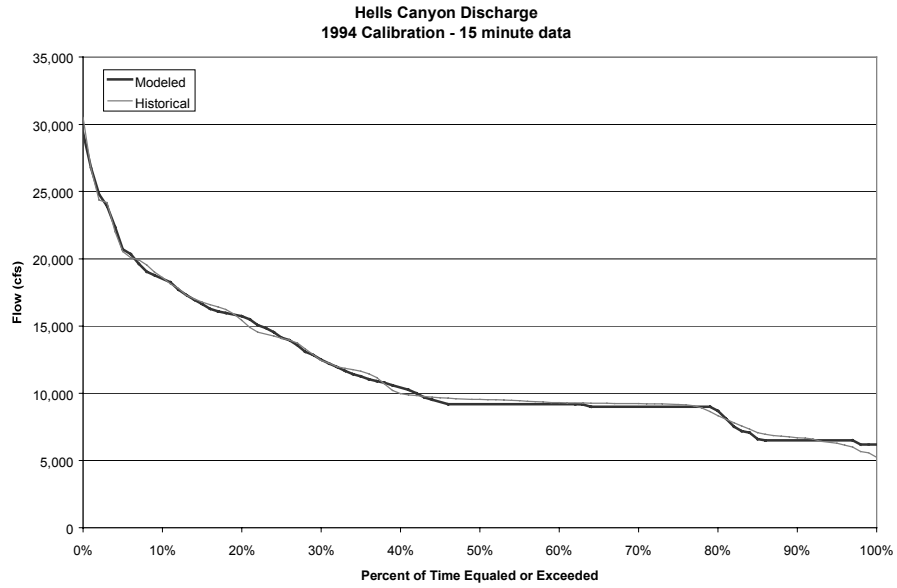


Figure 6. Duration curves created from historical data and model output data (15-minute increments) for Hells Canyon Dam discharge for calibration year 1994.

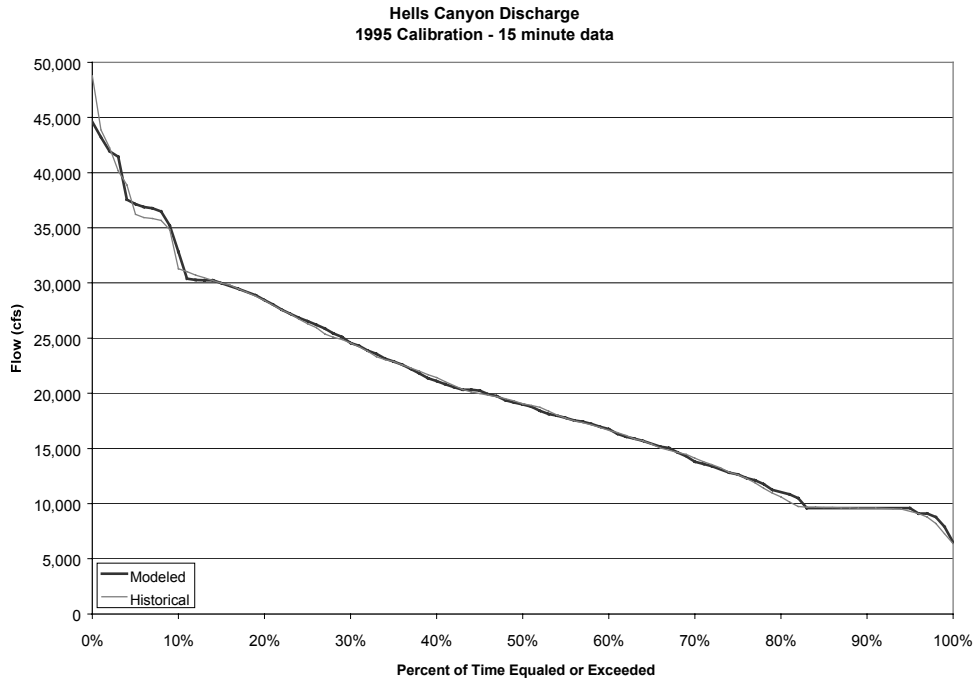


Figure 7. Duration curves created from historical data and model output data (15-minute increments) for Hells Canyon Dam discharge for calibration year 1995.

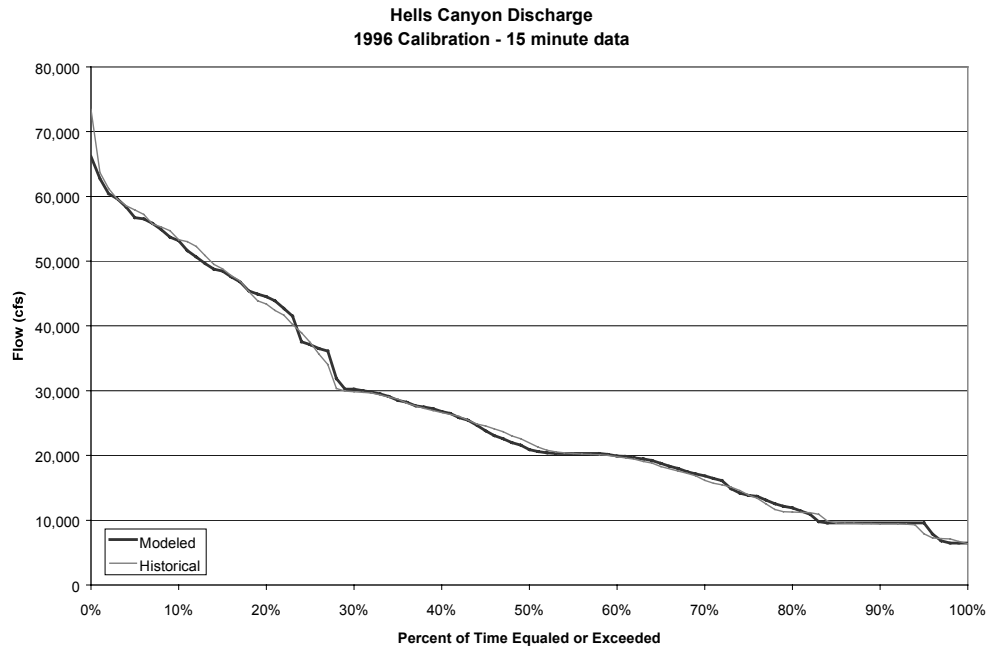


Figure 8. Duration curves created from historical data and model output data (15-minute increments) for Hells Canyon Dam discharge for calibration year 1996.

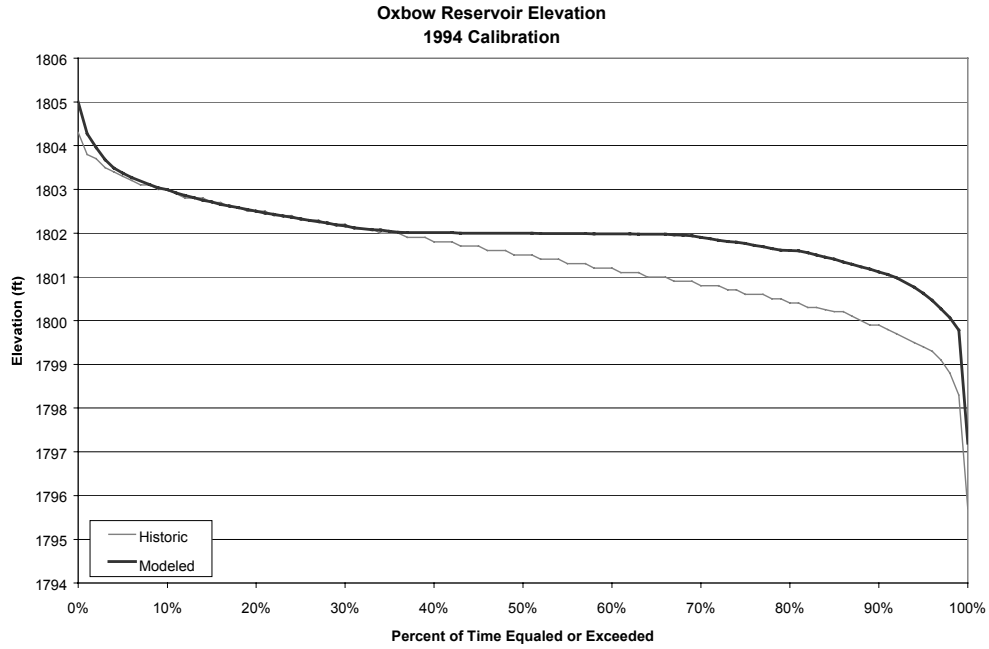


Figure 9. Duration curves created from Oxbow Reservoir historical data and model output data (hourly increments) for calibration year 1994.

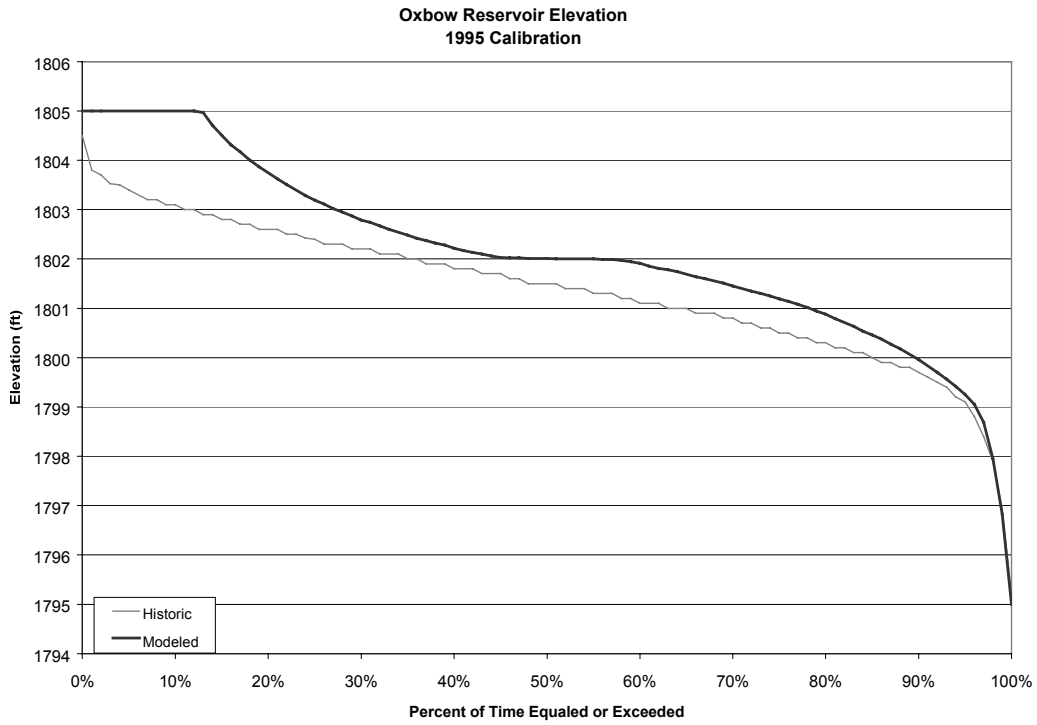


Figure 10. Duration curves created from Oxbow Reservoir historical data and model output data (hourly increments) for calibration year 1995.

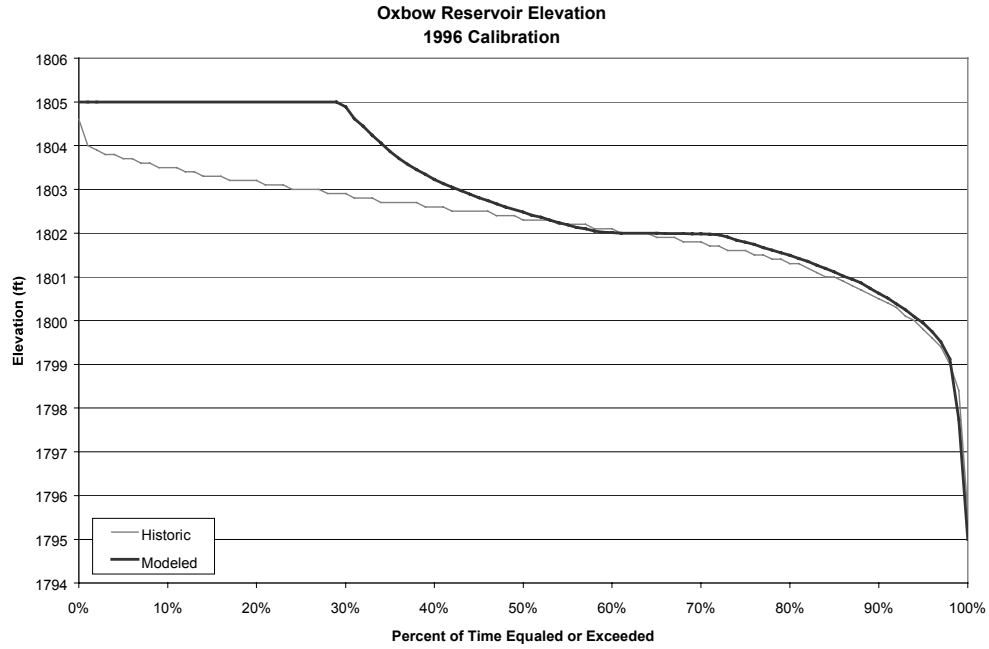


Figure 11. Duration curves created from Oxbow Reservoir historical data and model output data (hourly increments) for calibration year 1996.

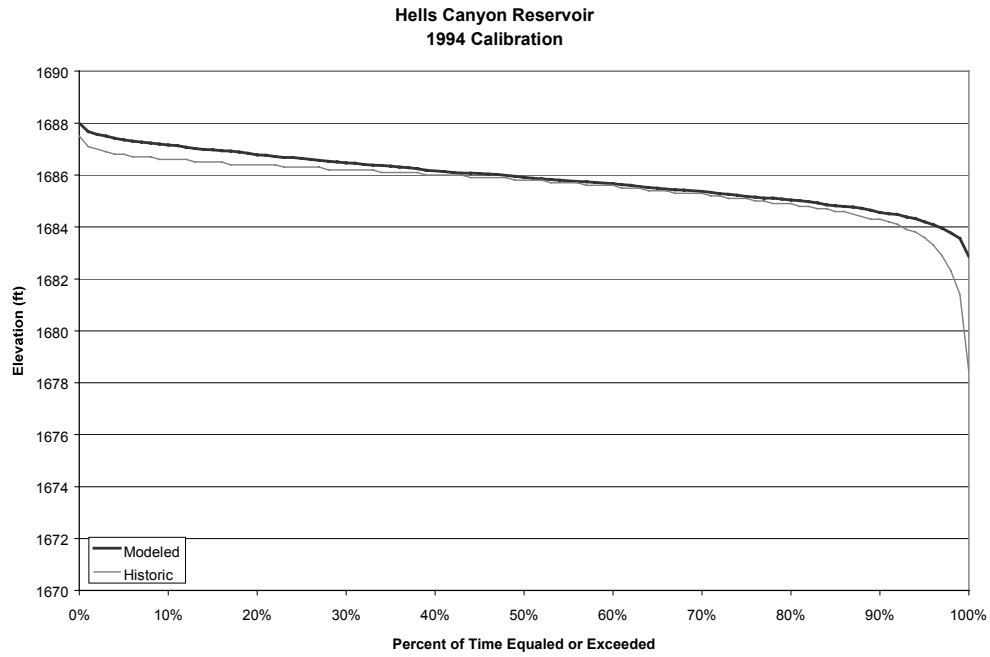


Figure 12. Duration curves created from Hells Canyon Reservoir historical data and model output data (hourly increments) for calibration year 1994.

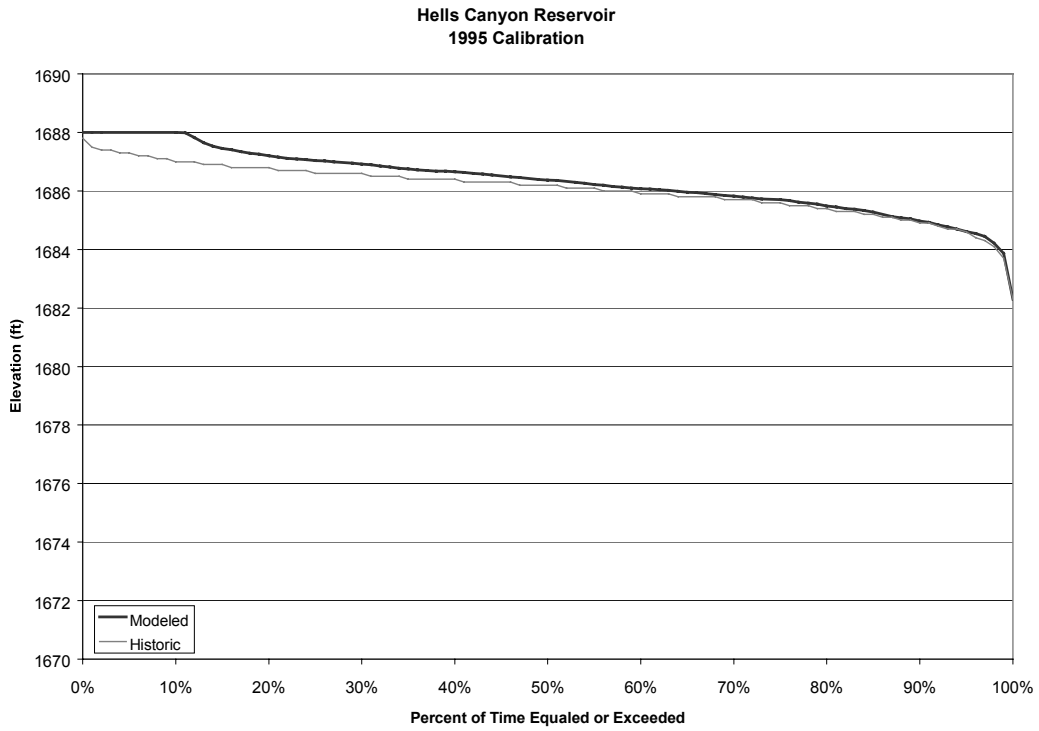


Figure 13. Duration curves created from Hells Canyon Reservoir historical data and model output data (hourly increments) for calibration year 1995.

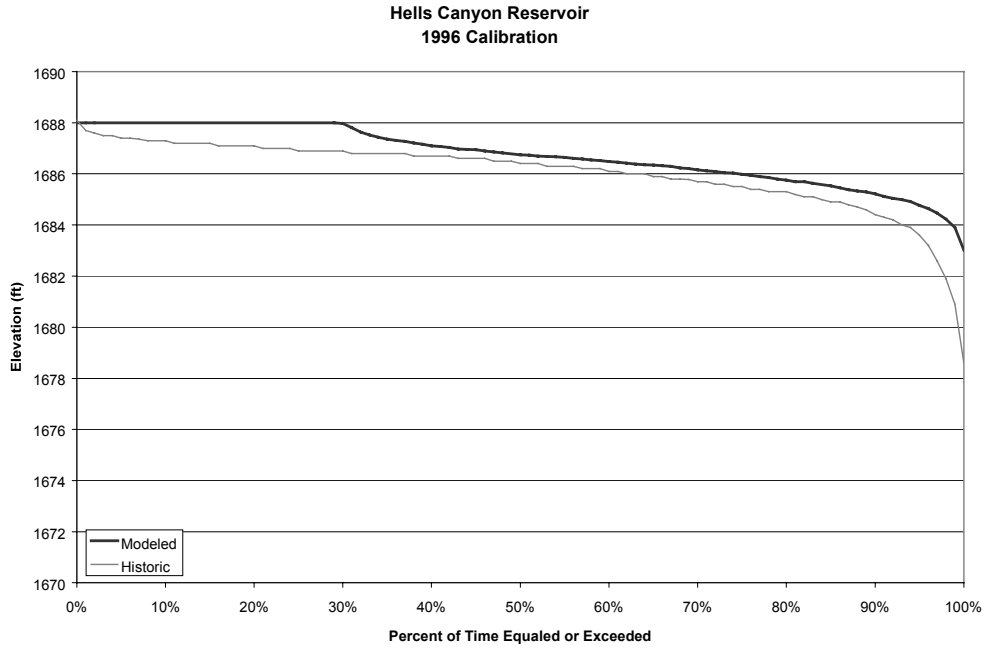


Figure 14. Duration curves created from Hells Canyon Reservoir historical data and model output data (hourly increments) for calibration year 1996.

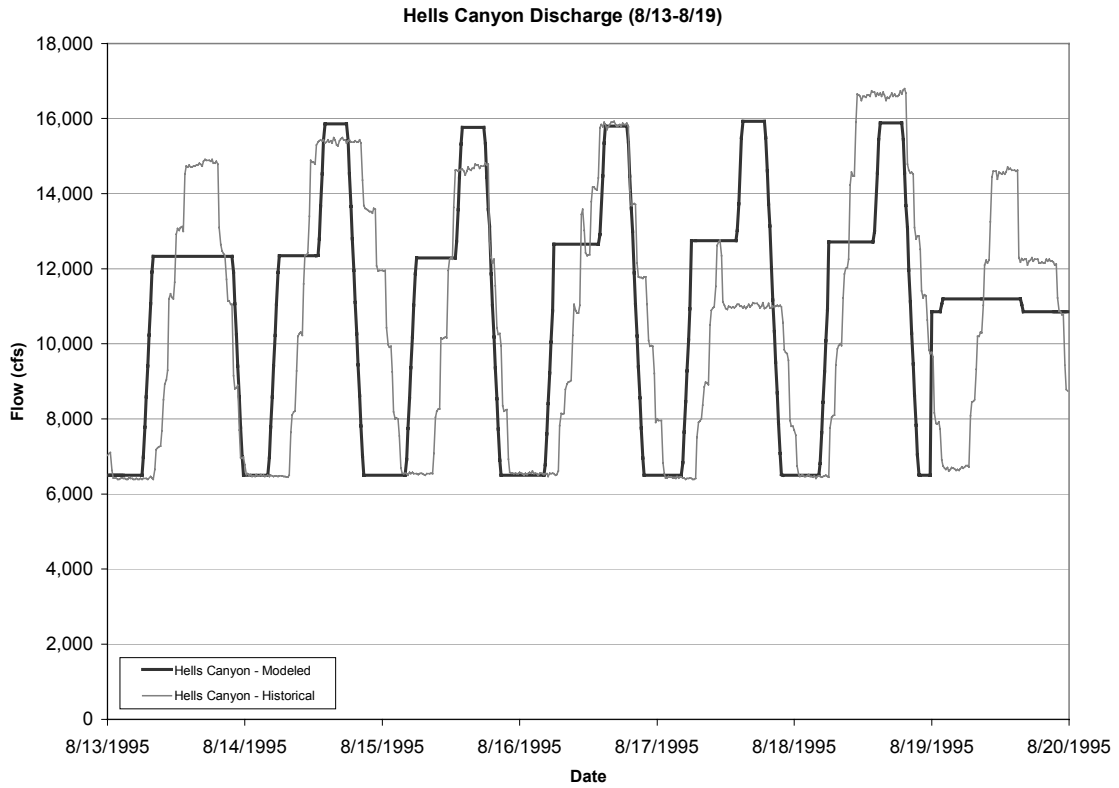


Figure 15. Modeled and historical operations for August 13–19, 1995 (15-minute increments).

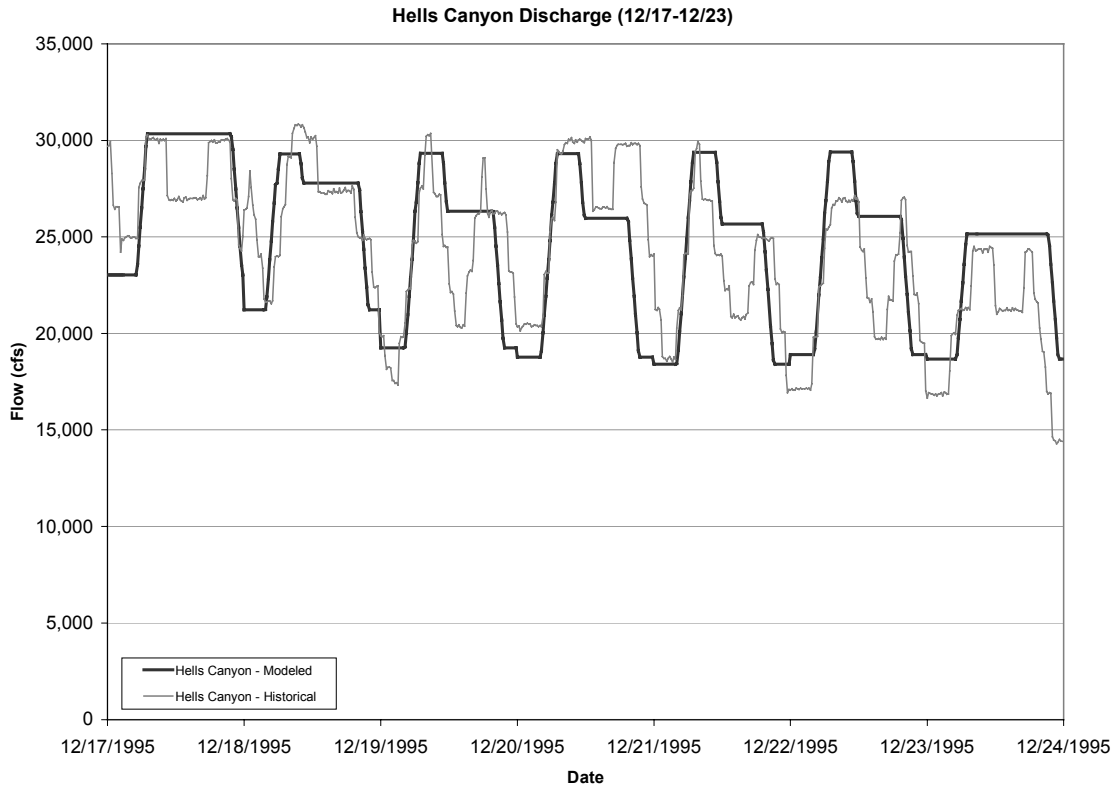


Figure 16. Modeled and historical operations for December 17–23, 1995 (15-minute increments).

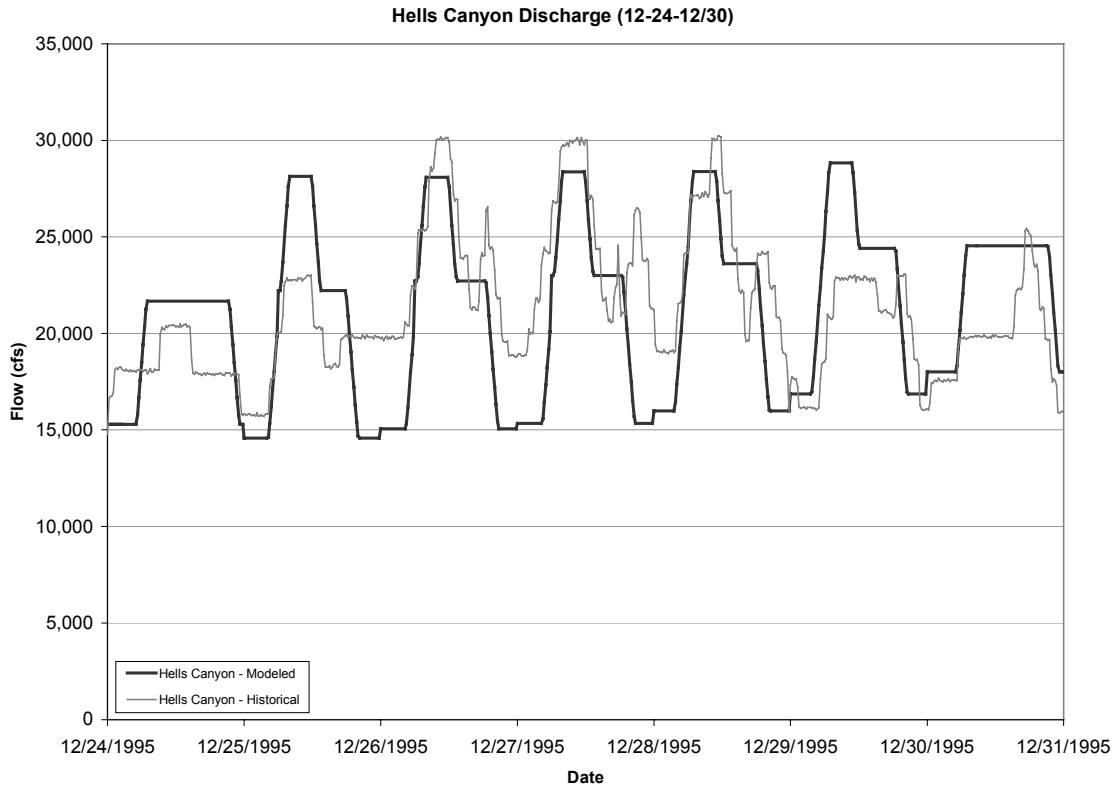


Figure 17. Modeled and historical operations for December 24–30, 1995 (15-minute increments).

