US Army Corps of Engineers®
Omaha District

Yellowtail Dam Reallocation Study

Draft

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Executive Summary

As part of the 1944 Flood Control Act, Congress authorized the design, construction, and operation of Yellowtail Dam. Yellowtail Dam sits on the border of Wyoming and Montana, and forms a reservoir along the Bighorn River. The dam is a concrete arch dam with a structural height of 525 ft, a crest length of 1,480 ft, a crest elevation of 3,660 ft msl, and a total reservoir capacity of 1,381,189 ac-ft. Yellowtail Dam has a drainage area of 19,650 square miles (BOR, 2009). During normal operations, the dam is managed by the U.S. Bureau of Reclamation. However, when the reservoir is operating within the exclusive flood control zone operation is performed by the U.S. Army Corps of Engineers.

Recently, it was proposed that storage currently within the exclusive flood control pool (below elevation 3645 ft msl) be reallocated and placed in the joint use pool. This would allow for an additional five feet of water, which could be used for conservation purposes in most years. The objective of this study was to evaluate the change in flood reduction benefits due to the reallocation of exclusive flood control storage to joint use storage for Yellowtail Dam.

The study was completed by using the model HEC-ResSim. This model was developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center, and is a computer simulation model that is capable of modeling complex reservoir systems. Several models were created to evaluate the impacts of the proposed reallocation of exclusive flood control storage to joint use storage. The generated models included: a period of record simulation, the inflow design flood, the project design flood, and the 1923 historic event. These models were calibrated to develop a baseline condition for each simulation. Next, the top of joint use pool was raised from elevation 3640 ft msl to 3645 ft msl and the models were re-run. Finally, results from the baseline and reallocated HEC-ResSim models could be analyzed and compared. The purpose of this report is to summarize these results, but not to provide a specific recommendation for or against the reallocation.

Several different analyses were completed to evaluate the period of record simulation. They included studying the reservoir elevation and outflow data and developing several statistical relationships (pool duration, flow duration, pool probability, and flow frequency). Lastly, flood damages were studied to determine the impact of the reallocation on downstream reaches. Results from the flood damage calculations found that areas downstream of the Bighorn River on the Yellowstone River were more sensitive to the change in outflows as a result of the reallocation. However, when studying the period of record, flood damages did not consistently increase. Some locations reported increases in flood damages, while others saw decreases.

The event based simulations were evaluated only by studying the reservoir elevation and outflow data. There were several issues that will need to be reviewed in relation to operations as a result of the reallocation. These items are listed here:

1. For the inflow design flood, the reallocated condition reaches a peak pool elevation that is only 1.1 ft from the top of Yellowtail Dam.
2. For the project design flood, the reservoir outflow is 1,150 cfs over the capacity of the Yellowtail Afterbay dam.
3. For the 1923 event, the reservoir outflow is 8,050 cfs over the capacity of the Yellowtail Afterbay dam.

Introduction

The objective of this study was to evaluate the change in flood reduction benefits due to the reallocation of exclusive flood control storage to joint use storage for Yellowtail Dam. Results from this analysis will be used by water managers from both the U.S. Bureau of Reclamation (known from here on as BOR) and the U.S. Army Corps of Engineers (known from here on as USACE) to determine if the reallocation of flood storage to joint use storage can be implemented into the operating plan for Yellowtail Dam. This study was completed by the Hydrology Section of the Omaha District USACE at the request of the staff of the Montana Area Office BOR.

Yellowtail Dam, authorized as part of the 1944 Flood Control Act, is located along the Bighorn River in Montana 45 miles southwest of Hardin, MT. The dam is a concrete arch dam with a structural height of 525 ft, a crest length of 1,480 ft, a crest elevation of 3,660 ft msl, and a total reservoir capacity of 1,381,189 ac-ft. Yellowtail Dam has a drainage area of 19,650 square miles (BOR, 2009). Average annual precipitation at Yellowtail Dam is approximately 17.9 inches. Much of this precipitation comes in the form of snow, and due to the mountainous terrain is very variable with some locations in the drainage area receiving less than 6.0 inches per year. Average annual maximum and minimum temperatures at Yellowtail Dam are 63.2 and 37.5 ^{o}F, respectively (WRCC, 2009). Summer months can provide temperatures above 90 ^{o}F, while the winter months have temperatures that can be below 0 ^{o}F.

Figure 1. Yellowtail Dam and the Bighorn River (photo: USBR).

Background

Construction on Yellowtail Dam began in May 1961 and was completed in December 1967. The project was authorized as a multi-purpose reservoir with the authorized purposes including irrigation, flood control, hydroelectric power, and recreation (BOR, 2009). BOR owns and operates Yellowtail Dam for all the authorized purposes except flood control. USACE is responsible for management of the dam when the reservoir pool elevation is in the exclusive flood control zone – although management of the dam is returned to BOR if the pool elevation gets above the exclusive flood control zone and into the surcharge zone.

Yellowtail Dam creates a reservoir with six distinct storage allocations. Those allocations include the surcharge zone, the exclusive flood control zone, the joint use zone, the active conservation zone, the inactive conservation zone, and dead storage. Figure 2 provides the storage volume and pool elevations for all six allocations.

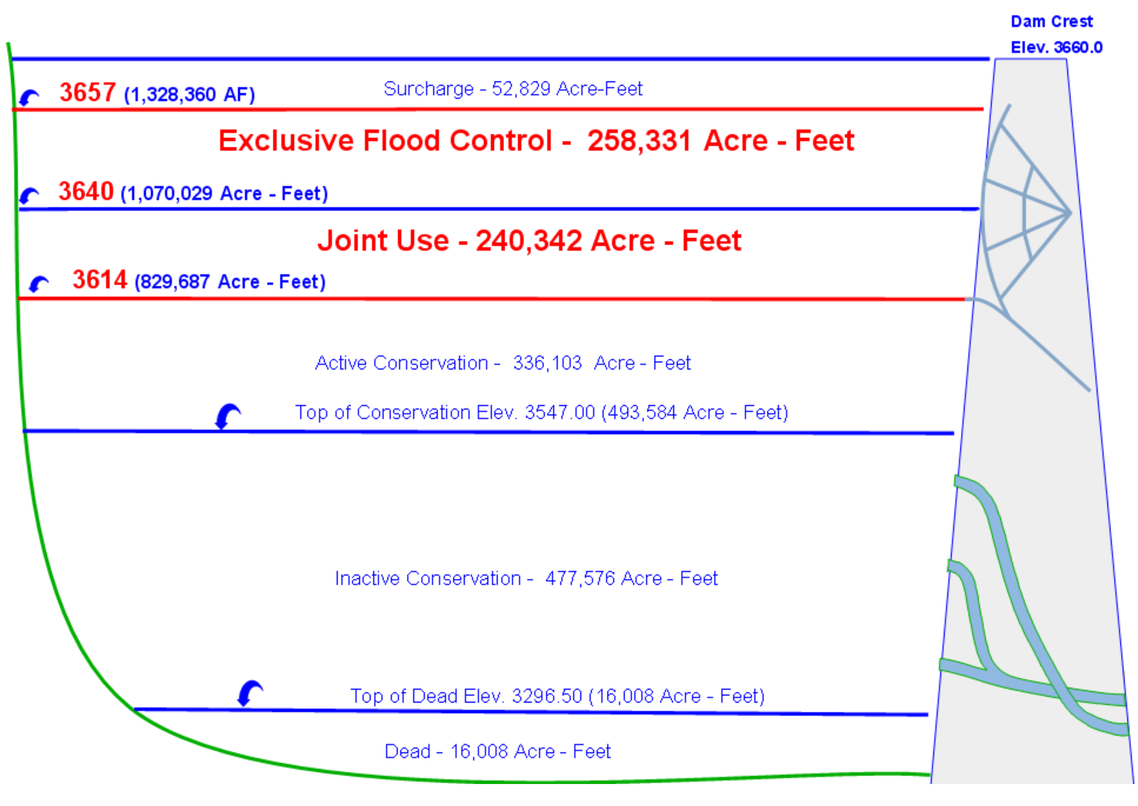

Figure 2. Yellowtail Dam current storage allocations. Image is courtesy of USBR.

It was said that the objective of this study was to evaluate the change in flood reduction benefits due to the reallocation of exclusive flood control storage to joint use storage for Yellowtail Dam. Upon further review this objective creates a few questions, which have answers provided.

1. How much exclusive flood control storage would be reallocated?
    a. Under the current reallocation proposal, the bottom of the exclusive flood control zone would be increased from elevation 3,640 ft msl to elevation 3,645 ft msl. This change would result in the volume of the exclusive flood control zone being decreased by approximately 67,485 ac-ft. Figure 3 shows the proposed allocation changes.
2. What is the motivation for changing the current storage allocations?
    a. By reducing the amount of storage in the exclusive flood control zone, the amount of water that can be stored in the dam for other authorized purposes (ex. environmental, recreation) is increased.
3. Are there any safety concerns with decreasing the amount of exclusive flood control storage?
    a. A detailed analysis has been completed and is presented in this report to look at this very question. This reallocation proposal can only be enacted if it does not jeopardize the success of other Yellowtail Dam project purposes and if water managers from BOR and USACE determine the dam can be successfully managed during flood events even with the decreased exclusive flood control storage.

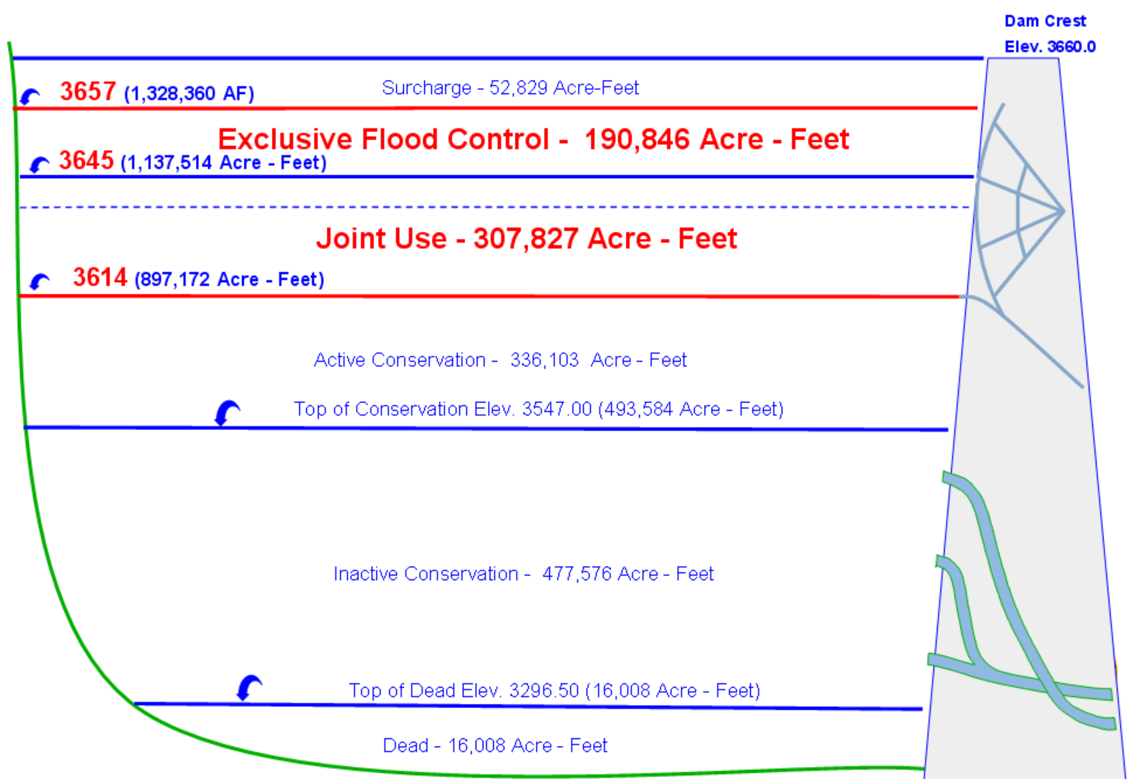

Figure 3. Yellowtail Dam proposed storage allocations. Dashed line indicates elev. 3640 ft msl – the current bottom of the exclusive flood control zone. Image is courtesy of USBR.

Methodology

To simulate the operation of Yellowtail Dam for both the existing and reallocated conditions, the model HEC-ResSim (USACE, 2007) was used. HEC-ResSim is a reservoir operations model developed by the USACE Hydrologic Engineering Center. The model incorporates user defined rules with other conditions such as inflow, pool elevation, downstream flows, etc to determine the optimum reservoir outflow. Several different HEC-ResSim models were created to model the period of record (modeled as 1967-2006), as well as design storms including the inflow design flood, the project design flood, and the 1923 flood event.

The first step to creating the HEC-ResSim models was to collect all of the input data required. This consisted of determining downstream observation points and calculating routing parameters. Furthermore, the physical characteristics of Yellowtail Dam needed to be input into the model. This included the elevation vs. storage curve, the elevation vs. area curve, flood control regulation curves, and outlet works capacities. Lastly, all of the actual data needed to be placed into the model. Some of the data, such as Yellowtail Dam inflow, is used directly by the model while other data, such as Yellowtail Dam pool elevation, is used for comparison purposes during the calibration process.

Once all of the input data were collected, the calibration process could begin. Each different HEC-ResSim model was calibrated separately. This was accomplished by defining rules that HEC-ResSim would use to operate Yellowtail Dam. There are several different ways these rules are defined. They can be based on pool elevation, inflow, downstream flow conditions, or a host of other options. The goal in this process was to create models that replicated the actual historical operations of the dam. Indicators of well-calibrated models included comparing the actual vs. modeled pool elevation. Furthermore, in the case of the period of record simulations, comparing actual to modeled pool duration curves were used as a calibration tool. A pool duration curve provides the percentage of time a reservoir is at a particular elevation during the simulation period.

Upon completion of the calibration phase, the baseline and reallocated conditions were established for all the HEC-ResSim models. The baseline simulations were obtained by executing the calibrated HEC-ResSim models and taking the computed results from the models. The reallocated simulations were obtained by changing the bottom of the exclusive flood control zone from 3640 to 3645 ft msl. Leaving all other model data the same, HEC-ResSim was executed and the computed results were compared to those of the baseline condition. It is important to note the reallocated results were compared to the HEC-ResSim baseline condition – not the actual operation. Comparing the reallocated model results to the calibrated baseline condition provided an evenhanded indicator of the impacts the reallocation has on operations of the dam.

Results from the baseline and reallocated condition of each model (period of record, inflow design flood, project design flood, and 1923 flood) were analyzed and compared to each other. For all of the models, the Yellowtail Dam pool elevations and outflows were compared. The goal was to determine if the pool elevations and outflows from the reallocated simulations remained at acceptable levels. Further analysis was performed for the period of record simulations. This included developing pool probability, pool duration, flow duration, and flow frequency relationships. The pool and flow duration relationships were developed for both annual and seasonal periods. Flow frequency relationships were developed on an annual basis using the guidelines set out by the Water Resources Council Bulletin 17B (USGS, 1982). Downstream annual flood damages were also computed and compared. Downstream computations (flow frequency and flood damages) were completed along the Bighorn River at Yellowtail Dam, MT; St. Xavier, MT; and Bighorn, MT. Flood damages were also computed at Hardin, MT which is located between St. Xavier and Bighorn. All of the calculations were conducted along the Yellowstone River at Miles City, MT and Sidney, MT. Figure 4 provides a schematic showing the computation points used within HEC-ResSim.

Figure 4. Schematic showing Yellowtail Dam and other computation points within the HEC-ResSim model. Inflows were placed into the model at the Yellowtail Inflow and Billings computation points. Dam outflow was computed at the Yellowtail Outflow computation point and downstream flows were computed at all other locations. Figure is not to scale.

The preceding paragraph contains some terms that some readers may not be familiar with, so definitions for those terms are provided. Pool probability relationships define the annual probability of the reservoir pool reaching or exceeding a certain elevation. Typically, this is expressed as a “percent chance of exceedance”. For example, a pool elevation with an annual exceedance probability of 0.01 would have a 1.0% chance of being equaled or exceeded in any year. The pool probability plots were calculated using the Weibull plotting position (equation 1). This plotting position assumes no occurrence in the data series has a probability of 100%. This is accomplished by assuming a return period one year longer than the period of record for the largest value. This is a good assumption since there is no way of knowing if a dataset truly possesses the maximum value possible (Chow et al., 1988).

$$P(X \geq x_m) = \frac{m}{n+1} \qquad (1)$$

where:

$P(X \geq x_m)$ = Weibull plotting position for value
m = rank of value (ranked high to low)
n = total number of values

Flow duration curves define the percent of time that a given flow is equaled or exceeded during the simulation period. This definition is comparable to the definition of a pool duration curve. In both cases, it is important to note that these curves are not necessarily defined on an annual basis. A duration curve developed over an annual period uses all of the data through the entire simulation period. In contrast, a duration curve developed for the summer months would use the summer month’s data through the simulation period.

Flow frequency relationships were developed using a log-Pearson type III distribution. This distribution was found to best describe the relationship between annual peak flows and exceedance probability for streams and rivers. It is typically not recommended for use on heavily regulated streams, but was used in this case because it was still able to provide a relative difference in peak flow exceedance probabilities for both the baseline and reallocated scenarios. Guidelines for this method can be found in Bulletin 17B (USGS, 1982). In this case, the software package HEC-SSP (USACE 2008), which is a statistical software package developed by the USACE Hydrologic Engineering Center, was used for the analysis.

For the baseline and reallocated conditions, annual flood damages were compared at downstream locations described earlier by taking annual peak flows and determining the flood damages associated with those flows. The analysis is based on flood damage curves from the Yellowtail Report of Reservoir Regulations for Flood Control manual (USACE, 1974), and the curves were adjusted to October 2007 dollars using the builders cost index (McGraw Hill Construction, 2009) and the normalized crop price index (Kitch, 2007). Figures 5 through 9 provide the flood damage curves used in the analysis.

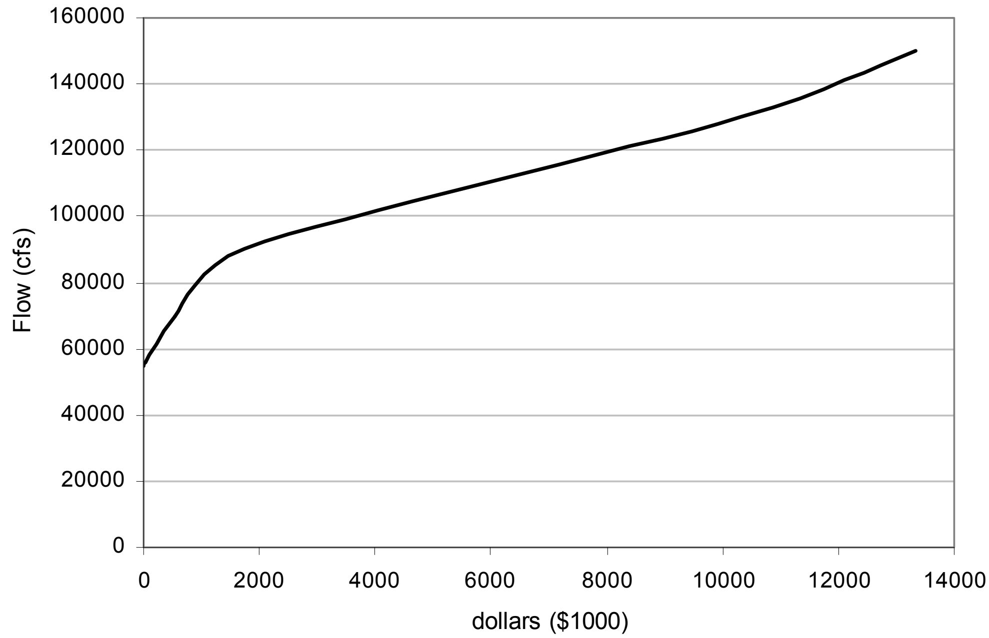

Figure 5. Discharge vs. damage curve for Reach 1 (developed by Omaha District USACE). Reach 1 represents the Yellowstone River from Bighorn to Miles City and is evaluated by obtaining the annual peak flows at Miles City.

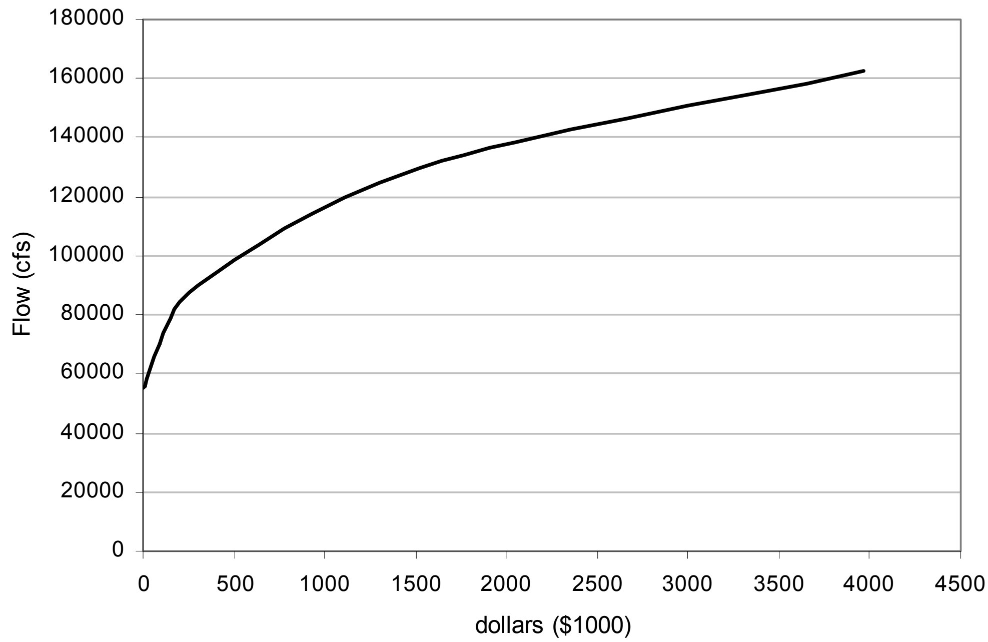

Figure 6. Discharge vs. damage curve for Reach 2 (developed by Omaha District USACE). Reach 2 represents the Yellowstone River from Miles City to Glendive, MT and is evaluated by obtaining the annual peak flows at Miles City.

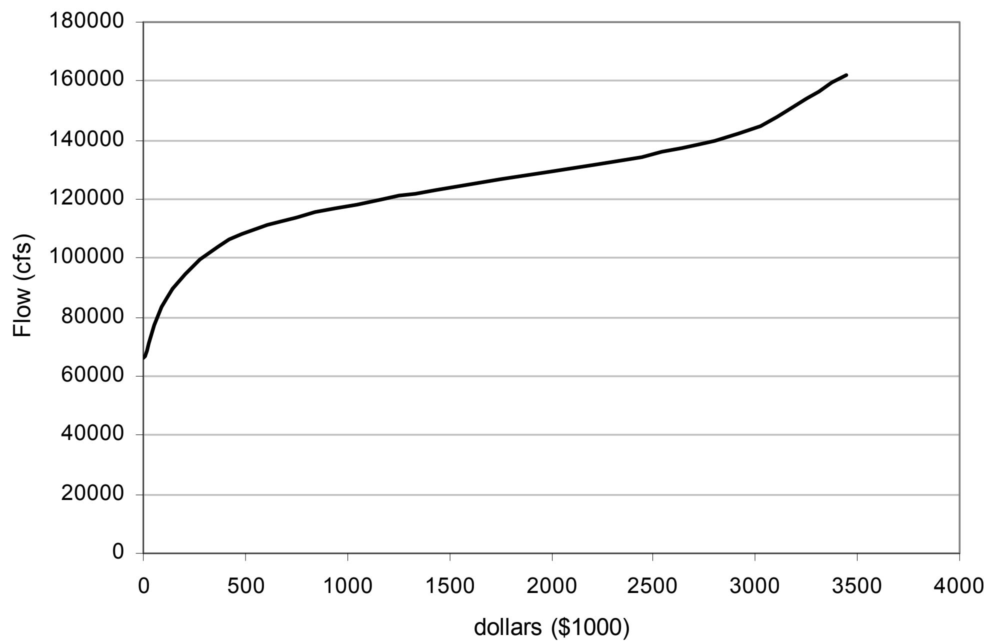

Figure 7. Discharge vs. damage curve for Reach 3 (developed by Omaha District USACE). Reach 3 represents the Yellowstone River from Glendive to Sidney and is evaluated by obtaining the annual peak flows at Sidney.