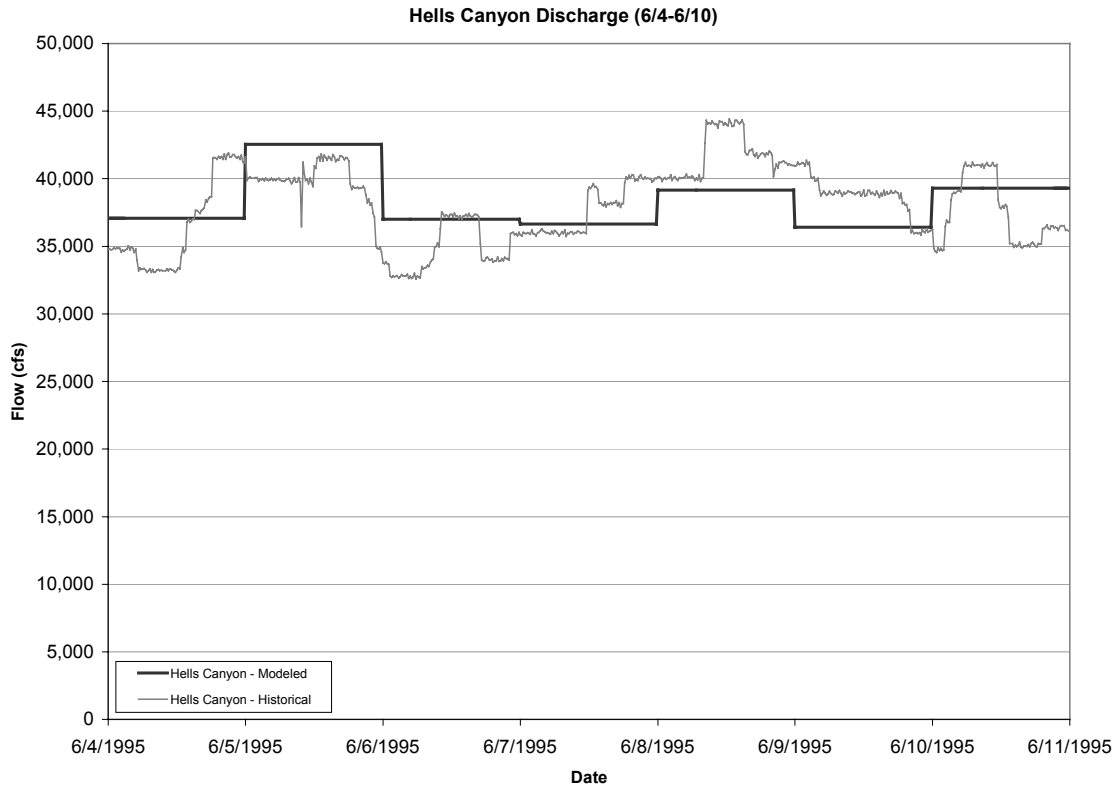


Figure 18. Modeled and historical operations for June 4–10, 1995 (15-minute increments).

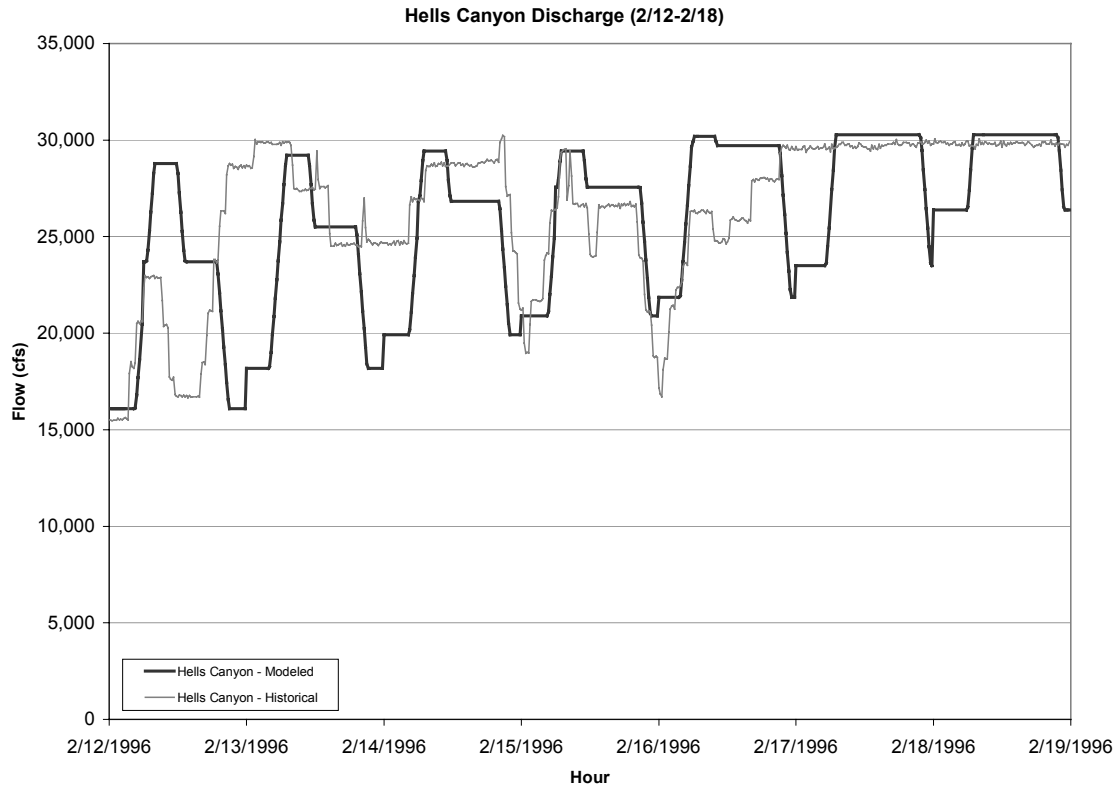


Figure 19. Modeled and historical operations for February 12–18, 1996 (15-minute increments).

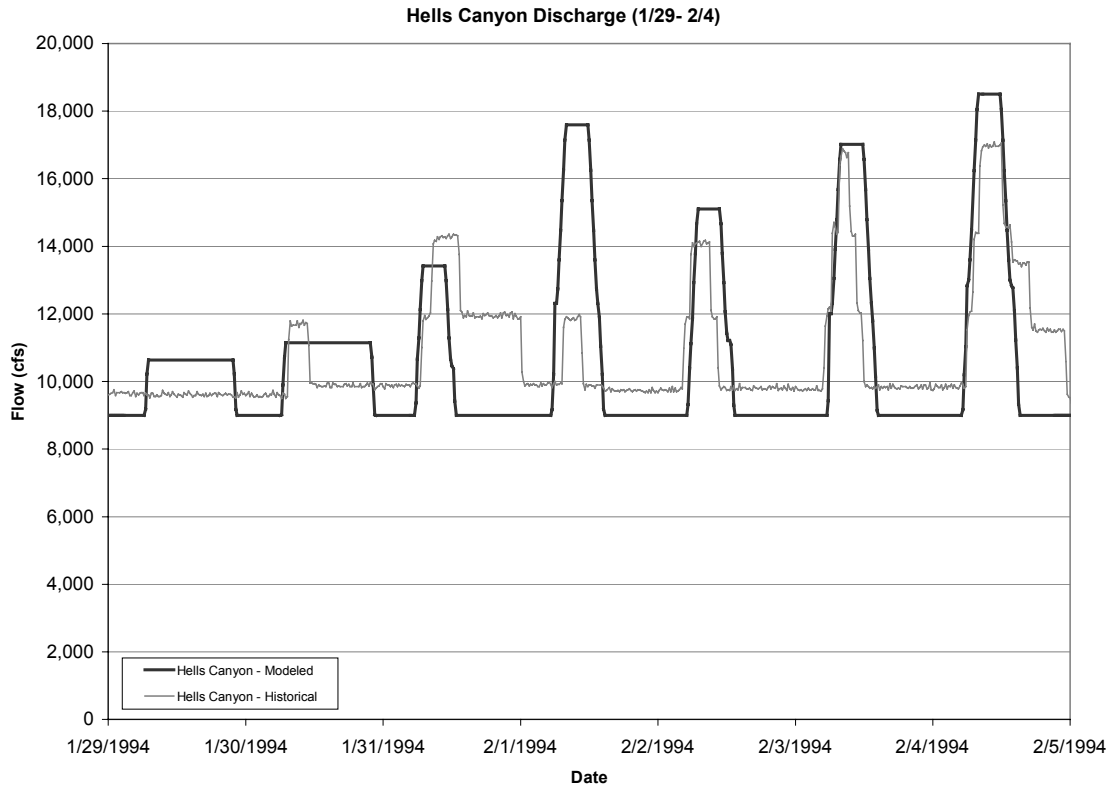


Figure 20. Modeled and historical operations for January 29–February 4, 1994 (15-minute increments).

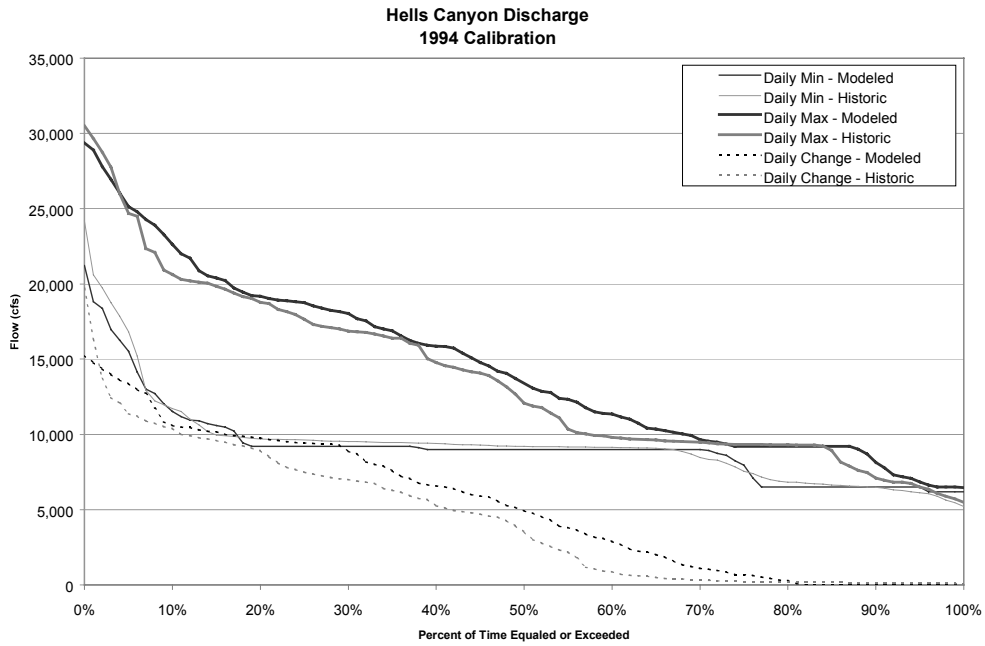


Figure 21. Modeled and historical daily comparisons of Hells Canyon Project duration curves for calibration year 1994.

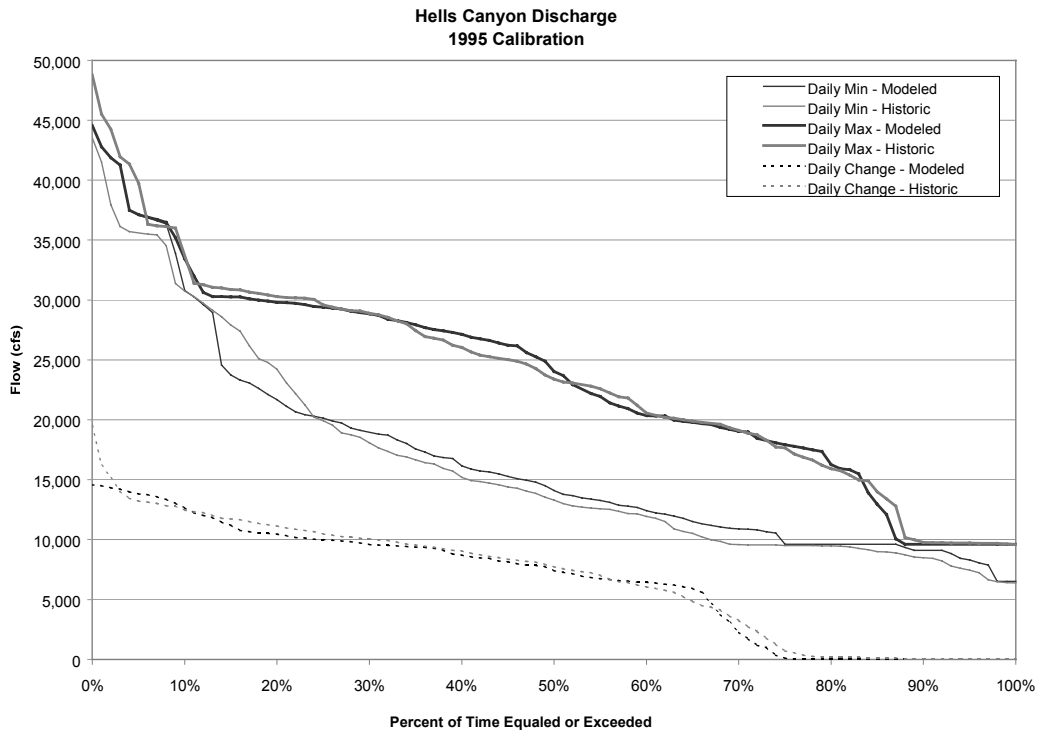


Figure 22. Modeled and historical daily comparisons of Hells Canyon Project duration curves for calibration year 1995.

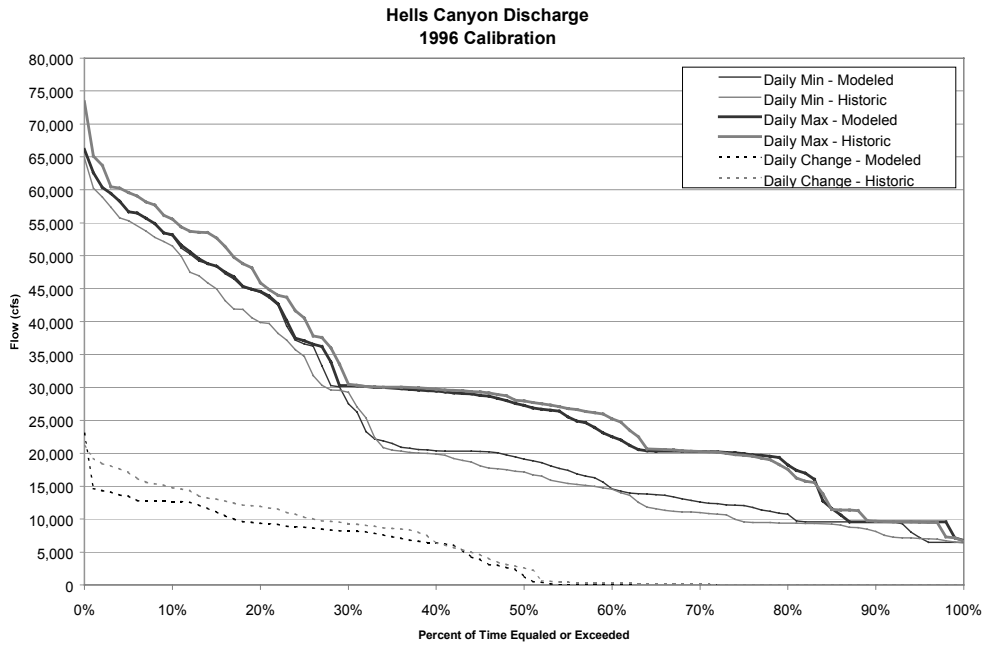


Figure 23. Modeled and historical daily comparisons of Hells Canyon Project duration curves for calibration year 1996.

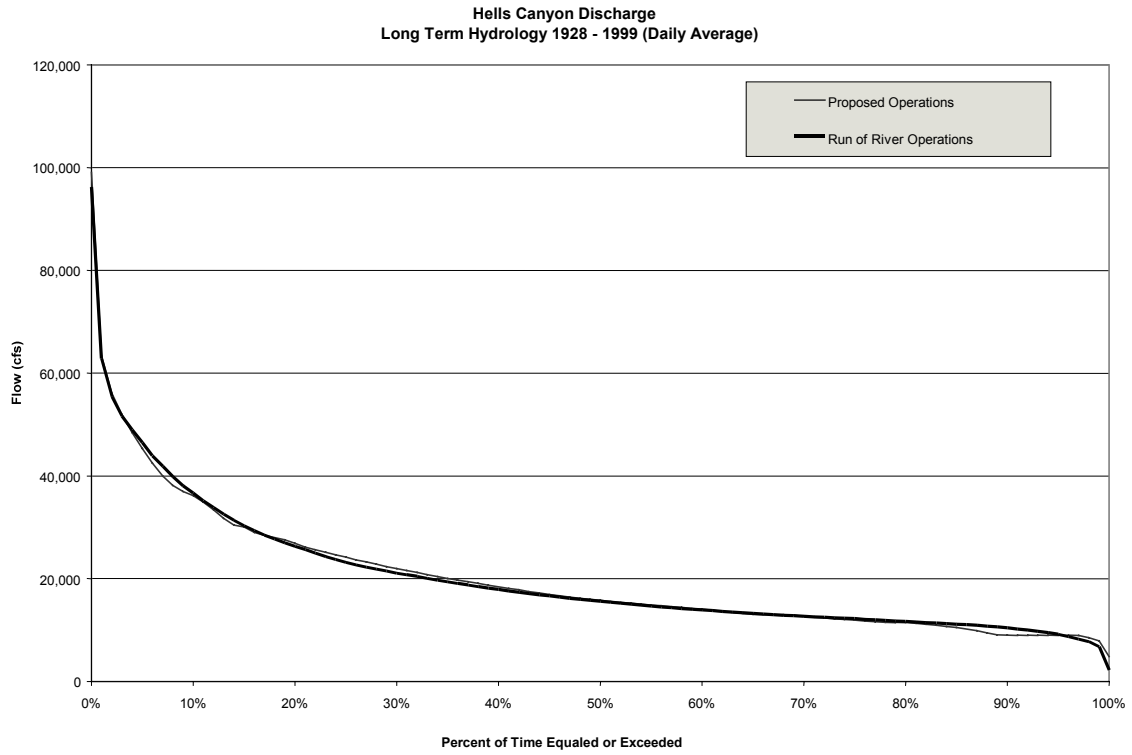


Figure 24. Proposed operations and full pool run-of-river operations for long-term period of record below Hells Canyon Dam.

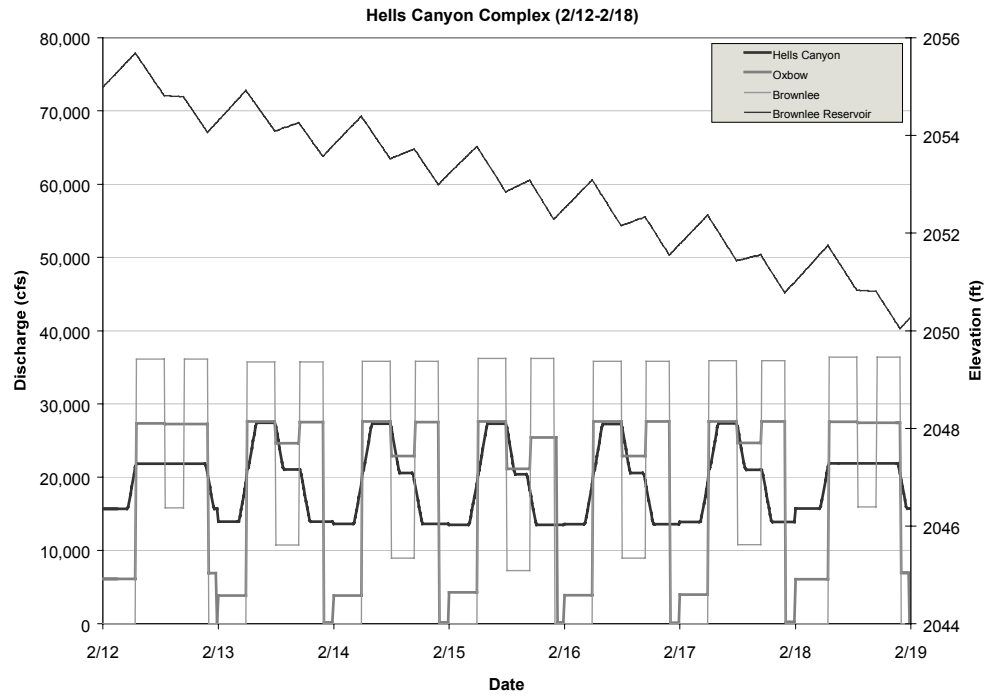


Figure 25. Modeled proposed operations for an average water year (15-minute increments).

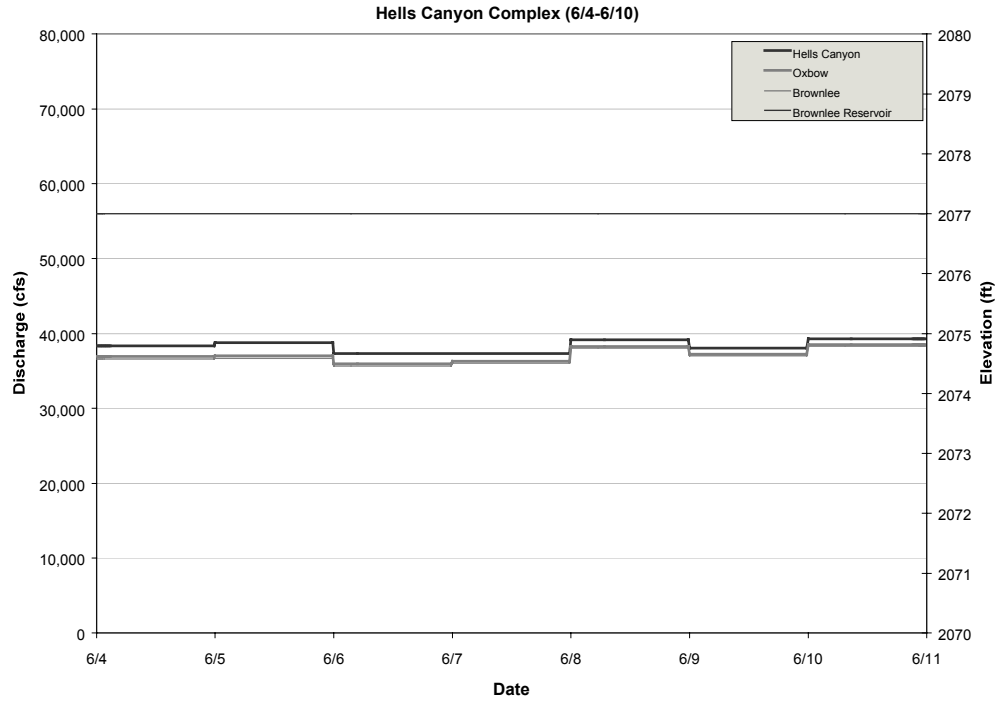


Figure 26. Modeled proposed operations for several days in June for an average water year (15-minute increments).

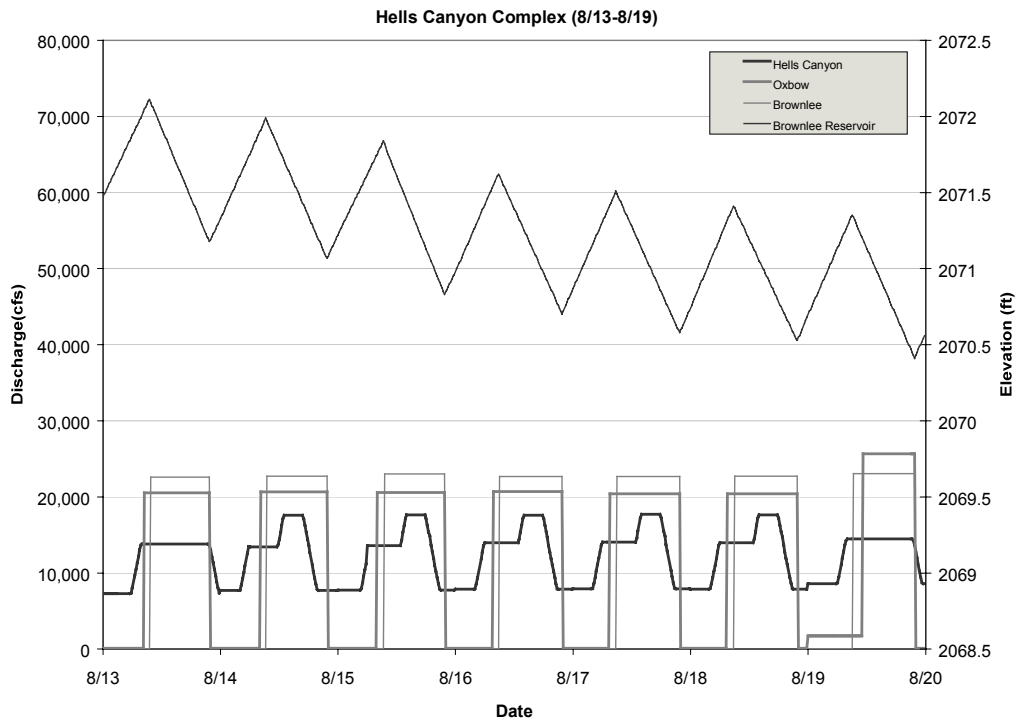


Figure 27. Modeled proposed operations in August for an average water year (15-minute increments).

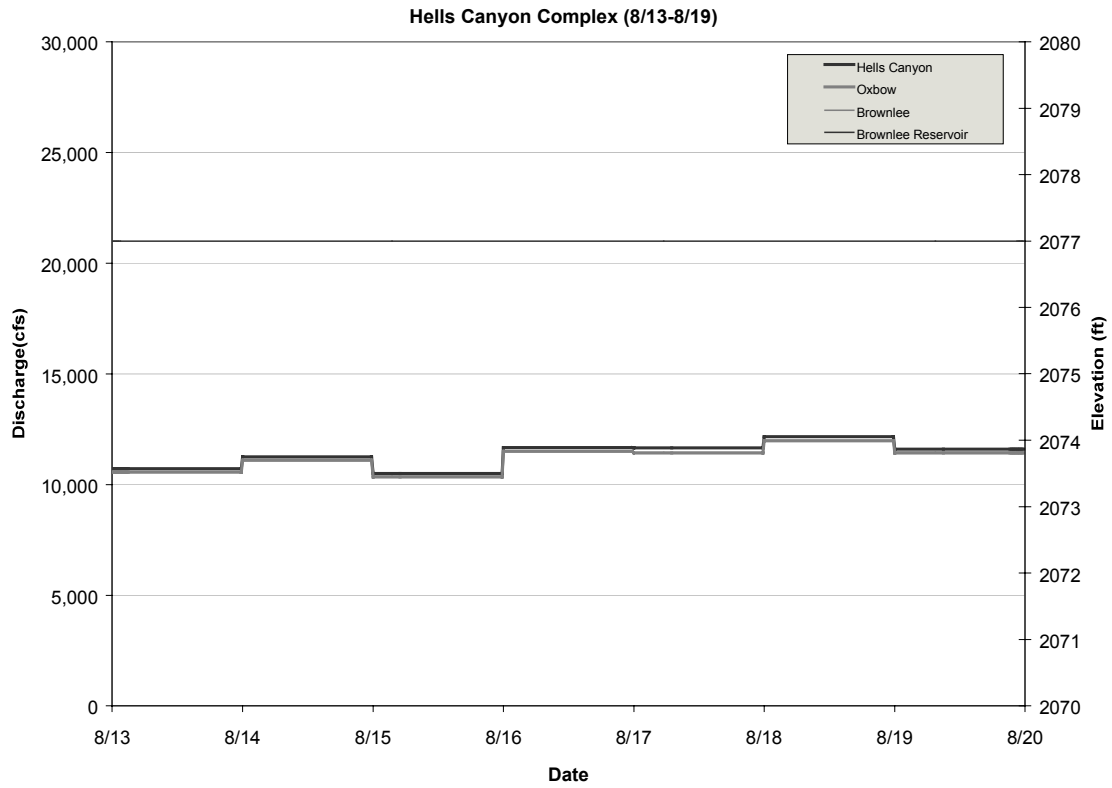


Figure 28. Modeled full pool run-of-river operations in August for an average water year (15-minute increments).

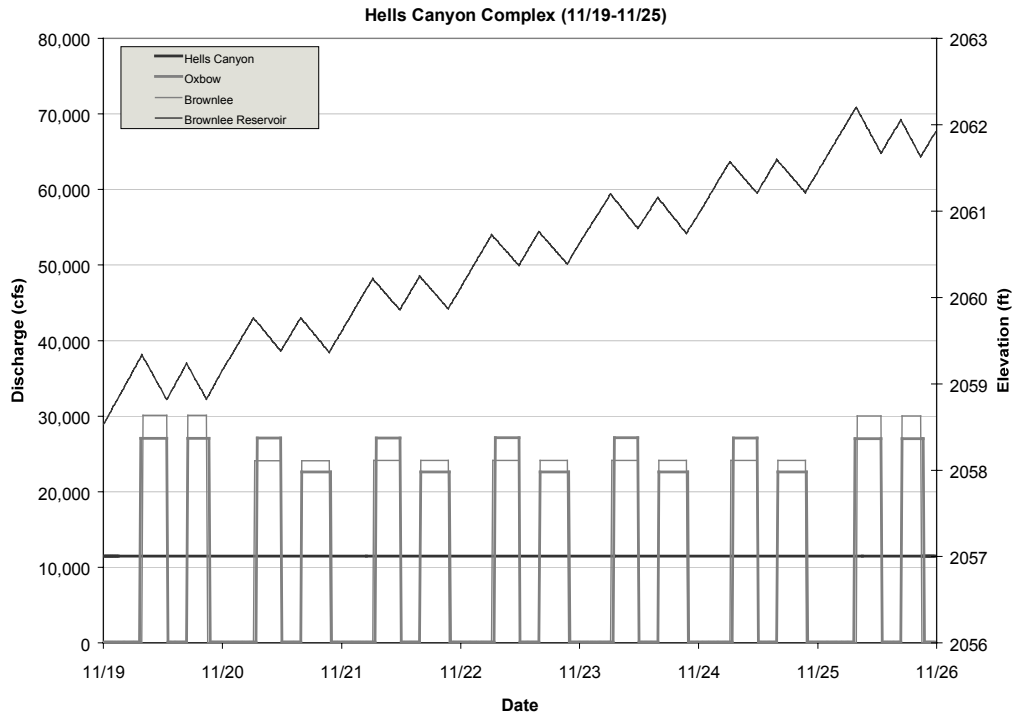


Figure 29. Modeled proposed operations during the fall chinook program for an average water year (15-minute increments).

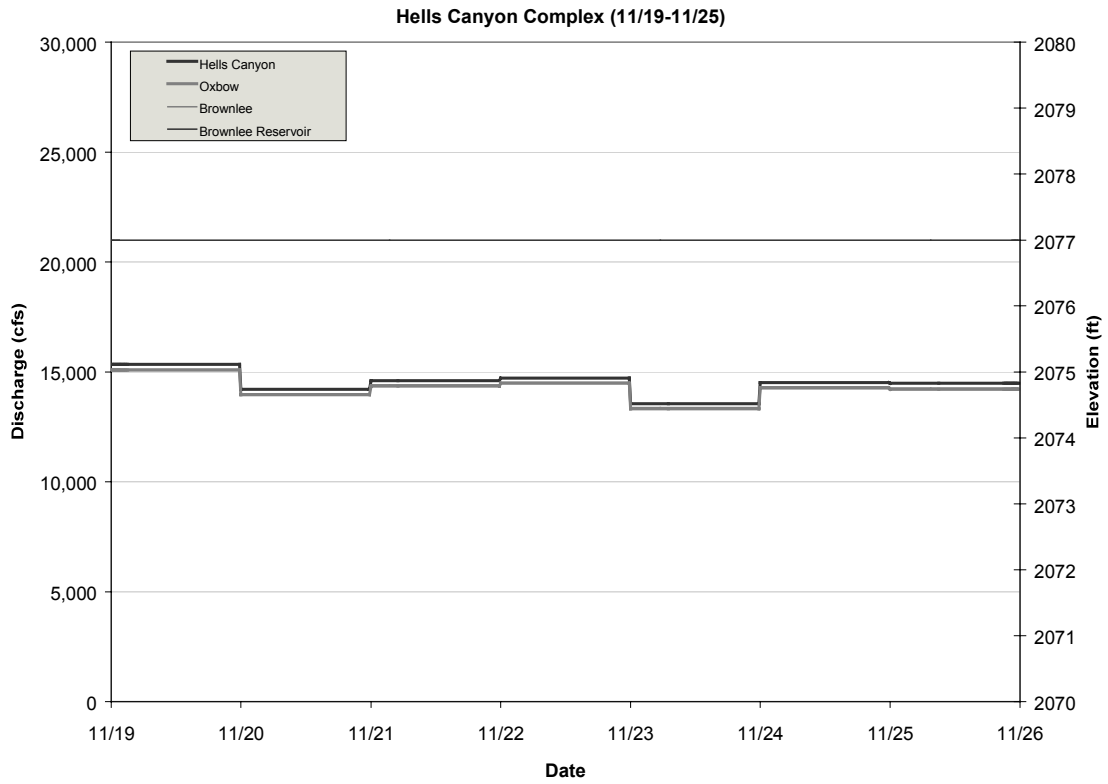


Figure 30. Modeled full pool run-of-river operations during the fall for an average water year (15-minute increments).

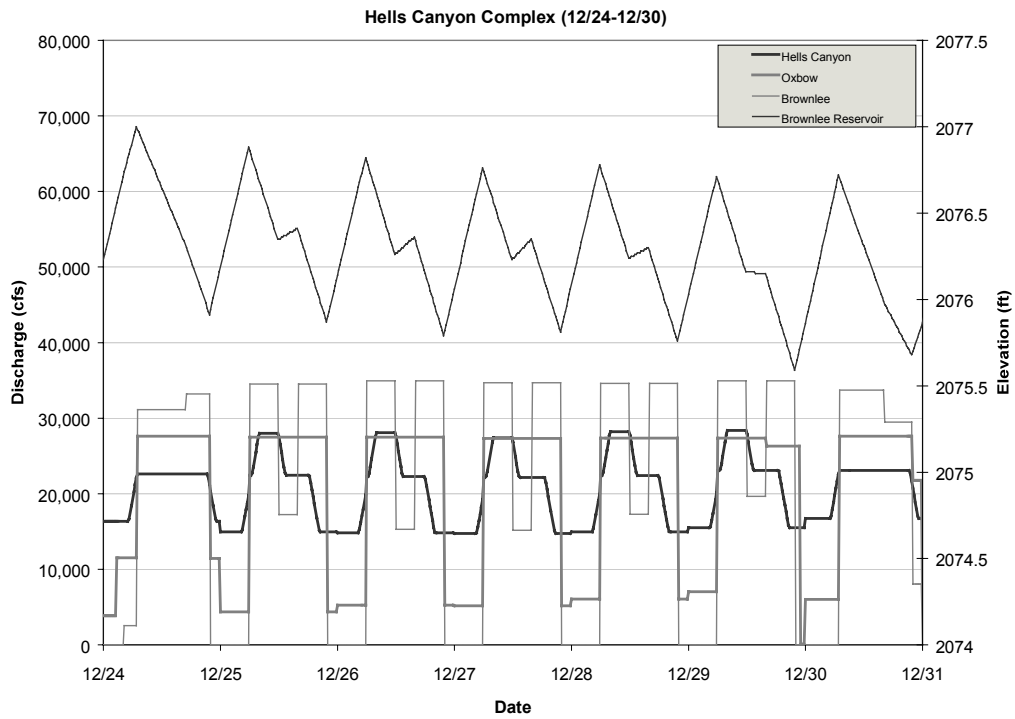


Figure 31. Modeled proposed operations in December for an average water year (15-minute increments).

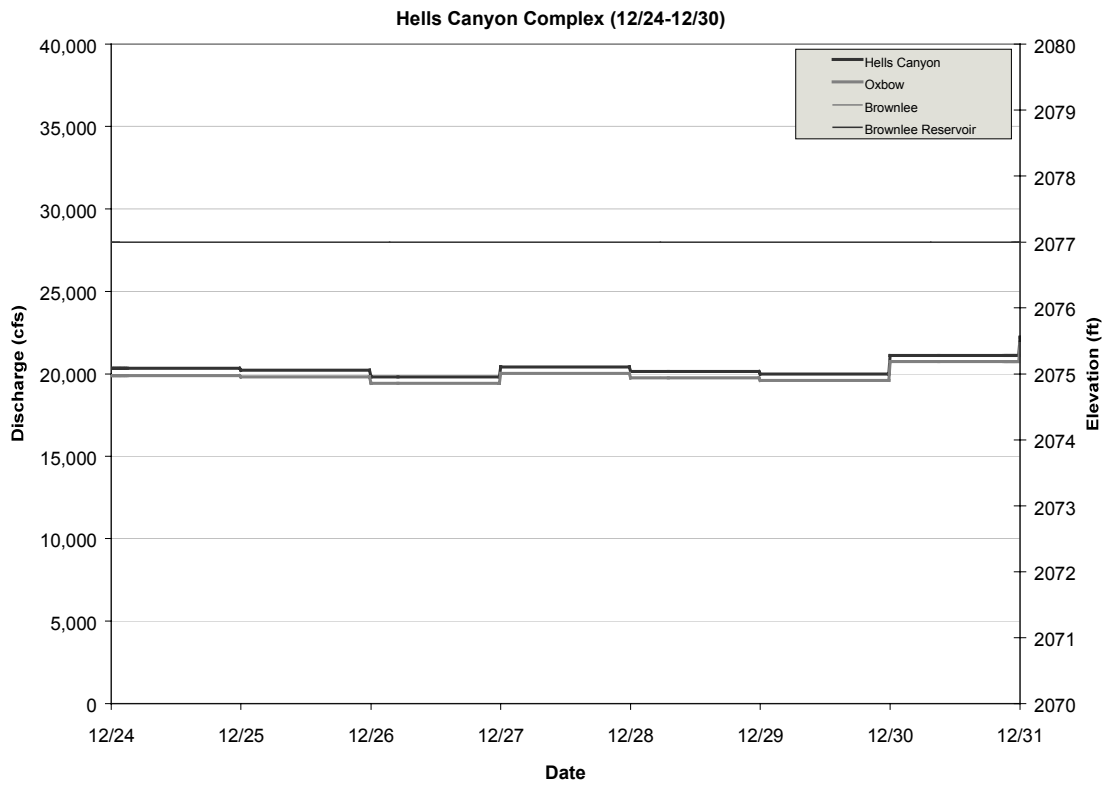


Figure 32. Full pool run-of-river operations in December for an average water year (15-minute increments).

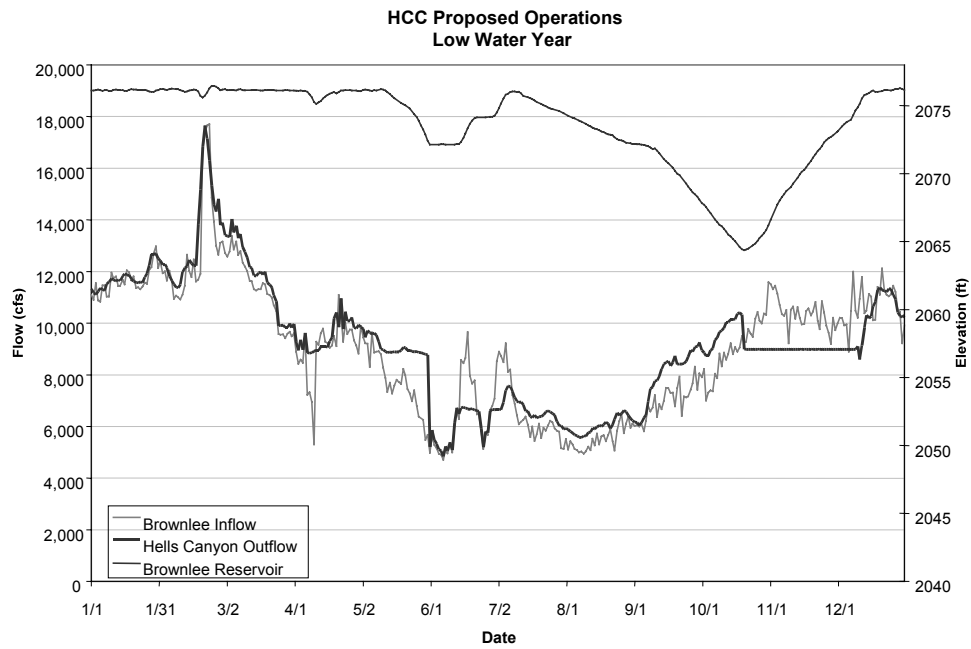


Figure 33. Modeled proposed operations for a low water year (daily average, 1992 inflow hydrology).

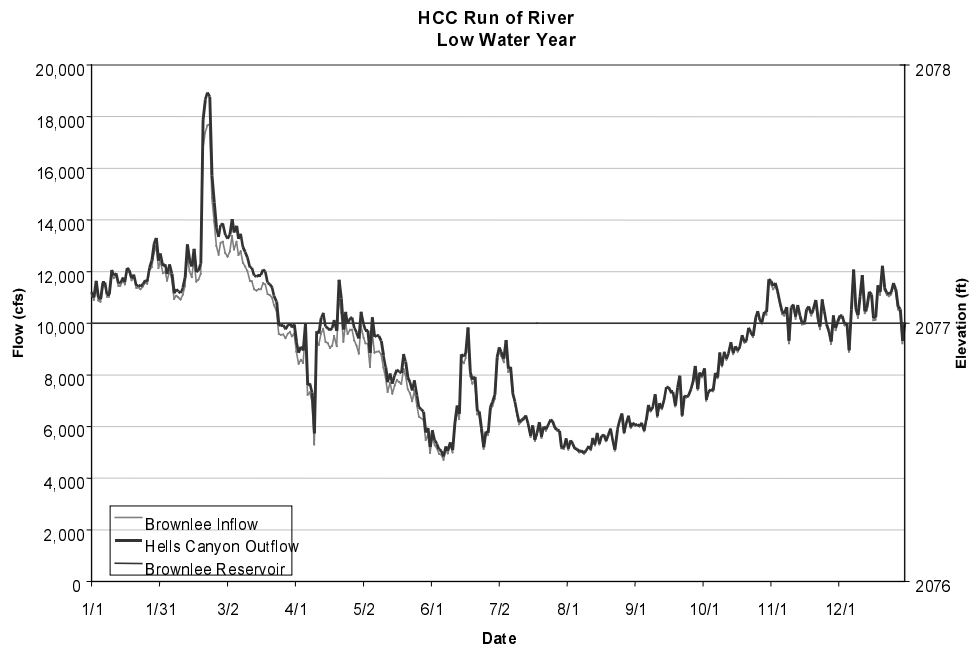


Figure 34. Modeled full pool run-of-river operations for a low water year (daily average, 1992 inflow hydrology).

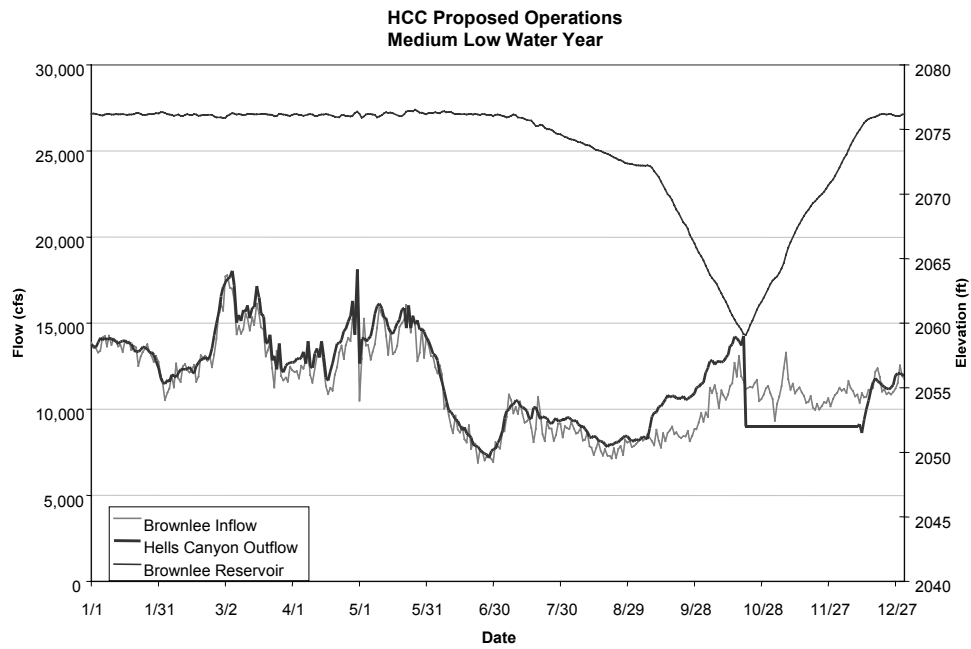


Figure 35. Modeled proposed operations for a medium-low water year (daily average, 1994 inflow hydrology).

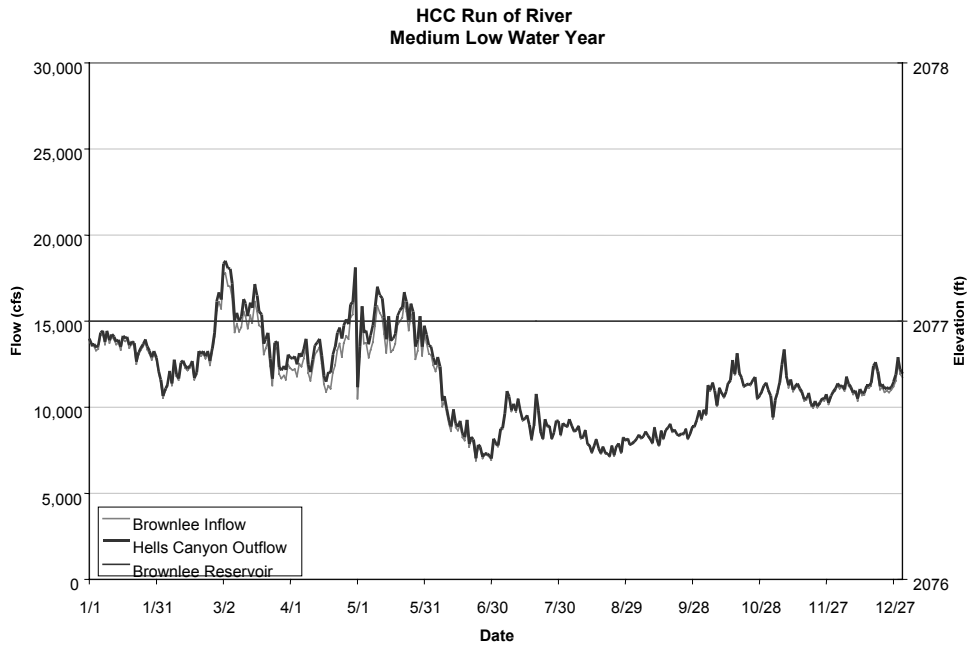


Figure 36. Modeled full pool run-of-river operations for a medium-low water year (daily average, 1994 inflow hydrology).

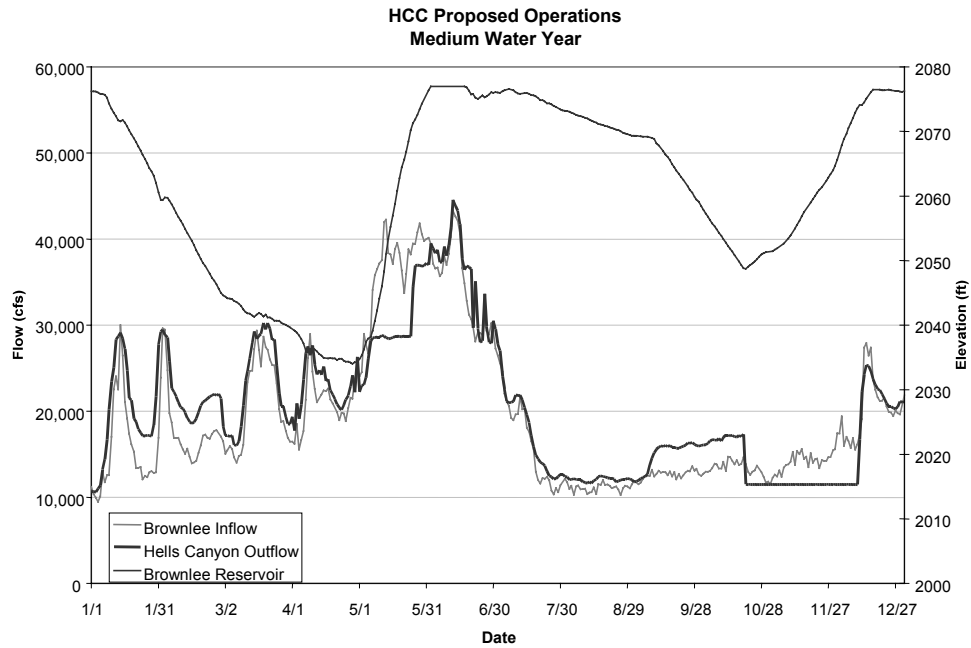


Figure 37. Modeled proposed operations for a medium water year (daily average, 1995 inflow hydrology).

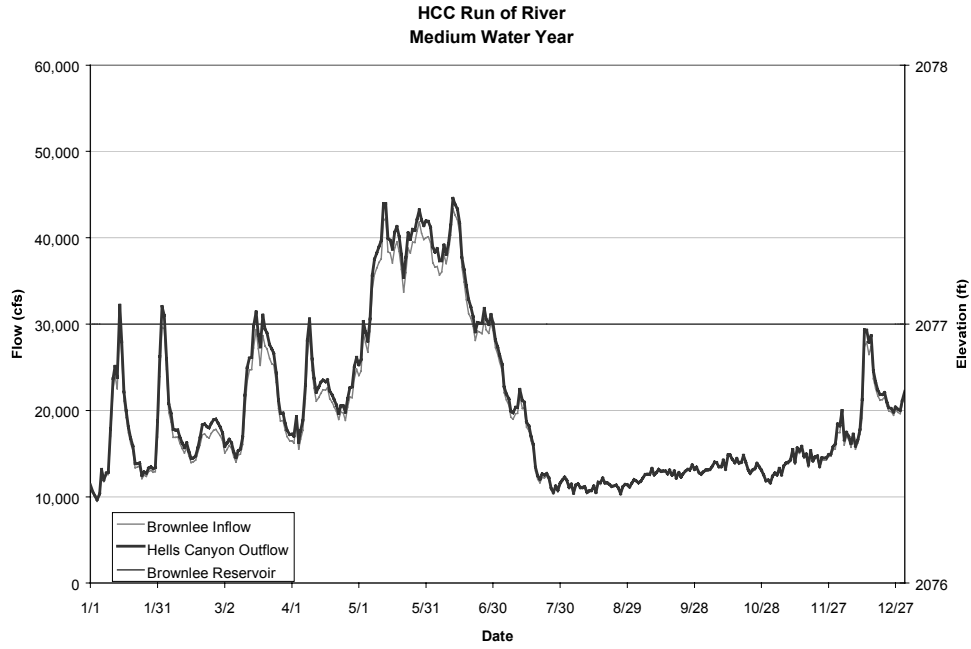


Figure 38. Modeled full pool run-of-river operations for a medium water year (daily average, 1995 inflow hydrology).

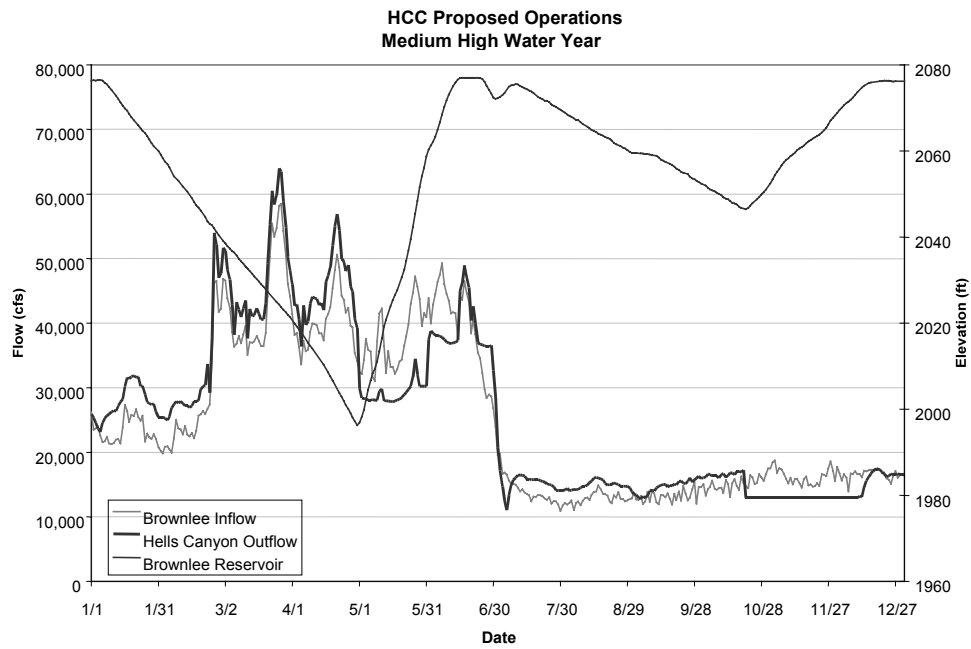


Figure 39. Modeled proposed operations for a medium-high water year (daily average, 1999 inflow hydrology).

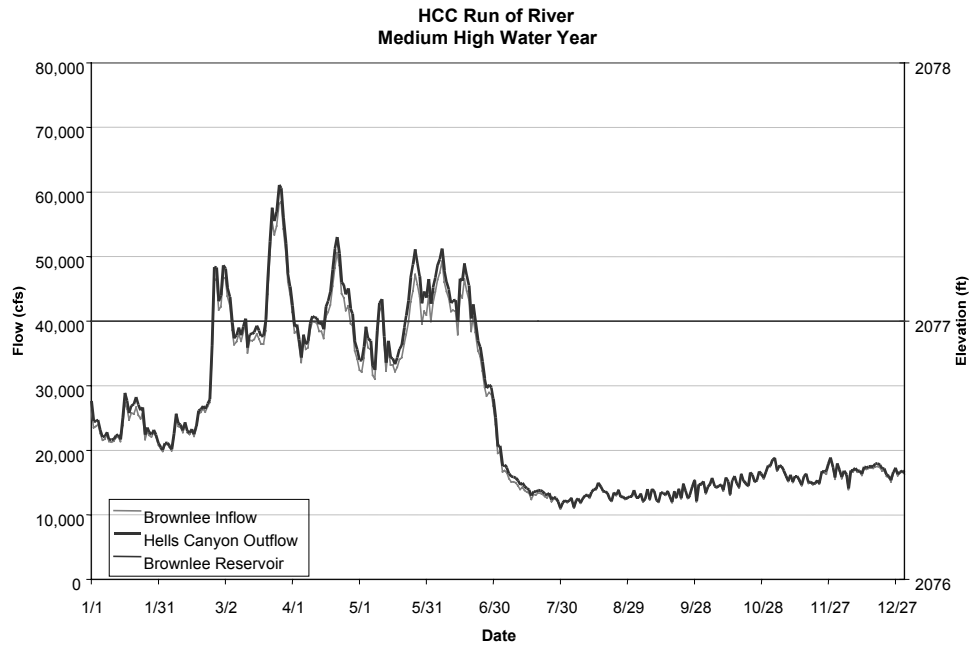


Figure 40. Modeled full pool run-of-river operations for a medium-high water year (daily average, 1999 inflow hydrology).

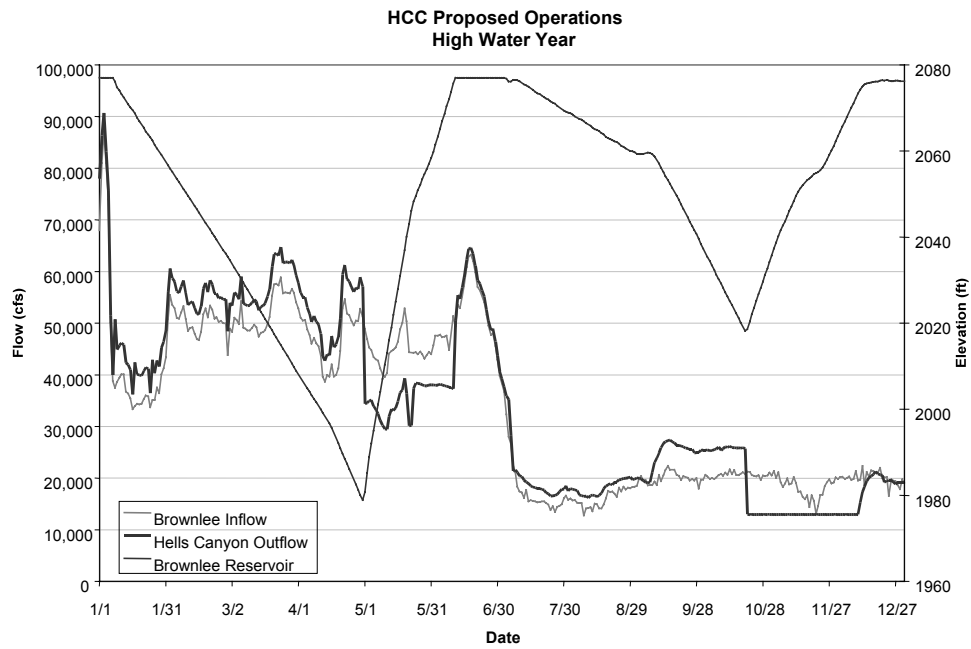


Figure 41. Modeled proposed operations for a high water year (daily average, 1997 inflow hydrology).