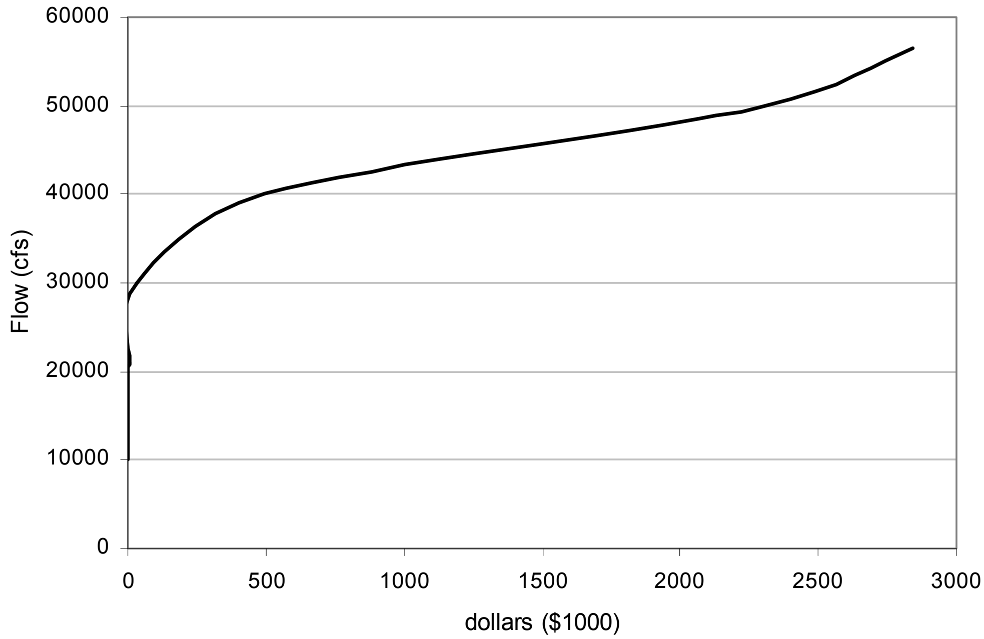

Figure 8. Discharge vs. damage curve for Reach 5 (developed by Omaha District USACE). Reach 5 represents the Bighorn River from Yellowtail Dam to Hardin and is evaluated by obtaining the annual peak flows at Hardin.

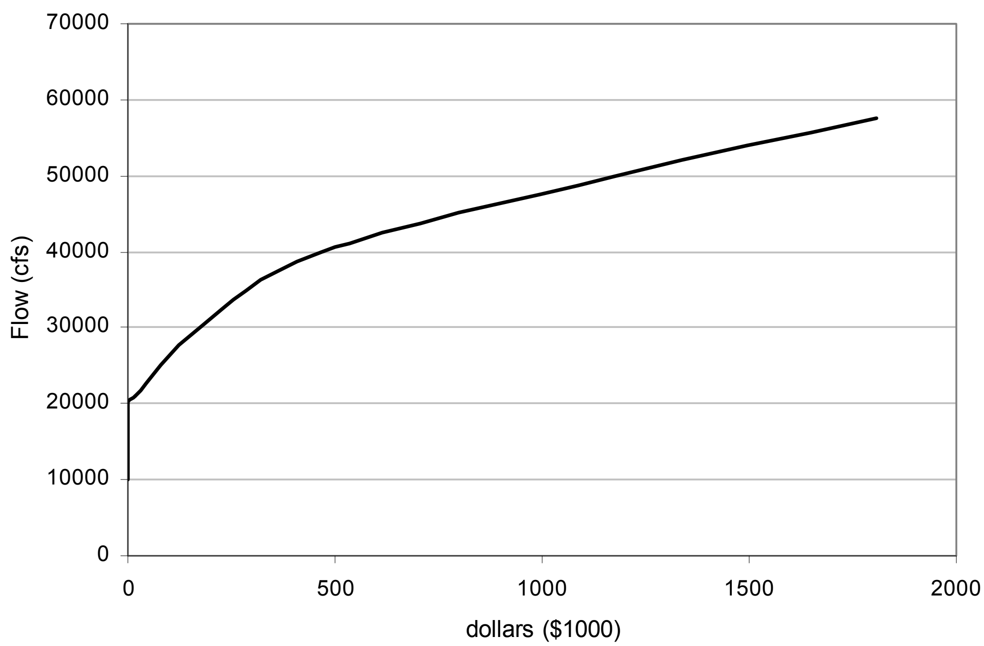

Figure 9. Discharge vs. damage curve for Reach 6 (developed by Omaha District USACE). Reach 6 represents the Bighorn River from Hardin to Bighorn and is evaluated by obtaining the annual peak flows at Hardin.

HEC-ResSim Model Information

This section provides input information for the HEC-ResSim models. Figures 10, 11, and 12 provide the elevation/storage relationship, the elevation/area relationship, and the family of flood control rule curves placed in the HEC-ResSim model. These data were found in the Yellowtail Report of Reservoir Regulations for Flood Control manual (USACE, 1974), the Yellowtail Standard Operating Procedure manual (USBR, 2000), and the BOR Hydromet website (USBR, 2009). Table 1 lists the monthly evaporation data used in the model (Lidstone and Associates, 2003). Tables 2, 3, 4, and 5 provide the operation rules used in the period of record, inflow design flood, project design flood, and 1923 flood HEC-ResSim models, respectively. Additionally, table 6 shows the guide curve elevations used in both the baseline and reallocated HEC-ResSim period of record models. The guide curve is the elevation at a specific time of year the reservoir is managed to be at – assuming “normal” conditions. For the event based models, the guide curve was set to a constant elevation equal to the top of the joint use pool. This is the elevation where all exclusive flood control storage would be evacuated. HEC-ResSim uses the user defined rules, the guide curve, and other criteria (downstream conditions, etc.) when modeling a reservoir system. The operating criteria used in the model for Yellowtail Dam were determined by using the Yellowtail Standard Operating Procedure manual (USBR, 2000), consulting with water managers for the USBR and USACE, and through calibration.

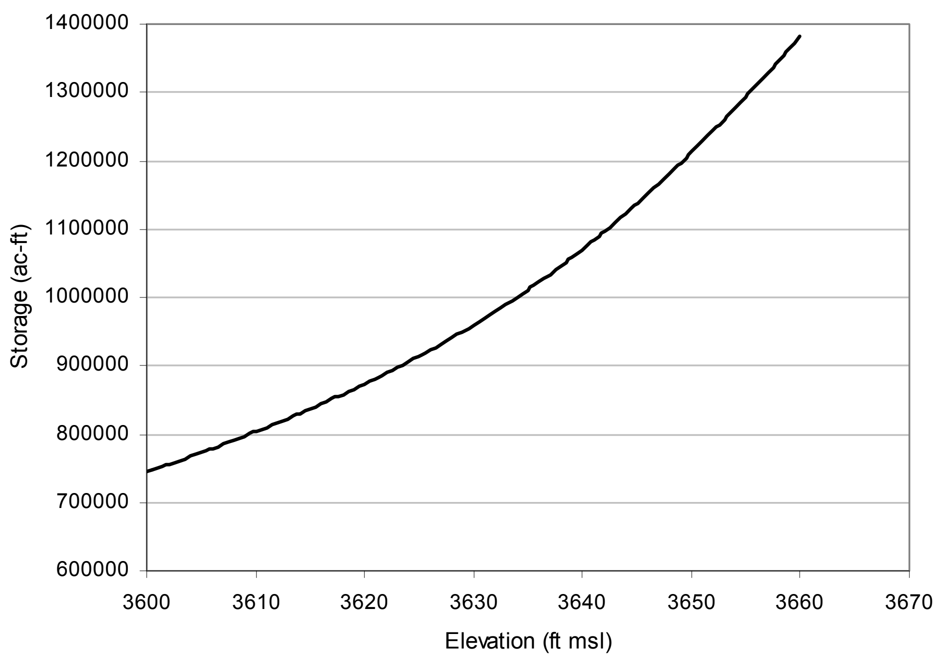

Figure 10. Storage vs. elevation curve for Yellowtail Dam. This curve was used in the HEC-ResSim models, and is from the 1982 re-survey of the reservoir (USBR, 2000).

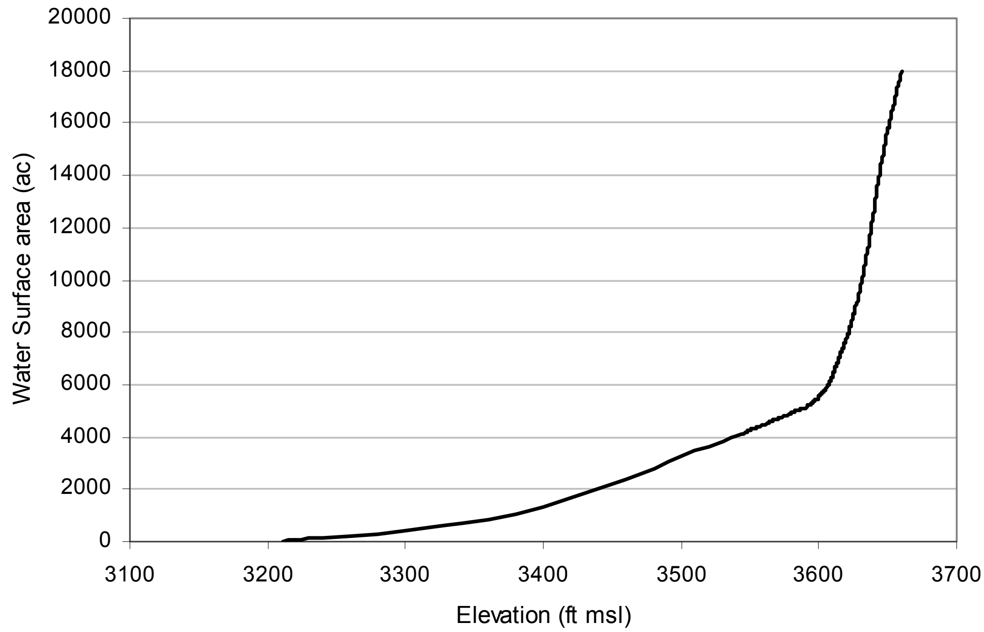

Figure 11. Water surface area vs. elevation curve for Yellowtail Dam. This curve was used in the HEC-ResSim models, and is from the 1982 re-survey of the reservoir (USBR, 2000).

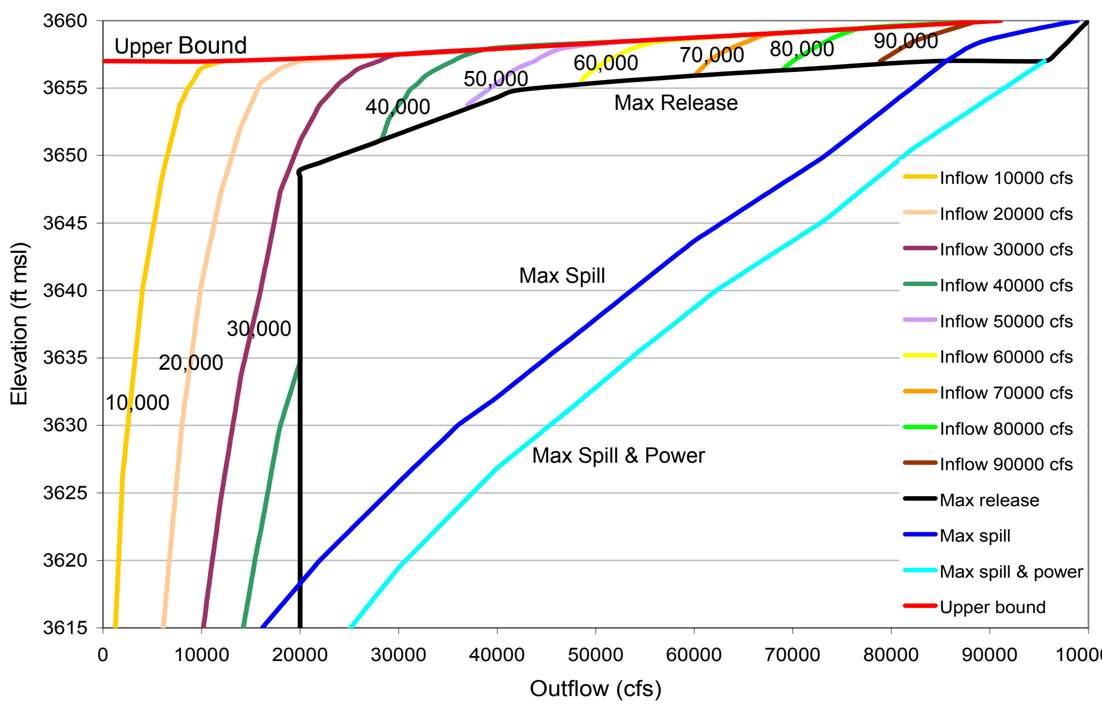

Figure 12. Yellowtail flood control rule curves used in the HEC-ResSim models (USACE, 1974).

Table 1. Monthly lake evaporation data used in the HEC-ResSim models (Lidstone and Associates, 2003).

Month	*Evaporation (in)*
January	1.05
February	0.63
March	2.10
April	3.15
May	4.62
June	6.30
July	7.98
August	7.14
September	4.20
October	2.52
November	1.26
December	1.05

Table 2. HEC-ResSim operation rules for the Yellowtail Dam period of record simulations. These rules remained the same for both the baseline and reallocated simulations. The difference in the simulations was the top of joint use pool was changed from 3640 ft msl to 3645 ft msl. These rules should not be compared to the Yellowtail Operations Manual as they could be different. Rules from the manual were tailored specifically for this simulation to provide the best calibration. The rules are listed in their order of priority – except for the downstream control limits which are prioritized as a group as opposed to by individual rule. Any rule providing a maximum limit can be exceeded if the model deems it necessary. The rules are used in conjunction with other criteria to determine the outflow.

Pool Zone	*Rule Name*	*Description*
Surcharge		
	Max Rising	Maximum elevation/outflow curve displayed in figure 12 as Max Release curve. Rule only used when reservoir elevation is rising.
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
Exclusive Flood Control		
	Max Rising	Maximum elevation/outflow curve displayed in figure 12 as Max Release curve. Rule only used when reservoir elevation is rising.
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	1,350 cfs Minimum	Specified minimum reservoir release of 1,350 cfs.
	If Statement (St Xavier)	If reservoir elevation is < 3,645 ft msl downstream limit of 10,000 cfs is used. If elevation is > 3,645 ft msl 14,000 cfs is used.

	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
	DS Limit Bighorn	Specified downstream flow limit of 25,000 cfs at Bighorn, MT.
	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
Joint Use		
	Max Rising	Maximum elevation/outflow curve displayed in figure 12 as Max Release curve. Rule only used when reservoir elevation is rising.
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	1,350 cfs Minimum	Specified minimum reservoir release of 1,350 cfs.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
	DS Limit Bighorn	Specified downstream flow limit of 25,000 cfs at Bighorn, MT.
	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
	If Statement (St Xavier)	If reservoir elevation is < 3,645 ft msl downstream limit of 10,000 cfs is used. If elevation is > 3,645 ft msl 14,000 cfs is used.
Active Conservation		
	1,350 cfs Minimum	Specified minimum reservoir release of 1,350 cfs.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
	DS Limit Bighorn	Specified downstream flow limit of 25,000 cfs at Bighorn, MT.
	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
Inactive Conservation		
	None	n/a

Table 3. HEC-ResSim operation rules for the Yellowtail Dam inflow design flood simulations. These rules remained the same for both the baseline and reallocated simulations. The difference in the simulations was the top of joint use pool was changed from 3640 ft msl to 3645 ft msl. These rules should not be compared to the Yellowtail Operations Manual as they could be different. Rules from the manual were tailored specifically for this simulation to provide the best calibration. The rules are listed in their order of priority – except for the downstream control limits which are prioritized as a group as opposed to by individual rule. Any rule providing a maximum limit can be exceeded if the model deems it necessary. The rules are used in conjunction with other criteria to determine the outflow.

Pool Zone	*Rule Name*	*Description*
Surcharge		
	Max Rising	Maximum elevation/outflow curve displayed in figure 12 as Max Release curve. Rule only used when reservoir elevation is rising.
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
Exclusive Flood Control		
	Max Rising	Maximum elevation/outflow curve displayed in figure 12 as Max Release curve. Rule only used when reservoir elevation is rising.
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	1,500 cfs Minimum	Specified minimum reservoir release of 1,500 cfs.
	If Statement (St Xavier)	If reservoir elevation is < 3,645 ft msl downstream limit of 10,000 cfs is used. If elevation is > 3,645 ft msl 14,000 cfs is used.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
	DS Limit Bighorn	Specified downstream flow limit of 25,000 cfs at Bighorn, MT.
	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
Joint Use		
	Max Rising	Maximum elevation/outflow curve displayed in figure 12 as Max Release curve. Rule only used when reservoir elevation is rising.

	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	1,500 cfs Minimum	Specified minimum reservoir release of 1,500 cfs.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
	DS Limit Bighorn	Specified downstream flow limit of 25,000 cfs at Bighorn, MT.
	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
	If Statement (St Xavier)	If reservoir elevation is < 3,645 ft msl downstream limit of 10,000 cfs is used. If elevation is > 3,645 ft msl 14,000 cfs is used.
Active Conservation		
	1,500 cfs Minimum	Specified minimum reservoir release of 1,500 cfs.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
	DS Limit Bighorn	Specified downstream flow limit of 25,000 cfs at Bighorn, MT.
	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
Inactive Conservation		
	None	n/a

Table 4. HEC-ResSim operation rules for the Yellowtail Dam project design flood simulations. These rules remained the same for both the baseline and reallocated simulations. The difference in the simulations was the top of joint use pool was changed from 3640 ft msl to 3645 ft msl. These rules should not be compared to the Yellowtail Operations Manual as they could be different. Rules from the manual were tailored specifically for this simulation to provide the best calibration. The rules are listed in their order of priority – except for the downstream control limits which are prioritized as a group as opposed to by individual rule. Any rule providing a maximum limit can be exceeded if the model deems it necessary. The rules are used in conjunction with other criteria to determine the outflow.

Pool Zone	*Rule Name*	*Description*
Surcharge		
	Max Rising	Maximum elevation/outflow curve displayed in figure 12 as Max Release curve. Rule only used when reservoir elevation is rising.
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
Exclusive Flood Control		
	Max Rising	Maximum elevation/outflow curve displayed in figure 12 as Max Release curve. Rule only used when reservoir elevation is rising.
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	10,000 cfs Minimum	Specified minimum reservoir release of 10,000 cfs.
	If Statement (St Xavier)	If reservoir elevation is < 3,645 ft msl downstream limit of 10,000 cfs is used. If elevation is > 3,645 ft msl 14,000 cfs is used.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
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	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
Joint Use		

	Max Rising	Maximum elevation/outflow curve displayed in figure 12 as Max Release curve. Rule only used when reservoir elevation is rising.
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	10,000 cfs Minimum	Specified minimum reservoir release of 10,000 cfs.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
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	10,000 cfs Minimum	Specified minimum reservoir release of 10,000 cfs.
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	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 1.0 ft per 24 hrs.
Inactive Conservation		
	None	n/a

Table 5. HEC-ResSim operation rules for the Yellowtail Dam 1923 flood simulations. These rules remained the same for both the baseline and reallocated simulations. The difference in the simulations was the top of joint use pool was changed from 3640 ft msl to 3645 ft msl. These rules should not be compared to the Yellowtail Operations Manual as they could be different. Rules from the manual were tailored specifically for this simulation to provide the best calibration. The rules are listed in their order of priority – except for the downstream control limits which are prioritized as a group as opposed to by individual rule. Any rule providing a maximum limit can be exceeded if the model deems it necessary. The rules are used in conjunction with other criteria to determine the outflow.

Pool Zone	*Rule Name*	*Description*
Surcharge		
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	Rate of Drawdown	Specified maximum reservoir drawdown of 5.0 ft per 24 hrs.
Exclusive Flood Control		
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	1,350 cfs Minimum	Specified minimum reservoir release of 1,350 cfs.
	If Statement (St Xavier)	If reservoir elevation is < 3,645 ft msl downstream limit of 10,000 cfs is used. If elevation is > 3,645 ft msl 14,000 cfs is used.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
	DS Limit Bighorn	Specified downstream flow limit of 25,000 cfs at Bighorn, MT.
	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 5.0 ft per 24 hrs.
Joint Use		
	Induced Surcharge	Family of release curves based on inflow shown in figure 12.
	Release Function	Specified maximum reservoir release of 20,000 cfs. This release can be exceeded during induced surcharge operation.
	1,350 cfs Minimum	Specified minimum reservoir release of 1,350 cfs.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.

	DS Limit Bighorn	Specified downstream flow limit of 25,000 cfs at Bighorn, MT.
	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 5.0 ft per 24 hrs.
Active Conservation		
	1,350 cfs Minimum	Specified minimum reservoir release of 1,350 cfs.
	DS Limit St. Xavier	Specified downstream flow limit of 14,000 cfs at St. Xavier, MT.
	DS Limit Bighorn	Specified downstream flow limit of 25,000 cfs at Bighorn, MT.
	DS Limit Miles City	Specified downstream flow limit of 65,000 cfs at Miles City, MT.
	DS Limit Sidney	Specified downstream flow limit of 100,000 cfs at Sidney, MT.
	Rate of Drawdown	Specified maximum reservoir drawdown of 5.0 ft per 24 hrs.
Inactive Conservation		
	None	n/a

Table 6. Guide curve elevations used in the HEC-ResSim period of record simulations.

Date	*Elevation (ft msl)*	
	Baseline	Reallocated
01 Jan	3,624	3,624
31 Mar	3,600	3,600
01 Jul	3,640	3,645
15 Oct	3,635	3,635
30 Nov	3,630	3,630

Local flows and routing conditions for downstream reaches were input into the HEC-ResSim models. Local flows were calculated over the period of record by taking the gage records at the locations described earlier (see figure 4) and subtracting the downstream location from the upstream location. This provided information for each specific reach on what the incremental, or local, flow was. In regards to routing, the coefficient routing method was used. The Hydrologic Engineering Center (2007) has provided the following definition for the coefficient routing method. "Each coefficient equates to the fraction of the flow entering the reach that will reach the downstream end at the end of each time step in the table. The value in the table must sum up to 1.0." Table 7 summarizes the routing coefficients used for all reaches in the HEC-ResSim models.

Table 7. Routing coefficients used in all of the HEC-ResSim models for all reaches.

Time Step	*Coefficient*
1	0.00
2	0.50
3	0.50
4	0.00

HEC-ResSim Results

Period of Record

The period of record simulation was started in 1967, which allowed it to capture the large runoff event of that year. This start date means the simulation also includes 1968. This was a year where the dam wasn't under normal operations due to repair work as a result of the large amount of runoff from the previous year. However, it was extremely important to have 1967 as a part of the simulations, and the impact of the 1968 year on the statistics and other results was minimal. The simulation ended in 2006 because when the HEC-ResSim modeling effort was initialized reliable input data was only available through that time.

The period of record modeled provides a good spectrum of data. It contains periods of varying runoff conditions with the high events being in 1967 and 1997 and the low event being the drought from 2001-2004. While it is fortunate the period of record was able to capture these events, it should be noted these events most likely do not represent extremes on either end of the flood/drought continuum.

The results from the HEC-ResSim model were used to perform several different analyses during calibration as well as to study the impacts of the reallocation. The analyses included a flow frequency analysis, pool probability analysis, flow duration analysis, pool duration analysis, downstream flood damage calculations, examination of the annual maximum/minimum pool elevations as well as the timing of these extremes, and a comparison of outflow data from the dam.

Figures 13 through 22 provide a comparison of the actual and modeled Yellowtail Dam reservoir elevation and outflow information. An inspection of the data shows HEC-ResSim's ability to model the period of record. While differences do exist from year to year, most of these differences can be attributed to the guide curve elevations provided in the model (table 6). These elevations were selected based on the reservoir operating criteria (USBR, 2000) and calibration, and weren't changed from year to year within HEC-ResSim. Consequently, the model provides results that are not perfect in any given year but that do reflect the nature of how Yellowtail Dam has been operated over the period of record. One of the most noticeable issues is the draft elevation. This issue was dealt with in the simulation provided in Appendix A.

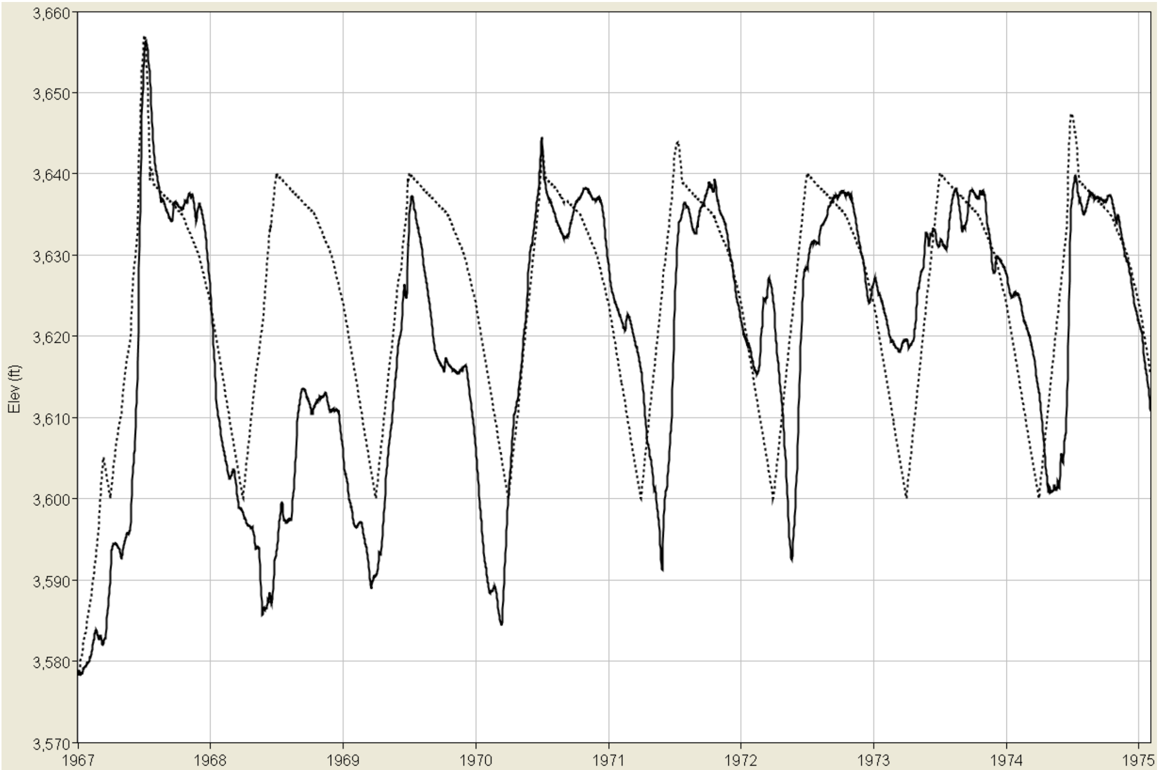

Figure 13. Actual and HEC-ResSim Yellowtail Dam elevation data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1967-1975.

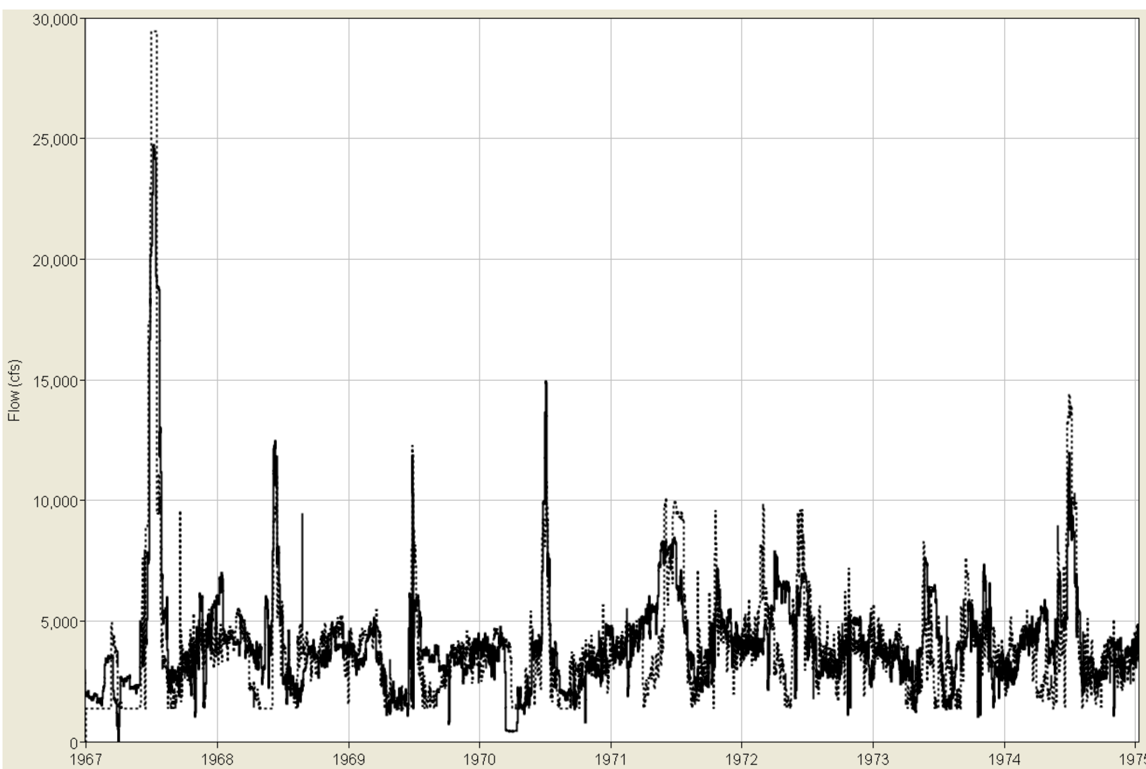

Figure 14. Actual and HEC-ResSim Yellowtail Dam outflow data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1967-1975.

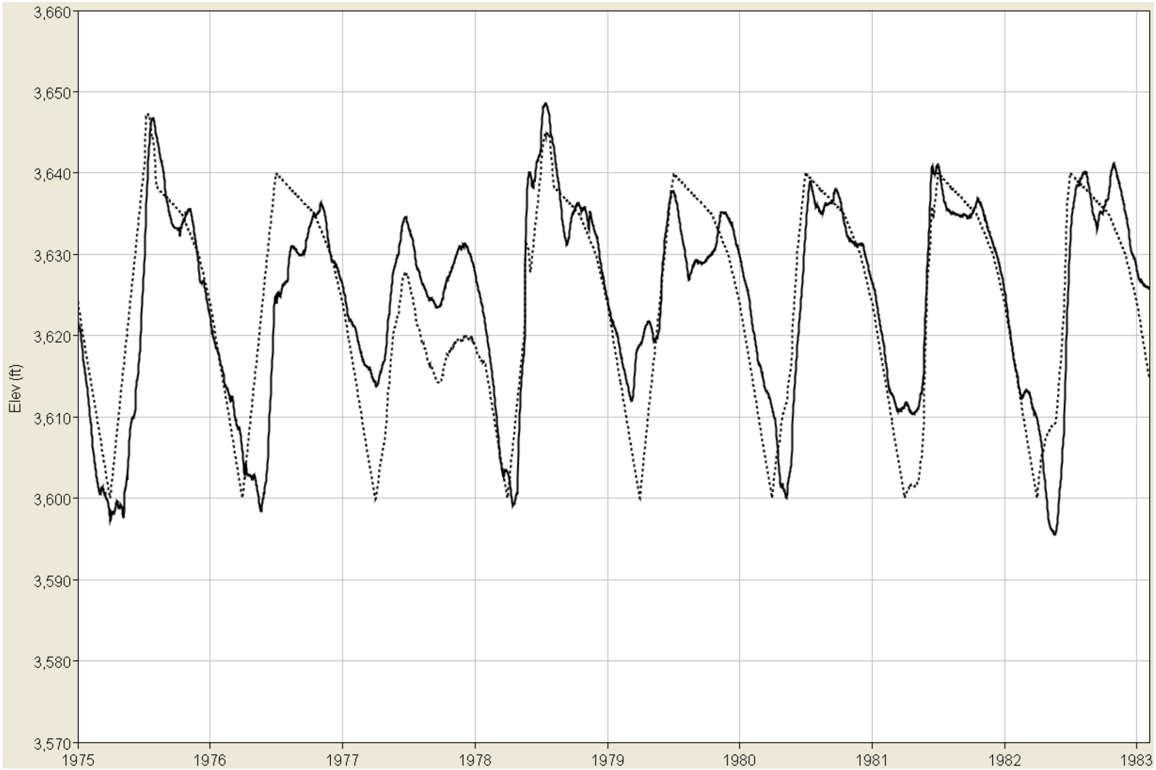

Figure 15. Actual and HEC-ResSim Yellowtail Dam elevation data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1975-1983.

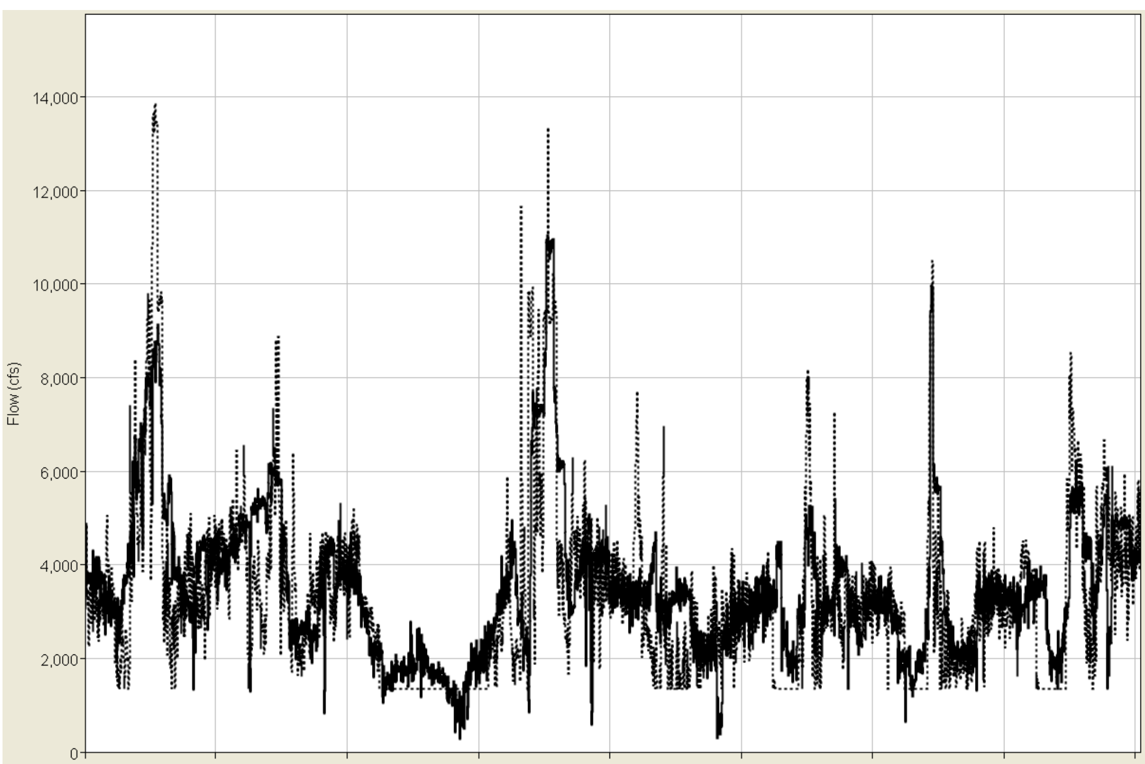

Figure 16. Actual and HEC-ResSim Yellowtail Dam outflow data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1975-1983.

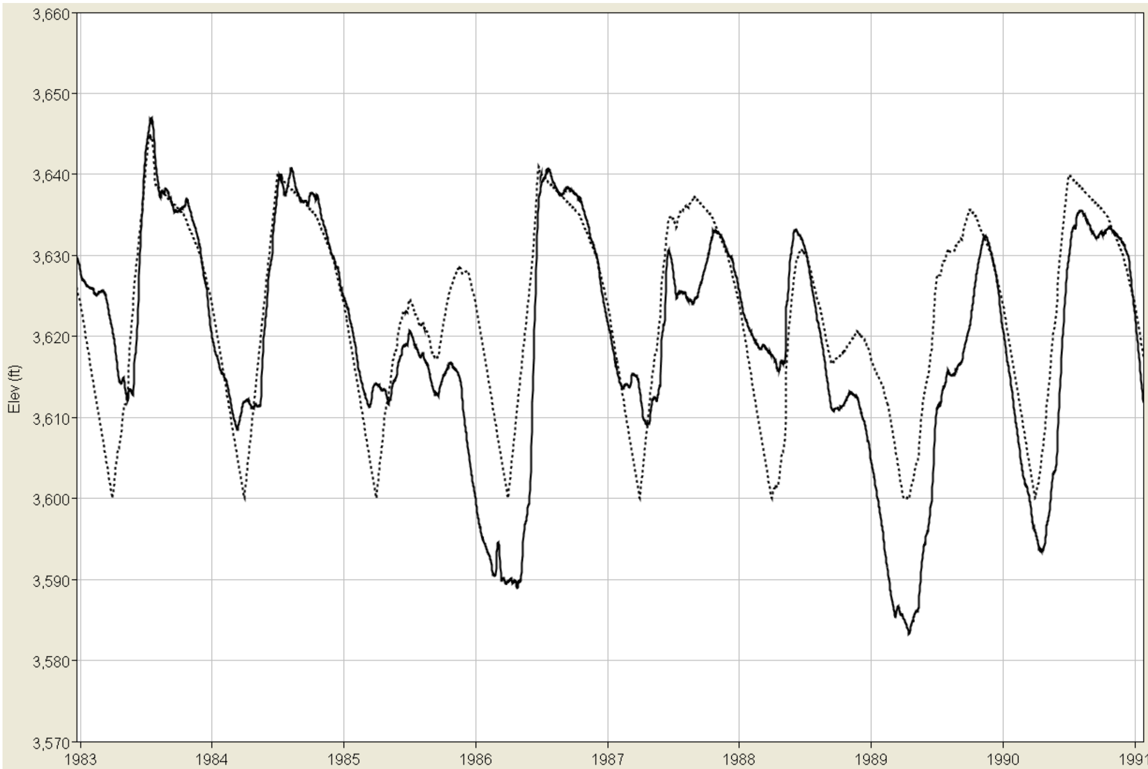

Figure 17. Actual and HEC-ResSim Yellowtail Dam elevation data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1983-1991.

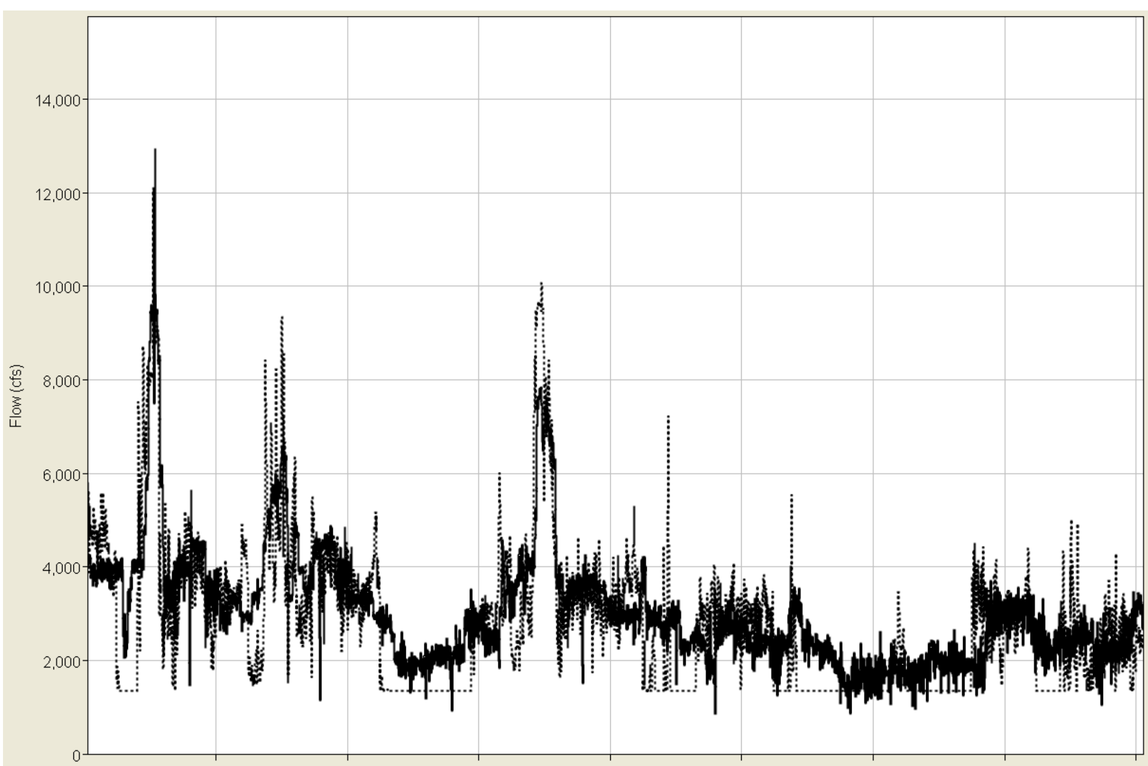

Figure 18. Actual and HEC-ResSim Yellowtail Dam outflow data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1983-1991.

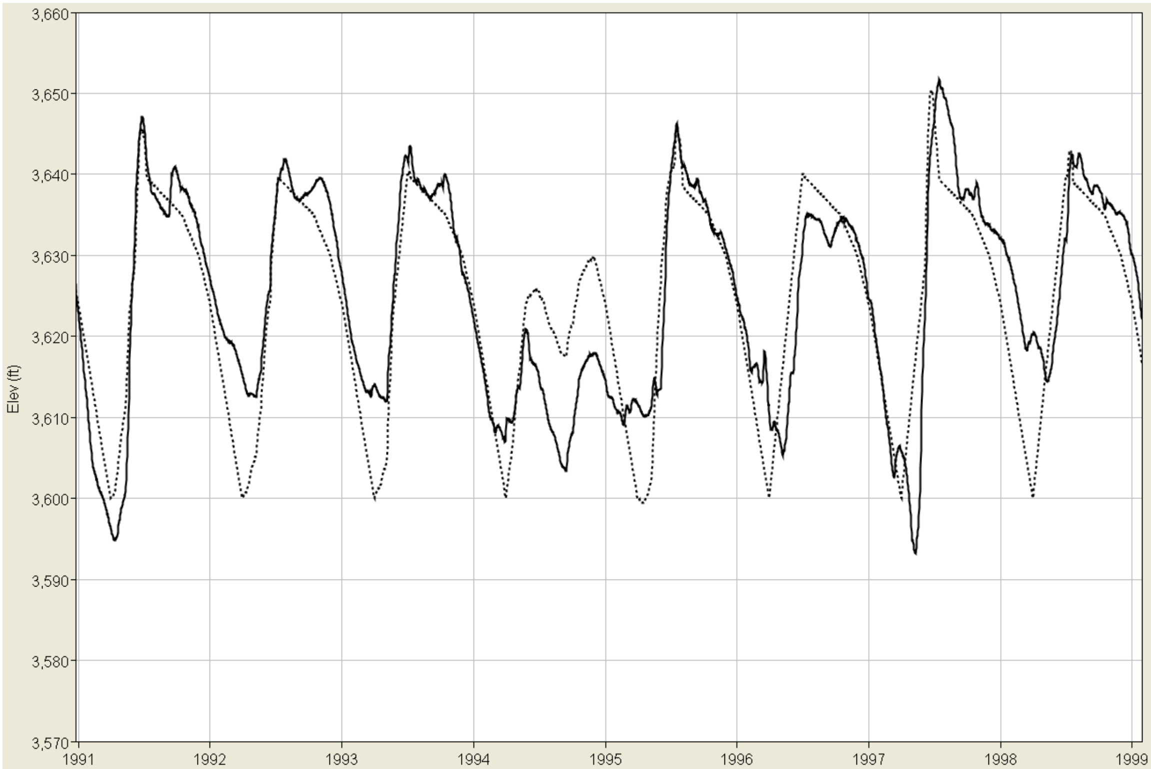

Figure 19. Actual and HEC-ResSim Yellowtail Dam elevation data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1991-1999.

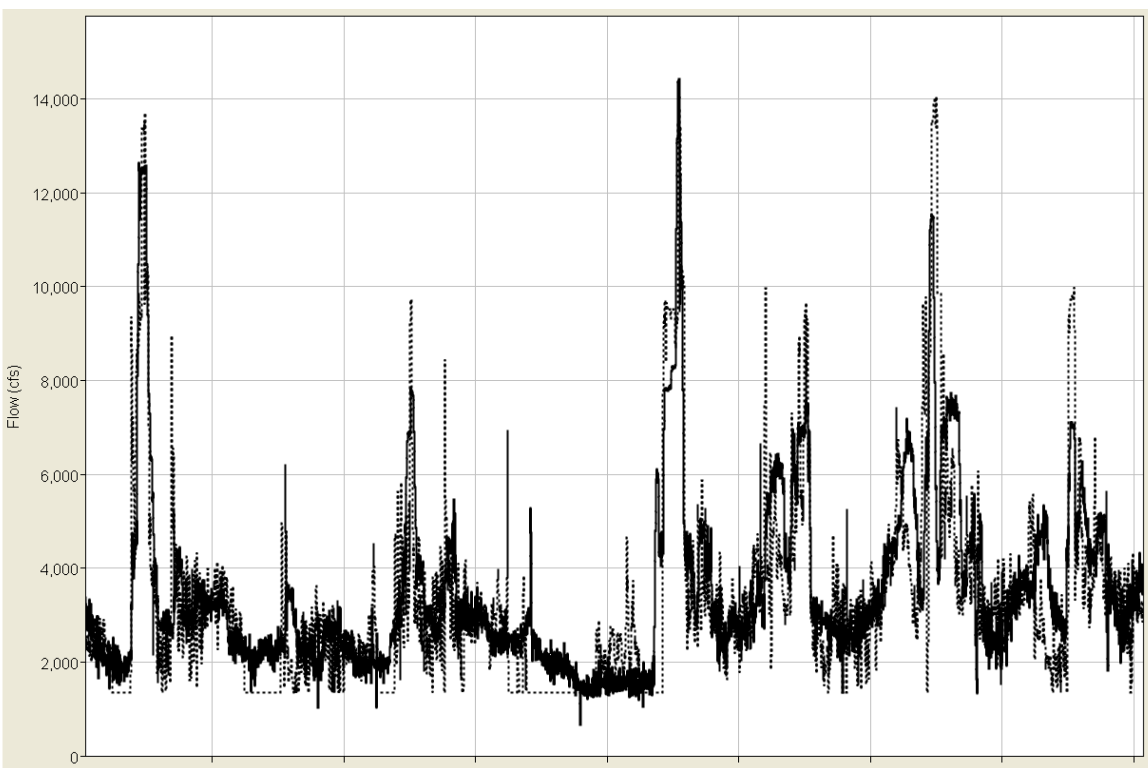

Figure 20. Actual and HEC-ResSim Yellowtail Dam outflow data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1991-1999.

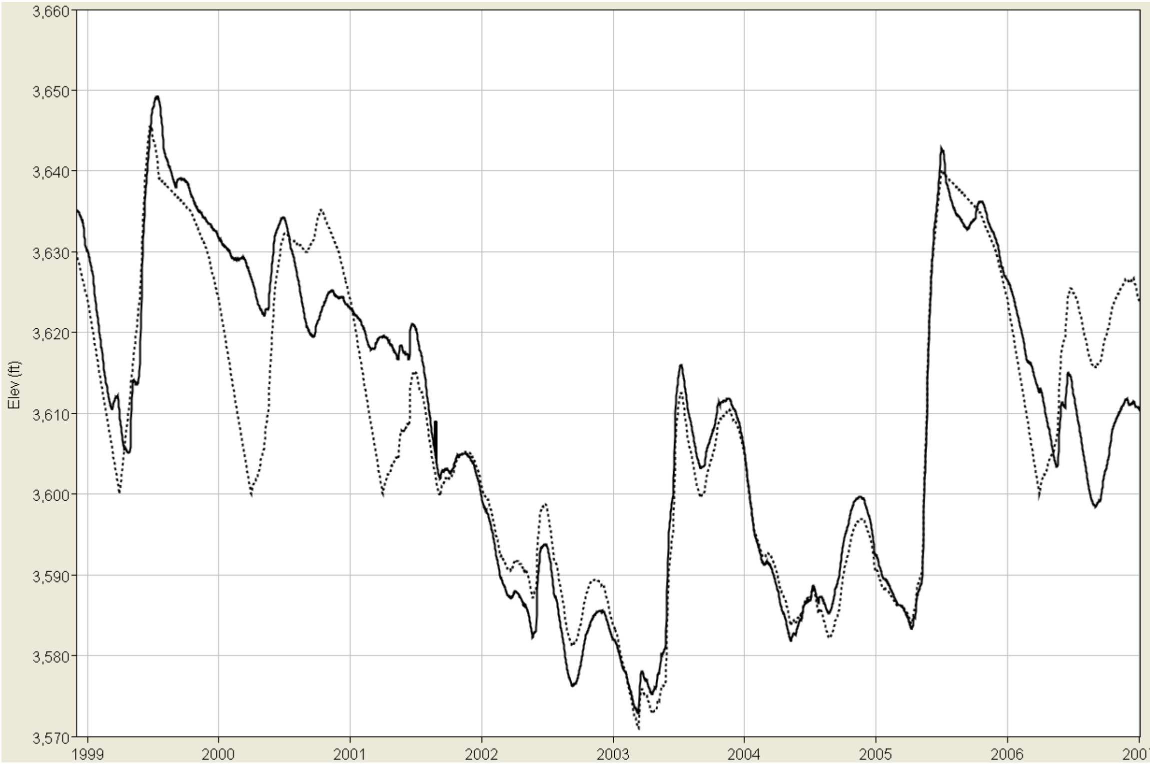

Figure 21. Actual and HEC-ResSim Yellowtail Dam elevation data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1999-2006.