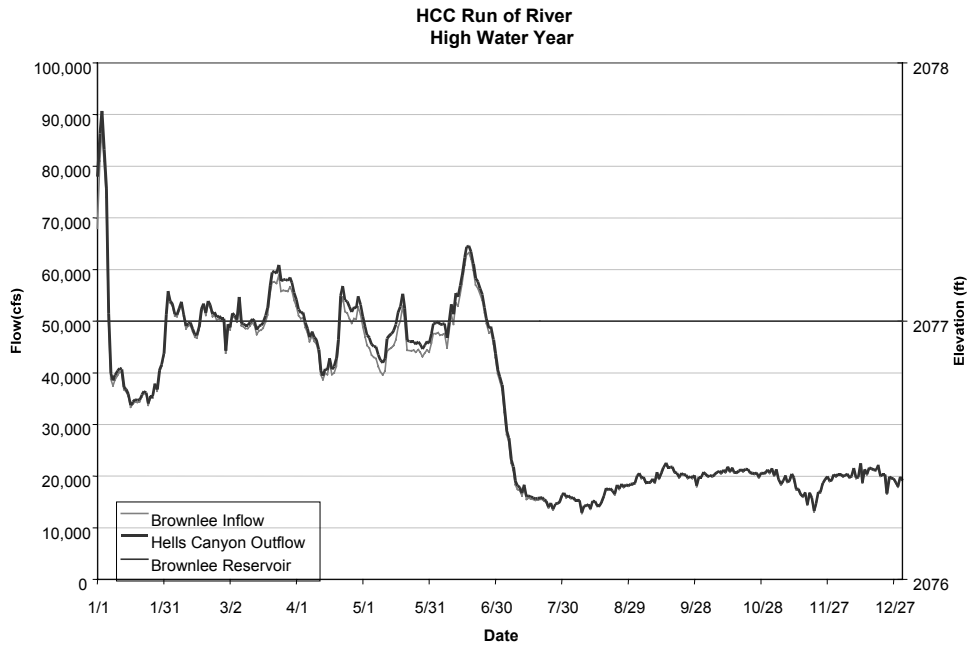
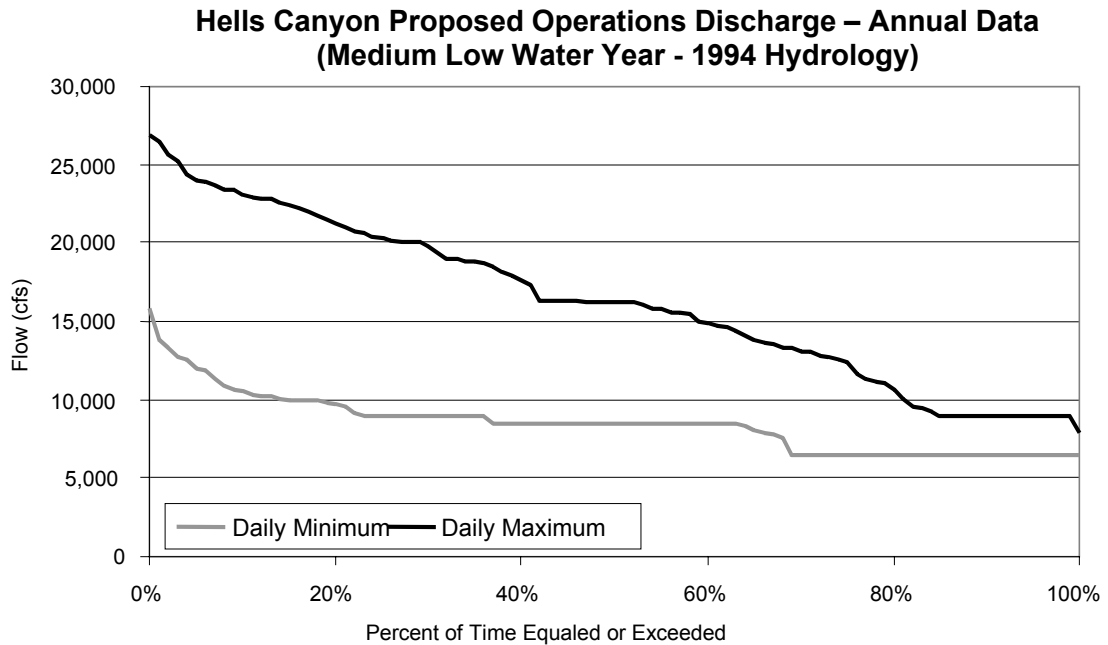
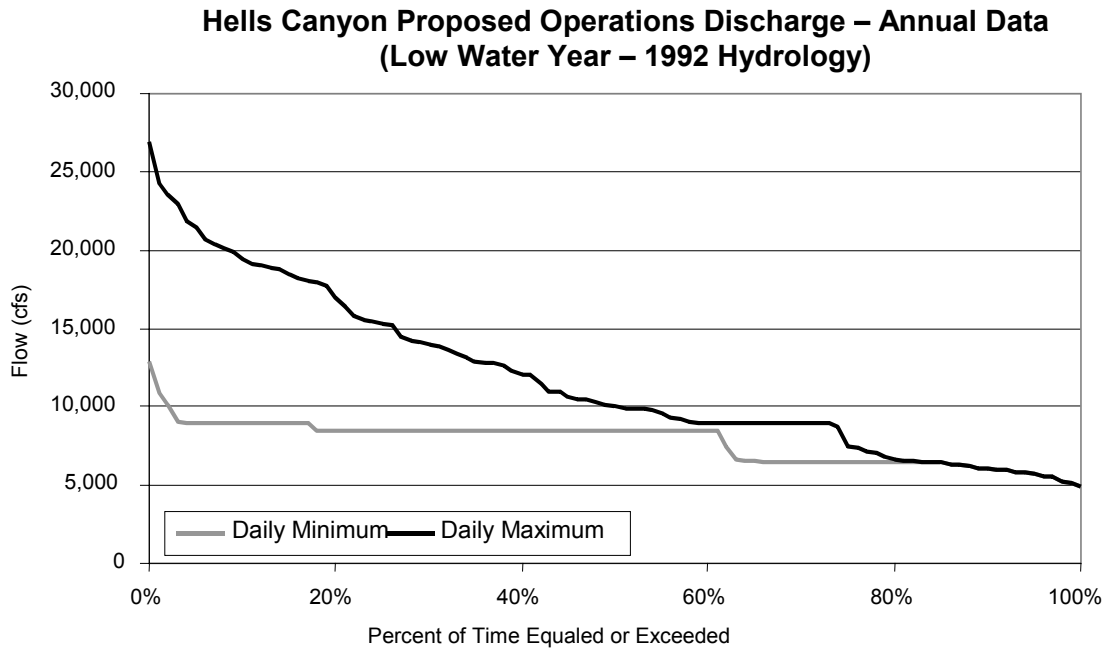
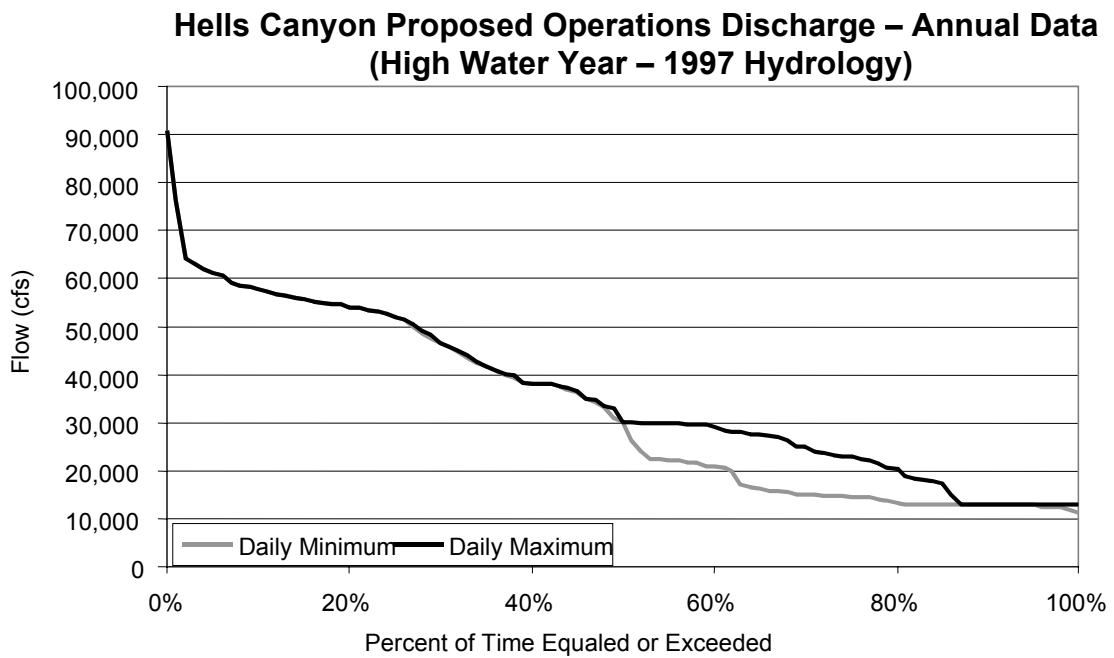
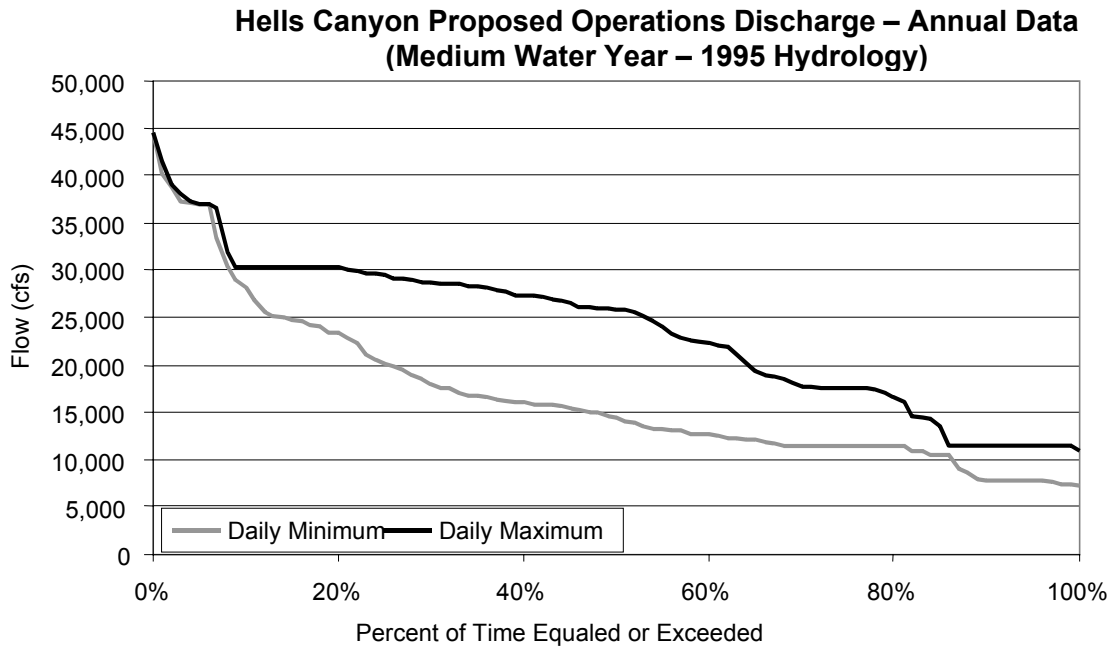


Figure 42. Modeled full pool run-of-river operations for an high water year (daily average, 1997 inflow hydrology).

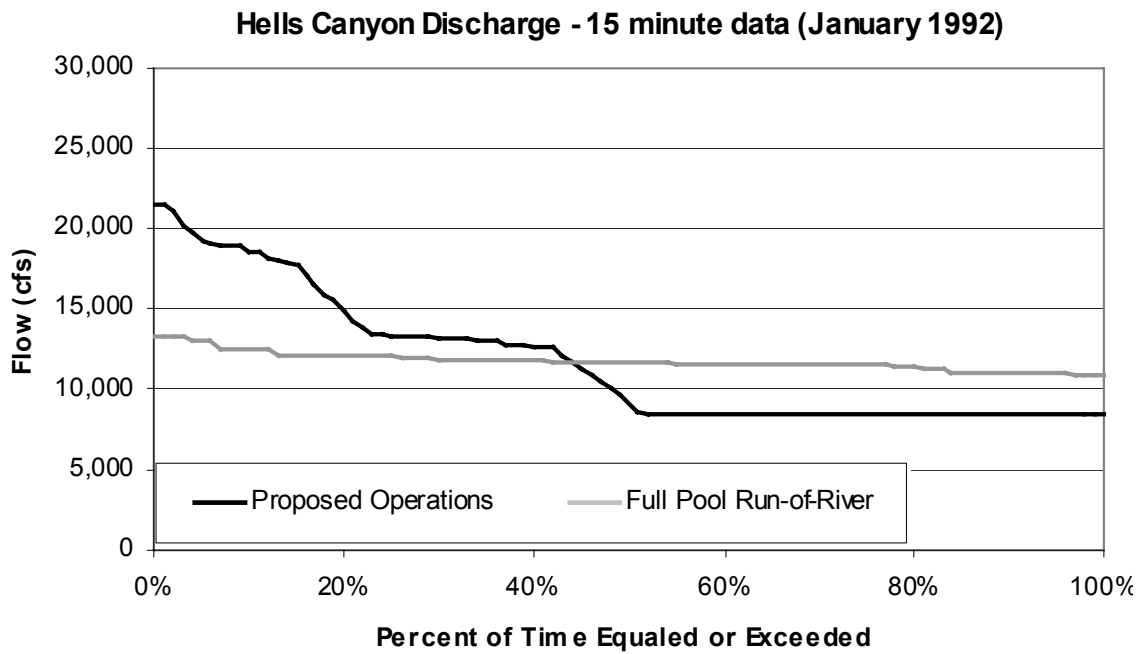
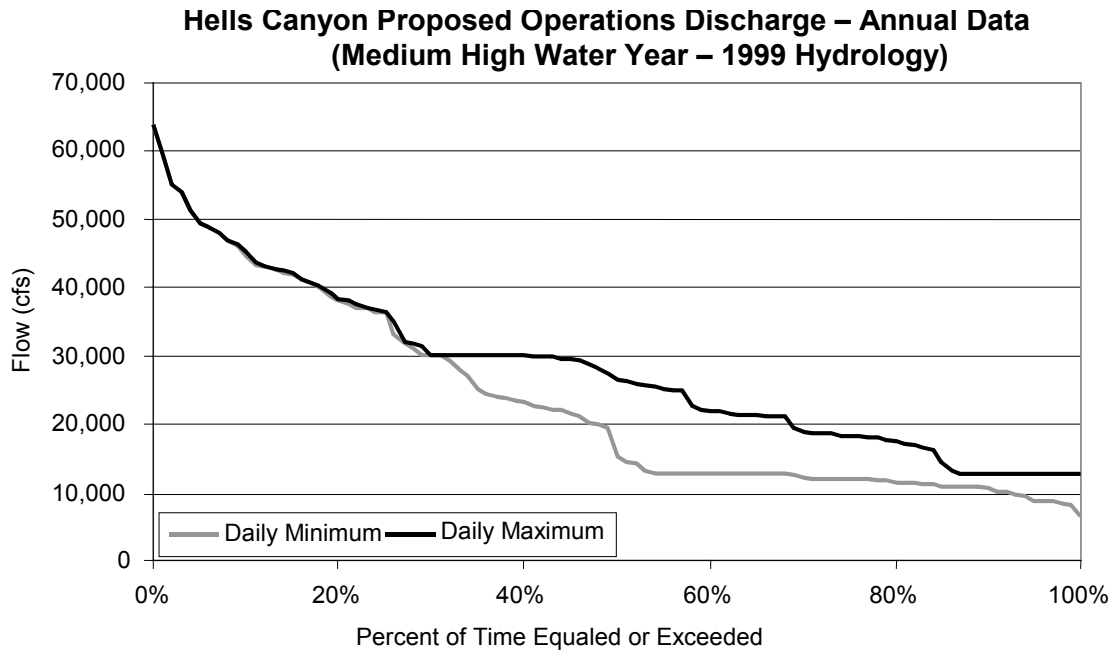
Appendix 1. Additional CHEOPS model output below Hells Canyon Dam for the relicensing scenarios.



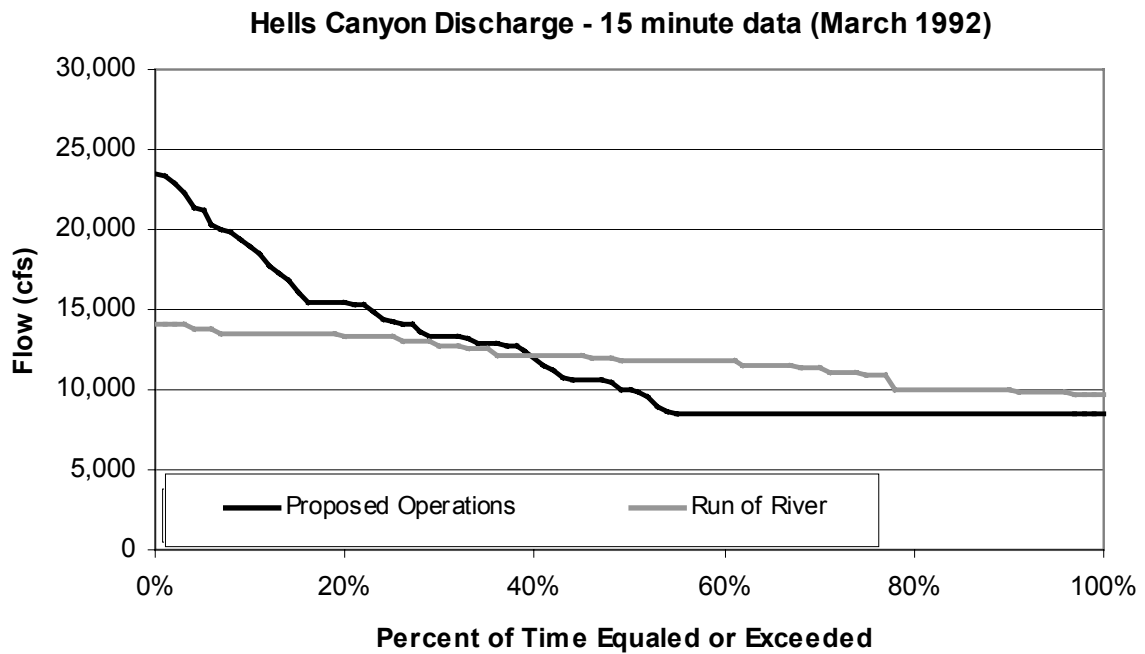
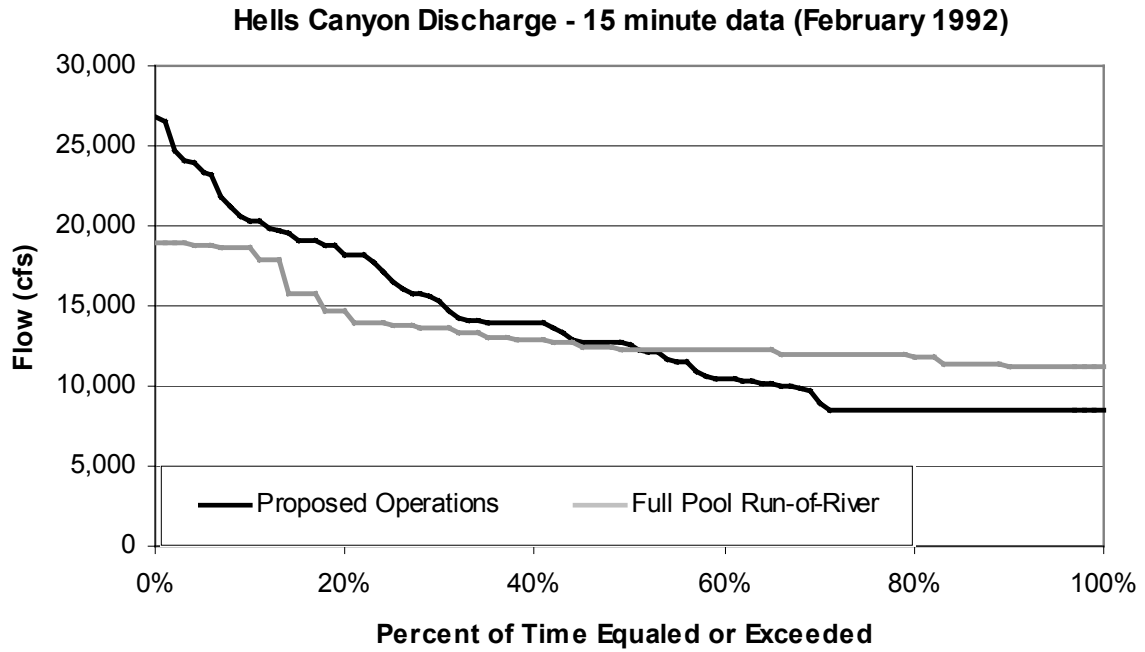
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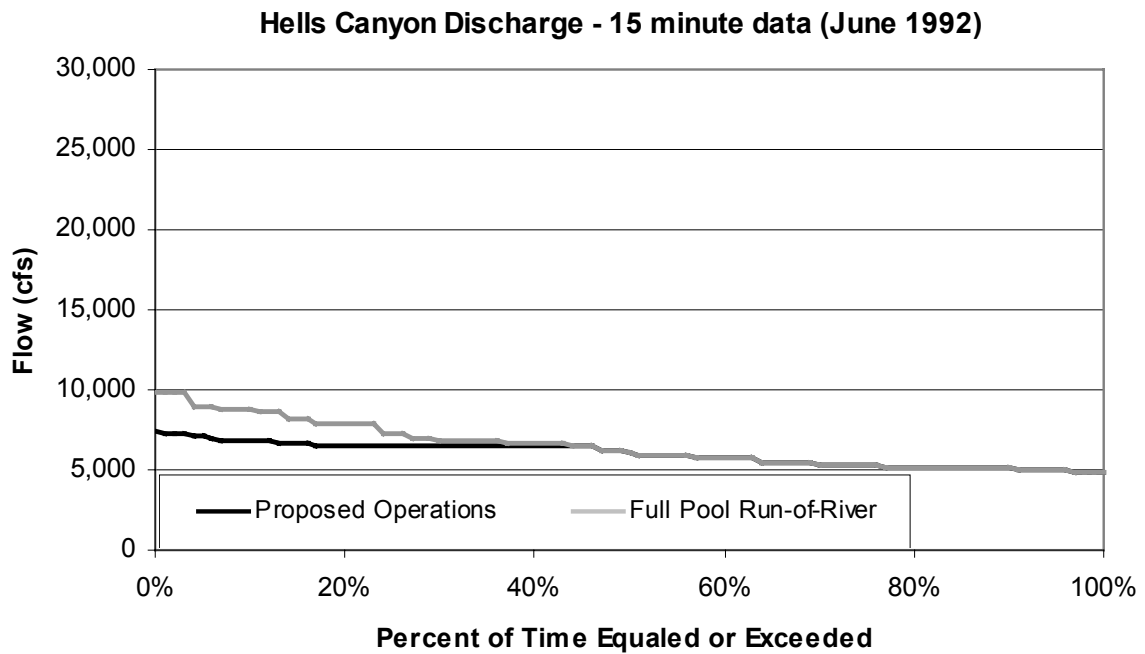
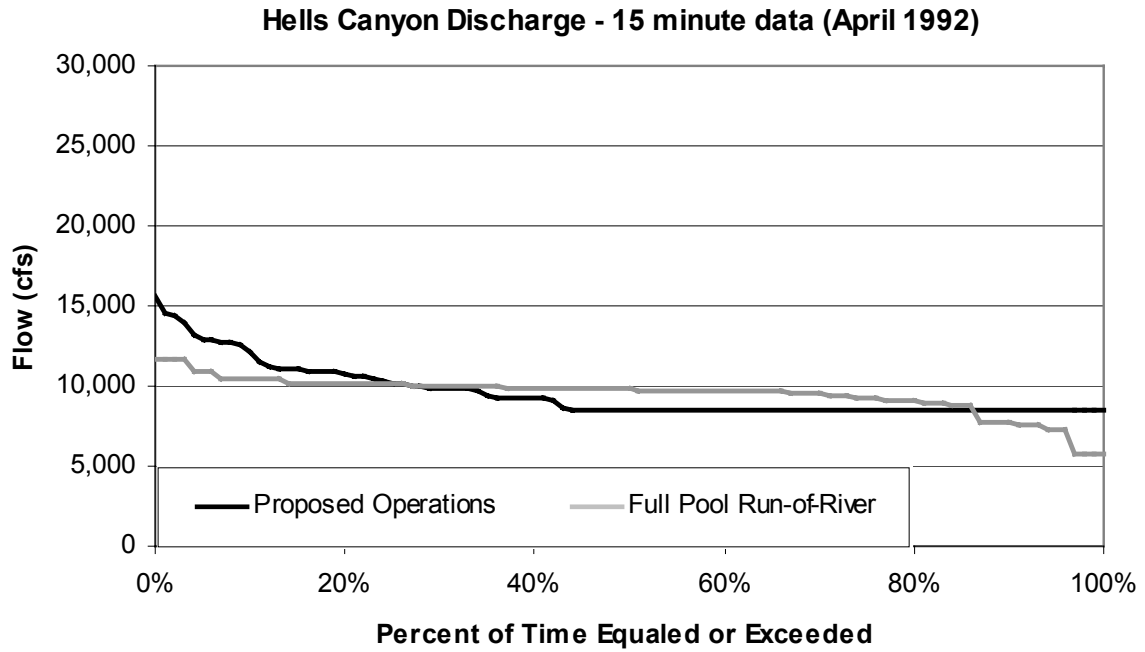
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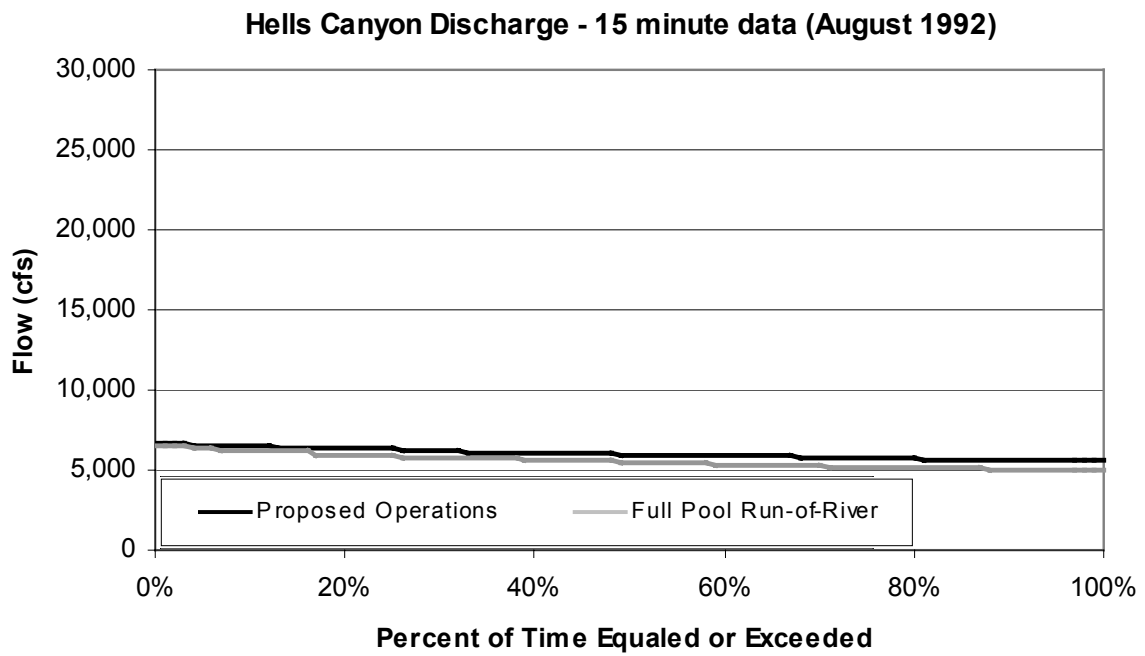
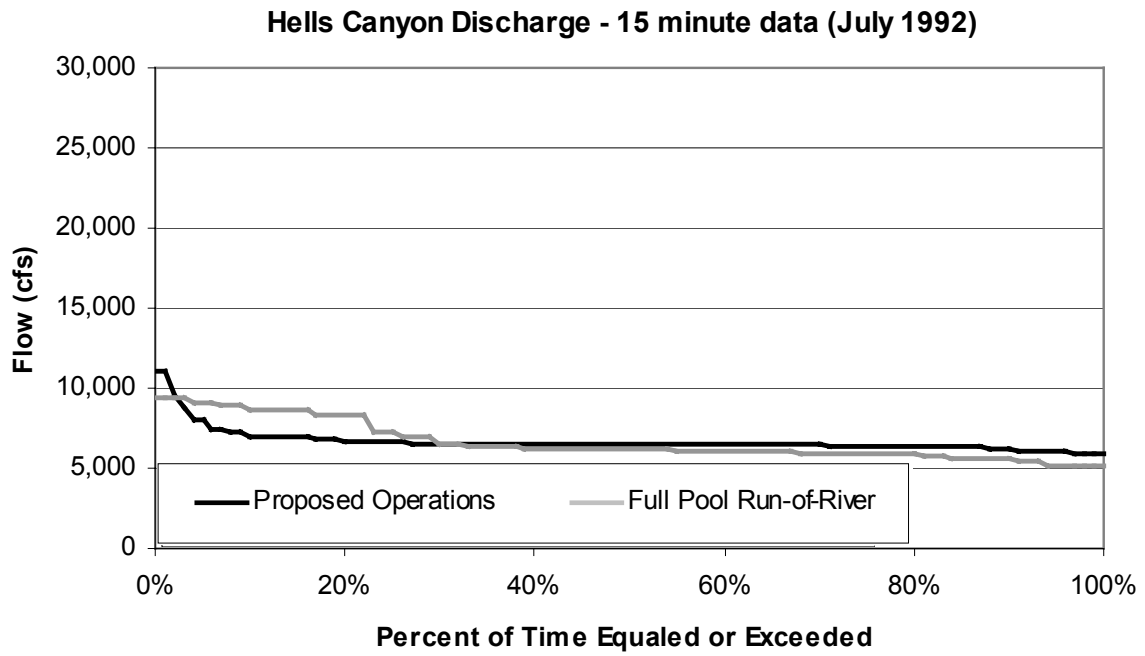
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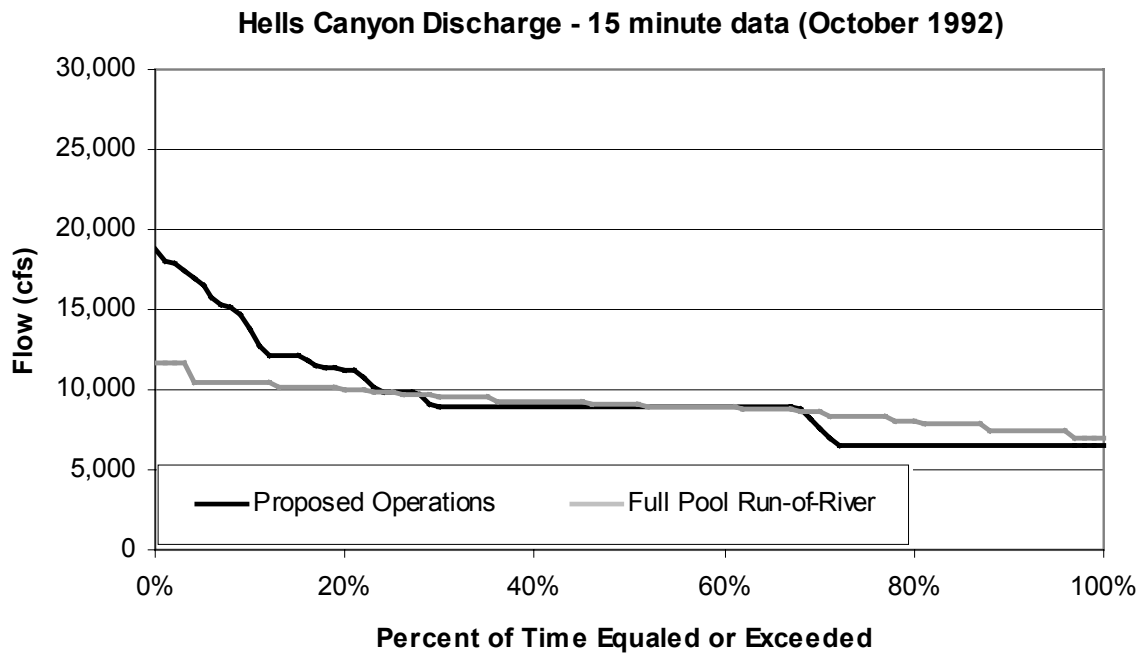
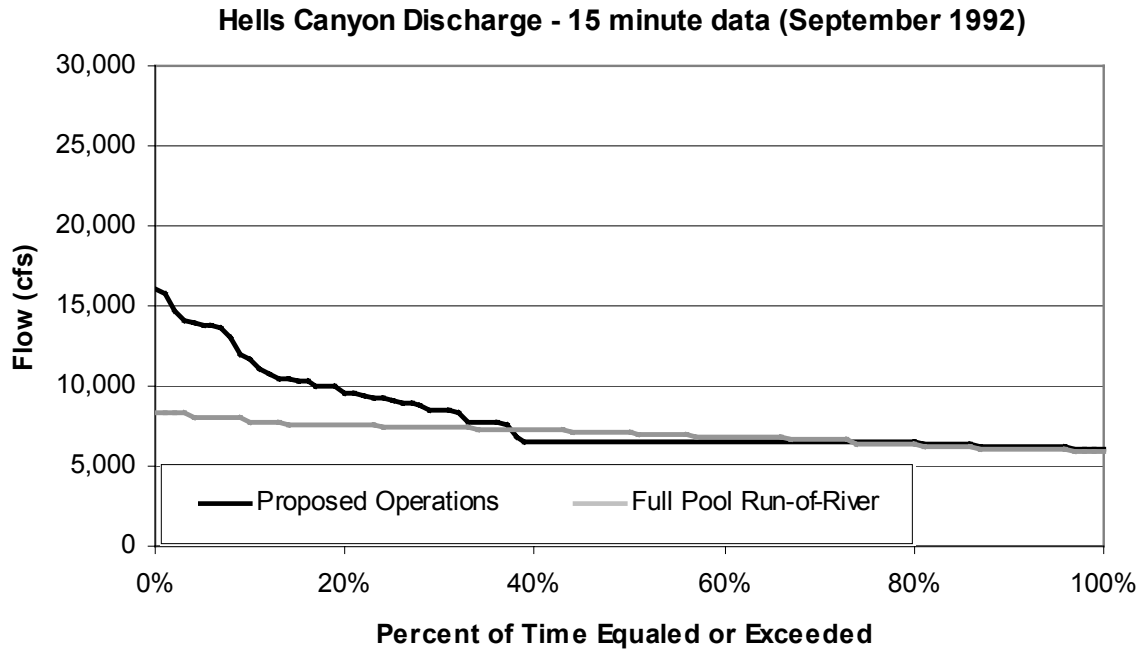
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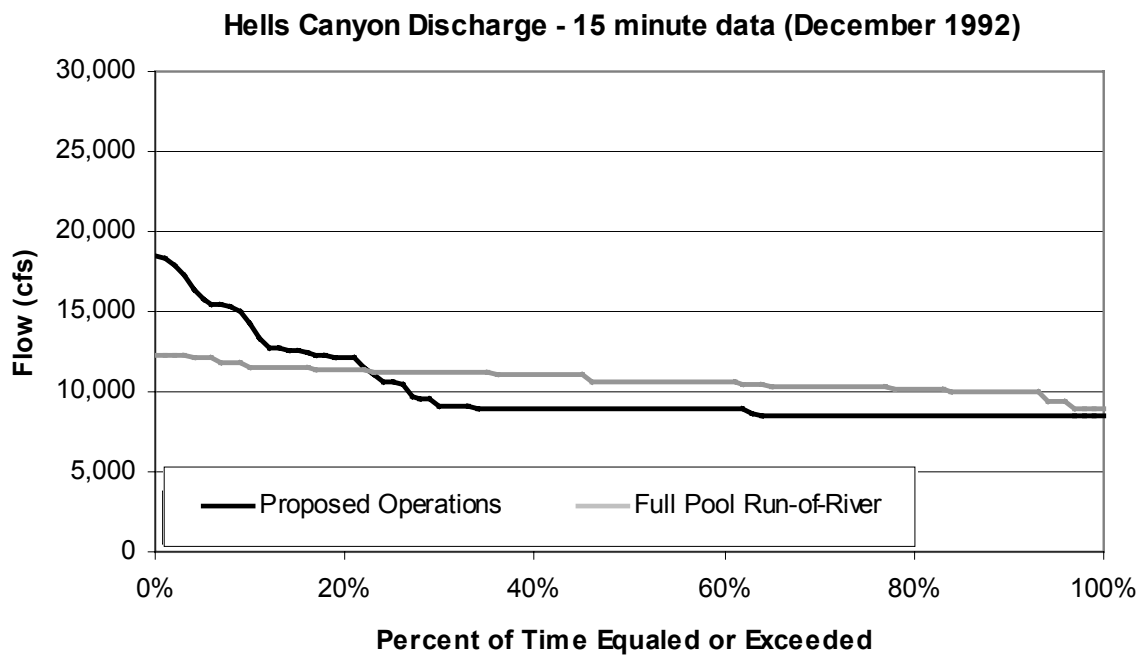
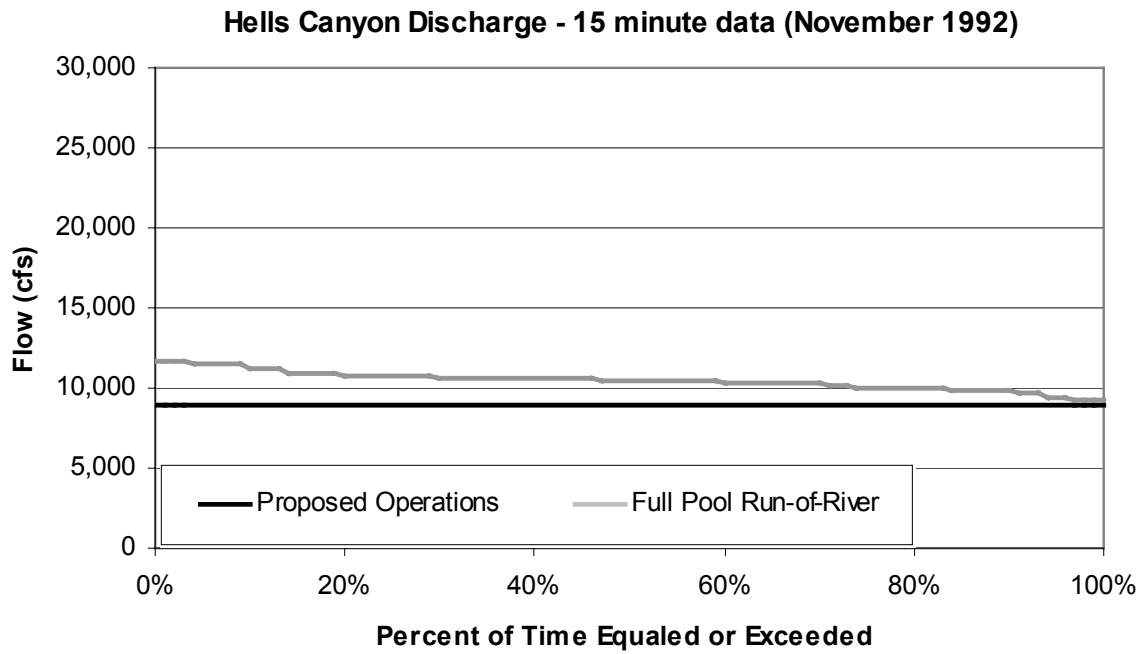
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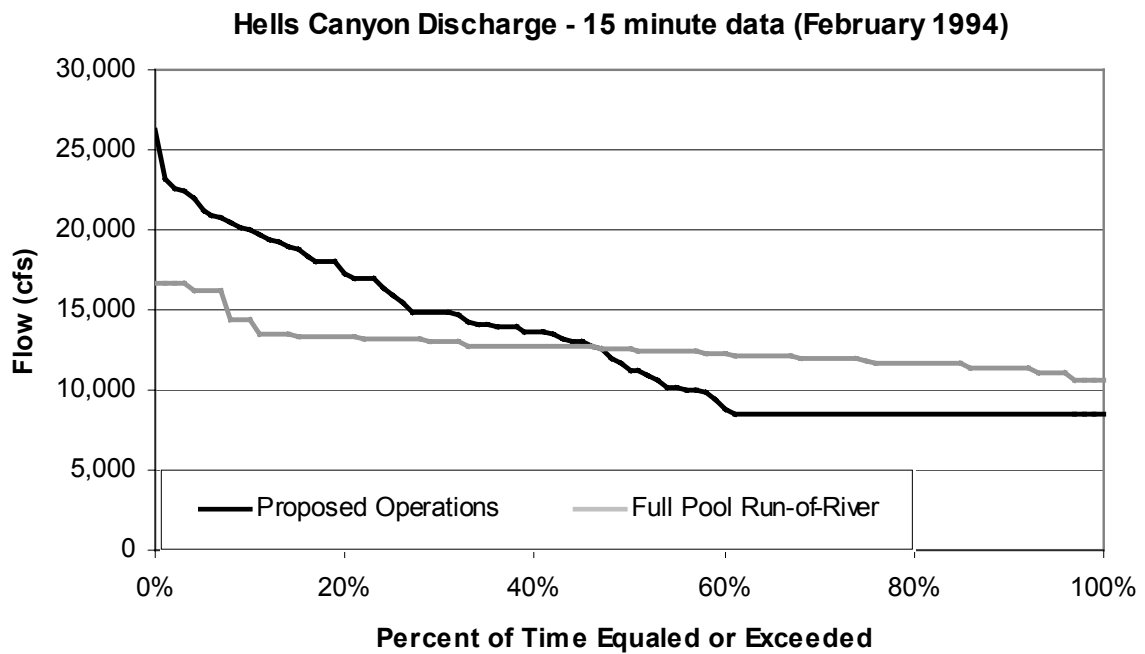
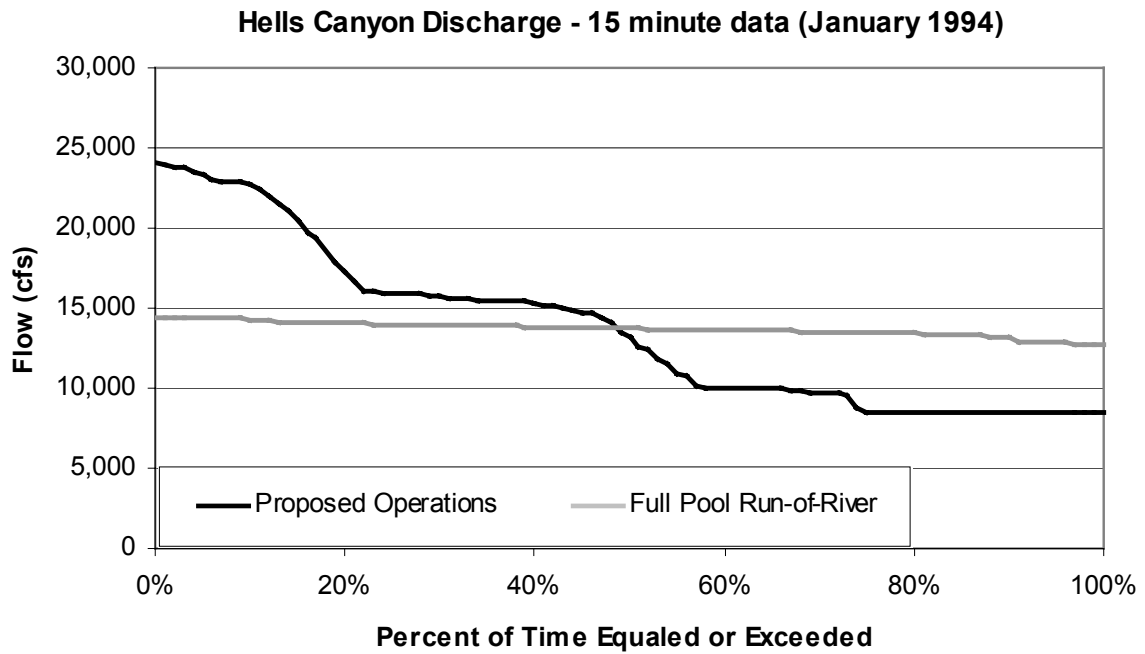
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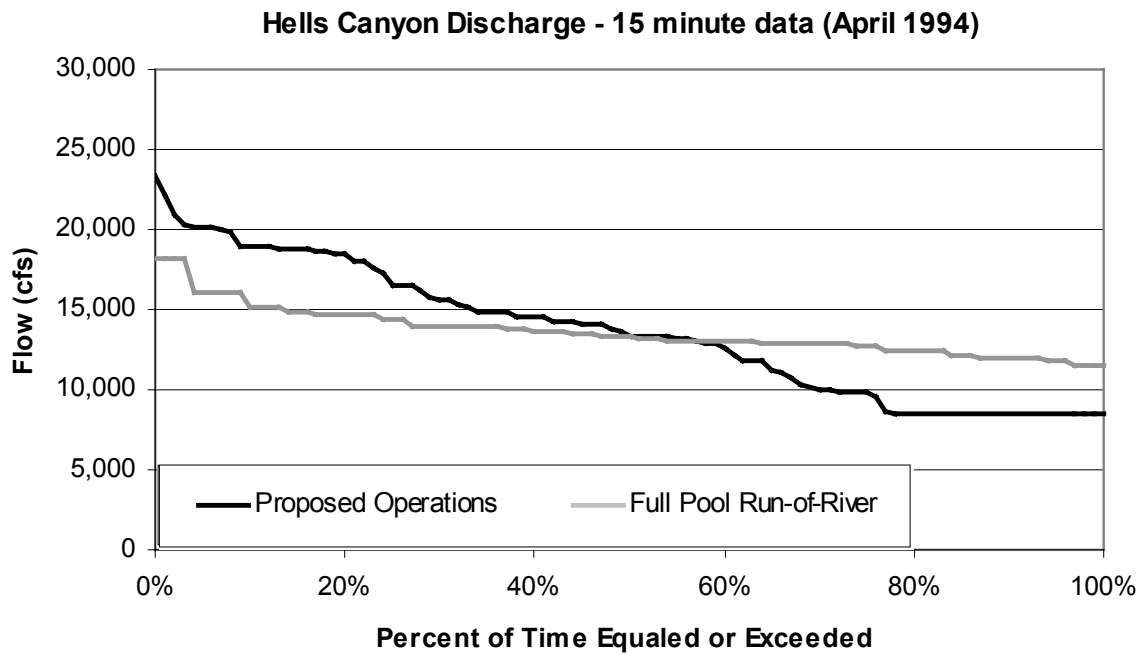
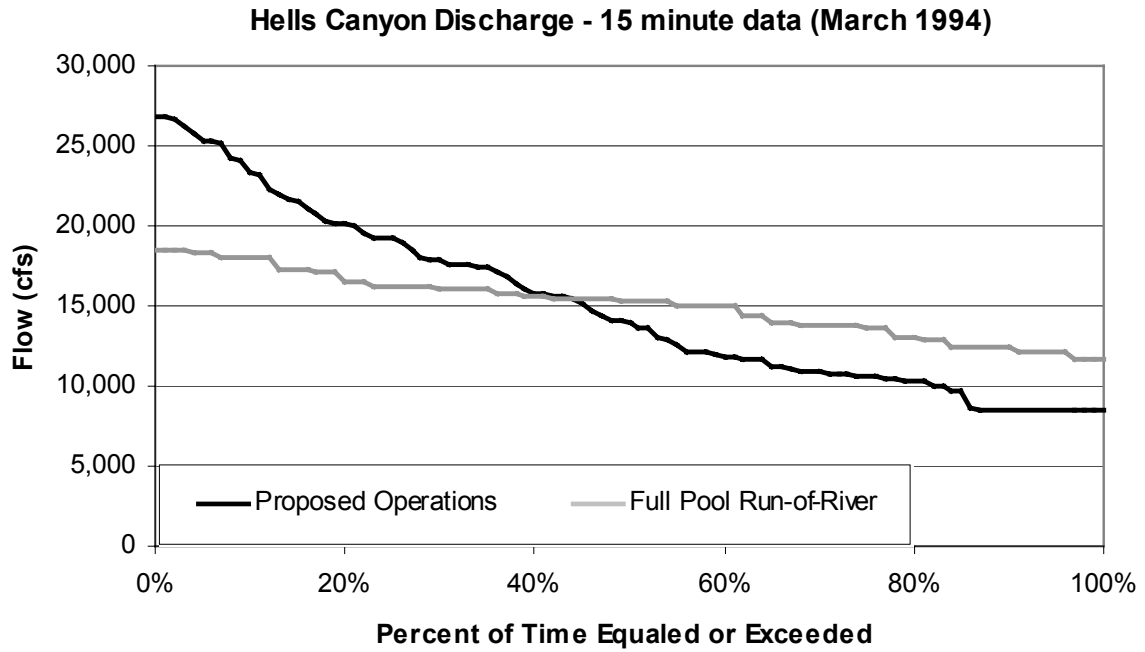
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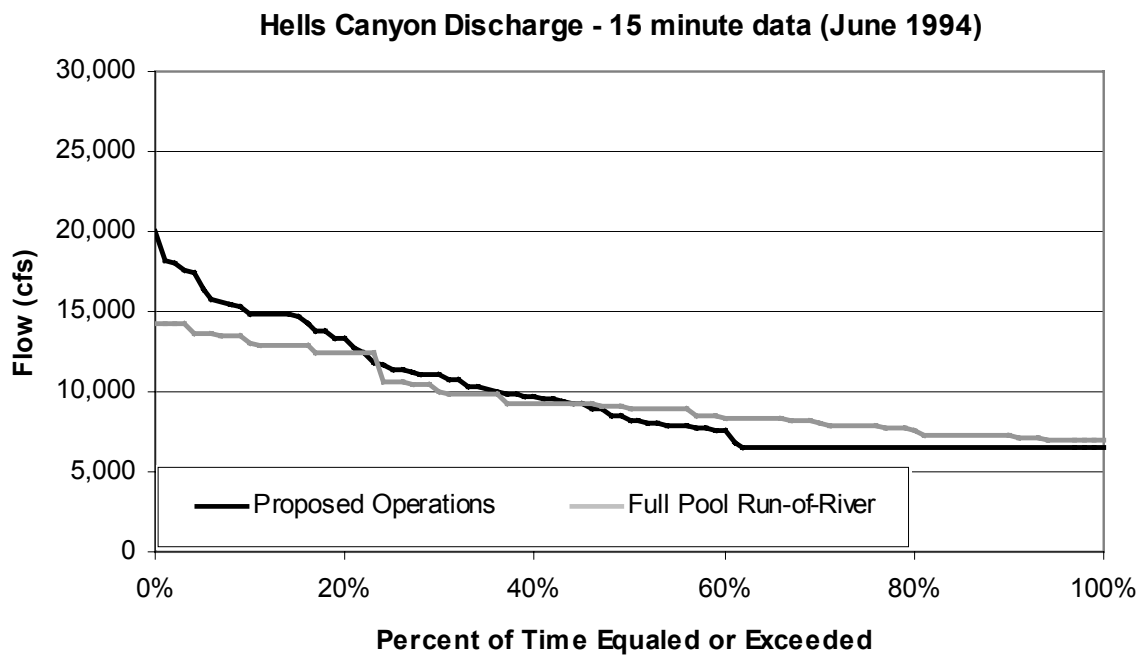
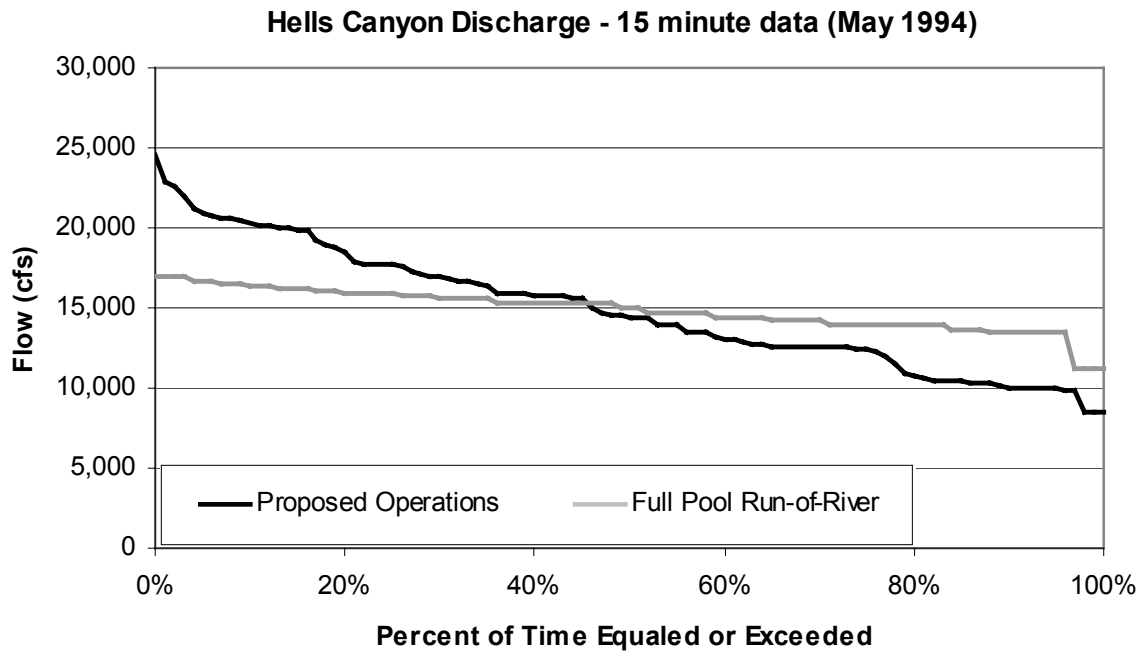
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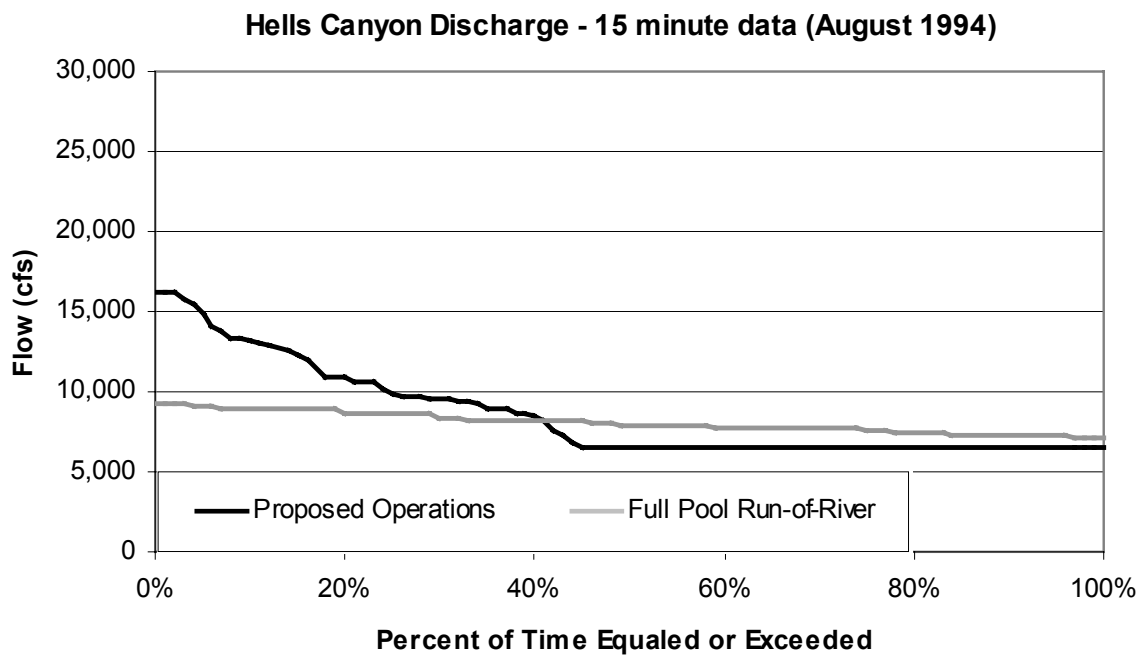