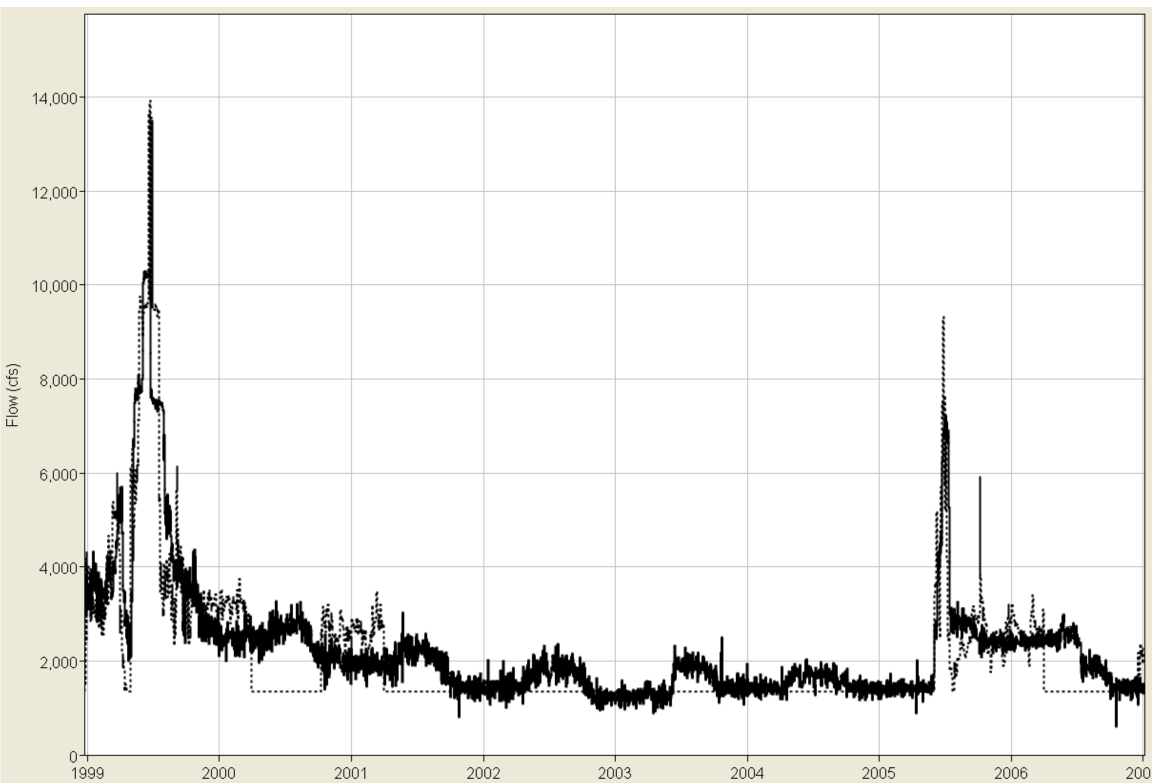

Figure 22. Actual and HEC-ResSim Yellowtail Dam outflow data. Actual data is the solid line, and HEC-ResSim a dashed line. This figure shows the period of 1999-2006.

Tables 8, 9, and 10 provide information related to the pool duration analysis that was completed for Yellowtail Dam. These tables provide a comparison between actual data and HEC-ResSim data. Five timeframes were evaluated as part of this analysis. They included annual, winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep), and fall (Oct-Dec) timeframes. The Julian days these timeframes represent are 1-365, 1-90, 91-181, 182-273, and 274-365, respectively. Figures of the pool duration curves can be found in Appendix B.

There are some differences between the actual and HEC-ResSim pool duration data. First, the HEC-ResSim annual data tends to spend a higher percentage of time around 3,600 ft msl. The reason for this is the guide curve draft elevation was set to 3,600 ft msl, and this shows the model reaches that draft elevation a higher percentage of time than what actually occurred. This isn't a surprise since current operations of the reservoir draft to an elevation determined by the spring snowmelt forecast – and not to almost the same elevation each year like HEC-ResSim. The 3,600 ft msl was used because it provided the best calibration results within the model.

Second, the pool duration data for the winter season shows HEC-ResSim tends to track lower than the actual data up to around the 75% duration, and then HEC-ResSim tracks above the actual data. Most of this is due to the draft elevation of 3,600 ft msl. The reservoir is drafting down during the winter season more than the actual data, so it spends less time at the higher elevations. On the other hand, it spends more time at the lower elevations because while it reaches those elevations most years, the actual data does not in many years.

Third, the spring flow duration data shows the HEC-ResSim data tends to track above the actual data for the entire duration. This pattern exists because HEC-ResSim begins filling the reservoir earlier in many years as compared to actual operations. HEC-ResSim is using the guide curve to know when to begin filling the reservoir each year, and this guide curve is fixed from year to year. In contrast, water managers are able to begin filling the reservoir each year at the appropriate time based on the inflow forecasts for the reservoir – thus changing the time when filling would begin from year to year.

Fourth, examining the summer pool duration data shows HEC-ResSim predicts higher elevations at lower duration percentages (0-20% approximately). The summer data also shows HEC-ResSim achieves elevation 3,640 ft msl a higher percentage of time than what has actually occurred over the period of record. This is because the desired high elevation, as specified by the guide curve, is elevation 3,640 ft msl. As a result of spending a higher percentage of time at elevation 3,640 ft msl, HEC-ResSim also maintains higher elevations through the remainder of the duration percentages (approximately >25%). In all likelihood, Yellowtail Dam could not be operated to remain at elevation 3,640 ft msl in a manner similar to this HEC-ResSim simulation due to constraints on the reservoir that HEC-ResSim cannot account for.

Fifth, the fall pool duration analysis yielded HEC-ResSim results that differ between the 70-95% duration percentages. At this location, HEC-ResSim provides elevations higher than what have occurred historically. Actual data suggests the reservoir doesn't spend as much time at the lower elevations as HEC-ResSim – at least between 3,600 and 3,625 ft msl. Once again, the reason for this is because HEC-ResSim drafts to nearly the same elevation most years whereas in reality the reservoir is drafted to an appropriate elevation as determined by spring snowmelt runoff coming into the reservoir.

Table 8. Pool duration analysis for the annual and winter timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Annual			Winter		
Percent exceeded	HEC-ResSim (ft msl)	Actual (ft msl)	Difference (ft)	HEC-ResSim (ft msl)	Actual (ft msl)	Difference (ft)
0.01	3,657.0	3,656.3	0.7	3,623.7	3,632.0	-8.3
0.05	3,654.2	3,654.0	0.2	3,623.7	3,632.0	-8.3
0.1	3,652.1	3,652.4	-0.3	3,623.7	3,631.8	-8.1
0.2	3,649.2	3,650.7	-1.5	3,623.6	3,631.6	-8.0
0.5	3,645.7	3,648.6	-2.9	3,623.4	3,631.1	-7.7
1.0	3,644.3	3,646.5	-2.2	3,623.3	3,630.4	-7.1
2.0	3,641.2	3,643.0	-1.8	3,623.1	3,629.1	-6.0
5.0	3,639.2	3,639.5	-0.3	3,622.4	3,626.8	-4.4
10.0	3,637.9	3,637.6	0.3	3,621.0	3,625.1	-4.1
15.0	3,636.8	3,636.2	0.6	3,619.5	3,623.3	-3.8
20.0	3,635.8	3,634.8	1.0	3,618.1	3,621.8	-3.7
30.0	3,632.5	3,631.5	1.0	3,615.4	3,619.4	-4.0
40.0	3,628.3	3,626.5	1.8	3,612.7	3,617.3	-4.6
50.0	3,623.5	3,621.0	2.5	3,610.2	3,614.6	-4.4
60.0	3,618.1	3,616.3	1.8	3,607.3	3,612.0	-4.7
70.0	3,612.1	3,612.0	0.1	3,604.7	3,606.7	-2.0
80.0	3,606.2	3,605.1	1.1	3,602.0	3,597.6	4.4
85.0	3,603.5	3,600.6	2.9	3,600.6	3,592.7	7.9
90.0	3,601.1	3,594.9	6.2	3,596.6	3,589.2	7.4
95.0	3,590.9	3,587.1	3.8	3,587.7	3,585.0	2.7
98.0	3,584.8	3,582.7	2.1	3,582.0	3,581.2	0.8
99.0	3,581.2	3,579.0	2.2	3,580.2	3,579.9	0.3
99.5	3,575.5	3,576.9	-1.4	3,578.8	3,578.8	0.0
99.8	3,574.2	3,575.3	-1.1	3,577.3	3,577.7	-0.4
99.9	3,573.7	3,574.8	-1.1	3,576.4	3,577.0	-0.6
99.95	3,573.2	3,574.4	-1.2	3,575.6	3,576.4	-0.8
99.99	3,572.4	3,573.8	-1.4	3,574.1	3,575.2	-1.1

Table 9. Pool duration analysis for the spring and summer timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Spring			Summer		
Percent exceeded	HEC-ResSim (ft msl)	Actual (ft msl)	Difference (ft)	HEC-ResSim (ft msl)	Actual (ft msl)	Difference (ft)
0.01	3,656.4	3,652.8	3.6	3,657.1	3,656.4	0.7
0.05	3,656.0	3,652.6	3.4	3,656.2	3,656.2	0.0
0.1	3,654.6	3,651.7	2.9	3,653.4	3,655.6	-2.2
0.2	3,652.3	3,650.2	2.1	3,650.0	3,654.6	-4.6
0.5	3,648.2	3,647.3	0.9	3,647.0	3,652.7	-5.7
1.0	3,644.8	3,644.7	0.1	3,645.7	3,650.8	-5.1
2.0	3,641.6	3,641.9	-0.3	3,644.5	3,648.6	-4.1
5.0	3,638.6	3,637.8	0.8	3,641.7	3,644.4	-2.7
10.0	3,635.5	3,632.8	2.7	3,639.6	3,640.8	-1.2
15.0	3,632.3	3,629.6	2.7	3,639.2	3,639.4	-0.2
20.0	3,629.6	3,625.5	4.1	3,638.8	3,638.5	0.3
30.0	3,624.9	3,619.6	5.3	3,638.2	3,637.3	0.9
40.0	3,620.2	3,615.9	4.3	3,637.6	3,635.8	1.8
50.0	3,615.3	3,612.7	2.6	3,636.9	3,634.3	2.6
60.0	3,610.5	3,609.6	0.9	3,636.4	3,631.8	4.6
70.0	3,606.7	3,603.4	3.3	3,635.7	3,625.5	10.2
80.0	3,603.2	3,597.7	5.5	3,623.8	3,615.7	8.1
85.0	3,601.9	3,594.8	7.1	3,618.9	3,611.2	7.7
90.0	3,600.2	3,590.2	10.0	3,614.4	3,604.8	9.6
95.0	3,588.6	3,585.1	3.5	3,599.0	3,595.2	3.8
98.0	3,583.6	3,582.6	1.0	3,584.8	3,585.9	-1.1
99.0	3,582.0	3,581.6	0.4	3,584.2	3,584.0	0.2
99.5	3,580.7	3,580.7	0.0	3,583.7	3,582.7	1.0
99.8	3,579.3	3,579.7	-0.4	3,583.2	3,581.4	1.8
99.9	3,578.4	3,579.1	-0.7	3,582.9	3,580.6	2.3
99.95	3,577.6	3,578.6	-1.0	3,582.6	3,579.9	2.7
99.99	3,576.1	3,577.5	-1.4	3,582.1	3,578.7	3.4

Table 10. Pool duration analysis for the fall timeframe. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Fall		
Percent exceeded	HEC-ResSim (ft msl)	Actual (ft msl)	Difference (ft)
0.01	3,635.6	3,641.1	-5.5
0.05	3,635.6	3,641.0	-5.4
0.1	3,635.6	3,640.8	-5.2
0.2	3,635.6	3,640.5	-4.9
0.5	3,635.6	3,639.9	-4.3
1.0	3,635.5	3,639.4	-3.9
2.0	3,635.5	3,638.8	-3.3
5.0	3,635.4	3,637.9	-2.5
10.0	3,635.1	3,637.1	-2.0
15.0	3,634.6	3,636.3	-1.7
20.0	3,633.9	3,635.6	-1.7
30.0	3,632.6	3,634.0	-1.4
40.0	3,631.3	3,632.5	-1.2
50.0	3,630.1	3,630.6	-0.5
60.0	3,628.1	3,628.4	-0.3
70.0	3,626.4	3,624.7	1.7
80.0	3,624.7	3,615.0	9.7
85.0	3,620.6	3,611.6	9.0
90.0	3,615.0	3,607.9	7.1
95.0	3,600.0	3,599.8	0.2
98.0	3,590.8	3,587.0	3.8
99.0	3,587.3	3,584.1	3.2
99.5	3,585.3	3,583.2	2.1
99.8	3,584.8	3,582.3	2.5
99.9	3,584.6	3,581.7	2.9
99.95	3,584.4	3,581.3	3.1
99.99	3,584.2	3,580.4	3.8

Tables 11, 12, and 13 provide information related to the flow duration analysis that was completed for Yellowtail Dam. These tables provide a comparison between actual data and HEC-ResSim data. Five timeframes were evaluated as part of this analysis. They included annual, winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep), and fall (Oct-Dec) timeframes. The Julian days these timeframes represent are 1-365, 1-90, 91-181, 182-273, and 274-365, respectively. This same flow duration analysis was also performed at four downstream locations including St. Xavier, Bighorn, Miles City, and Sidney. Data from these analyses can be found in tables 14 through 25. Figures of the flow duration curves can be found in Appendix C.

Studying tables 11, 12, and 13 shows HEC-ResSim tends to over predict peak outflows from Yellowtail Dam. This is a common theme for all five timeframes. Most likely this over prediction in outflow is due to the guide curve and HEC-

ResSim's lack of ability to change the date it begins filling the reservoir following the spring mountain snowmelt. As was explained earlier, this is also one of the reason's HEC-ResSim over predicts annual peak pool elevation. If the reservoir fills too quickly during the annual snowmelt event, then higher elevations can be achieved. This can trigger higher releases out of the dam due to the flood control rules that help govern Yellowtail Dam's operations.

The tables also show HEC-ResSim over predicts on the low flow side of the pendulum as well. Most of this is because of the 1,350 cfs minimum flow requirement rule. Within HEC-ResSim, the reservoir makes releases of 1,350 cfs even when, in actuality, lower releases were required. Since releases lower than 1,350 cfs occur very rarely, this is most noticeable at flow duration percentages greater than 98%.

When comparing HEC-ResSim to actual results for downstream locations, an examination of tables 14 through 25 yield findings similar to what was discussed in the previous few paragraphs. However, there are a few additional observations. First, actual flows tend to be higher than HEC-ResSim flows at flow duration percentages greater than 98% at downstream locations. Second, the annual flow duration table at Bighorn, MT shows a large difference between the flows at the 0.01-0.2% exceeded. This is because HEC-ResSim has a larger number of higher flows when compared to actual data. For comparison, there was one value higher than 26,000 cfs for the actual data and 17 values for HEC-ResSim. This results in higher flows at low exceedance percentages in the case of HEC-ResSim. Lastly, the spring analysis for Bighorn shows an incrementally larger difference (when compared to differences at other duration percentages) at the 0.05% exceeded. While the flows are similar between the actual and modeled results, there is enough of a difference in this area that the curve flattens out a bit more for the HEC-ResSim case – causing the flow at the 0.05% exceeded location to be higher. In turn, this results in a higher flow differential than what is observed in other cases.

Table 11. Flow duration analysis at Yellowtail Dam for the annual and winter timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Annual				Winter			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	29,354	24,590	4,764	19.4	9,959	6,997	2,962	42.3
0.05	27,029	21,263	5,766	27.1	9,775	6,927	2,847	41.1
0.1	25,258	18,742	6,516	34.8	9,135	6,716	2,420	36.0
0.2	22,233	15,862	6,371	40.2	8,192	6,464	1,728	26.7
0.5	14,345	12,080	2,265	18.8	6,877	6,020	857	14.2
1.0	9,930	10,110	-180	1.8	6,163	5,569	593	10.7
2.0	9,535	8,094	1,441	17.8	5,543	5,000	543	10.9
5.0	6,781	6,704	77	1.1	4,921	4,543	378	8.3
10.0	4,865	5,276	-411	7.8	4,575	4,173	402	9.6
15.0	4,387	4,559	-172	3.8	4,343	3,955	388	9.8
20.0	4,059	4,166	-107	2.6	4,136	3,748	388	10.3
30.0	3,537	3,641	-104	2.9	3,761	3,446	315	9.1
40.0	3,138	3,246	-108	3.3	3,468	3,237	232	7.2
50.0	2,752	2,897	-145	5.0	3,209	2,989	220	7.4
60.0	2,285	2,561	-276	10.8	2,950	2,686	264	9.8
70.0	1,369	2,256	-887	39.3	2,671	2,384	287	12.1
80.0	1,351	1,927	-576	29.9	2,264	1,961	303	15.4
85.0	1,351	1,756	-405	23.1	1,749	1,744	6	0.3
90.0	1,351	1,555	-204	13.1	1,394	1,500	-106	7.0
95.0	1,351	1,383	-32	2.3	1,386	1,345	41	3.0
98.0	1,350	1,223	127	10.4	1,379	1,208	170	14.1
99.0	1,350	1,097	253	23.1	1,374	1,105	269	24.4
99.5	1,350	836	514	61.5	1,371	559	812	145.2
99.8	1,350	486	864	177.8	1,367	480	887	184.7
99.9	1,350	446	904	202.7	1,365	468	897	191.7
99.95	1,350	414	936	226.1	1,363	458	904	197.4
99.99	1,350	360	990	275.0	1,359	442	917	207.4

Table 12. Flow duration analysis at Yellowtail Dam for the spring and summer timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Spring				Summer			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	22,963	20,148	2,815	14.0	29,445	24,721	4,724	19.1
0.05	22,688	19,813	2,875	14.5	29,230	24,299	4,931	20.3
0.1	21,650	18,637	3,013	16.2	28,450	22,822	5,628	24.7
0.2	19,827	16,786	3,041	18.1	27,116	20,427	6,689	32.7
0.5	16,198	13,764	2,434	17.7	24,361	16,239	8,122	50.0
1.0	12,536	11,586	950	8.2	16,505	12,765	3,740	29.3
2.0	9,776	10,061	-285	2.8	10,091	10,478	-387	3.7
5.0	9,158	7,789	1,369	17.6	9,429	7,700	1,729	22.5
10.0	6,671	6,715	-44	0.7	6,524	6,556	-32	0.5
15.0	4,977	5,975	-998	16.7	4,927	5,420	-493	9.1
20.0	4,116	5,366	-1,250	23.3	4,206	4,624	-418	9.0
30.0	2,748	4,154	-1,406	33.8	3,459	3,805	-346	9.1
40.0	2,021	3,355	-1,334	39.8	2,970	3,285	-315	9.6
50.0	1,399	2,821	-1,422	50.4	2,453	2,881	-428	14.9
60.0	1,394	2,466	-1,072	43.5	1,962	2,565	-603	23.5
70.0	1,389	2,179	-790	36.3	1,398	2,256	-858	38.0
80.0	1,384	1,896	-512	27.0	1,392	2,006	-614	30.6
85.0	1,381	1,750	-369	21.1	1,388	1,910	-522	27.3
90.0	1,378	1,570	-192	12.2	1,384	1,794	-410	22.9
95.0	1,374	1,408	-34	2.4	1,378	1,656	-278	16.8
98.0	1,369	1,247	122	9.8	1,373	1,529	-156	10.2
99.0	1,367	1,109	258	23.3	1,370	1,460	-90	6.2
99.5	1,365	711	654	92.0	1,367	1,397	-30	2.1
99.8	1,362	481	881	183.2	1,364	1,305	59	4.5
99.9	1,361	465	896	192.7	1,362	1,223	139	11.4
99.95	1,360	452	908	200.9	1,361	1,145	216	18.9
99.99	1,357	431	926	214.8	1,358	1,084	274	25.3

Table 13. Flow duration analysis at Yellowtail Dam for the fall timeframe. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Fall			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	9,564	7,333	2,231	30.4
0.05	8,875	7,268	1,607	22.1
0.1	7,504	7,046	458	6.5
0.2	6,784	6,698	86	1.3
0.5	6,017	6,132	-116	1.9
1.0	5,581	5,721	-140	2.4
2.0	5,169	5,287	-118	2.2
5.0	4,669	4,871	-203	4.2
10.0	4,338	4,445	-108	2.4
15.0	4,130	4,201	-71	1.7
20.0	3,912	3,945	-34	0.8
30.0	3,541	3,527	14	0.4
40.0	3,244	3,182	62	2.0
50.0	2,991	2,851	140	4.9
60.0	2,713	2,535	178	7.0
70.0	2,355	2,214	142	6.4
80.0	1,399	1,699	-300	17.7
85.0	1,394	1,519	-125	8.2
90.0	1,389	1,406	-17	1.2
95.0	1,382	1,269	113	8.9
98.0	1,376	1,089	287	26.3
99.0	1,372	897	475	52.9
99.5	1,369	714	655	91.7
99.8	1,366	538	828	153.9
99.9	1,364	481	883	183.5
99.95	1,362	444	918	207.0
99.99	1,358	379	979	258.1

Table 14. Flow duration analysis at St. Xavier for the annual and winter timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Annual				Winter			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	31,089	24,667	6,422	26.0	10,021	6,880	3,141	45.7
0.05	27,710	21,312	6,398	30.0	9,817	6,816	3,001	44.0
0.1	25,331	18,805	6,526	34.7	9,119	6,631	2,488	37.5
0.2	22,423	15,990	6,433	40.2	8,106	6,399	1,707	26.7
0.5	15,745	12,433	3,312	26.6	6,768	5,961	807	13.5
1.0	10,192	10,526	-334	3.2	6,080	5,526	554	10.0
2.0	9,974	8,061	1,913	23.7	5,498	5,007	491	9.8
5.0	7,145	6,665	480	7.2	4,997	4,667	330	7.1
10.0	5,026	5,334	-308	5.8	4,622	4,122	500	12.1
15.0	4,510	4,638	-128	2.8	4,394	4,019	376	9.3
20.0	4,191	4,221	-30	0.7	4,196	3,803	393	10.3
30.0	3,677	3,692	-15	0.4	3,806	3,527	279	7.9
40.0	3,315	3,305	10	0.3	3,523	3,315	208	6.3
50.0	2,949	2,962	-13	0.4	3,292	3,090	202	6.5
60.0	2,553	2,641	-88	3.3	3,030	2,816	215	7.6
70.0	2,032	2,314	-282	12.2	2,791	2,440	351	14.4
80.0	1,670	1,984	-314	15.8	2,464	2,097	367	17.5
85.0	1,519	1,799	-280	15.6	2,060	1,879	181	9.6
90.0	1,427	1,610	-183	11.4	1,538	1,646	-108	6.5
95.0	1,334	1,465	-131	8.9	1,439	1,522	-83	5.5
98.0	1,239	1,317	-78	5.9	1,368	1,391	-23	1.7
99.0	1,169	1,237	-68	5.5	1,324	1,350	-26	1.9
99.5	1,086	946	140	14.8	1,278	992	286	28.8
99.8	967	740	227	30.7	1,214	875	339	38.8
99.9	918	640	278	43.4	1,158	808	350	43.4
99.95	875	562	313	55.7	1,087	755	332	44.0
99.99	797	405	392	96.8	911	666	245	36.8

Table 15. Flow duration analysis at St. Xavier for the spring and summer timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Spring				Summer			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	20,882	19,500	1,382	7.1	31,228	24,800	6,428	25.9
0.05	20,700	19,214	1,486	7.7	30,895	24,344	6,551	26.9
0.1	19,972	18,202	1,770	9.7	29,727	22,775	6,952	30.5
0.2	18,596	16,586	2,010	12.1	27,818	20,296	7,522	37.1
0.5	15,563	13,870	1,693	12.2	24,363	16,178	8,185	50.6
1.0	12,113	11,785	328	2.8	18,804	13,084	5,720	43.7
2.0	10,093	10,348	-255	2.5	10,505	10,982	-477	4.3
5.0	9,732	7,805	1,927	24.7	9,959	7,722	2,237	29.0
10.0	6,780	6,684	96	1.4	7,301	6,566	735	11.2
15.0	5,175	6,003	-828	13.8	5,333	5,448	-115	2.1
20.0	4,245	5,476	-1,231	22.5	4,585	4,582	3	0.1
30.0	2,960	4,279	-1,319	30.8	3,807	3,815	-8	0.2
40.0	2,258	3,416	-1,158	33.9	3,322	3,279	43	1.3
50.0	1,926	2,834	-908	32.0	2,842	2,835	7	0.2
60.0	1,729	2,449	-720	29.4	2,416	2,572	-156	6.1
70.0	1,543	2,175	-632	29.1	2,053	2,280	-227	10.0
80.0	1,425	1,939	-514	26.5	1,887	2,049	-162	7.9
85.0	1,375	1,770	-395	22.3	1,804	1,953	-149	7.6
90.0	1,324	1,602	-278	17.4	1,658	1,790	-132	7.4
95.0	1,248	1,467	-219	14.9	1,431	1,612	-181	11.2
98.0	1,142	1,308	-166	12.7	1,312	1,429	-117	8.2
99.0	999	1,246	-247	19.8	1,247	1,355	-108	8.0
99.5	943	978	-35	3.6	1,188	1,278	-90	7.0
99.8	884	650	234	36.0	1,107	1,205	-98	8.1
99.9	848	523	325	62.1	1,092	1,197	-105	8.8
99.95	817	449	368	82.0	1,082	1,194	-112	9.4
99.99	760	321	439	136.8	1,065	1,188	-123	10.4

Table 16. Flow duration analysis at St. Xavier for the fall timeframe. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Fall			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	9,258	7,380	1,878	25.4
0.05	7,535	7,302	233	3.2
0.1	6,939	7,040	-101	1.4
0.2	6,549	6,641	-91	1.4
0.5	6,112	6,030	82	1.4
1.0	5,669	5,622	47	0.8
2.0	5,178	5,296	-118	2.2
5.0	4,713	4,960	-248	5.0
10.0	4,434	4,589	-155	3.4
15.0	4,214	4,305	-92	2.1
20.0	4,012	4,082	-70	1.7
30.0	3,672	3,677	-5	0.1
40.0	3,412	3,259	154	4.7
50.0	3,175	3,014	161	5.3
60.0	2,913	2,754	159	5.8
70.0	2,588	2,346	242	10.3
80.0	1,677	1,764	-87	4.9
85.0	1,506	1,593	-87	5.5
90.0	1,418	1,496	-78	5.2
95.0	1,326	1,346	-20	1.5
98.0	1,230	1,221	8	0.7
99.0	1,166	928	239	25.7
99.5	1,107	779	328	42.1
99.8	1,011	636	376	59.1
99.9	985	563	422	75.0
99.95	967	518	449	86.7
99.99	936	489	447	91.5

Table 17. Flow duration analysis at Bighorn for the annual and winter timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Annual				Winter			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	49,076	24,314	24,762	101.8	13,113	12,800	313	2.4
0.05	34,247	18,544	15,703	84.7	12,986	12,624	362	2.9
0.1	27,119	16,774	10,345	61.7	12,511	11,981	530	4.4
0.2	22,397	15,243	7,154	46.9	11,711	10,940	771	7.0
0.5	16,440	13,211	3,229	24.4	10,238	9,150	1,088	11.9
1.0	12,780	11,248	1,532	13.6	8,909	7,721	1,188	15.4
2.0	10,856	9,561	1,295	13.5	7,545	6,564	981	14.9
5.0	8,339	7,511	828	11.0	6,035	5,546	489	8.8
10.0	5,811	6,085	-274	4.5	5,169	4,932	237	4.8
15.0	4,971	5,247	-276	5.3	4,858	4,488	370	8.2
20.0	4,593	4,746	-153	3.2	4,610	4,263	347	8.1
30.0	4,019	4,117	-98	2.4	4,167	3,932	235	6.0
40.0	3,636	3,644	-8	0.2	3,863	3,624	239	6.6
50.0	3,244	3,246	-2	0.1	3,607	3,387	220	6.5
60.0	2,820	2,874	-54	1.9	3,307	3,034	273	9.0
70.0	2,248	2,506	-258	10.3	3,026	2,720	306	11.3
80.0	1,788	2,102	-314	14.9	2,623	2,347	276	11.8
85.0	1,655	1,892	-237	12.5	2,074	2,097	-23	1.1
90.0	1,537	1,675	-138	8.2	1,701	1,856	-155	8.4
95.0	1,403	1,475	-72	4.9	1,524	1,641	-117	7.1
98.0	1,265	1,299	-34	2.6	1,428	1,478	-50	3.4
99.0	1,164	1,170	-6	0.5	1,359	1,430	-71	5.0
99.5	1,075	1,074	1	0.1	1,273	1,382	-109	7.9
99.8	948	932	16	1.7	1,133	1,314	-181	13.8
99.9	752	789	-37	4.7	485	1,247	-762	61.1
99.95	565	652	-87	13.3	398	1,197	-799	66.8
99.99	369	488	-119	24.4	262	1,158	-896	77.4

Table 18. Flow duration analysis at Bighorn for the spring and summer timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Spring				Summer			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	49,812	50,000	-188	0.4	30,964	25,200	5,764	22.9
0.05	37,007	26,749	10,258	38.3	30,633	25,044	5,589	22.3
0.1	23,982	21,950	2,032	9.3	29,484	23,998	5,486	22.9
0.2	20,616	19,238	1,378	7.2	27,641	21,465	6,176	28.8
0.5	16,855	16,527	328	2.0	24,373	16,705	7,668	45.9
1.0	14,521	14,553	-32	0.2	18,657	13,090	5,567	42.5
2.0	12,599	11,824	775	6.6	12,314	10,950	1,364	12.5
5.0	10,564	9,374	1,190	12.7	9,922	8,230	1,692	20.6
10.0	8,246	8,114	132	1.6	7,694	6,706	988	14.7
15.0	6,578	7,047	-469	6.7	5,576	5,545	31	0.6
20.0	5,501	6,443	-942	14.6	4,682	4,659	23	0.5
30.0	4,073	5,343	-1,270	23.8	3,818	3,826	-8	0.2
40.0	3,224	4,424	-1,200	27.1	3,266	3,245	21	0.6
50.0	2,594	3,495	-901	25.8	2,756	2,821	-65	2.3
60.0	2,171	2,954	-783	26.5	2,287	2,513	-226	9.0
70.0	1,922	2,604	-682	26.2	1,906	2,204	-298	13.5
80.0	1,720	2,283	-563	24.7	1,681	1,906	-225	11.8
85.0	1,635	2,080	-445	21.4	1,588	1,769	-181	10.2
90.0	1,538	1,865	-327	17.5	1,484	1,586	-102	6.4
95.0	1,413	1,533	-120	7.8	1,360	1,469	-109	7.4
98.0	1,288	1,398	-110	7.9	1,250	1,319	-69	5.2
99.0	1,201	1,251	-50	4.0	1,190	1,228	-38	3.1
99.5	1,101	1,152	-51	4.4	1,138	1,154	-16	1.4
99.8	983	1,064	-81	7.6	1,098	1,022	76	7.4
99.9	801	829	-28	3.4	1,085	993	92	9.3
99.95	605	497	108	21.7	1,075	985	90	9.1
99.99	417	454	-37	8.1	1,055	972	83	8.5

Table 19. Flow duration analysis at Bighorn for the fall timeframe. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Fall			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	9,990	8,140	1,850	22.7
0.05	9,102	8,022	1,080	13.5
0.1	7,490	7,679	-189	2.5
0.2	6,961	7,281	-320	4.4
0.5	6,464	6,565	-102	1.5
1.0	6,113	5,998	115	1.9
2.0	5,624	5,648	-24	0.4
5.0	5,033	5,309	-276	5.2
10.0	4,743	4,934	-191	3.9
15.0	4,530	4,651	-121	2.6
20.0	4,334	4,346	-12	0.3
30.0	3,965	4,035	-70	1.7
40.0	3,698	3,643	54	1.5
50.0	3,451	3,300	151	4.6
60.0	3,170	3,006	164	5.4
70.0	2,813	2,490	323	13.0
80.0	1,854	1,948	-94	4.8
85.0	1,614	1,683	-68	4.1
90.0	1,481	1,513	-32	2.1
95.0	1,336	1,305	31	2.4
98.0	1,139	1,115	24	2.1
99.0	1,034	1,014	21	2.0
99.5	975	956	19	2.0
99.8	917	895	23	2.5
99.9	880	854	26	3.0
99.95	847	818	28	3.4
99.99	781	748	34	4.5

Table 20. Flow duration analysis at Miles City for the annual and winter timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Annual				Winter			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	87,615	82,099	5,516	6.7	43,994	45,000	-1,006	2.2
0.05	76,207	76,537	-330	0.4	43,150	42,976	174	0.4
0.1	71,749	70,669	1,080	1.5	40,307	37,420	2,887	7.7
0.2	67,181	66,068	1,113	1.7	36,327	32,847	3,480	10.6
0.5	60,580	59,509	1,071	1.8	29,138	27,498	1,640	6.0
1.0	52,948	52,124	824	1.6	23,076	22,207	869	3.9
2.0	45,133	44,505	628	1.4	17,705	16,712	993	5.9
5.0	34,408	33,916	492	1.5	13,488	12,936	552	4.3
10.0	24,325	24,759	-434	1.8	10,743	10,647	96	0.9
15.0	17,515	17,569	-54	0.3	9,723	9,589	134	1.4
20.0	13,572	13,979	-407	2.9	9,073	8,827	246	2.8
30.0	10,462	10,783	-321	3.0	8,124	7,860	264	3.4
40.0	9,004	9,177	-173	1.9	7,354	7,218	136	1.9
50.0	8,001	8,061	-60	0.7	6,780	6,617	163	2.5
60.0	7,209	7,218	-9	0.1	6,244	6,047	197	3.3
70.0	6,433	6,481	-48	0.7	5,672	5,528	144	2.6
80.0	5,543	5,641	-98	1.7	4,877	4,917	-40	0.8
85.0	5,034	5,154	-120	2.3	4,419	4,544	-125	2.8
90.0	4,451	4,609	-158	3.4	3,959	4,126	-167	4.0
95.0	3,818	3,990	-172	4.3	3,481	3,562	-81	2.3
98.0	3,144	3,312	-168	5.1	2,876	2,907	-31	1.1
99.0	2,770	2,909	-139	4.8	2,548	2,617	-69	2.6
99.5	2,467	2,583	-116	4.5	2,256	2,359	-103	4.4
99.8	2,153	2,231	-78	3.5	2,002	2,052	-50	2.4
99.9	1,980	2,056	-76	3.7	1,957	1,981	-24	1.2
99.95	1,841	1,967	-126	6.4	1,921	1,946	-25	1.3
99.99	1,577	1,838	-261	14.2	1,860	1,889	-29	1.5

Table 21. Flow duration analysis at Miles City for the spring and summer timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Spring				Summer			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	88,645	82,300	6,345	7.7	71,317	69,700	1,617	2.3
0.05	86,292	81,808	4,484	5.5	70,852	69,217	1,635	2.4
0.1	80,670	80,260	410	0.5	69,542	67,503	2,039	3.0
0.2	75,850	76,684	-834	1.1	67,126	64,665	2,461	3.8
0.5	69,009	68,983	26	0.0	61,922	59,343	2,579	4.3
1.0	63,487	63,174	313	0.5	54,659	48,449	6,210	12.8
2.0	56,978	56,831	147	0.3	43,833	40,625	3,208	7.9
5.0	47,397	47,658	-261	0.5	34,598	32,448	2,150	6.6
10.0	39,859	39,404	455	1.2	26,421	25,774	647	2.5
15.0	34,000	34,292	-292	0.9	21,187	19,925	1,262	6.3
20.0	29,883	30,586	-703	2.3	16,856	16,214	642	4.0
30.0	22,282	23,568	-1,286	5.5	12,380	12,305	75	0.6
40.0	16,961	17,653	-692	3.9	10,458	10,354	104	1.0
50.0	13,080	14,413	-1,333	9.2	8,885	8,903	-18	0.2
60.0	10,478	12,140	-1,662	13.7	7,719	7,821	-102	1.3
70.0	8,428	9,672	-1,244	12.9	6,504	6,622	-118	1.8
80.0	6,906	7,916	-1,010	12.8	5,428	5,646	-218	3.9
85.0	6,275	7,131	-856	12.0	4,896	5,035	-139	2.8
90.0	5,681	6,445	-764	11.9	4,247	4,388	-141	3.2
95.0	4,970	5,507	-537	9.8	3,523	3,673	-150	4.1
98.0	4,267	4,582	-315	6.9	2,968	3,059	-91	3.0
99.0	3,898	4,043	-145	3.6	2,874	2,946	-72	2.4
99.5	3,552	3,820	-268	7.0	2,799	2,880	-81	2.8
99.8	3,200	3,627	-427	11.8	2,719	2,812	-93	3.3
99.9	3,022	3,524	-502	14.2	2,670	2,770	-100	3.6
99.95	2,964	3,442	-478	13.9	2,628	2,735	-107	3.9
99.99	2,878	3,288	-410	12.5	2,550	2,669	-119	4.5

Table 22. Flow duration analysis at Miles City for the fall timeframe. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Fall			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	19,882	19,800	82	0.4
0.05	19,730	19,641	89	0.5
0.1	19,185	19,073	112	0.6
0.2	18,266	18,121	145	0.8
0.5	16,547	16,355	192	1.2
1.0	14,951	14,738	213	1.4
2.0	13,233	13,033	200	1.5
5.0	11,166	11,097	69	0.6
10.0	10,316	10,390	-74	0.7
15.0	9,786	9,856	-70	0.7
20.0	9,260	9,352	-92	1.0
30.0	8,505	8,351	154	1.8
40.0	7,886	7,762	124	1.6
50.0	7,416	7,225	191	2.6
60.0	7,000	6,832	168	2.5
70.0	6,312	6,260	52	0.8
80.0	5,356	5,404	-48	0.9
85.0	4,811	4,996	-185	3.7
90.0	4,425	4,582	-157	3.4
95.0	3,972	4,135	-163	3.9
98.0	3,343	3,597	-254	7.1
99.0	2,806	3,113	-307	9.9
99.5	2,317	2,638	-321	12.2
99.8	1,953	2,097	-144	6.9
99.9	1,809	1,968	-159	8.1
99.95	1,687	1,905	-218	11.4
99.99	1,468	1,801	-333	18.5

Table 23. Flow duration analysis at Sidney for the annual and winter timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Annual				Winter			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	104,540	102,749	1,791	1.7	75,321	75,000	321	0.4
0.05	79,684	82,149	-2,465	3.0	73,584	73,063	521	0.7
0.1	75,633	76,319	-686	0.9	67,540	66,437	1,103	1.7
0.2	72,329	71,645	684	1.0	58,531	56,875	1,656	2.9
0.5	64,289	63,162	1,127	1.8	45,665	44,356	1,309	3.0
1.0	56,752	55,943	809	1.4	36,855	36,689	166	0.5
2.0	49,664	48,384	1,280	2.6	25,546	25,604	-58	0.2
5.0	36,596	36,134	462	1.3	16,245	16,091	154	1.0
10.0	25,321	25,610	-289	1.1	12,576	12,532	44	0.4
15.0	18,156	18,250	-94	0.5	11,050	10,861	189	1.7
20.0	14,175	14,560	-385	2.6	10,168	9,820	348	3.5
30.0	10,918	11,183	-265	2.4	9,023	8,749	274	3.1
40.0	9,459	9,514	-55	0.6	8,085	7,957	128	1.6
50.0	8,306	8,378	-72	0.9	7,367	7,312	55	0.8
60.0	7,394	7,472	-78	1.0	6,744	6,609	135	2.0
70.0	6,551	6,581	-30	0.5	6,077	6,090	-13	0.2
80.0	5,533	5,636	-103	1.8	5,131	5,233	-102	1.9
85.0	4,904	5,106	-202	4.0	4,665	4,815	-150	3.1
90.0	4,344	4,519	-175	3.9	4,267	4,416	-149	3.4
95.0	3,519	3,733	-214	5.7	3,631	3,887	-256	6.6
98.0	2,458	2,715	-257	9.5	2,836	3,018	-182	6.0
99.0	1,831	2,044	-213	10.4	2,393	2,595	-202	7.8
99.5	1,427	1,755	-328	18.7	2,069	2,279	-210	9.2
99.8	1,068	1,459	-391	26.8	1,217	1,892	-675	35.7
99.9	921	1,287	-366	28.4	928	1,490	-562	37.7
99.95	805	1,154	-349	30.2	798	1,141	-343	30.1
99.99	597	978	-381	39.0	578	936	-358	38.2

Table 24. Flow duration analysis at Sidney for the spring and summer timeframes. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Spring				Summer			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	106,452	104,000	2,452	2.4	72,963	76,300	-3,337	4.4
0.05	102,096	101,097	999	1.0	72,801	75,330	-2,529	3.4
0.1	90,085	92,359	-2,274	2.5	72,206	72,448	-242	0.3
0.2	79,643	82,362	-2,719	3.3	71,174	68,942	2,232	3.2
0.5	73,179	74,025	-846	1.1	67,264	62,466	4,798	7.7
1.0	67,457	67,649	-192	0.3	57,996	54,283	3,713	6.8
2.0	59,891	59,886	5	0.0	48,339	44,455	3,884	8.7
5.0	51,155	50,737	418	0.8	37,104	34,747	2,357	6.8
10.0	41,686	41,916	-230	0.5	27,556	26,863	693	2.6
15.0	35,000	35,728	-728	2.0	22,087	20,668	1,419	6.9
20.0	30,089	31,023	-934	3.0	17,000	16,278	722	4.4
30.0	22,217	23,265	-1,048	4.5	12,314	12,222	92	0.8
40.0	16,966	17,891	-925	5.2	10,031	9,939	92	0.9
50.0	13,332	14,683	-1,351	9.2	8,310	8,427	-117	1.4
60.0	10,841	12,449	-1,608	12.9	6,889	6,929	-40	0.6
70.0	8,973	10,034	-1,061	10.6	5,666	5,779	-113	2.0
80.0	7,258	8,191	-933	11.4	4,481	4,704	-223	4.7
85.0	6,625	7,571	-946	12.5	3,968	4,140	-172	4.2
90.0	5,986	6,581	-595	9.0	3,387	3,598	-211	5.9
95.0	5,213	5,671	-458	8.1	2,436	2,621	-185	7.1
98.0	4,498	4,985	-487	9.8	1,652	1,913	-261	13.6
99.0	3,988	4,262	-274	6.4	1,315	1,768	-453	25.6
99.5	3,508	3,715	-207	5.6	1,096	1,651	-555	33.6
99.8	2,762	2,938	-176	6.0	992	1,527	-535	35.0
99.9	1,911	2,480	-569	22.9	969	1,451	-482	33.2
99.95	1,283	2,128	-845	39.7	950	1,385	-435	31.4
99.99	886	1,964	-1,078	54.9	919	1,262	-343	27.2

Table 25. Flow duration analysis at Sidney for the fall timeframe. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

	Fall			
Percent exceeded	HEC-ResSim (cfs)	Actual (cfs)	Difference (cfs)	% of actual
0.01	30,291	29,800	491	1.6
0.05	27,577	27,231	346	1.3
0.1	21,609	21,555	54	0.3
0.2	18,974	18,974	0	0.0
0.5	16,723	16,704	19	0.1
1.0	15,180	15,135	45	0.3
2.0	13,756	13,684	72	0.5
5.0	11,998	11,917	81	0.7
10.0	10,749	10,742	7	0.1
15.0	10,184	10,191	-7	0.1
20.0	9,718	9,756	-38	0.4
30.0	8,972	8,856	116	1.3
40.0	8,255	8,194	61	0.7
50.0	7,651	7,522	129	1.7
60.0	7,145	6,925	220	3.2
70.0	6,424	6,332	92	1.5
80.0	5,491	5,461	30	0.5
85.0	4,979	5,088	-109	2.1
90.0	4,474	4,613	-139	3.0
95.0	3,861	4,045	-184	4.5
98.0	2,765	3,150	-385	12.2
99.0	1,974	2,485	-511	20.6
99.5	1,443	1,956	-513	26.2
99.8	1,011	1,510	-499	33.0
99.9	881	1,244	-363	29.2
99.95	774	1,068	-294	27.5
99.99	587	968	-381	39.4

Tables 26 through 29 provide the results of the flow frequency analysis that was performed. This analysis compared the flow frequency relationships from the historical period of record and HEC-ResSim. The data are presented in graphical form in Appendix D. Further statistical information is also available in the appendix.

When studying the data from St. Xavier and Bighorn, the difference in the skew between the actual and HEC-ResSim data stands out. This can be seen easily by studying the figures in Appendix D, or looking at the flow values in tables 26 and 27. The computed HEC-ResSim curve tends to track above the actual curve between exceedance probabilities 0.99 and 0.05. At exceedance probabilities less than 0.05, the actual data actually provides flow values higher than the HEC-ResSim data – showing the impact of the skew value on the HEC-ResSim data. The cause of this difference is primarily with the decision making of HEC-ResSim. The model makes more annual peak releases between 10-14,000 cfs than what actually occurred. This results in a flatter curve at these upper release rates, and bends the curve down in comparison to the actual curve, where the releases are more evenly distributed.

It appears the actual and HEC-ResSim flow frequency analyses are more similar at locations farther downstream (Miles City and Sidney). The magnitude of the flow difference at specific probabilities does not change greatly moving downstream, but skew values are more alike than at the upstream locations. The results also show these locations differ from the closer locations in that flows tend to be higher for the actual condition at higher exceedance probabilities, but this reverses as the exceedance probability is reduced until the HEC-ResSim condition provides the higher flow values.

The log-Pearson type III distribution is not intended for use on highly regulated streams. Application of the distribution is the source of much of the differences at the Bighorn River locations. Figures D.1 and D.2 show the actual and HEC-ResSim frequency curves actually cross at the more extreme events – reflecting HEC-ResSim's more rigid style of setting releases as compared to actual data. An eye-fit graphical frequency curve may have not had the same level of difference at the extreme events as the log-Pearson type III curve at these locations. However, the methodology was used to provide consistency within the study at all downstream locations. The Yellowstone River locations fit the log-Pearson type III distribution much better since the influence of regulation from Yellowtail Dam diminishes at those locations.