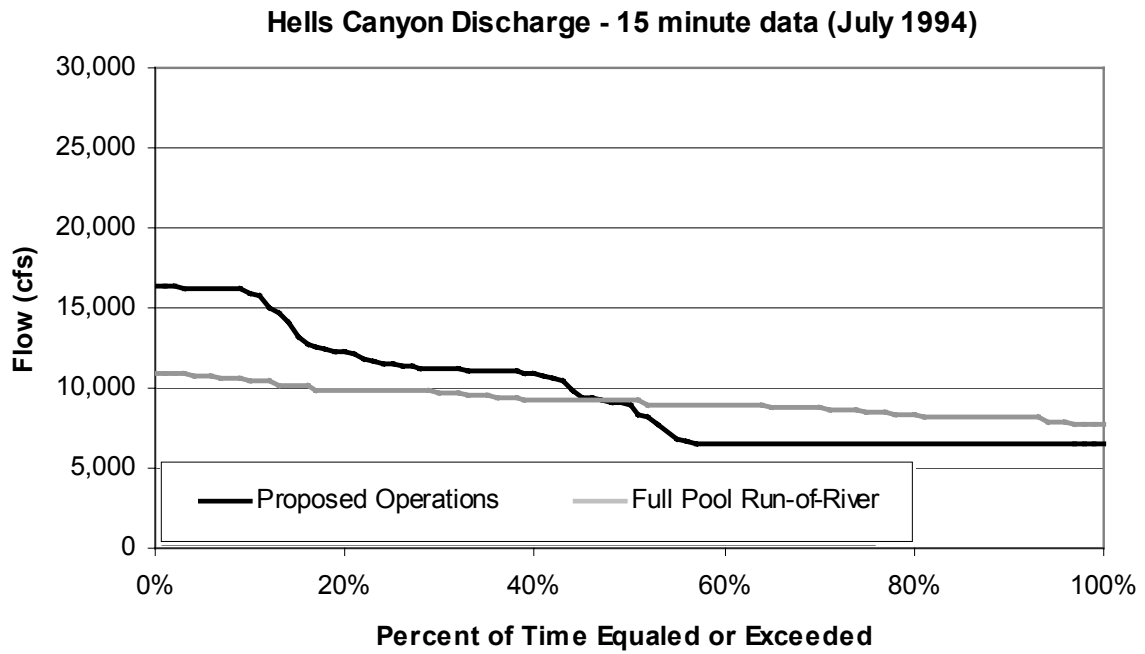
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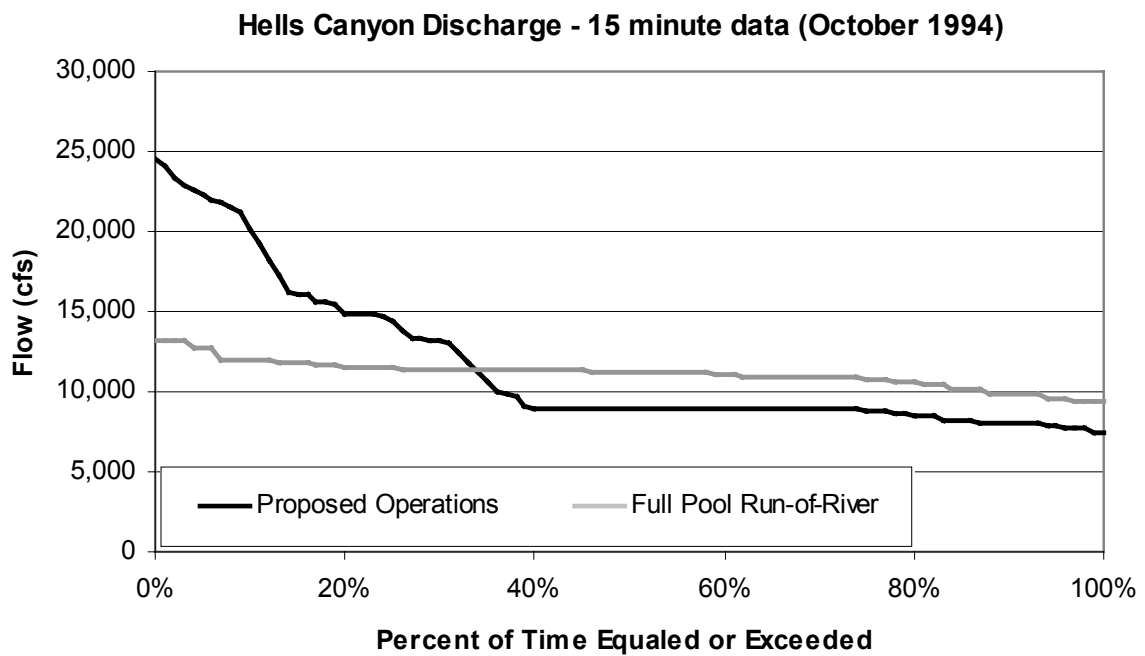
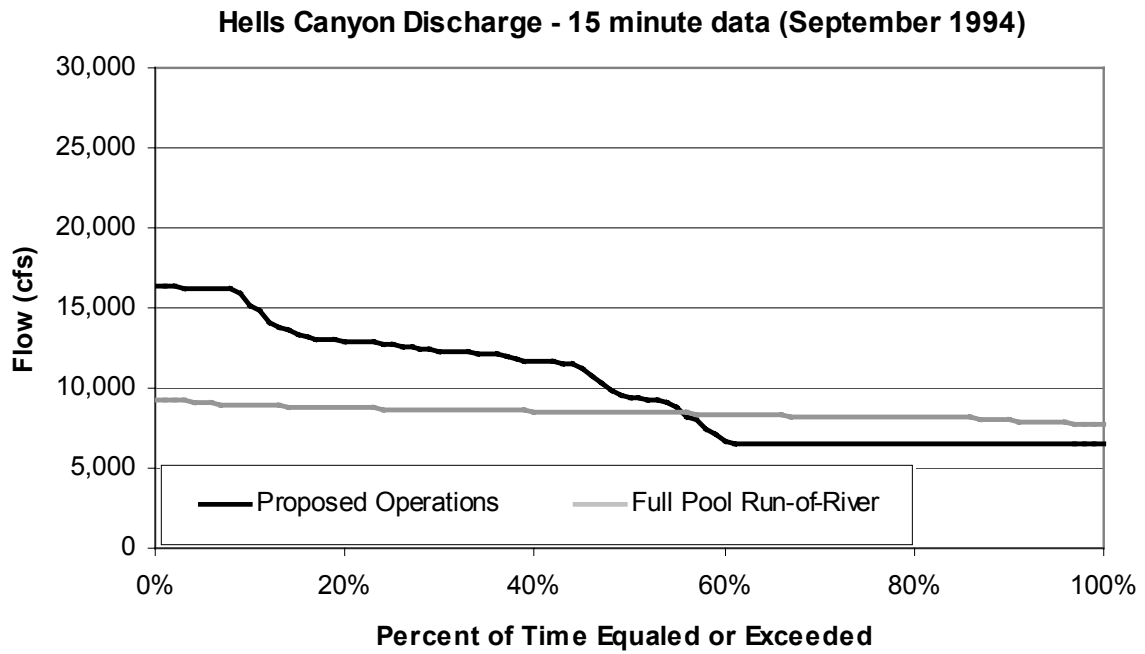
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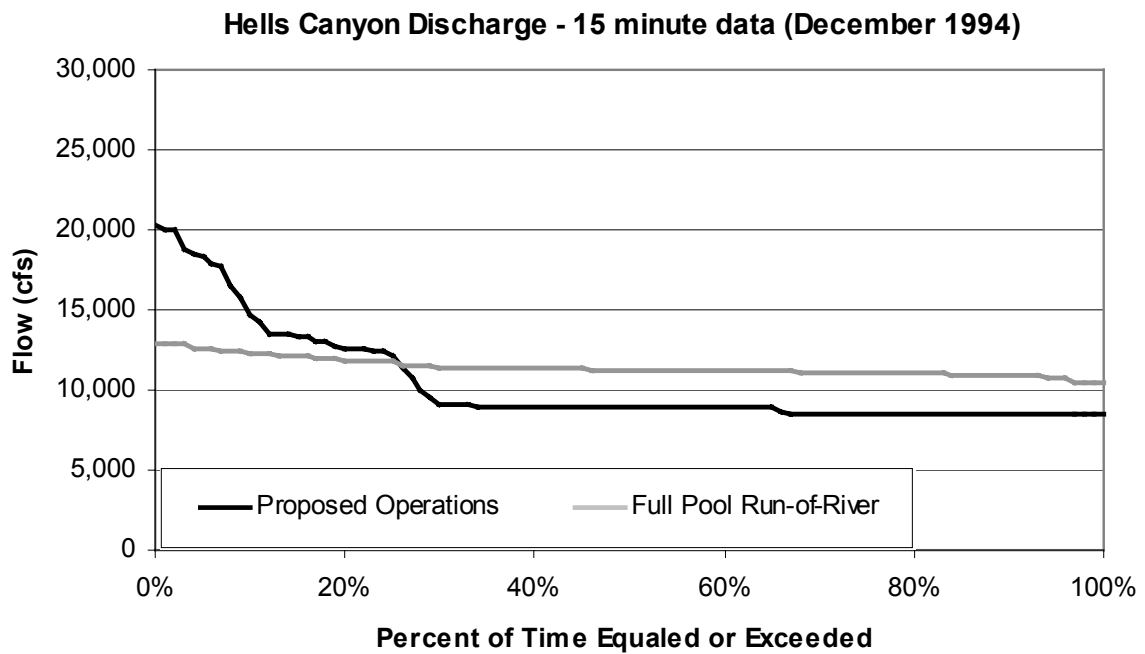
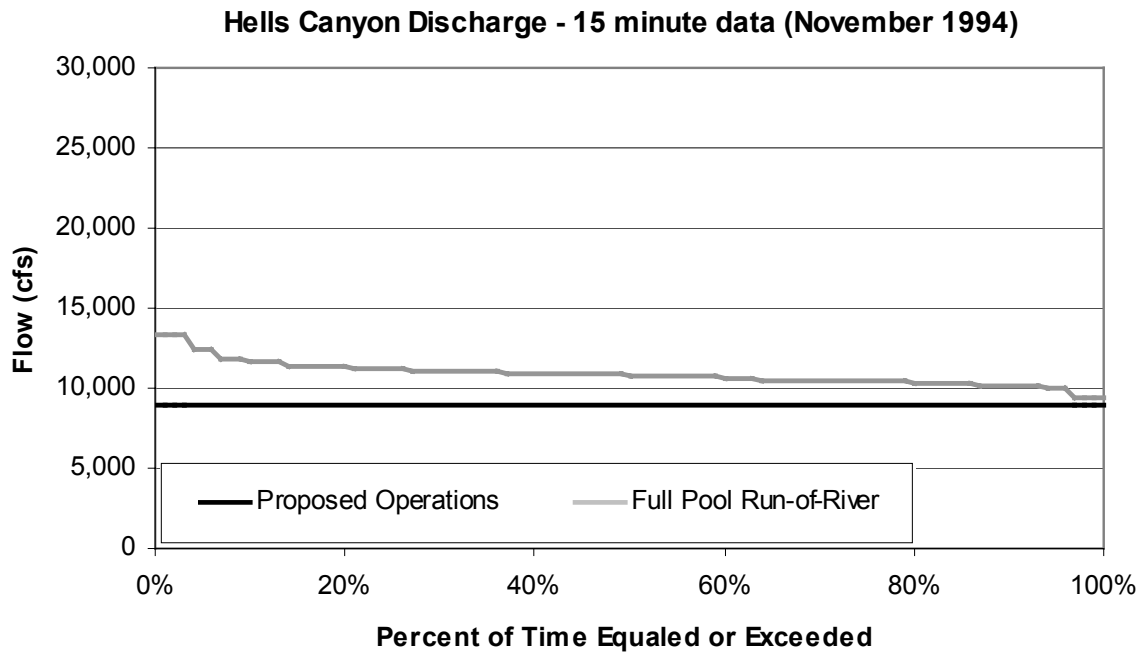
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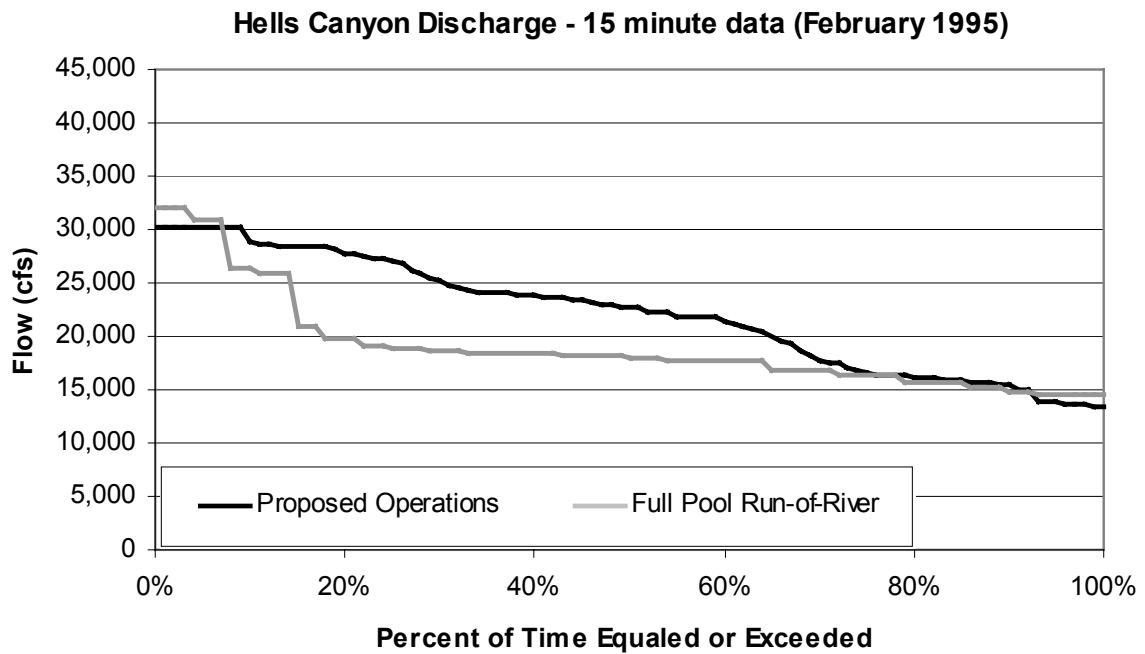
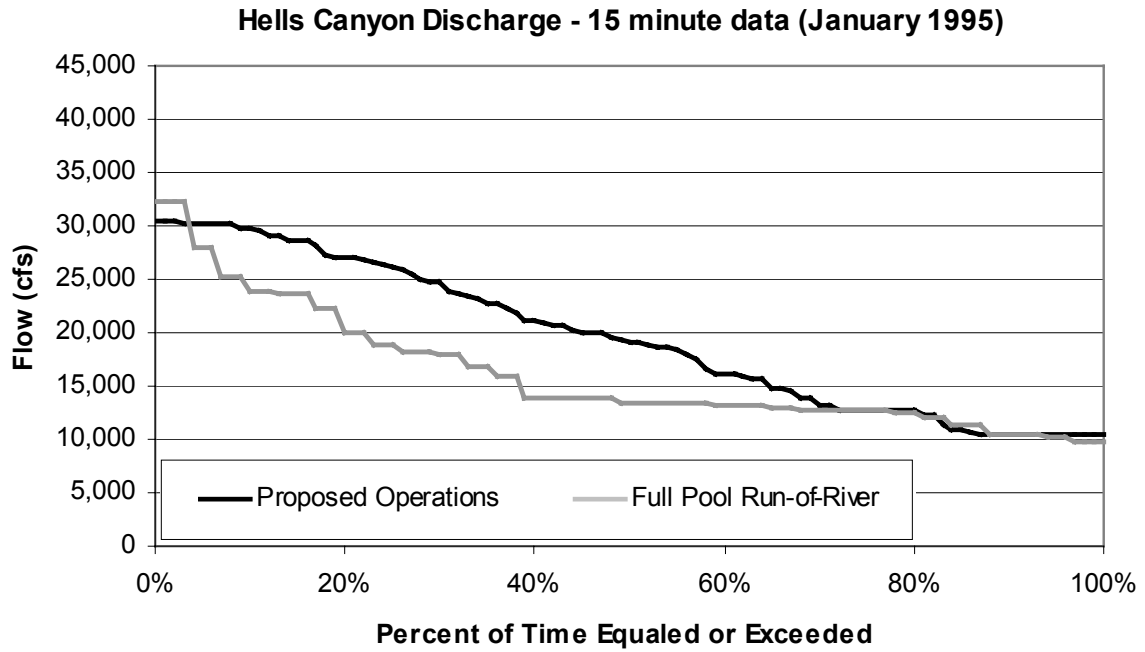
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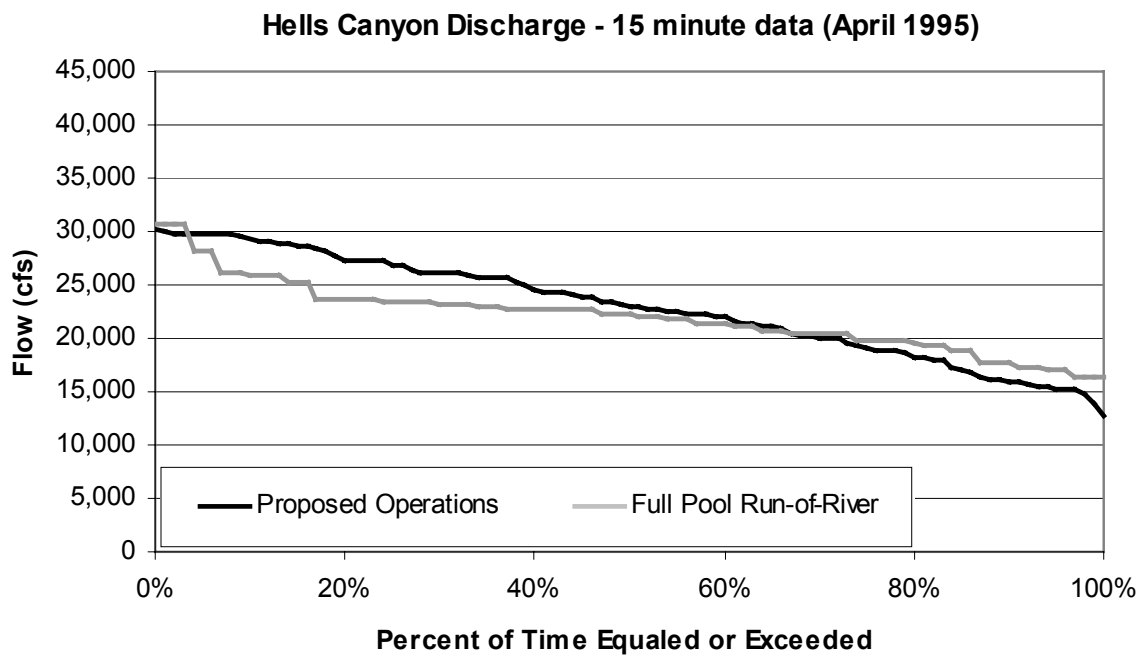
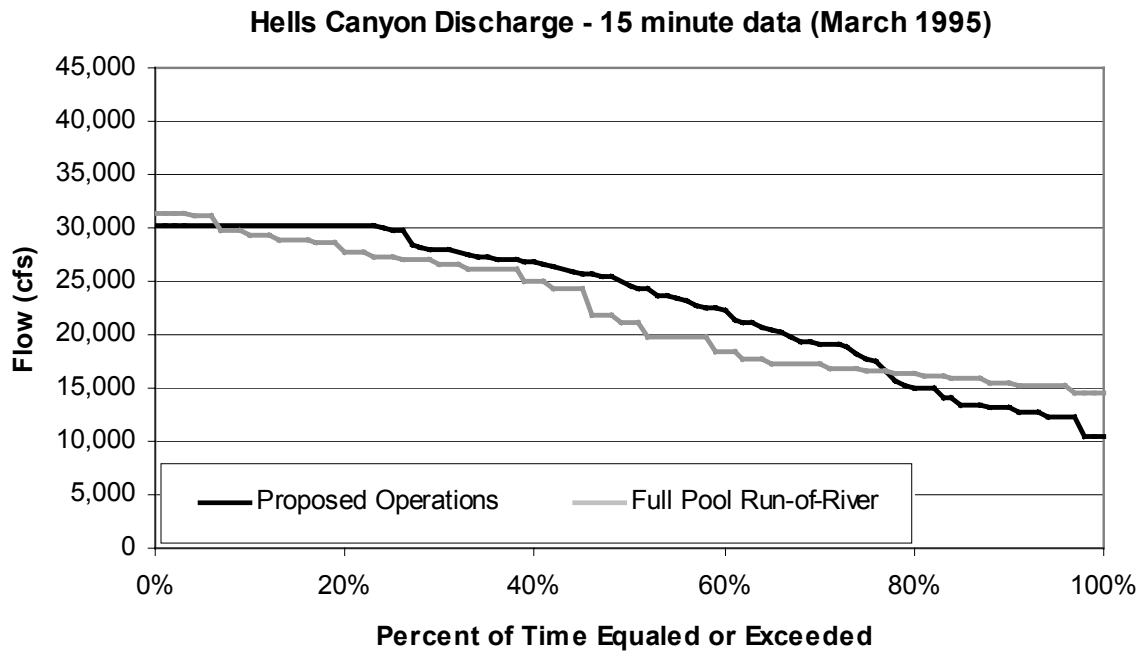
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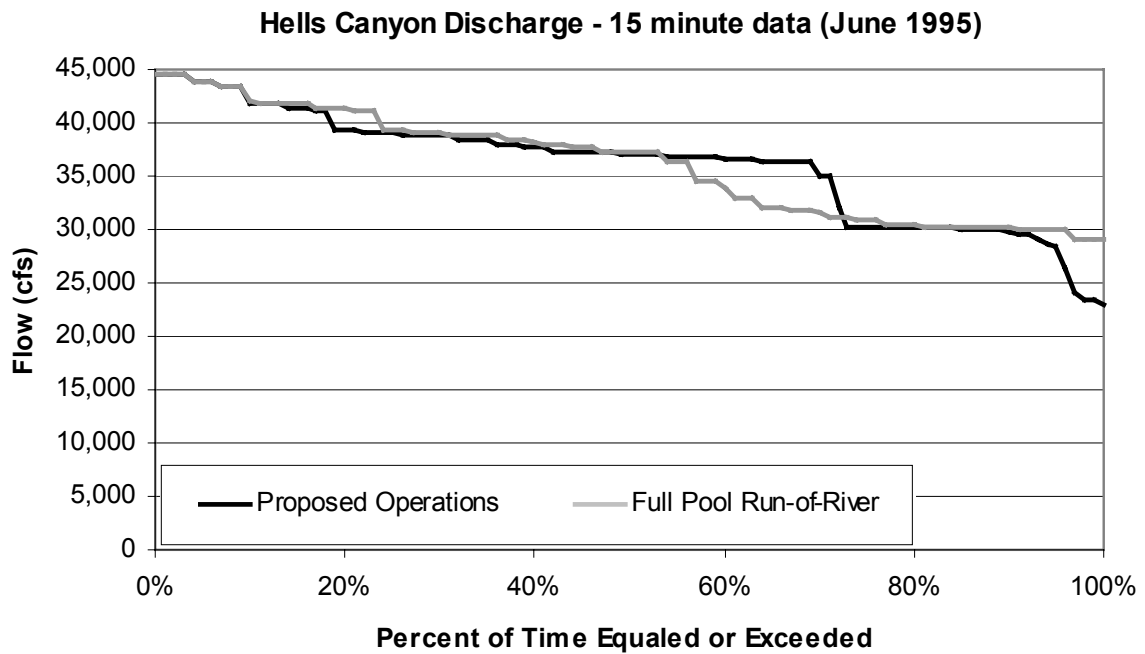
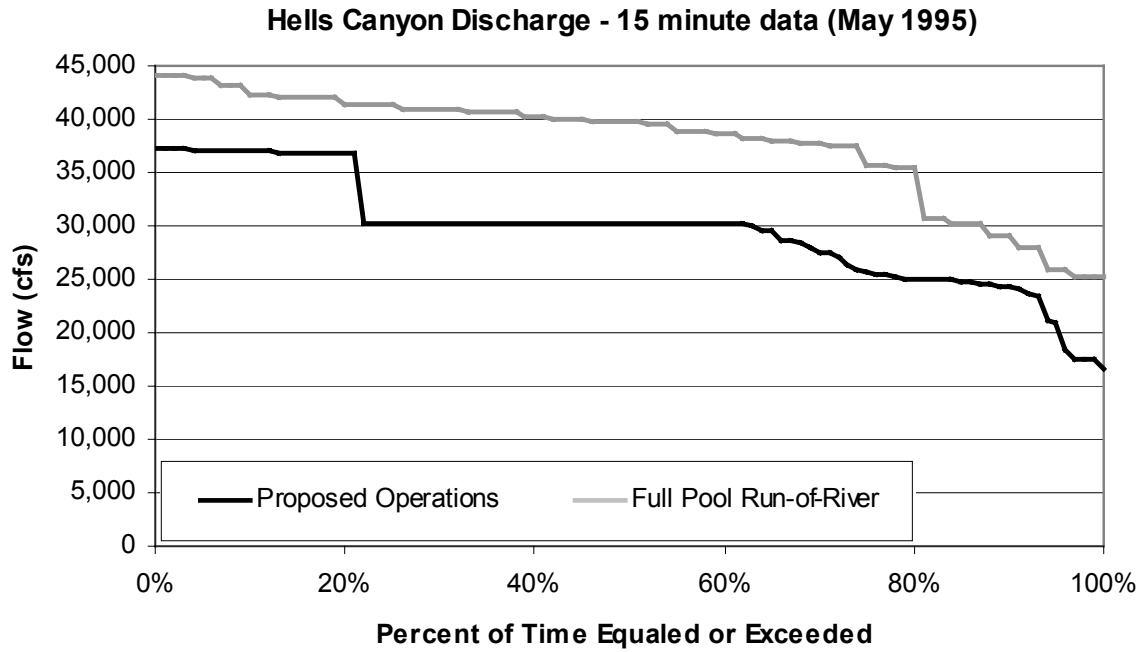
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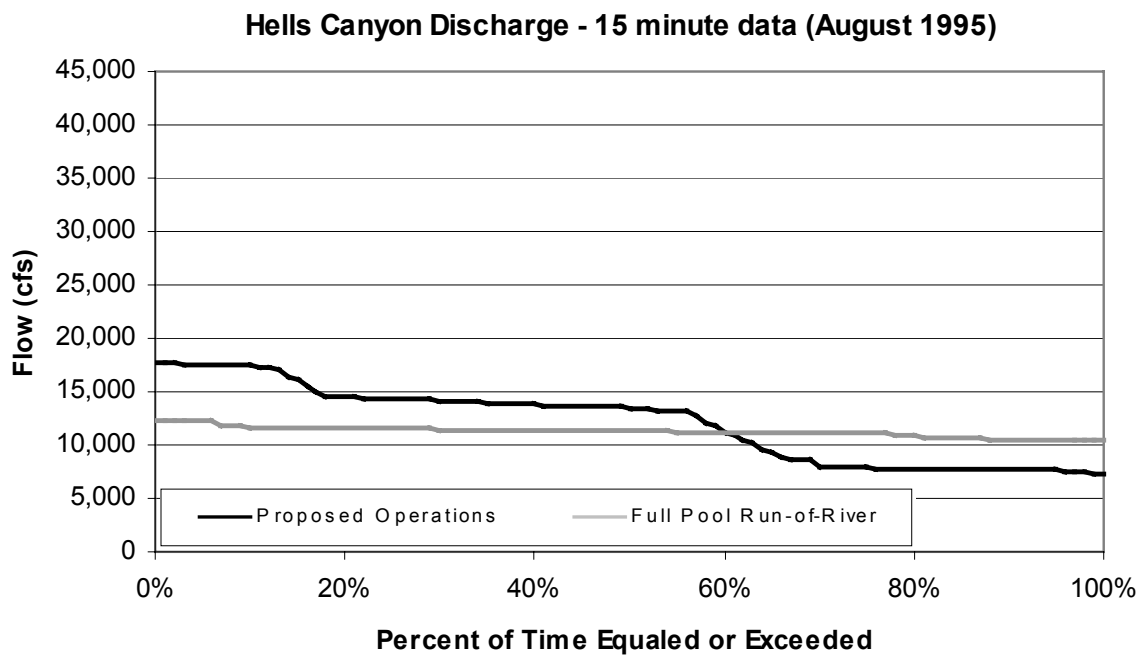
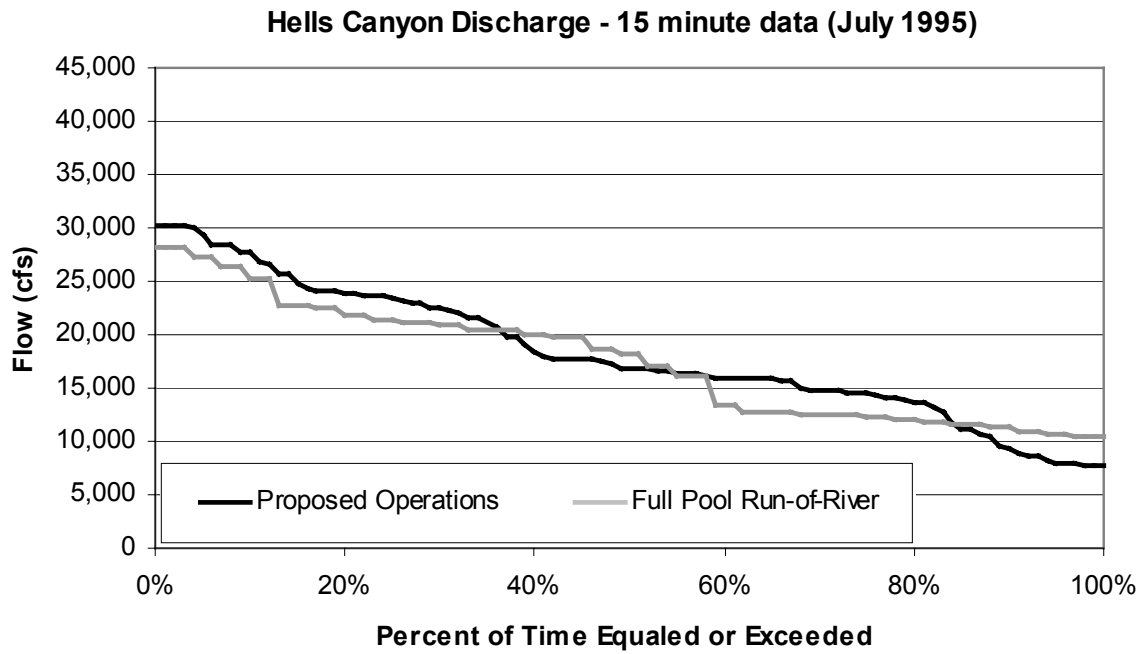
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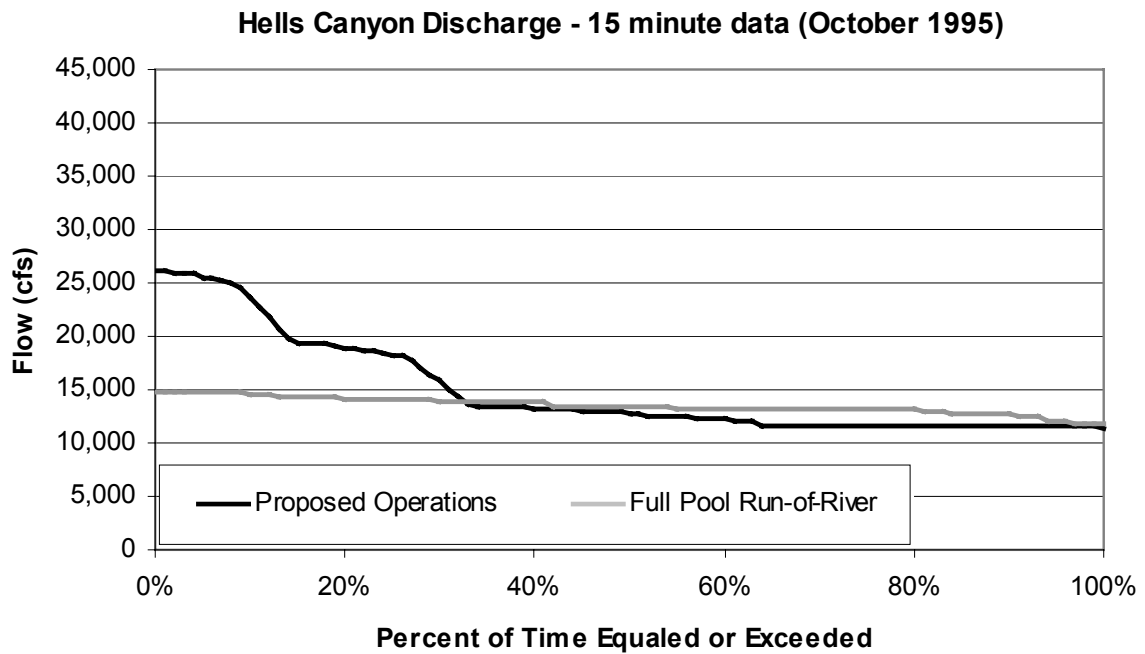
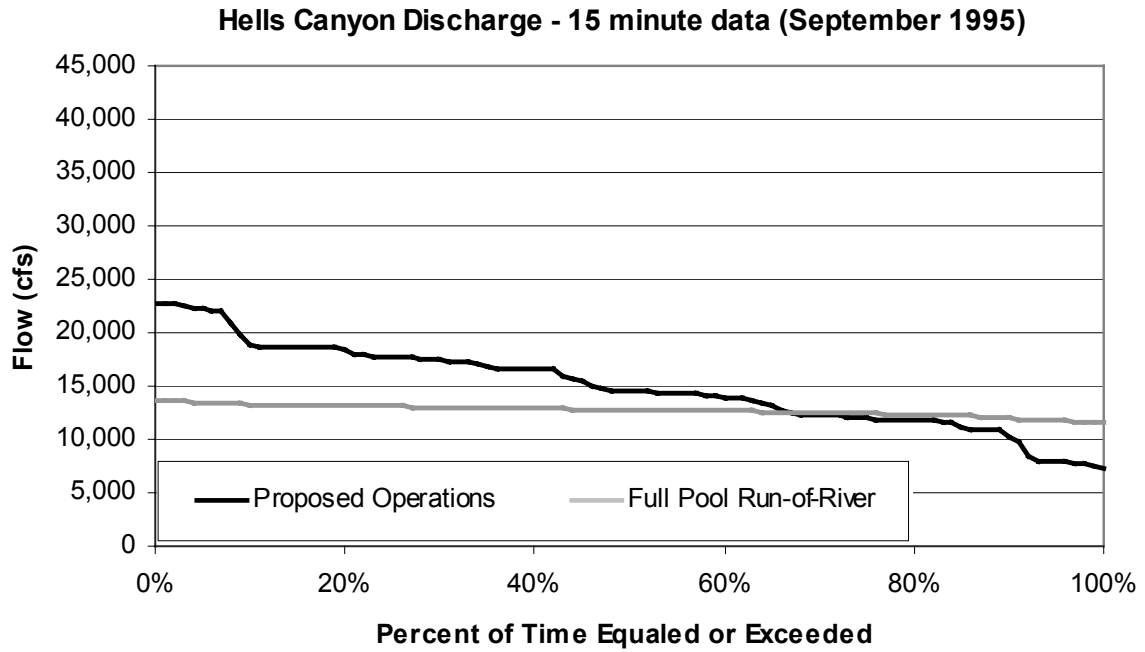
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Appendix 1. (Cont.)