Table 26. Annual flow frequency analysis at St. Xavier. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

HEC-ResSim Computed Probability		Actual Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Actual
0.002	27,378	0.002	33,897	-6,519	19.2
0.005	25,220	0.005	28,854	-3,634	12.6
0.01	23,414	0.01	25,205	-1,791	7.1
0.02	21,437	0.02	21,693	-256	1.2
0.05	18,509	0.05	17,239	1,270	7.4
0.1	15,998	0.1	13,988	2,010	14.4
0.2	13,138	0.2	10,796	2,342	21.7
0.5	8,437	0.5	6,455	1,982	30.7
0.8	4,939	0.8	3,764	1,175	31.2
0.9	3,590	0.9	2,811	779	27.7
0.95	2,701	0.95	2,197	504	22.9
0.99	1,503	0.99	1,366	137	10.0

Table 27. Annual flow frequency analysis at Bighorn. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

HEC-ResSim Computed Probability		Actual Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Actual
0.002	51,460	0.002	66,561	-15,101	22.7
0.005	43,617	0.005	51,628	-8,011	15.5
0.01	37,962	0.01	42,058	-4,096	9.7
0.02	32,535	0.02	33,778	-1,243	3.7
0.05	25,685	0.05	24,537	1,148	4.7
0.1	20,714	0.1	18,641	2,073	11.1
0.2	15,861	0.2	13,518	2,343	17.3
0.5	9,329	0.5	7,566	1,763	23.3
0.8	5,343	0.8	4,425	918	20.7
0.9	3,950	0.9	3,400	550	16.2
0.95	3,060	0.95	2,760	300	10.9
0.99	1,870	0.99	1,904	-34	1.8

Table 28. Annual flow frequency analysis at Miles City. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

HEC-ResSim Computed Probability		Actual Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Actual
0.002	119,042	0.002	111,030	8,012	7.2
0.005	108,239	0.005	101,463	6,776	6.7
0.01	99,928	0.01	94,107	5,821	6.2
0.02	91,442	0.02	86,597	4,845	5.6
0.05	79,817	0.05	76,300	3,517	4.6
0.1	70,528	0.1	68,055	2,473	3.6
0.2	60,491	0.2	59,113	1,378	2.3
0.5	44,582	0.5	44,819	-237	0.5
0.8	32,360	0.8	33,652	-1,292	3.8
0.9	27,201	0.9	28,857	-1,656	5.7
0.95	23,490	0.95	25,365	-1,875	7.4
0.99	17,698	0.99	19,813	-2,115	10.7

Table 29. Annual flow frequency analysis at Sidney. Table compares actual data to data from HEC-ResSim. Difference is calculated as HEC-ResSim-actual.

HEC-ResSim Computed Probability		Actual Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Actual
0.002	129,513	0.002	126,971	-2,542	2.0
0.005	118,545	0.005	115,872	-2,673	2.3
0.01	109,906	0.01	107,272	-2,634	2.5
0.02	100,904	0.02	98,435	-2,469	2.5
0.05	88,275	0.05	86,234	-2,041	2.4
0.1	77,943	0.1	76,405	-1,538	2.0
0.2	66,549	0.2	65,702	-847	1.3
0.5	48,076	0.5	48,561	485	1.0
0.8	33,672	0.8	35,247	1,575	4.5
0.9	27,601	0.9	29,591	1,990	6.7
0.95	23,266	0.95	25,513	2,247	8.8
0.99	16,608	0.99	19,134	2,526	13.2

Figure 23 displays pool probability curves comparing actual period of record data to that of HEC-ResSim. Studying the two pool probability curves shows HEC-ResSim's ability to have annual peak elevations at or near 3,640 ft msl when compared to the actual data. The reason for this has already been discussed, so no further discussion will be provided here. Second, examining the upper ends of the probability plots show HEC-ResSim over predicts annual peak elevations in many years. However, this doesn't always happen and the magnitude of over prediction, when it occurs, seems to decrease above elevation 3,640 ft msl.

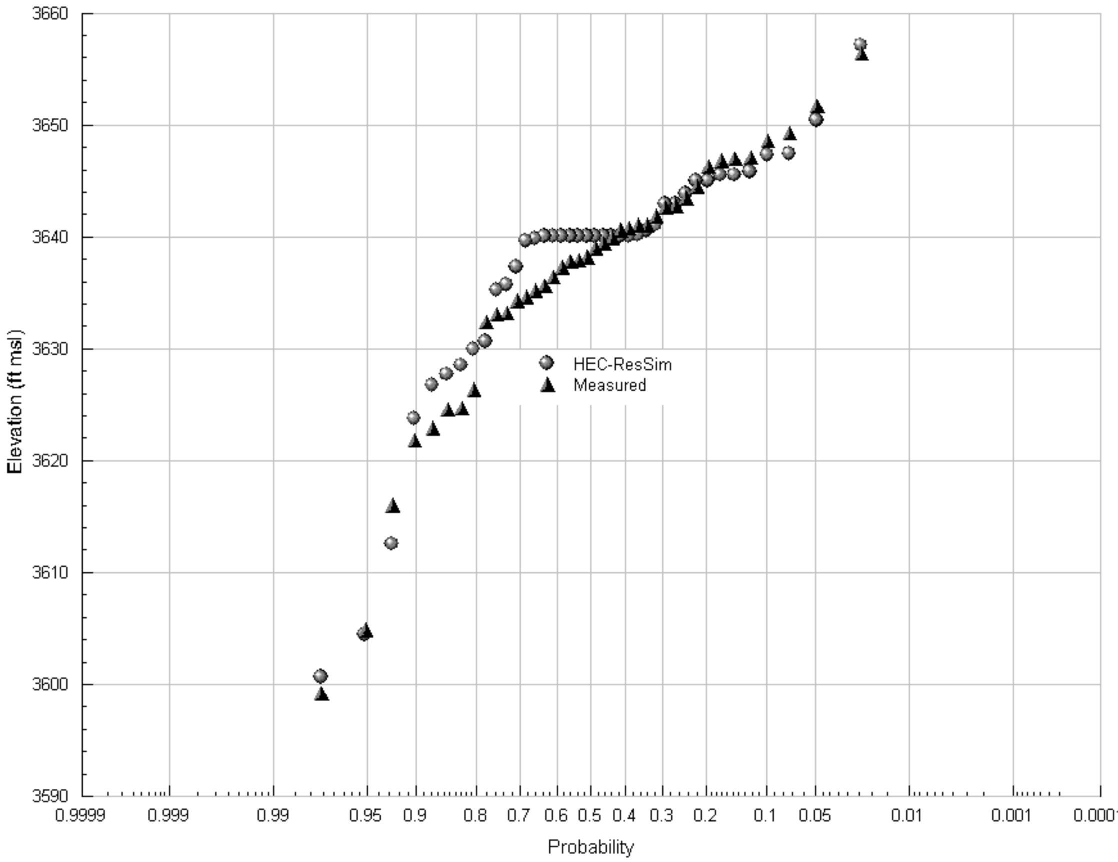

Figure 23. Pool probability plot comparing HEC-ResSim data with actual data over the modeled period of record.

Upon completion of the model calibration, results from the reallocated simulation could be evaluated. Figures 24 through 33 provide a comparison of the baseline and reallocated Yellowtail Dam reservoir elevation and outflow information. Inspecting the elevation data shows the reallocated condition normally reached a higher annual peak elevation than the baseline condition.

Studying the outflow data showed higher pool elevations did not always translate into higher releases. Depending on the circumstance, releases from the reallocated condition exceeded the baseline condition, decreased compared to the baseline condition, were initiated earlier or held later with little change to maximum outflow, or were kept close to the same. Two example years when flow increases were observed were 1993 and 1998. Storing more water in the reservoir allowed it to reach elevation 3,645.0 ft msl both years. However, to evacuate this extra storage within the timeframe allocated required peak outflows be increased from approximately 9,700 cfs to 13,700 cfs and 10,000 cfs to 13,800 cfs, respectively. Though these releases were not made for a long period of time (1 day in 1993 and 5 days in 1998), this does show there is the possibility of needing to perform higher releases in order to evacuate extra reservoir storage as a result of the reallocation.

There are also times where the baseline condition released higher annual peak flows than the reallocated condition. One example when this happened was 1969. For the reallocated condition, maximum outflow was approximately 7,000 cfs. The baseline condition had a maximum outflow of approximately 12,000 cfs. In this case, the baseline condition was trying to evacuate storage and remain close to the guide curve. This resulted in higher releases. Conversely, for the reallocated condition additional storage allowed the reservoir to hold more water for longer – thus reducing the peak outflow while still maintaining close to the desired guide curve elevations.

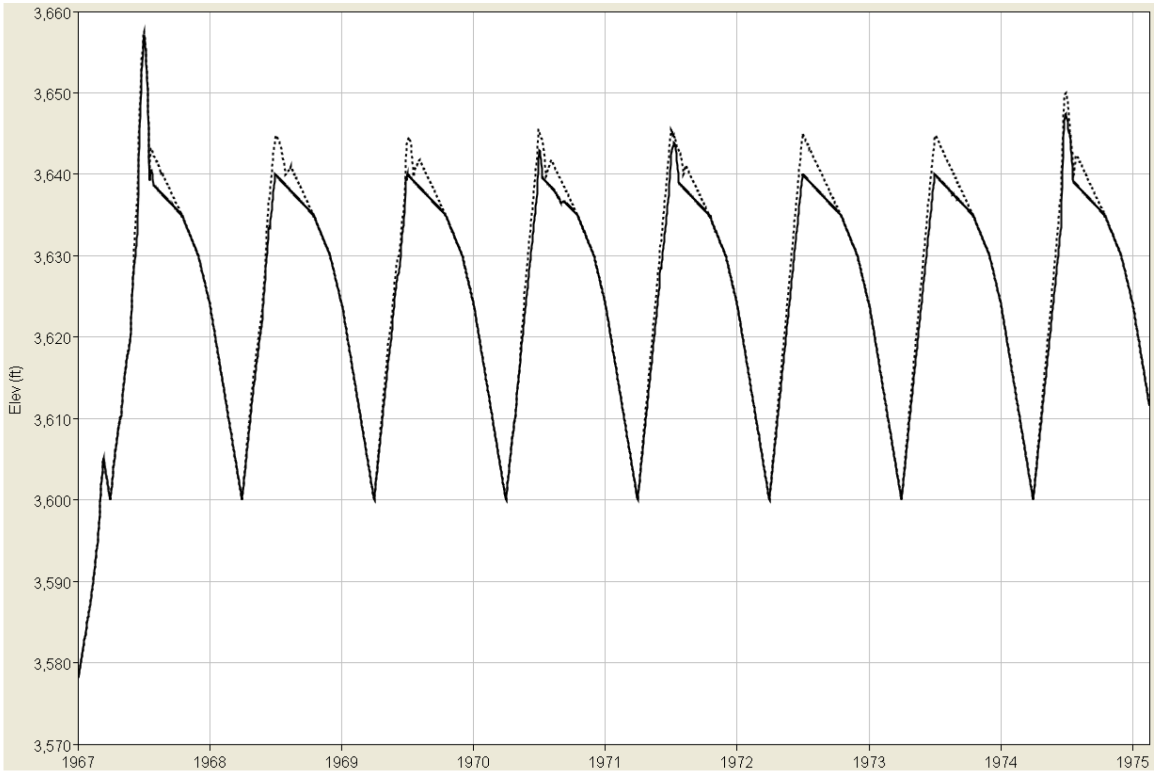

Figure 24. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1967-1975.

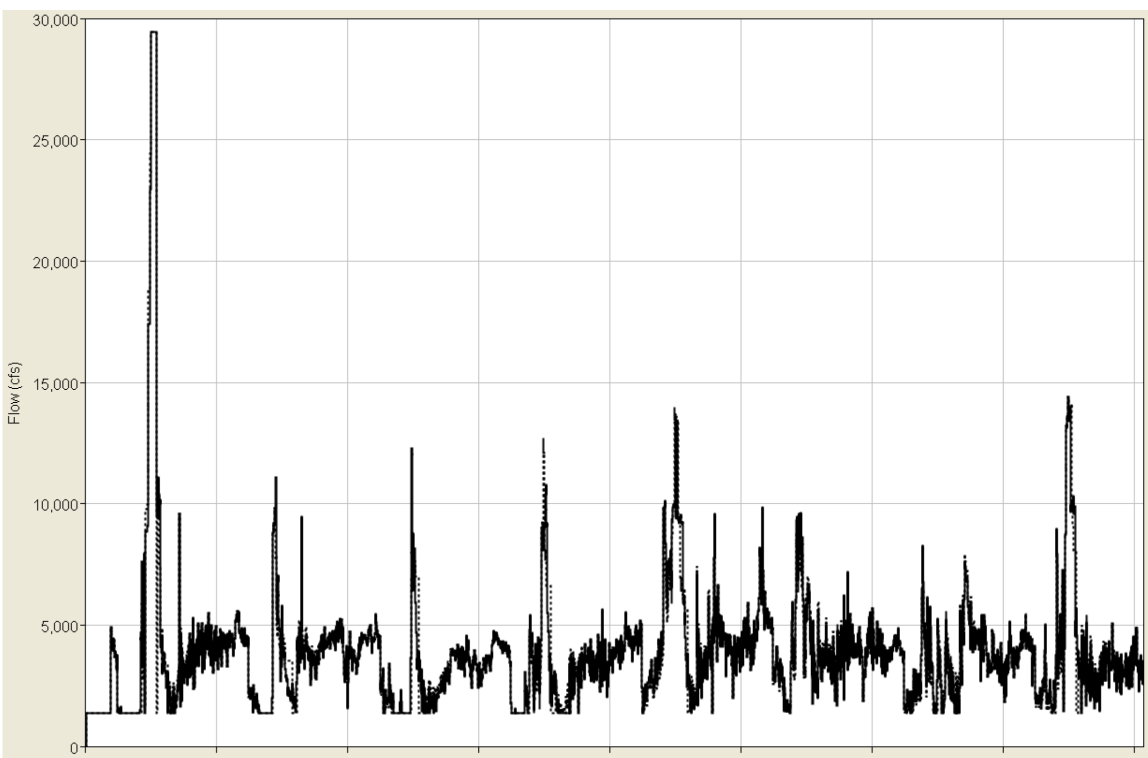

Figure 25. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1967-1975.

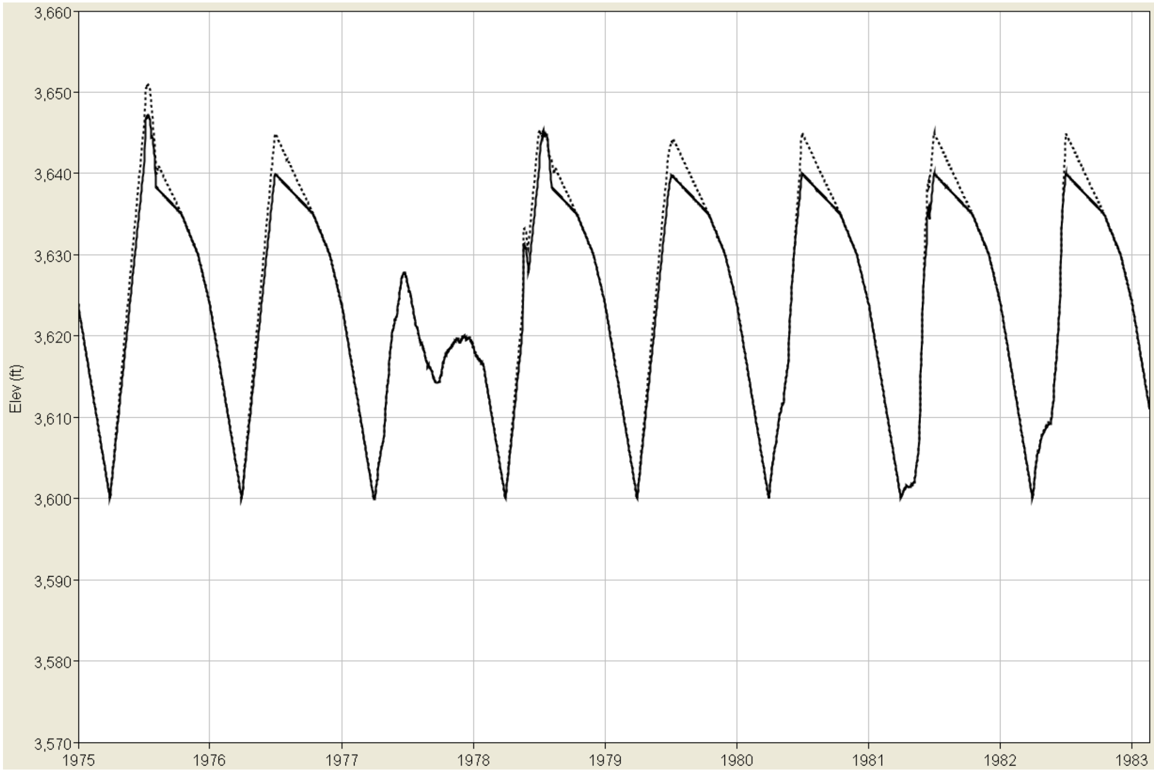

Figure 26. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1975-1983.

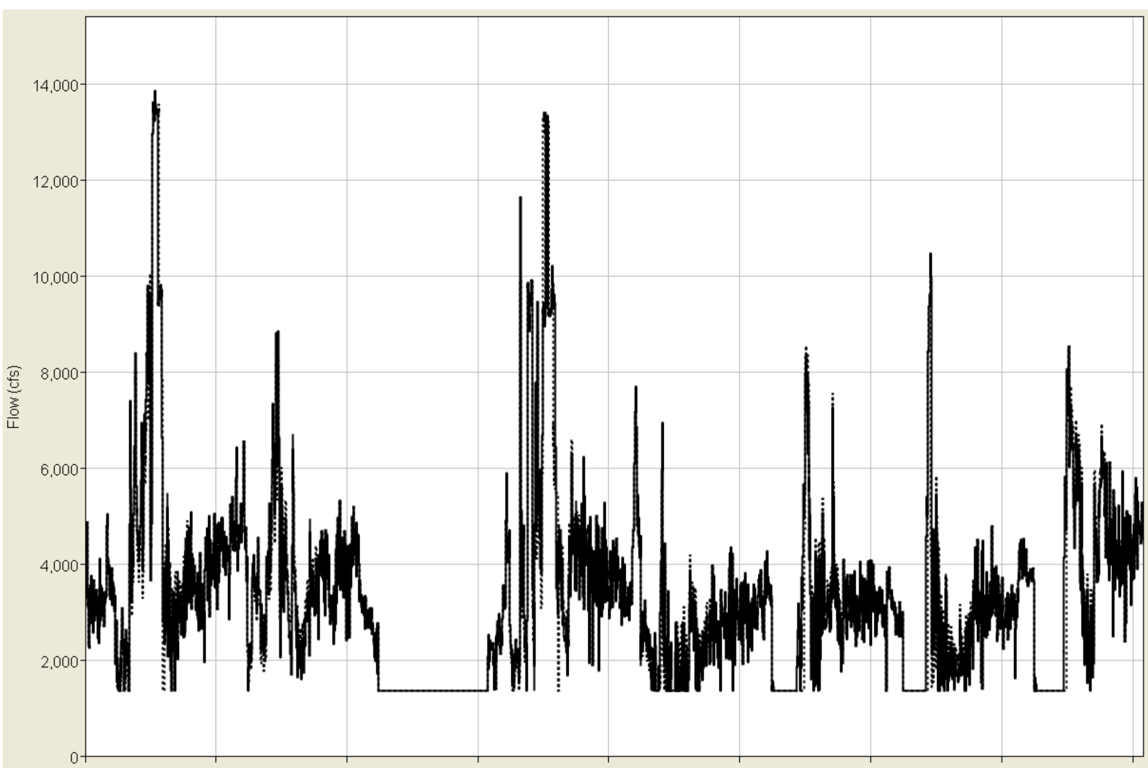

Figure 27. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1975-1983.

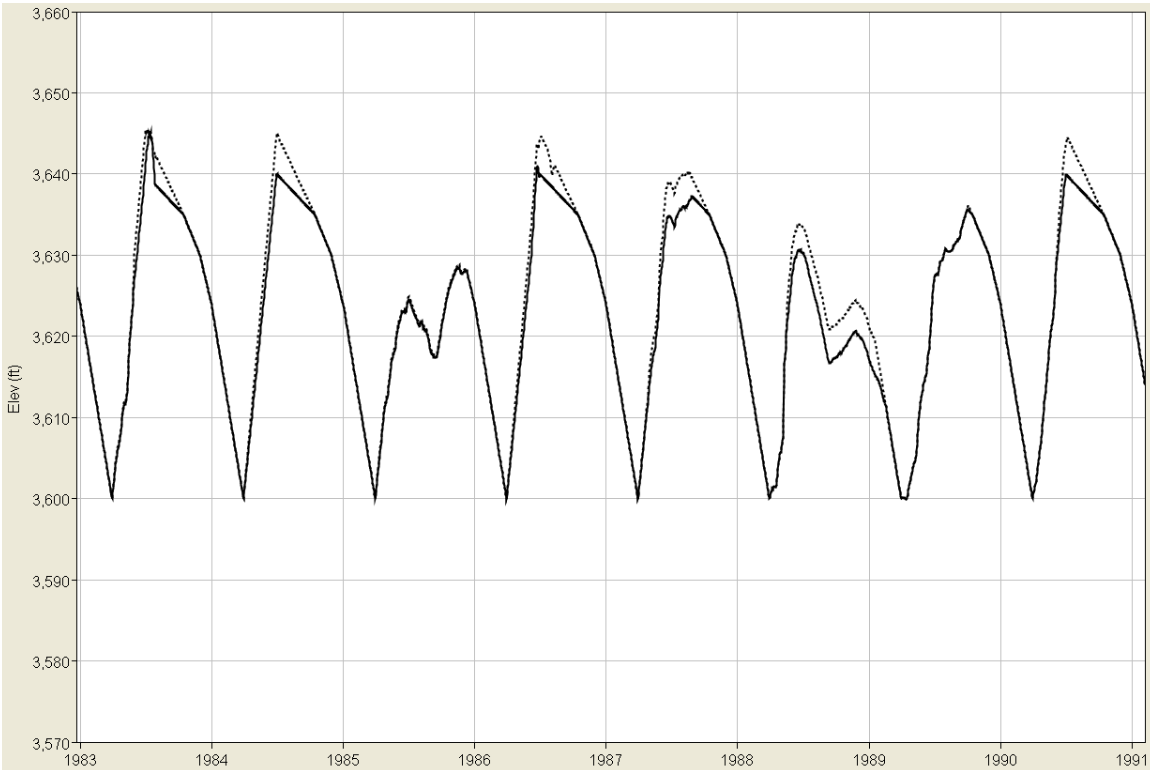

Figure 28. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1983-1991.

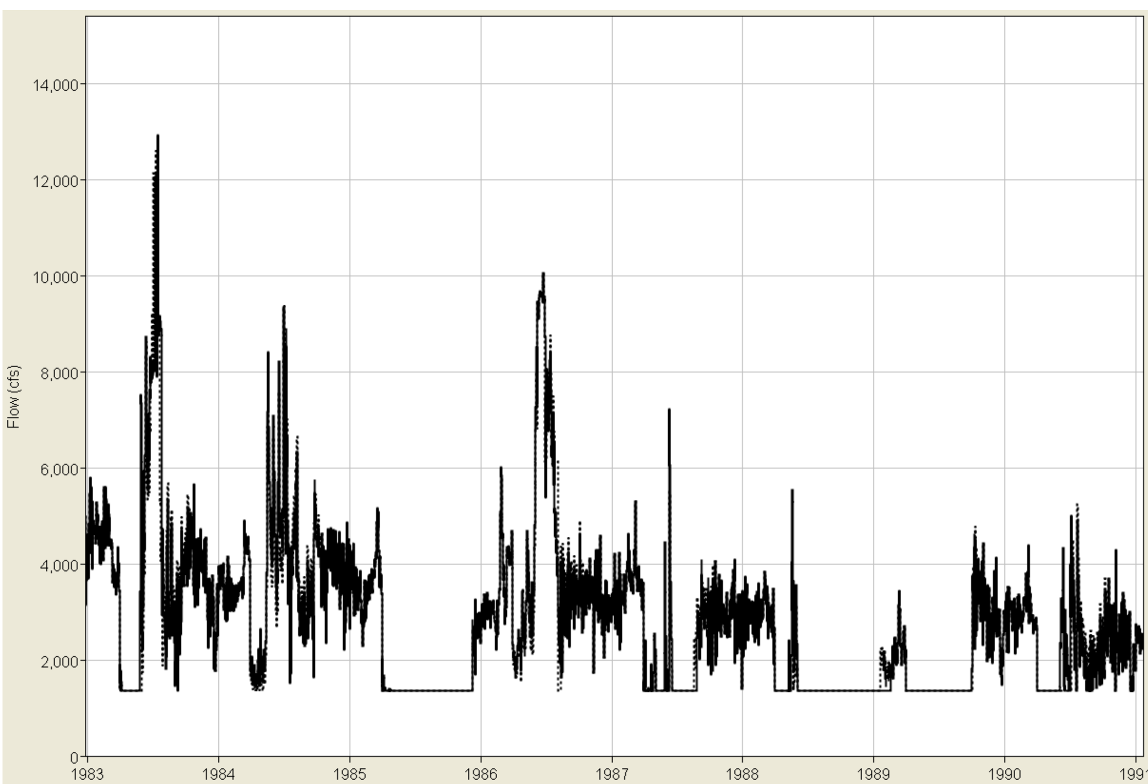

Figure 29. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1983-1991.

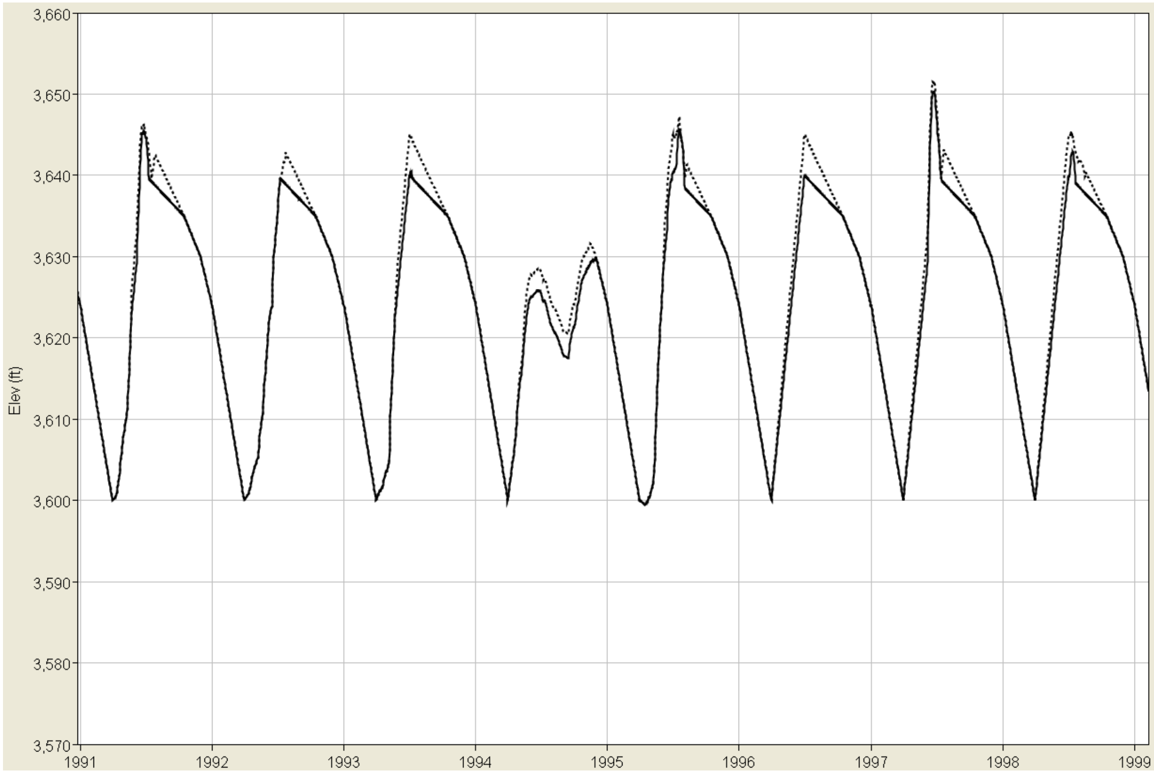

Figure 30. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1991-1999.

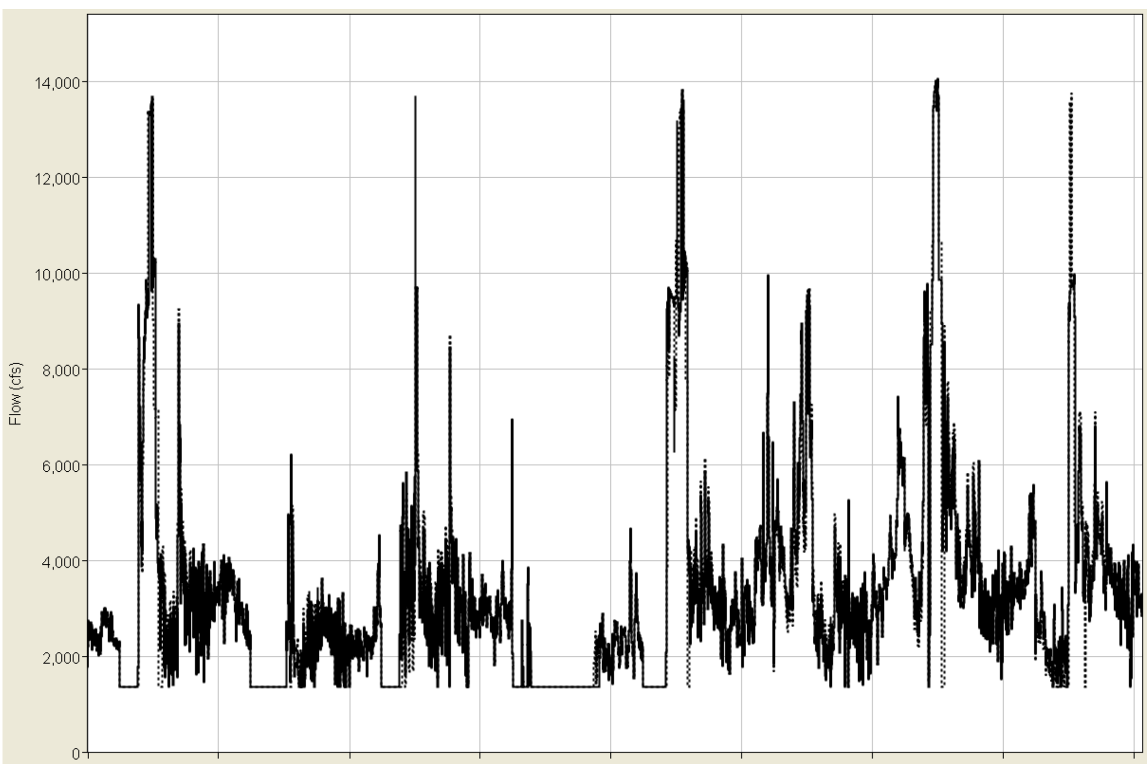

Figure 31. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1991-1999.

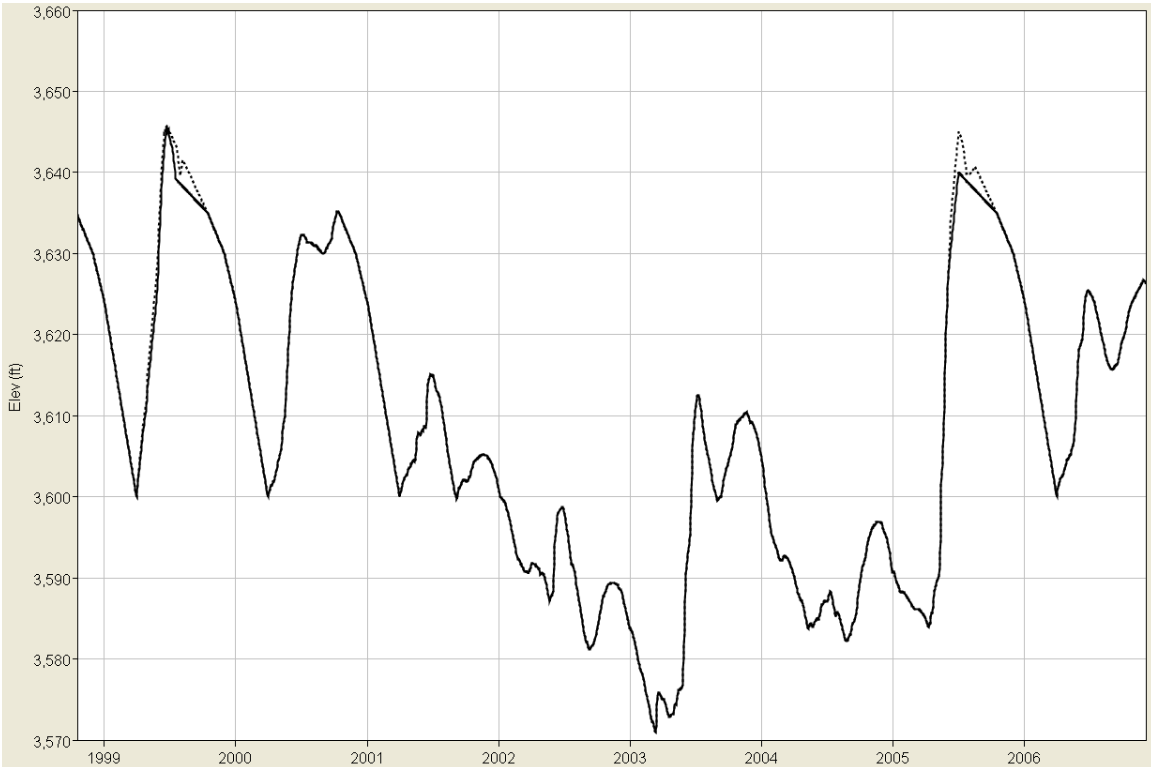

Figure 32. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1999-2006.

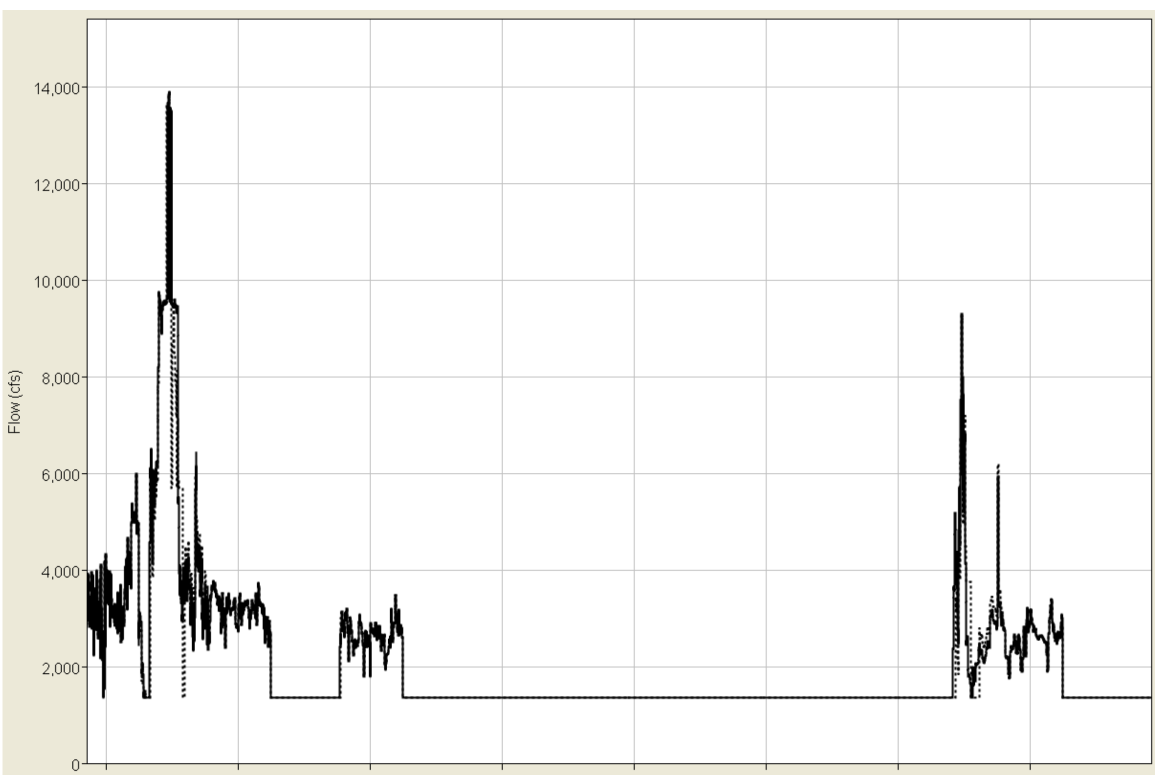

Figure 33. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1999-2006.

Tables 30, 31, and 32 provide information related to the pool duration analysis that was completed for Yellowtail Dam. These tables provide a comparison between the baseline and reallocated conditions. Five timeframes were evaluated as part of this analysis. They included annual, winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep), and fall (Oct-Dec) timeframes. The Julian days these timeframes represent are 1-365, 1-90, 91-181, 182-273, and 274-365, respectively. Figures of the pool duration curves can be found in Appendix B.

Results from this analysis show, with the exception of the winter analysis, the reallocated pool elevations being higher at duration percentages lower than about 80%. In addition, the largest incremental differences appear to be between roughly the 0.2 – 10% range. It does appear the spring and summer analyses are the most sensitive to the reallocation. This is because these are the timeframes when the reallocation of joint use storage would have the largest impact on the operation of Yellowtail Dam.

Table 30. Pool duration analysis for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual			Winter		
Percent exceeded	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)
0.01	3,657.0	3,657.4	0.4	3,623.7	3,623.7	0.0
0.05	3,654.2	3,655.2	1.0	3,623.7	3,623.7	0.0
0.1	3,652.1	3,653.5	1.4	3,623.7	3,623.7	0.0
0.2	3,649.2	3,651.5	2.3	3,623.6	3,623.6	0.0
0.5	3,645.7	3,647.8	2.1	3,623.4	3,623.4	0.0
1.0	3,644.3	3,645.4	1.1	3,623.3	3,623.3	0.0
2.0	3,641.2	3,644.7	3.5	3,623.1	3,623.1	0.0
5.0	3,639.2	3,642.9	3.7	3,622.4	3,622.4	0.0
10.0	3,637.9	3,640.7	2.8	3,621.0	3,621.0	0.0
15.0	3,636.8	3,639.0	2.2	3,619.5	3,619.7	0.2
20.0	3,635.8	3,637.0	1.2	3,618.1	3,618.2	0.1
30.0	3,632.5	3,633.0	0.5	3,615.4	3,615.5	0.1
40.0	3,628.3	3,629.1	0.8	3,612.7	3,612.7	0.0
50.0	3,623.5	3,624.2	0.7	3,610.2	3,610.2	0.0
60.0	3,618.1	3,618.8	0.7	3,607.3	3,607.3	0.0
70.0	3,612.1	3,612.4	0.3	3,604.7	3,604.7	0.0
80.0	3,606.2	3,606.3	0.1	3,602.0	3,602.0	0.0
85.0	3,603.5	3,603.5	0.0	3,600.6	3,600.6	0.0
90.0	3,601.1	3,601.2	0.1	3,596.6	3,596.6	0.0
95.0	3,590.9	3,590.9	0.0	3,587.7	3,587.7	0.0
98.0	3,584.8	3,584.8	0.0	3,582.0	3,582.0	0.0
99.0	3,581.2	3,581.2	0.0	3,580.2	3,580.2	0.0
99.5	3,575.5	3,575.5	0.0	3,578.8	3,578.8	0.0
99.8	3,574.2	3,574.2	0.0	3,577.3	3,577.3	0.0
99.9	3,573.7	3,573.7	0.0	3,576.4	3,576.4	0.0
99.95	3,573.2	3,573.2	0.0	3,575.6	3,575.6	0.0
99.99	3,572.4	3,572.4	0.0	3,574.1	3,574.1	0.0

Table 31. Pool duration analysis for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring			Summer		
Percent exceeded	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)
0.01	3,656.4	3,657.0	0.6	3,657.1	3,657.5	0.4
0.05	3,656.0	3,656.8	0.8	3,656.2	3,657.1	0.9
0.1	3,654.6	3,656.2	1.6	3,653.4	3,655.9	2.5
0.2	3,652.3	3,655.0	2.7	3,650.0	3,653.8	3.8
0.5	3,648.2	3,652.7	4.5	3,647.0	3,650.5	3.5
1.0	3,644.8	3,650.4	5.6	3,645.7	3,647.9	2.2
2.0	3,641.6	3,647.6	6.0	3,644.5	3,645.5	1.0
5.0	3,638.6	3,643.2	4.6	3,641.7	3,644.6	2.9
10.0	3,635.5	3,639.3	3.8	3,639.6	3,643.9	4.3
15.0	3,632.3	3,635.7	3.4	3,639.2	3,642.9	3.7
20.0	3,629.6	3,632.5	2.9	3,638.8	3,642.1	3.3
30.0	3,624.9	3,626.8	1.9	3,638.2	3,640.8	2.6
40.0	3,620.2	3,621.6	1.4	3,637.6	3,640.0	2.4
50.0	3,615.3	3,616.3	1.0	3,636.9	3,639.0	2.1
60.0	3,610.5	3,611.1	0.6	3,636.4	3,637.8	1.4
70.0	3,606.7	3,606.9	0.2	3,635.7	3,636.6	0.9
80.0	3,603.2	3,603.3	0.1	3,623.8	3,624.9	1.1
85.0	3,601.9	3,602.0	0.1	3,618.9	3,620.7	1.8
90.0	3,600.2	3,600.4	0.2	3,614.4	3,614.4	0.0
95.0	3,588.6	3,588.6	0.0	3,599.0	3,599.0	0.0
98.0	3,583.6	3,583.6	0.0	3,584.8	3,584.8	0.0
99.0	3,582.0	3,582.0	0.0	3,584.2	3,584.2	0.0
99.5	3,580.7	3,580.7	0.0	3,583.7	3,583.7	0.0
99.8	3,579.3	3,579.3	0.0	3,583.2	3,583.2	0.0
99.9	3,578.4	3,578.4	0.0	3,582.9	3,582.9	0.0
99.95	3,577.6	3,577.6	0.0	3,582.6	3,582.6	0.0
99.99	3,576.1	3,576.1	0.0	3,582.1	3,582.1	0.0

Table 32. Pool duration analysis for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall		
Percent exceeded	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)
0.01	3,635.6	3,636.2	0.6
0.05	3,635.6	3,636.2	0.6
0.1	3,635.6	3,636.2	0.6
0.2	3,635.6	3,636.2	0.6
0.5	3,635.6	3,636.1	0.5
1.0	3,635.5	3,636.1	0.6
2.0	3,635.5	3,636.0	0.5
5.0	3,635.4	3,635.7	0.3
10.0	3,635.1	3,635.2	0.1
15.0	3,634.6	3,634.6	0.0
20.0	3,633.9	3,633.9	0.0
30.0	3,632.6	3,632.6	0.0
40.0	3,631.3	3,631.4	0.1
50.0	3,630.1	3,630.2	0.1
60.0	3,628.1	3,628.3	0.2
70.0	3,626.4	3,626.5	0.1
80.0	3,624.7	3,624.7	0.0
85.0	3,620.6	3,623.7	3.1
90.0	3,615.0	3,615.0	0.0
95.0	3,600.0	3,600.0	0.0
98.0	3,590.8	3,590.8	0.0
99.0	3,587.3	3,587.3	0.0
99.5	3,585.3	3,585.3	0.0
99.8	3,584.8	3,584.8	0.0
99.9	3,584.6	3,584.6	0.0
99.95	3,584.4	3,584.4	0.0
99.99	3,584.2	3,584.2	0.0

Tables 33 through 47 display the results of the flow duration analyses for Yellowtail Dam, St. Xavier, Bighorn, Miles City, and Sidney, respectively. Graphical representations of these tables can be found in Appendix C. In most cases, the winter and fall analyses do not show a substantial change between the baseline and reallocated conditions. An exception to this would be the fall analysis for Miles City. It shows the baseline condition having higher flows at the 0.05-2% exceedance levels.

In general, the annual flow duration tables did not show a large increase in flow at the lowest exceedance level. Normally, the location on the curve showing the most difference is in the 0.2-1% duration range with the reallocated simulation having the higher flows as compared to the baseline condition. The spring and summer flow duration tables display some differences when comparing the baseline and reallocated conditions. The spring analyses at Yellowtail Dam and St. Xavier show higher flows for the reallocated condition when looking at the

0.01-1% durations. The Bighorn spring duration analysis displays the same descrepency as the calibration run with the baseline condition having a much higher flow at the 0.05% duration. The summer analyses show that at durations of 1-2% the reallocated condition has flows higher than the baseline condition at Yellowtail Dam, St. Xavier, and Bighorn.

The flow duration analysis shows the reallocation of flood control storage to joint use storage does have an impact on outflows from the dam. Furthermore, river flows at certain downstream locations are also impacted. However, the magnitude of the impact changes seasonally. It appears the spring and summer timeframes show the most sensitivity to the reallocation (similar to the pool duration analysis). This can most likely be attributed to the fact that Yellowtail Dam operations are most affected by the reallocation during those timeframes.

Table 33. Flow duration analysis at Yellowtail Dam for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	29,354	29,353	-1	0.0	9,959	9,959	0	0.0
0.05	27,029	27,083	54	0.2	9,775	9,775	0	0.0
0.1	25,258	25,402	144	0.6	9,135	9,135	0	0.0
0.2	22,233	23,192	959	4.3	8,192	8,192	0	0.0
0.5	14,345	18,002	3,657	25.5	6,877	6,877	0	0.0
1.0	9,930	11,556	1,626	16.4	6,163	6,163	0	0.0
2.0	9,535	9,471	-64	0.7	5,543	5,543	0	0.0
5.0	6,781	6,628	-153	2.3	4,921	4,921	0	0.0
10.0	4,865	4,872	7	0.1	4,575	4,575	0	0.0
15.0	4,387	4,397	10	0.2	4,343	4,341	-1	0.0
20.0	4,059	4,073	14	0.3	4,136	4,135	-1	0.0
30.0	3,537	3,565	28	0.8	3,761	3,761	0	0.0
40.0	3,138	3,168	30	1.0	3,468	3,468	0	0.0
50.0	2,752	2,770	18	0.7	3,209	3,209	0	0.0
60.0	2,285	2,258	-27	1.2	2,950	2,949	-1	0.0
70.0	1,369	1,351	-18	1.3	2,671	2,670	-2	0.1
80.0	1,351	1,351	0	0.0	2,264	2,260	-4	0.2
85.0	1,351	1,351	0	0.0	1,749	1,852	103	5.9
90.0	1,351	1,351	0	0.0	1,394	1,395	1	0.1
95.0	1,351	1,351	0	0.0	1,386	1,387	1	0.0
98.0	1,350	1,350	0	0.0	1,379	1,379	0	0.0
99.0	1,350	1,350	0	0.0	1,374	1,375	0	0.0
99.5	1,350	1,350	0	0.0	1,371	1,371	0	0.0
99.8	1,350	1,350	0	0.0	1,367	1,367	0	0.0
99.9	1,350	1,350	0	0.0	1,365	1,365	0	0.0
99.95	1,350	1,350	0	0.0	1,363	1,363	0	0.0
99.99	1,350	1,350	0	0.0	1,359	1,359	0	0.0

Table 34. Flow duration analysis at Yellowtail Dam for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	22,963	24,441	1,478	6.4	29,445	29,444	-1	0.0
0.05	22,688	24,165	1,477	6.5	29,230	29,223	-7	0.0
0.1	21,650	23,119	1,469	6.8	28,450	28,439	-11	0.0
0.2	19,827	21,267	1,440	7.3	27,116	27,139	23	0.1
0.5	16,198	17,535	1,337	8.3	24,361	24,760	399	1.6
1.0	12,536	13,710	1,174	9.4	16,505	21,323	4,818	29.2
2.0	9,776	9,826	50	0.5	10,091	14,893	4,802	47.6
5.0	9,158	8,894	-264	2.9	9,429	9,163	-266	2.8
10.0	6,671	5,953	-718	10.8	6,524	6,755	231	3.5
15.0	4,977	4,419	-558	11.2	4,927	5,475	548	11.1
20.0	4,116	3,547	-569	13.8	4,206	4,579	373	8.9
30.0	2,748	2,273	-475	17.3	3,459	3,745	286	8.3
40.0	2,021	1,480	-541	26.8	2,970	3,235	265	8.9
50.0	1,399	1,395	-4	0.3	2,453	2,700	247	10.1
60.0	1,394	1,391	-3	0.2	1,962	2,090	128	6.5
70.0	1,389	1,387	-2	0.1	1,398	1,398	0	0.0
80.0	1,384	1,382	-2	0.1	1,392	1,391	-1	0.1
85.0	1,381	1,379	-2	0.1	1,388	1,387	-1	0.1
90.0	1,378	1,376	-2	0.1	1,384	1,383	-1	0.1
95.0	1,374	1,372	-2	0.1	1,378	1,378	0	0.0
98.0	1,369	1,368	-1	0.1	1,373	1,372	-1	0.1
99.0	1,367	1,366	-1	0.1	1,370	1,369	-1	0.1
99.5	1,365	1,364	-1	0.1	1,367	1,367	0	0.0
99.8	1,362	1,362	0	0.0	1,364	1,364	0	0.0
99.9	1,361	1,361	0	0.0	1,362	1,362	0	0.0
99.95	1,360	1,359	-1	0.1	1,361	1,361	0	0.0
99.99	1,357	1,356	-1	0.1	1,358	1,357	-1	0.1