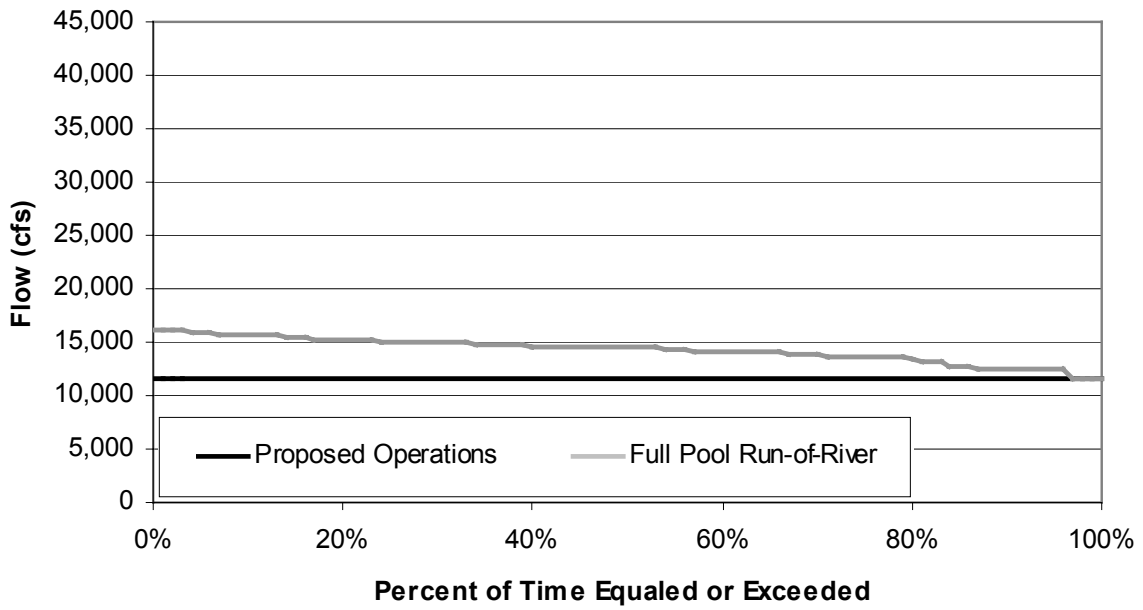


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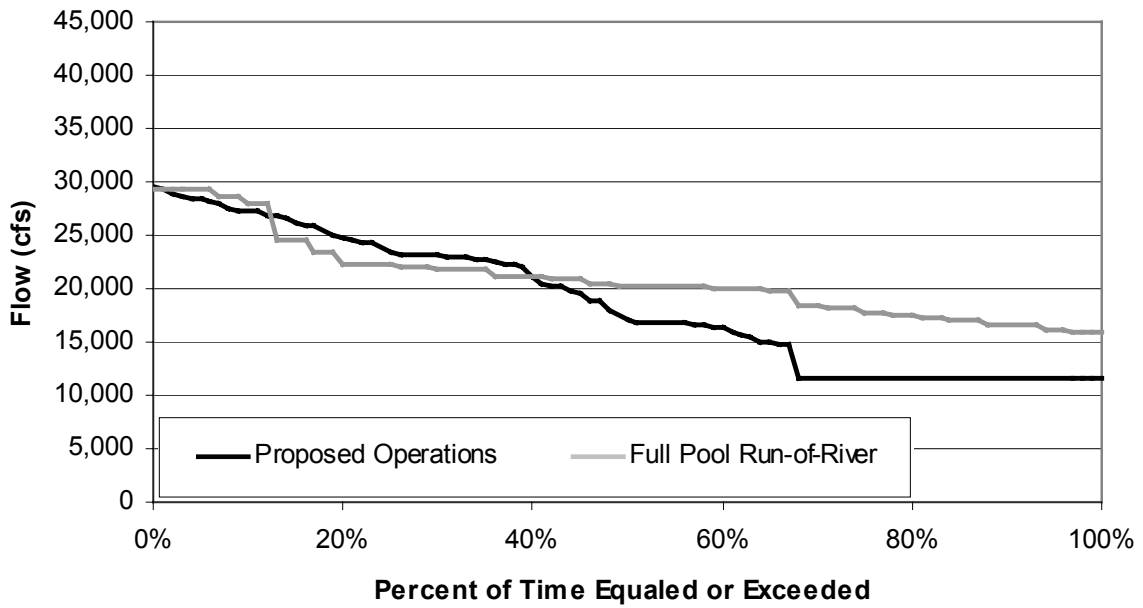


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Hells Canyon Discharge - 15 minute data (November 1995)

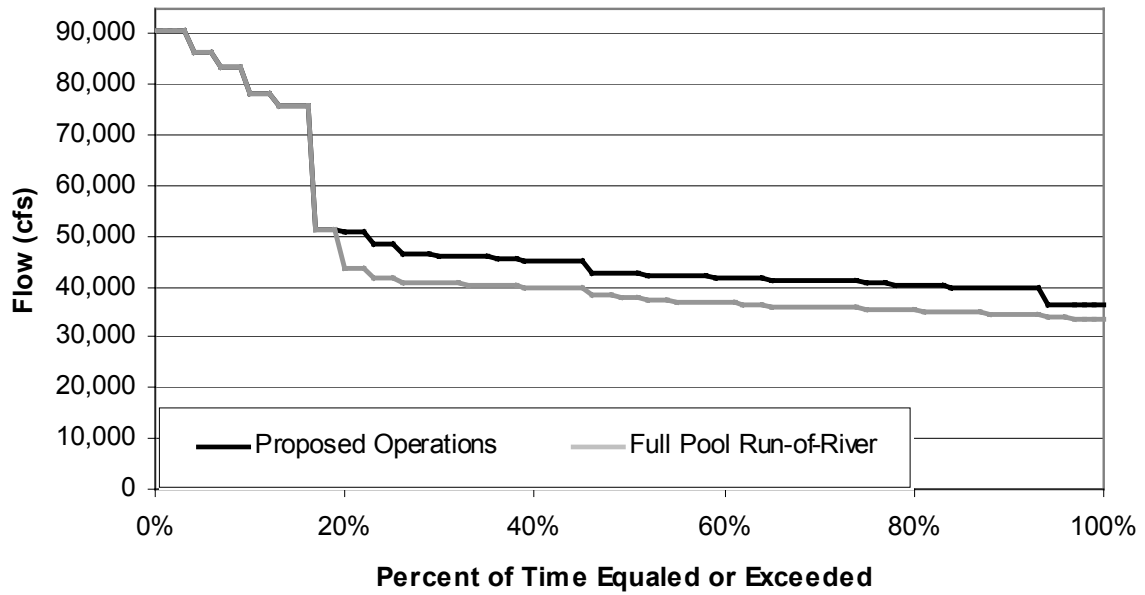


Hells Canyon Discharge - 15 minute data (December 1995)

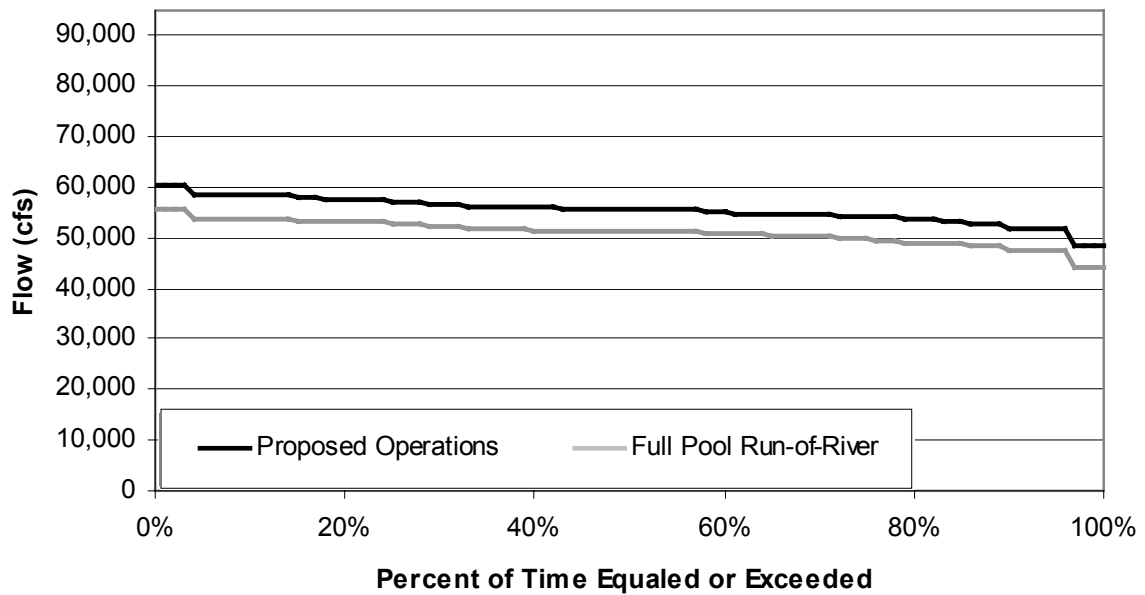


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Hells Canyon Discharge - 15 minute data (January 1997)

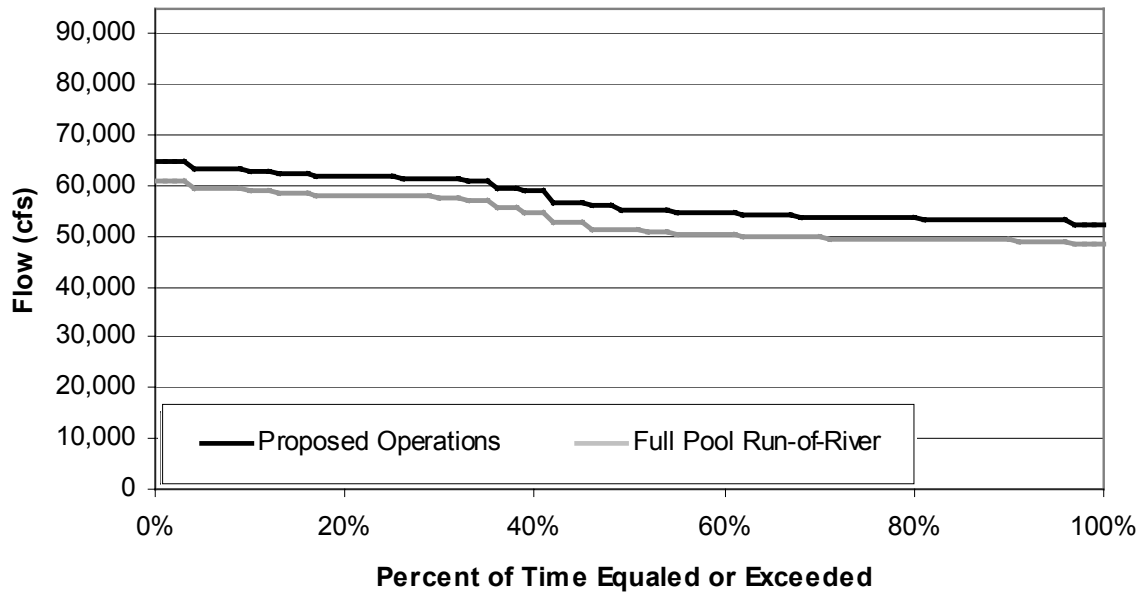


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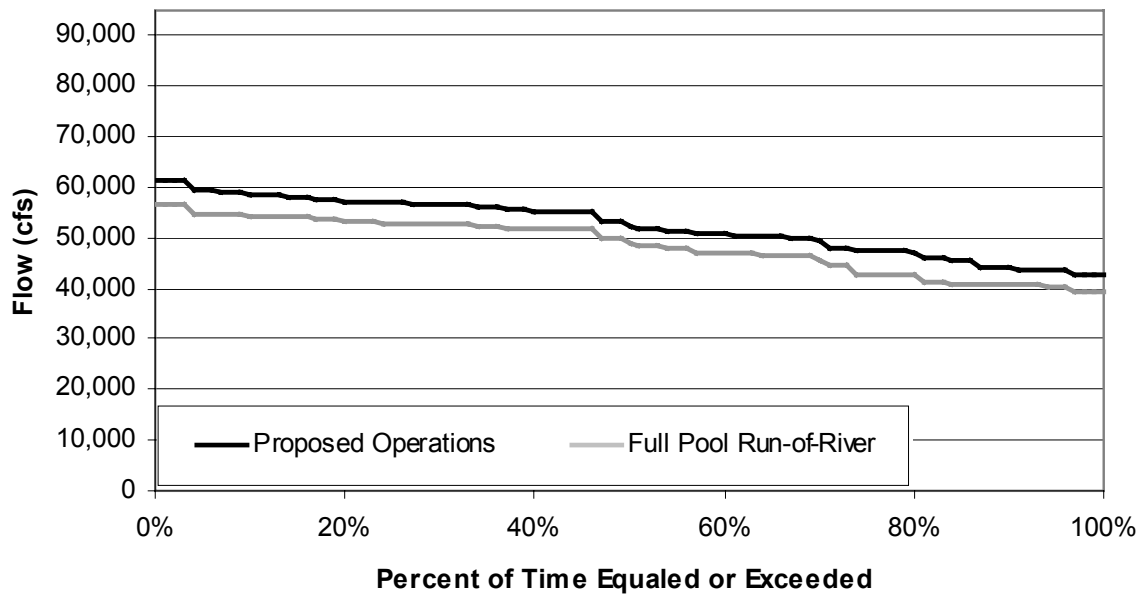


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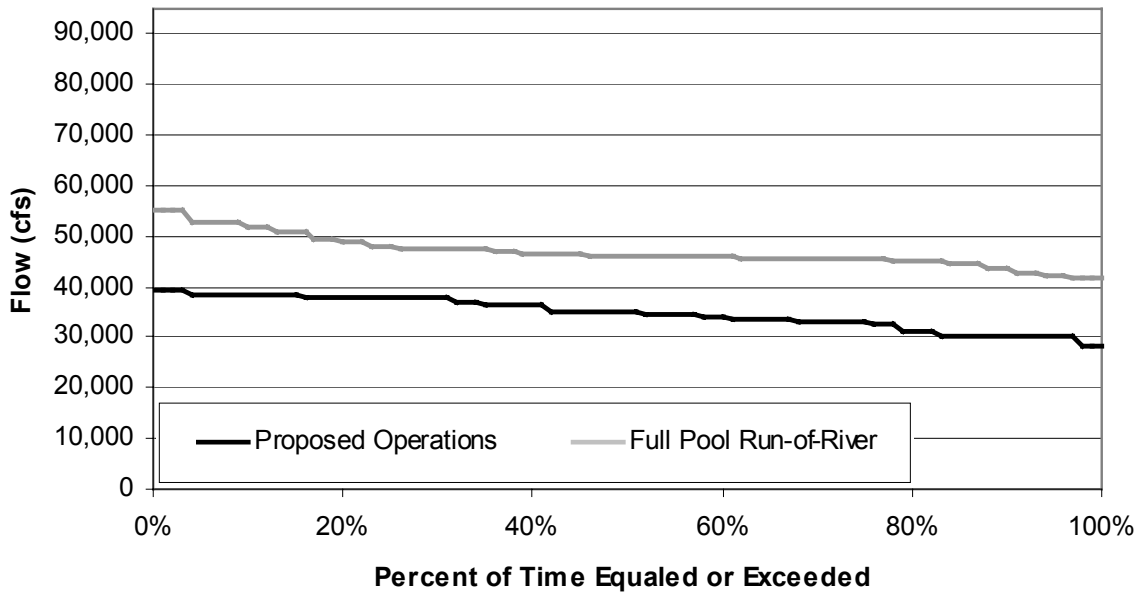


Hells Canyon Discharge - 15 minute data (April 1997)

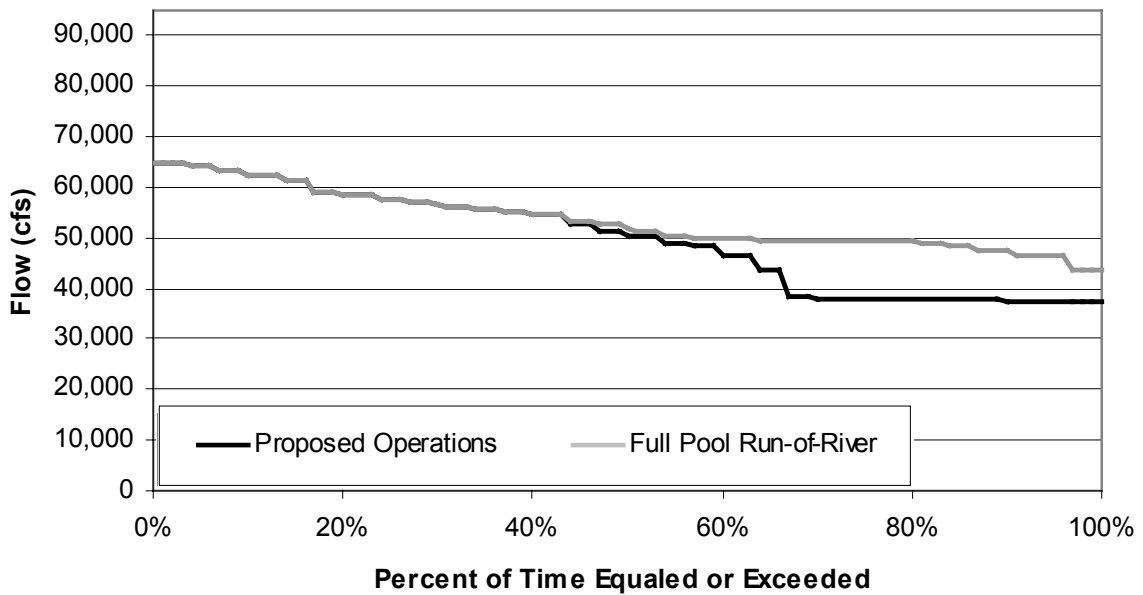


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Hells Canyon Discharge - 15 minute data (May 1997)

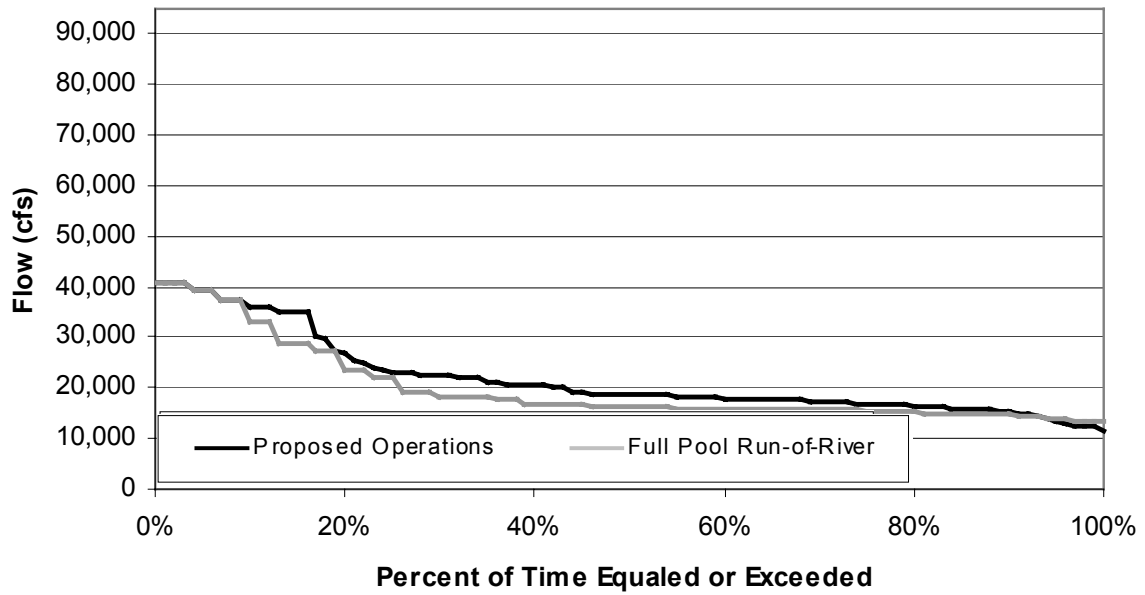


Hells Canyon Discharge - 15 minute data (June 1997)

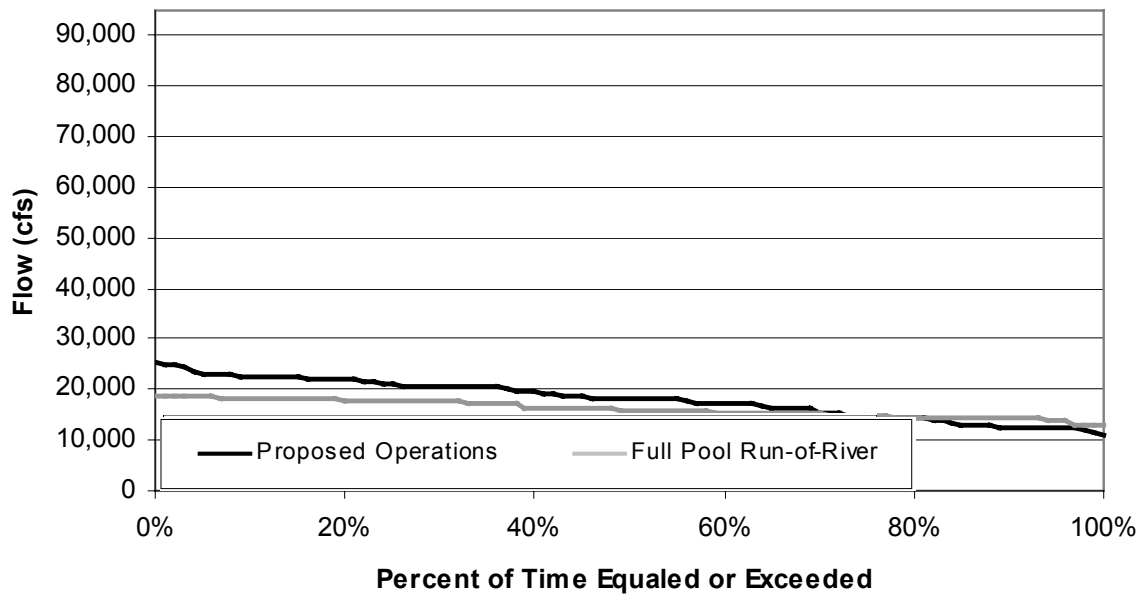


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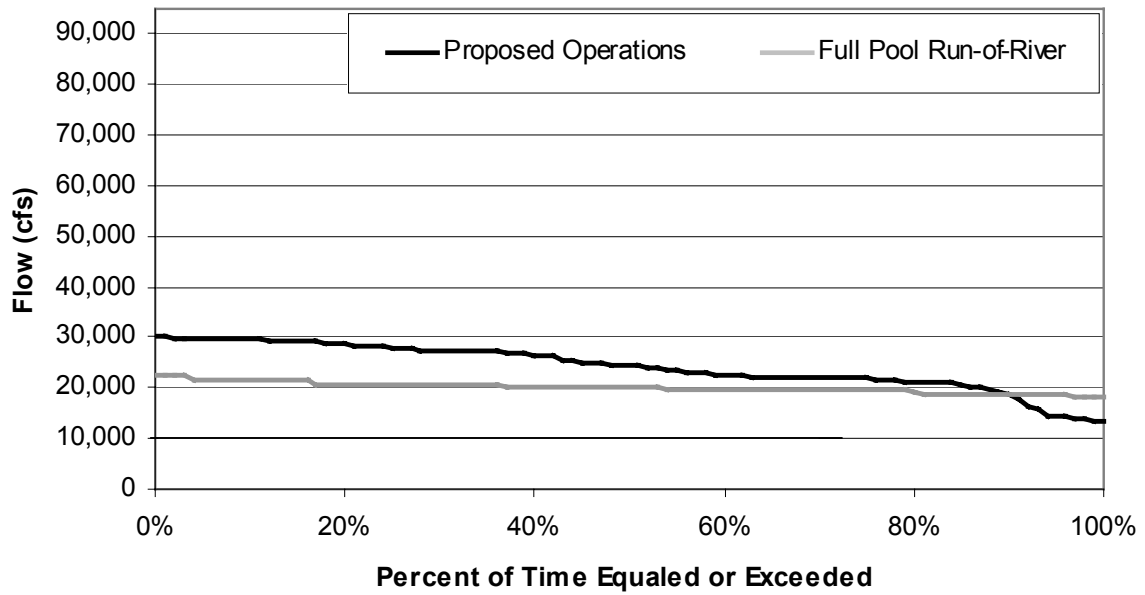


Hells Canyon Discharge - 15 minute data (August 1997)

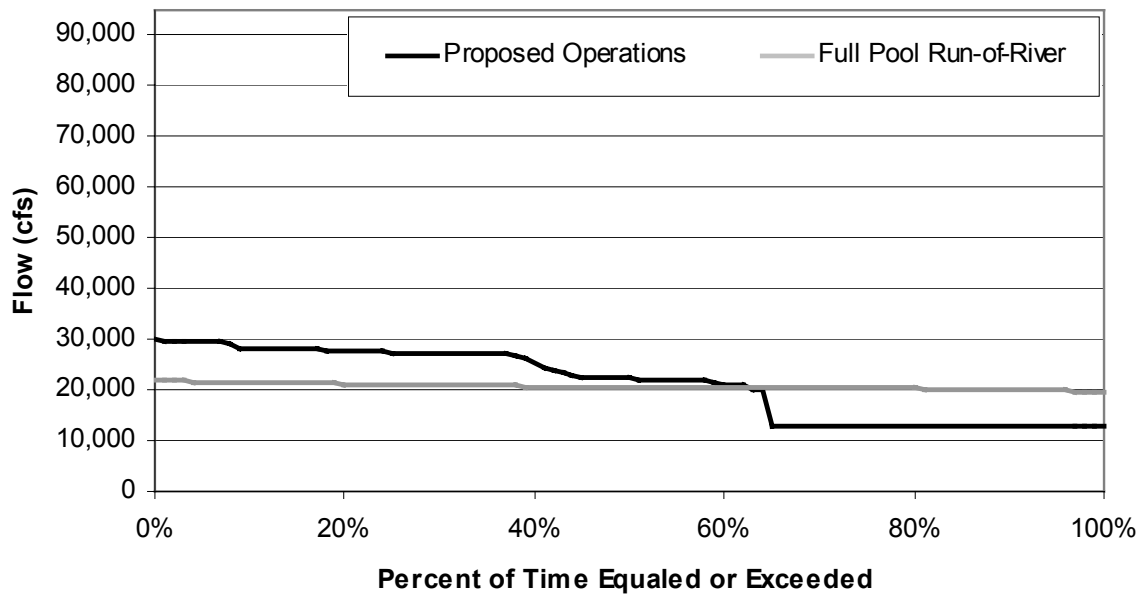


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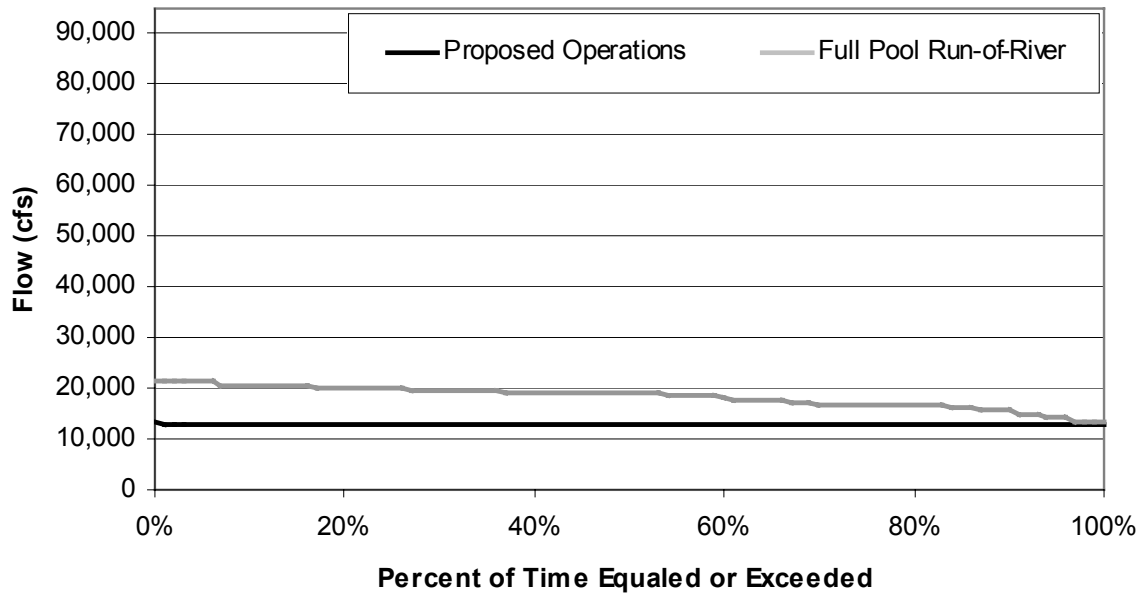


Hells Canyon Discharge - 15 minute data (October 1997)

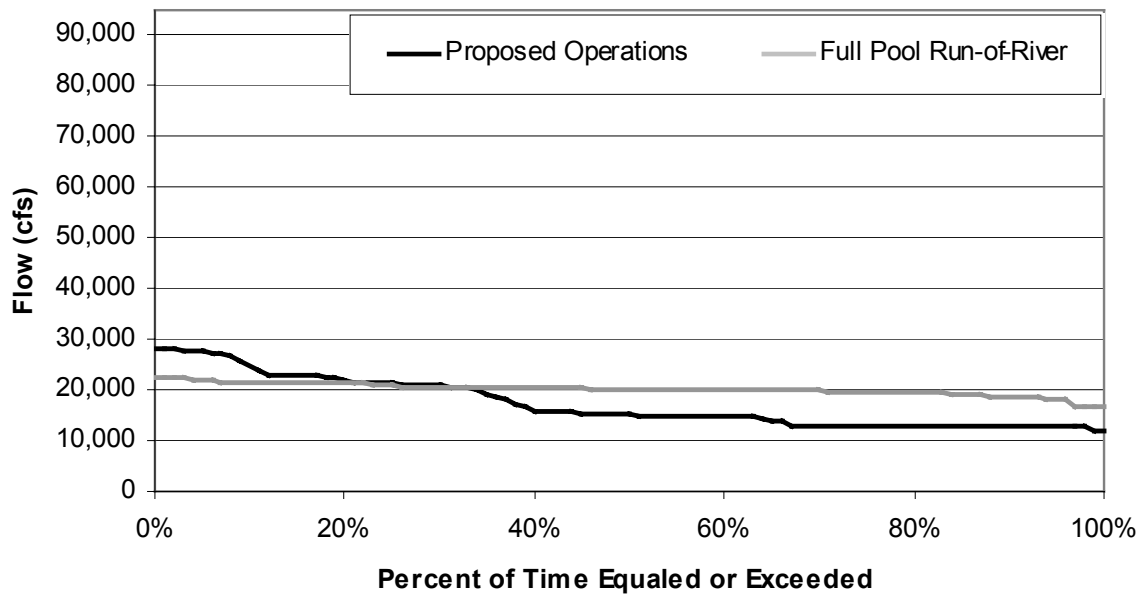


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Hells Canyon Discharge - 15 minute data (November 1997)

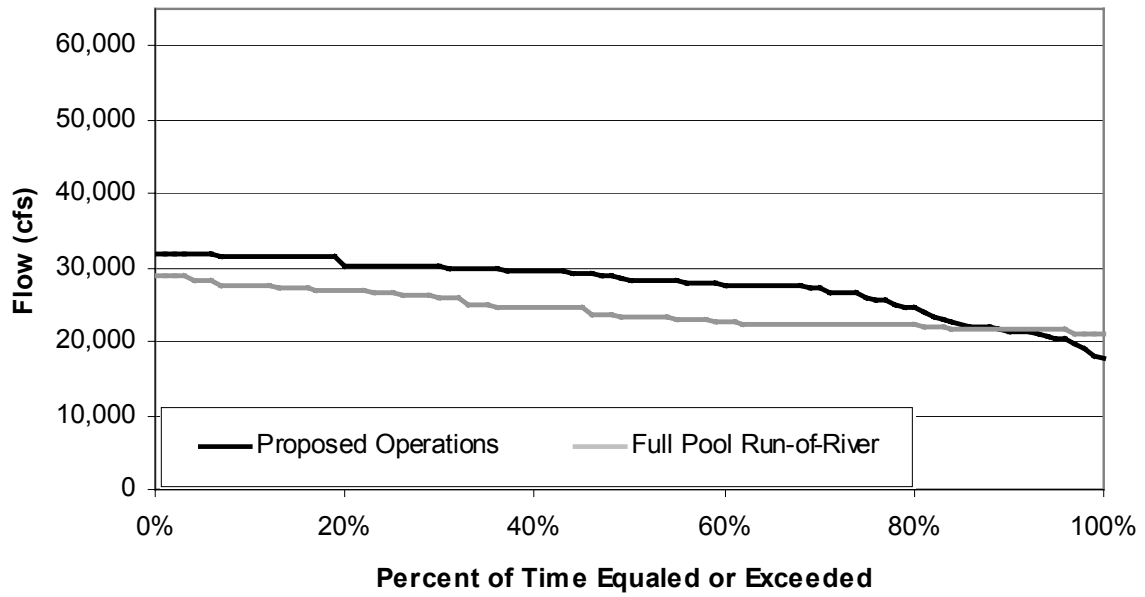


Hells Canyon Discharge - 15 minute data (December 1997)

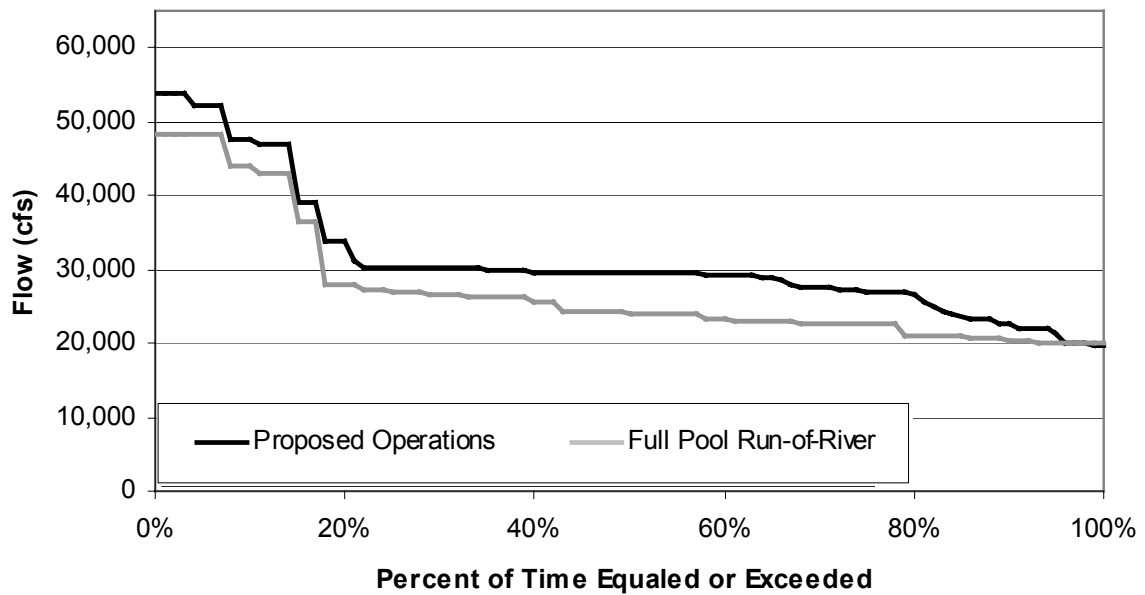


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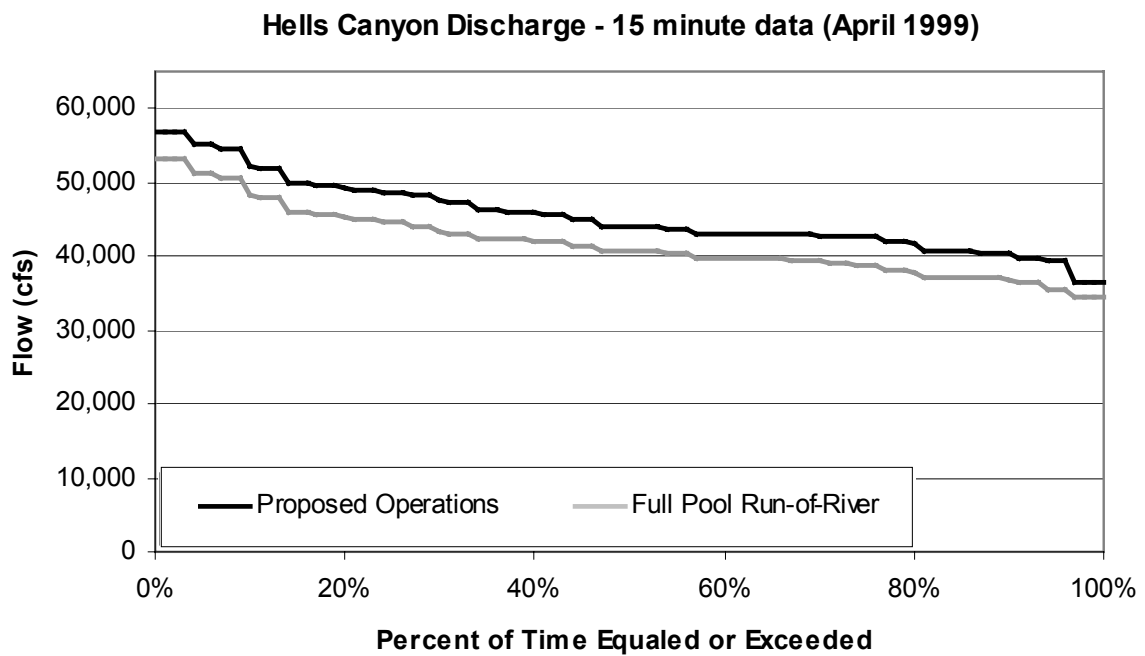
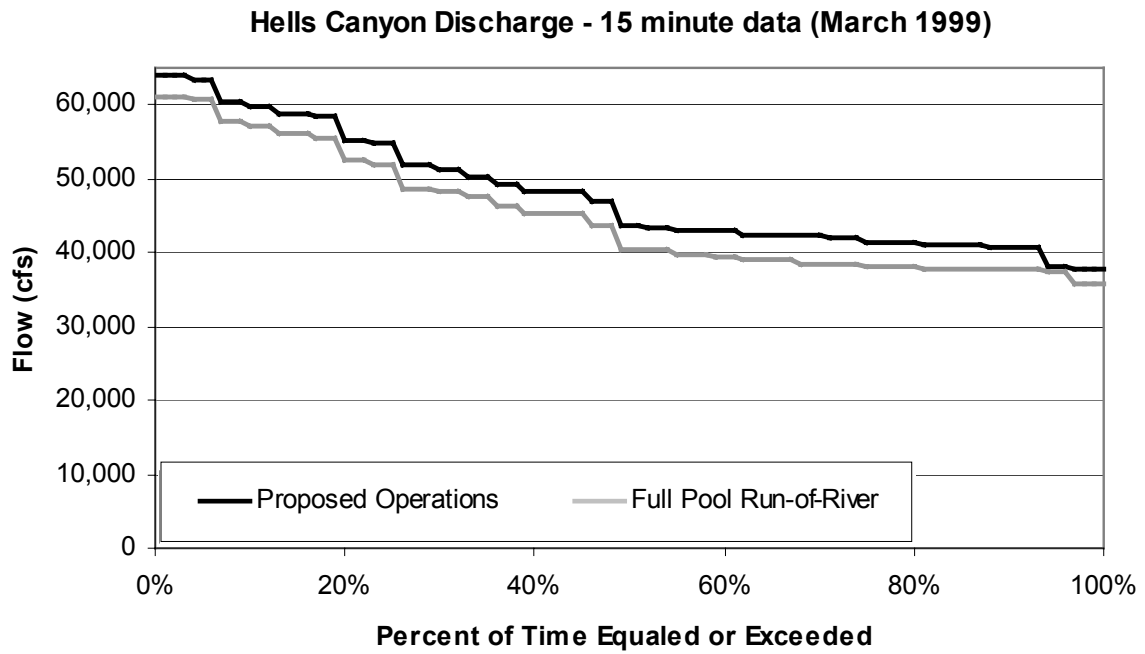
Hells Canyon Discharge - 15 minute data (January 1999)



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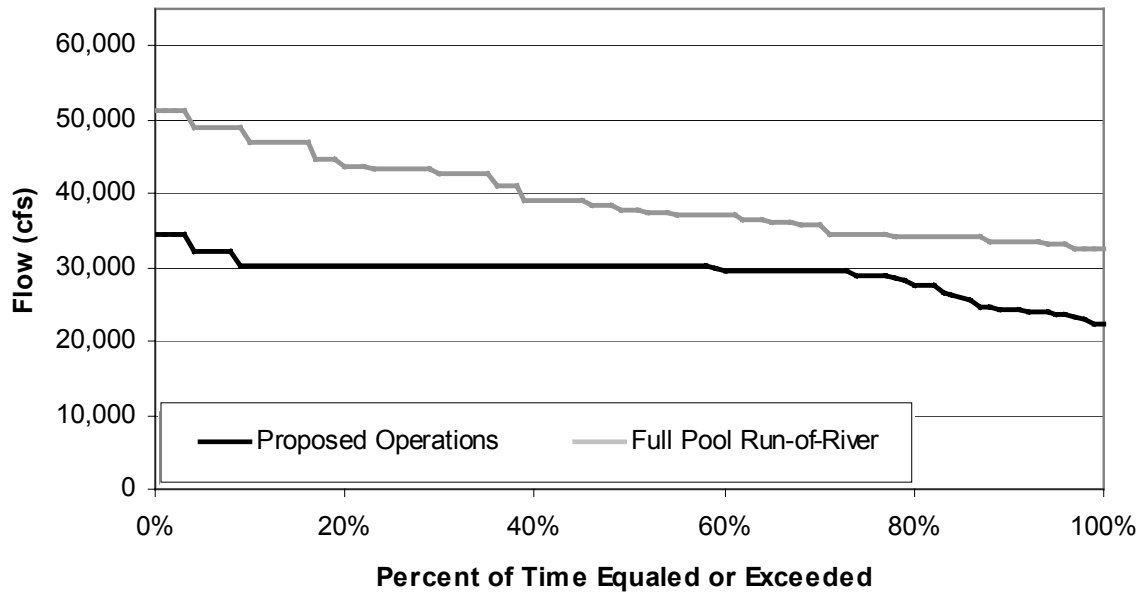


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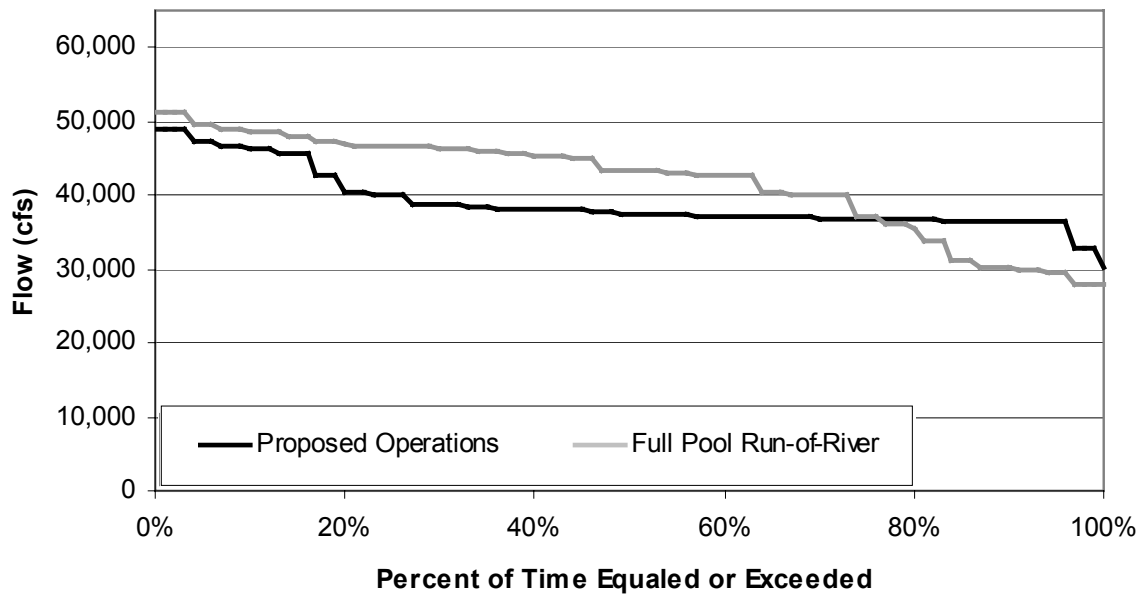


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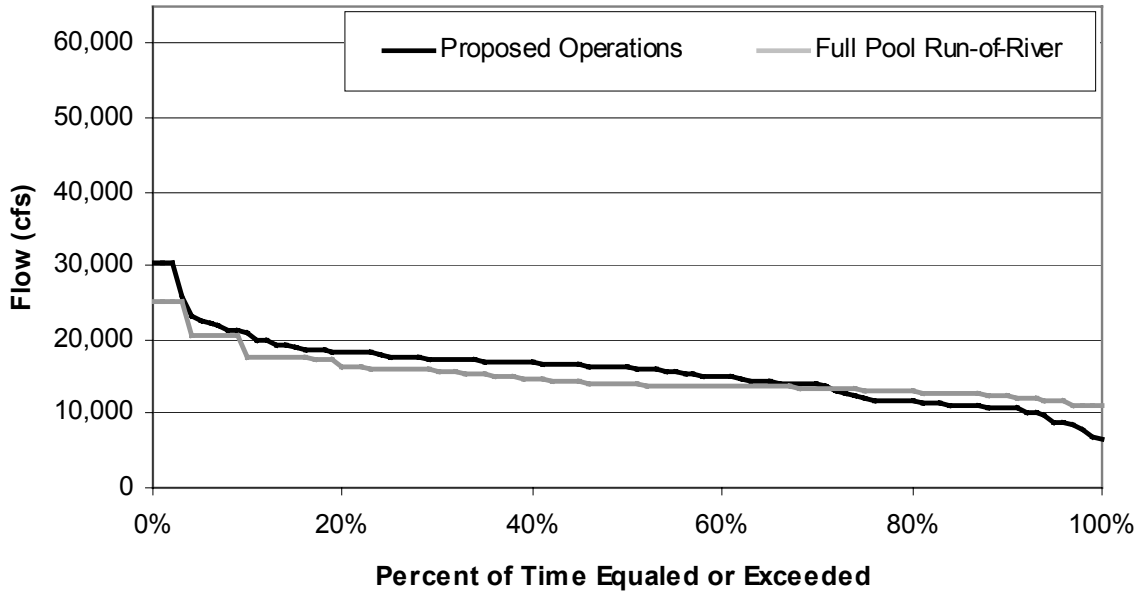


Hells Canyon Discharge - 15 minute data (June 1999)

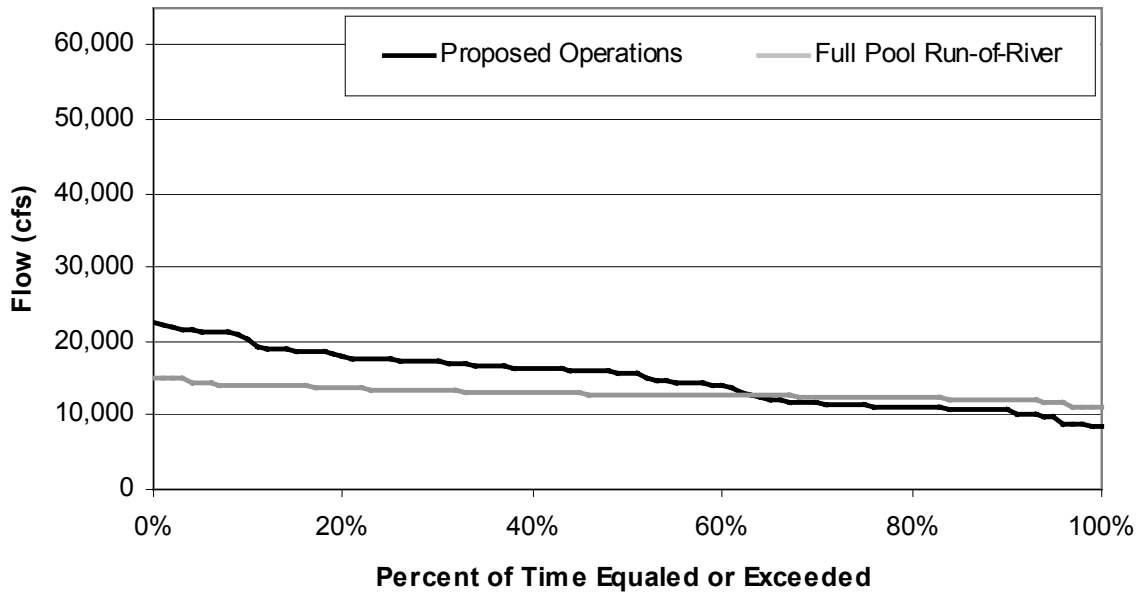


Appendix 1. (Cont.)

Hells Canyon Discharge - 15 minute data (July 1999)

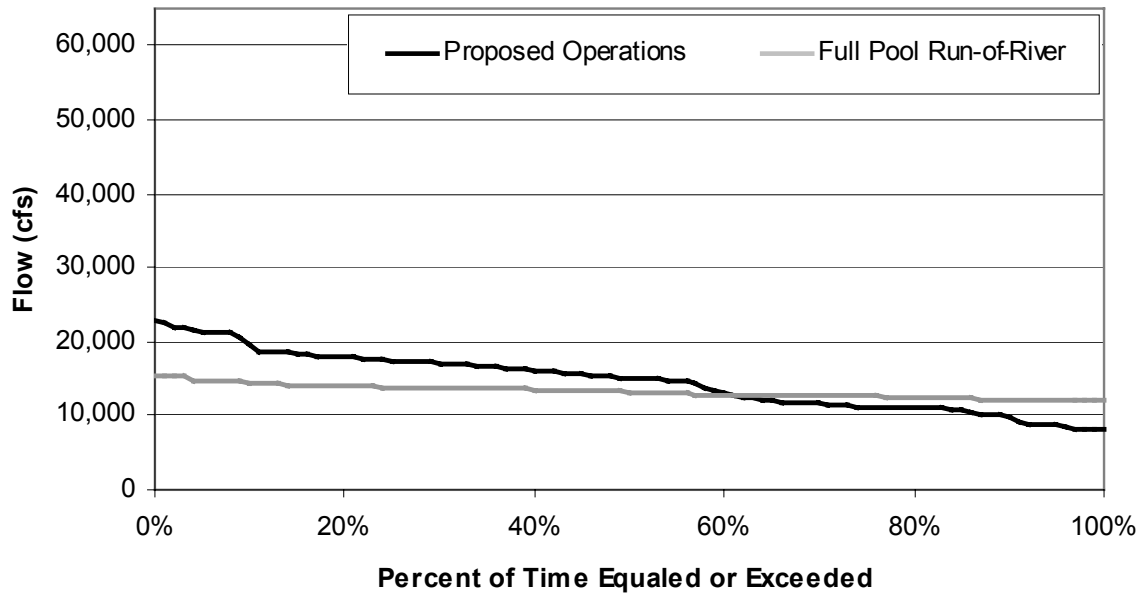


Hells Canyon Discharge - 15 minute data (August 1999)

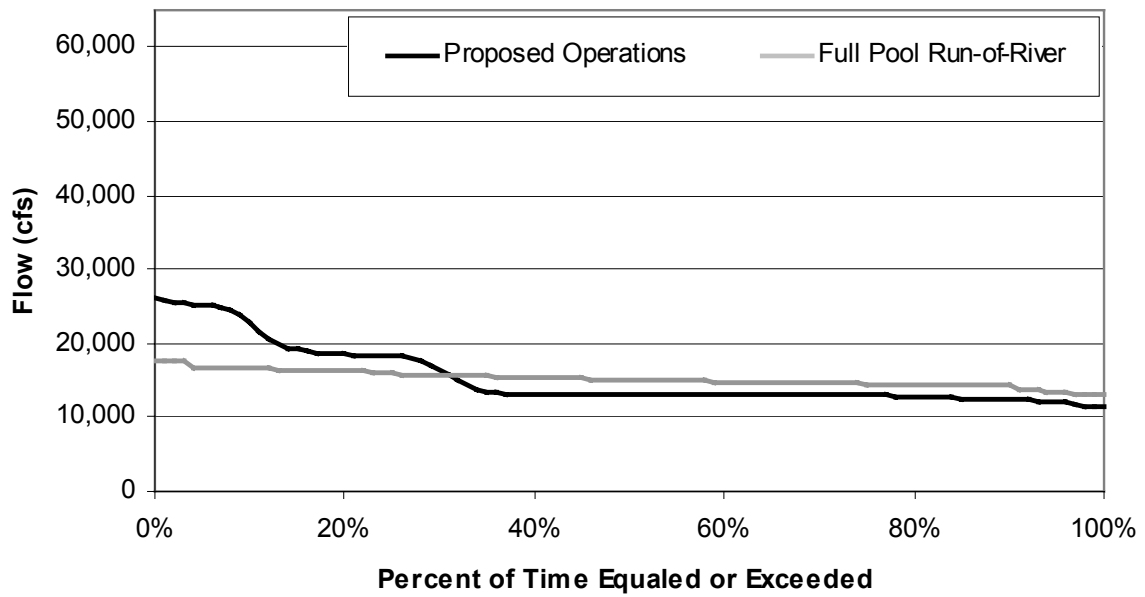


Appendix 1. (Cont.)

Hells Canyon Discharge - 15 minute data (September 1999)

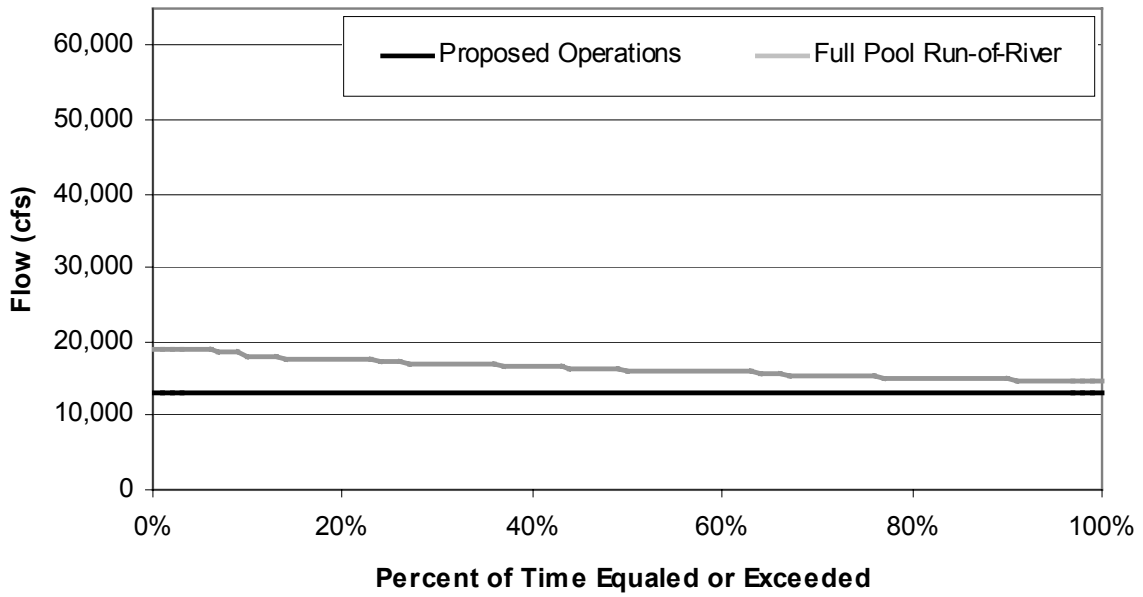


Hells Canyon Discharge - 15 minute data (October 1999)



Appendix 1. (Cont.)

Hells Canyon Discharge - 15 minute data (November 1999)



Hells Canyon Discharge - 15 minute data (December 1999)