Table 35. Flow duration analysis at Yellowtail Dam for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	9,564	9,564	0	0.0
0.05	8,875	8,860	-15	0.2
0.1	7,504	7,496	-8	0.1
0.2	6,784	6,873	88	1.3
0.5	6,017	6,228	211	3.5
1.0	5,581	5,708	127	2.3
2.0	5,169	5,214	44	0.9
5.0	4,669	4,712	43	0.9
10.0	4,338	4,380	42	1.0
15.0	4,130	4,165	34	0.8
20.0	3,912	3,946	35	0.9
30.0	3,541	3,580	40	1.1
40.0	3,244	3,298	54	1.7
50.0	2,991	3,033	42	1.4
60.0	2,713	2,747	34	1.2
70.0	2,355	2,380	25	1.1
80.0	1,399	1,399	0	0.0
85.0	1,394	1,394	0	0.0
90.0	1,389	1,389	0	0.0
95.0	1,382	1,382	0	0.0
98.0	1,376	1,376	0	0.0
99.0	1,372	1,372	0	0.0
99.5	1,369	1,369	0	0.0
99.8	1,366	1,366	0	0.0
99.9	1,364	1,364	0	0.0
99.95	1,362	1,362	0	0.0
99.99	1,358	1,358	0	0.0

Table 36. Flow duration analysis at St. Xavier for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	31,089	31,079	-10	0.0	10,021	10,021	0	0.0
0.05	27,710	27,606	-104	0.4	9,817	9,817	0	0.0
0.1	25,331	25,307	-24	0.1	9,119	9,119	0	0.0
0.2	22,423	22,684	261	1.2	8,106	8,106	0	0.0
0.5	15,745	17,844	2,099	13.3	6,768	6,768	0	0.0
1.0	10,192	12,968	2,776	27.2	6,080	6,080	0	0.0
2.0	9,974	9,958	-16	0.2	5,498	5,498	0	0.0
5.0	7,145	6,901	-244	3.4	4,997	4,997	0	0.0
10.0	5,026	5,035	9	0.2	4,622	4,622	0	0.0
15.0	4,510	4,528	18	0.4	4,394	4,394	0	0.0
20.0	4,191	4,220	29	0.7	4,196	4,196	0	0.0
30.0	3,677	3,716	39	1.1	3,806	3,806	0	0.0
40.0	3,315	3,341	26	0.8	3,523	3,523	0	0.0
50.0	2,949	2,961	12	0.4	3,292	3,292	0	0.0
60.0	2,553	2,537	-16	0.6	3,030	3,030	0	0.0
70.0	2,032	1,974	-58	2.9	2,791	2,791	0	0.0
80.0	1,670	1,633	-37	2.2	2,464	2,466	2	0.1
85.0	1,519	1,505	-14	0.9	2,060	2,108	48	2.3
90.0	1,427	1,419	-8	0.6	1,538	1,549	11	0.7
95.0	1,334	1,328	-6	0.4	1,439	1,440	1	0.1
98.0	1,239	1,230	-9	0.7	1,368	1,372	4	0.3
99.0	1,169	1,158	-11	0.9	1,324	1,331	7	0.5
99.5	1,086	1,069	-17	1.6	1,278	1,291	13	1.0
99.8	967	913	-54	5.6	1,214	1,237	23	1.9
99.9	918	788	-130	14.2	1,158	1,194	36	3.1
99.95	875	673	-202	23.1	1,087	1,157	70	6.4
99.99	797	509	-288	36.1	911	880	-31	3.4

Table 37. Flow duration analysis at St. Xavier for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	20,882	22,218	1,336	6.4	31,228	31,228	0	0.0
0.05	20,700	21,956	1,256	6.1	30,895	30,862	-33	0.1
0.1	19,972	20,981	1,009	5.1	29,727	29,612	-115	0.4
0.2	18,596	19,306	710	3.8	27,818	27,662	-156	0.6
0.5	15,563	16,083	520	3.3	24,363	24,478	115	0.5
1.0	12,113	12,976	863	7.1	18,804	21,047	2,243	11.9
2.0	10,093	10,114	21	0.2	10,505	16,201	5,696	54.2
5.0	9,732	9,138	-594	6.1	9,959	9,897	-62	0.6
10.0	6,780	6,144	-636	9.4	7,301	7,192	-109	1.5
15.0	5,175	4,526	-649	12.5	5,333	5,842	509	9.5
20.0	4,245	3,704	-541	12.7	4,585	4,934	349	7.6
30.0	2,960	2,489	-471	15.9	3,807	4,086	279	7.3
40.0	2,258	2,024	-234	10.4	3,322	3,582	260	7.8
50.0	1,926	1,831	-95	4.9	2,842	3,081	239	8.4
60.0	1,729	1,655	-74	4.3	2,416	2,588	172	7.1
70.0	1,543	1,511	-32	2.1	2,053	2,051	-2	0.1
80.0	1,425	1,412	-13	0.9	1,887	1,863	-24	1.3
85.0	1,375	1,365	-10	0.7	1,804	1,765	-39	2.2
90.0	1,324	1,313	-11	0.8	1,658	1,606	-52	3.1
95.0	1,248	1,234	-14	1.1	1,431	1,404	-27	1.9
98.0	1,142	1,122	-20	1.8	1,312	1,298	-14	1.1
99.0	999	977	-22	2.2	1,247	1,231	-16	1.3
99.5	943	840	-103	10.9	1,188	1,168	-20	1.7
99.8	884	675	-209	23.6	1,107	1,095	-12	1.1
99.9	848	579	-269	31.7	1,092	1,049	-43	3.9
99.95	817	519	-298	36.5	1,082	1,014	-68	6.3
99.99	760	496	-264	34.7	1,065	996	-69	6.5

Table 38. Flow duration analysis at St. Xavier for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	9,258	9,258	0	0.0
0.05	7,535	7,531	-4	0.1
0.1	6,939	6,978	38	0.6
0.2	6,549	6,628	79	1.2
0.5	6,112	6,242	131	2.1
1.0	5,669	5,844	175	3.1
2.0	5,178	5,232	54	1.0
5.0	4,713	4,803	90	1.9
10.0	4,434	4,478	44	1.0
15.0	4,214	4,260	46	1.1
20.0	4,012	4,058	46	1.1
30.0	3,672	3,719	47	1.3
40.0	3,412	3,453	40	1.2
50.0	3,175	3,216	41	1.3
60.0	2,913	2,940	27	0.9
70.0	2,588	2,611	24	0.9
80.0	1,677	1,696	20	1.2
85.0	1,506	1,514	9	0.6
90.0	1,418	1,422	4	0.3
95.0	1,326	1,330	3	0.2
98.0	1,230	1,230	1	0.1
99.0	1,166	1,166	0	0.0
99.5	1,107	1,107	0	0.0
99.8	1,011	1,011	0	0.0
99.9	985	985	0	0.0
99.95	967	967	0	0.0
99.99	936	936	0	0.0

Table 39. Flow duration analysis at Bighorn for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	49,076	49,101	25	0.1	13,113	13,113	0	0.0
0.05	34,247	34,650	403	1.2	12,986	12,986	0	0.0
0.1	27,119	27,532	413	1.5	12,511	12,511	0	0.0
0.2	22,397	23,021	624	2.8	11,711	11,711	0	0.0
0.5	16,440	17,702	1,262	7.7	10,238	10,238	0	0.0
1.0	12,780	14,079	1,299	10.2	8,909	8,909	0	0.0
2.0	10,856	11,075	219	2.0	7,545	7,545	0	0.0
5.0	8,339	7,772	-567	6.8	6,035	6,035	0	0.0
10.0	5,811	5,747	-64	1.1	5,169	5,169	0	0.0
15.0	4,971	4,969	-2	0.0	4,858	4,858	0	0.0
20.0	4,593	4,604	11	0.2	4,610	4,610	0	0.0
30.0	4,019	4,037	18	0.4	4,167	4,167	0	0.0
40.0	3,636	3,651	15	0.4	3,863	3,863	0	0.0
50.0	3,244	3,256	12	0.4	3,607	3,607	0	0.0
60.0	2,820	2,840	20	0.7	3,307	3,307	0	0.0
70.0	2,248	2,259	11	0.5	3,026	3,026	0	0.0
80.0	1,788	1,790	2	0.1	2,623	2,623	0	0.0
85.0	1,655	1,654	-1	0.1	2,074	2,147	73	3.5
90.0	1,537	1,530	-7	0.5	1,701	1,722	21	1.2
95.0	1,403	1,393	-10	0.7	1,524	1,533	9	0.6
98.0	1,265	1,244	-21	1.7	1,428	1,435	7	0.5
99.0	1,164	1,138	-26	2.2	1,359	1,373	14	1.0
99.5	1,075	1,042	-33	3.1	1,273	1,294	21	1.6
99.8	948	840	-108	11.4	1,133	1,183	50	4.4
99.9	752	644	-108	14.4	485	485	0	0.0
99.95	565	505	-60	10.6	398	398	0	0.0
99.99	369	345	-24	6.5	262	262	0	0.0

Table 40. Flow duration analysis at Bighorn for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	49,812	49,812	0	0.0	30,964	30,963	-1	0.0
0.05	37,007	26,700	-10,307	27.9	30,633	30,612	-21	0.1
0.1	23,982	22,191	-1,791	7.5	29,484	29,416	-68	0.2
0.2	20,616	19,429	-1,187	5.8	27,641	27,550	-91	0.3
0.5	16,855	16,469	-386	2.3	24,373	24,478	105	0.4
1.0	14,521	14,599	78	0.5	18,657	20,640	1,983	10.6
2.0	12,599	12,821	222	1.8	12,314	15,553	3,239	26.3
5.0	10,564	10,027	-537	5.1	9,922	10,085	163	1.6
10.0	8,246	7,617	-629	7.6	7,694	7,373	-321	4.2
15.0	6,578	6,041	-537	8.2	5,576	5,955	379	6.8
20.0	5,501	4,955	-546	9.9	4,682	5,035	353	7.5
30.0	4,073	3,691	-382	9.4	3,818	4,107	289	7.6
40.0	3,224	2,942	-282	8.7	3,266	3,497	231	7.1
50.0	2,594	2,425	-169	6.5	2,756	2,980	224	8.1
60.0	2,171	2,097	-74	3.4	2,287	2,453	166	7.3
70.0	1,922	1,889	-33	1.7	1,906	1,944	38	2.0
80.0	1,720	1,709	-11	0.6	1,681	1,674	-7	0.4
85.0	1,635	1,629	-6	0.4	1,588	1,569	-19	1.2
90.0	1,538	1,532	-6	0.4	1,484	1,457	-27	1.8
95.0	1,413	1,409	-4	0.3	1,360	1,321	-39	2.9
98.0	1,288	1,282	-6	0.5	1,250	1,201	-49	3.9
99.0	1,201	1,191	-10	0.8	1,190	1,123	-67	5.6
99.5	1,101	1,101	0	0.0	1,138	1,005	-133	11.7
99.8	983	983	0	0.0	1,098	766	-332	30.2
99.9	801	801	0	0.0	1,085	592	-493	45.4
99.95	605	605	0	0.0	1,075	493	-582	54.1
99.99	417	417	0	0.0	1,055	382	-673	63.8

Table 41. Flow duration analysis at Bighorn for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	9,990	9,990	0	0.0
0.05	9,102	9,325	224	2.5
0.1	7,490	7,833	343	4.6
0.2	6,961	7,101	140	2.0
0.5	6,464	6,527	63	1.0
1.0	6,113	6,150	37	0.6
2.0	5,624	5,712	88	1.6
5.0	5,033	5,112	79	1.6
10.0	4,743	4,785	42	0.9
15.0	4,530	4,567	37	0.8
20.0	4,334	4,375	41	0.9
30.0	3,965	3,997	32	0.8
40.0	3,698	3,746	48	1.3
50.0	3,451	3,504	53	1.5
60.0	3,170	3,214	45	1.4
70.0	2,813	2,852	39	1.4
80.0	1,854	1,897	43	2.3
85.0	1,614	1,621	7	0.4
90.0	1,481	1,481	0	0.0
95.0	1,336	1,336	-1	0.0
98.0	1,139	1,139	0	0.0
99.0	1,034	1,034	0	0.0
99.5	975	975	0	0.0
99.8	917	917	0	0.0
99.9	880	880	0	0.0
99.95	847	847	0	0.0
99.99	781	781	0	0.0

Table 42. Flow duration analysis at Miles City for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	87,615	87,615	0	0.0	43,994	43,994	0	0.0
0.05	76,207	76,224	17	0.0	43,150	43,150	0	0.0
0.1	71,749	71,774	25	0.0	40,307	40,307	0	0.0
0.2	67,181	67,075	-106	0.2	36,327	36,327	0	0.0
0.5	60,580	60,122	-458	0.8	29,138	29,138	0	0.0
1.0	52,948	52,695	-253	0.5	23,076	23,076	0	0.0
2.0	45,133	45,041	-92	0.2	17,705	17,705	0	0.0
5.0	34,408	34,141	-267	0.8	13,488	13,488	0	0.0
10.0	24,325	23,974	-351	1.4	10,743	10,743	0	0.0
15.0	17,515	17,408	-107	0.6	9,723	9,723	0	0.0
20.0	13,572	13,640	68	0.5	9,073	9,073	0	0.0
30.0	10,462	10,507	45	0.4	8,124	8,124	0	0.0
40.0	9,004	9,065	61	0.7	7,354	7,354	0	0.0
50.0	8,001	8,059	58	0.7	6,780	6,780	0	0.0
60.0	7,209	7,237	28	0.4	6,244	6,244	0	0.0
70.0	6,433	6,462	29	0.5	5,672	5,672	0	0.0
80.0	5,543	5,575	32	0.6	4,877	4,882	5	0.1
85.0	5,034	5,057	23	0.5	4,419	4,443	24	0.5
90.0	4,451	4,464	13	0.3	3,959	3,980	21	0.5
95.0	3,818	3,822	4	0.1	3,481	3,496	15	0.4
98.0	3,144	3,151	7	0.2	2,876	2,896	20	0.7
99.0	2,770	2,783	13	0.5	2,548	2,569	21	0.8
99.5	2,467	2,491	24	1.0	2,256	2,311	55	2.4
99.8	2,153	2,185	32	1.5	2,002	2,046	44	2.2
99.9	1,980	2,009	29	1.5	1,957	1,980	23	1.2
99.95	1,841	1,867	26	1.4	1,921	1,944	23	1.2
99.99	1,577	1,596	19	1.2	1,860	1,883	23	1.2

Table 43. Flow duration analysis at Miles City for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	88,645	88,645	0	0.0	71,317	72,309	992	1.4
0.05	86,292	86,292	0	0.0	70,852	71,435	583	0.8
0.1	80,670	80,670	0	0.0	69,542	69,343	-199	0.3
0.2	75,850	75,859	9	0.0	67,126	66,456	-670	1.0
0.5	69,009	68,999	-10	0.0	61,922	60,963	-959	1.5
1.0	63,487	63,381	-106	0.2	54,659	53,972	-687	1.3
2.0	56,978	56,791	-187	0.3	43,833	44,650	817	1.9
5.0	47,397	46,852	-545	1.1	34,598	35,301	703	2.0
10.0	39,859	39,206	-653	1.6	26,421	26,072	-349	1.3
15.0	34,000	33,598	-402	1.2	21,187	21,022	-165	0.8
20.0	29,883	29,441	-442	1.5	16,856	16,700	-156	0.9
30.0	22,282	22,016	-266	1.2	12,380	12,640	260	2.1
40.0	16,961	16,835	-126	0.7	10,458	10,597	139	1.3
50.0	13,080	12,934	-146	1.1	8,885	9,134	249	2.8
60.0	10,478	10,377	-101	1.0	7,719	7,949	230	3.0
70.0	8,428	8,366	-62	0.7	6,504	6,667	163	2.5
80.0	6,906	6,860	-46	0.7	5,428	5,574	146	2.7
85.0	6,275	6,244	-31	0.5	4,896	4,986	90	1.8
90.0	5,681	5,627	-54	1.0	4,247	4,256	9	0.2
95.0	4,970	4,946	-24	0.5	3,523	3,522	-1	0.0
98.0	4,267	4,255	-12	0.3	2,968	2,968	0	0.0
99.0	3,898	3,900	2	0.1	2,874	2,874	0	0.0
99.5	3,552	3,552	0	0.0	2,799	2,799	0	0.0
99.8	3,200	3,200	0	0.0	2,719	2,719	0	0.0
99.9	3,022	3,022	0	0.0	2,670	2,670	0	0.0
99.95	2,964	2,964	0	0.0	2,628	2,628	0	0.0
99.99	2,878	2,878	0	0.0	2,550	2,550	0	0.0

Table 44. Flow duration analysis at Miles City for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	19,882	20,160	278	1.4
0.05	19,730	18,659	-1,071	5.4
0.1	19,185	17,238	-1,947	10.1
0.2	18,266	15,974	-2,292	12.5
0.5	16,547	14,516	-2,031	12.3
1.0	14,951	13,536	-1,415	9.5
2.0	13,233	12,605	-628	4.7
5.0	11,166	11,284	118	1.1
10.0	10,316	10,400	84	0.8
15.0	9,786	9,854	68	0.7
20.0	9,260	9,340	80	0.9
30.0	8,505	8,558	53	0.6
40.0	7,886	7,941	55	0.7
50.0	7,416	7,446	30	0.4
60.0	7,000	7,017	17	0.2
70.0	6,312	6,362	50	0.8
80.0	5,356	5,387	31	0.6
85.0	4,811	4,818	7	0.1
90.0	4,425	4,425	0	0.0
95.0	3,972	3,975	3	0.1
98.0	3,343	3,343	0	0.0
99.0	2,806	2,806	0	0.0
99.5	2,317	2,317	0	0.0
99.8	1,953	1,953	0	0.0
99.9	1,809	1,809	0	0.0
99.95	1,687	1,687	0	0.0
99.99	1,468	1,468	0	0.0

Table 45. Flow duration analysis at Sidney for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	104,540	104,786	246	0.2	75,321	75,321	0	0.0
0.05	79,684	80,813	1,129	1.4	73,584	73,584	0	0.0
0.1	75,633	76,252	619	0.8	67,540	67,540	0	0.0
0.2	72,329	72,842	513	0.7	58,531	58,531	0	0.0
0.5	64,289	64,472	183	0.3	45,665	45,665	0	0.0
1.0	56,752	56,512	-240	0.4	36,855	36,855	0	0.0
2.0	49,664	49,167	-497	1.0	25,546	25,546	0	0.0
5.0	36,596	36,474	-122	0.3	16,245	16,245	0	0.0
10.0	25,321	24,988	-333	1.3	12,576	12,576	0	0.0
15.0	18,156	18,087	-69	0.4	11,050	11,050	0	0.0
20.0	14,175	14,203	28	0.2	10,168	10,168	0	0.0
30.0	10,918	10,976	58	0.5	9,023	9,023	0	0.0
40.0	9,459	9,505	46	0.5	8,085	8,085	0	0.0
50.0	8,306	8,360	54	0.7	7,367	7,367	0	0.0
60.0	7,394	7,426	32	0.4	6,744	6,744	0	0.0
70.0	6,551	6,575	24	0.4	6,077	6,077	0	0.0
80.0	5,533	5,570	37	0.7	5,131	5,142	11	0.2
85.0	4,904	4,948	44	0.9	4,665	4,694	29	0.6
90.0	4,344	4,393	49	1.1	4,267	4,292	25	0.6
95.0	3,519	3,544	25	0.7	3,631	3,652	21	0.6
98.0	2,458	2,466	8	0.3	2,836	2,870	34	1.2
99.0	1,831	1,830	-1	0.1	2,393	2,402	9	0.4
99.5	1,427	1,426	-1	0.1	2,069	2,070	1	0.0
99.8	1,068	1,068	0	0.0	1,217	1,216	-1	0.1
99.9	921	921	0	0.0	928	928	0	0.0
99.95	805	805	0	0.0	798	798	0	0.0
99.99	597	597	0	0.0	578	578	0	0.0

Table 46. Flow duration analysis at Sidney for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	106,452	106,432	-20	0.0	72,963	73,979	1,016	1.4
0.05	102,096	102,665	569	0.6	72,801	73,755	954	1.3
0.1	90,085	91,834	1,749	1.9	72,206	72,942	736	1.0
0.2	79,643	80,969	1,326	1.7	71,174	71,552	378	0.5
0.5	73,179	74,013	834	1.1	67,264	66,720	-544	0.8
1.0	67,457	68,348	891	1.3	57,996	57,649	-347	0.6
2.0	59,891	59,881	-10	0.0	48,339	48,632	293	0.6
5.0	51,155	50,586	-569	1.1	37,104	37,160	56	0.2
10.0	41,686	41,252	-434	1.0	27,556	27,548	-8	0.0
15.0	35,000	34,620	-380	1.1	22,087	21,947	-140	0.6
20.0	30,089	29,674	-415	1.4	17,000	16,898	-102	0.6
30.0	22,217	21,932	-285	1.3	12,314	12,578	264	2.1
40.0	16,966	16,851	-115	0.7	10,031	10,272	241	2.4
50.0	13,332	13,180	-152	1.1	8,310	8,584	274	3.3
60.0	10,841	10,777	-64	0.6	6,889	7,066	177	2.6
70.0	8,973	8,929	-44	0.5	5,666	5,822	156	2.8
80.0	7,258	7,205	-53	0.7	4,481	4,617	136	3.0
85.0	6,625	6,578	-47	0.7	3,968	4,033	65	1.6
90.0	5,986	5,962	-24	0.4	3,387	3,417	30	0.9
95.0	5,213	5,208	-5	0.1	2,436	2,439	3	0.1
98.0	4,498	4,498	0	0.0	1,652	1,651	-1	0.1
99.0	3,988	3,988	0	0.0	1,315	1,315	0	0.0
99.5	3,508	3,508	0	0.0	1,096	1,096	0	0.0
99.8	2,762	2,762	0	0.0	992	992	0	0.0
99.9	1,911	1,911	0	0.0	969	969	0	0.0
99.95	1,283	1,283	0	0.0	950	950	0	0.0
99.99	886	886	0	0.0	919	919	0	0.0

Table 47. Flow duration analysis at Sidney for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	30,291	30,570	279	0.9
0.05	27,577	27,770	193	0.7
0.1	21,609	21,633	24	0.1
0.2	18,974	18,982	8	0.0
0.5	16,723	16,743	20	0.1
1.0	15,180	15,205	25	0.2
2.0	13,756	13,789	33	0.2
5.0	11,998	12,058	60	0.5
10.0	10,749	10,835	86	0.8
15.0	10,184	10,265	81	0.8
20.0	9,718	9,790	72	0.7
30.0	8,972	9,011	39	0.4
40.0	8,255	8,288	33	0.4
50.0	7,651	7,679	28	0.4
60.0	7,145	7,163	18	0.3
70.0	6,424	6,451	27	0.4
80.0	5,491	5,518	27	0.5
85.0	4,979	4,986	7	0.1
90.0	4,474	4,488	14	0.3
95.0	3,861	3,870	9	0.2
98.0	2,765	2,765	0	0.0
99.0	1,974	1,974	0	0.0
99.5	1,443	1,443	0	0.0
99.8	1,011	1,011	0	0.0
99.9	881	881	0	0.0
99.95	774	774	0	0.0
99.99	587	587	0	0.0

Flow frequency data comparing the baseline and reallocated simulations can be found in tables 48-51, with Appendix D containing graphical representations. The locations where they were developed include St. Xavier, Bighorn, Miles City, and Sidney. Studying the data from St. Xavier and Bighorn show the reallocated condition has higher flows than the baseline condition at probabilities less than 0.2. The largest incremental difference in both cases is at the 0.002 probability, and from there the differences gradually decrease as probabilities increase. At probabilities greater than 0.2, the baseline condition actually posts flows that are higher than the reallocated condition – though the differences are relatively small. While differences do exist along the Yellowstone River locations at Miles City and Sidney, the incremental differences are relatively small in comparison with the river flow.

Table 48. Annual flow frequency analysis at St. Xavier. Table compares the baseline and reallocated conditions. Difference is calculated as reallocated-baseline.

Baseline Computed Probability		Reallocated Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Baseline
0.002	27,378	0.002	32,567	5,189	19.0
0.005	25,220	0.005	29,343	4,123	16.3
0.01	23,414	0.01	26,759	3,345	14.3
0.02	21,437	0.02	24,036	2,599	12.1
0.05	18,509	0.05	20,192	1,683	9.1
0.1	15,998	0.1	17,055	1,057	6.6
0.2	13,138	0.2	13,651	513	3.9
0.5	8,437	0.5	8,411	-26	0.3
0.8	4,939	0.8	4,779	-160	3.2
0.9	3,590	0.9	3,438	-152	4.2
0.95	2,701	0.95	2,573	-128	4.7
0.99	1,503	0.99	1,428	-75	5.0

Table 49. Annual flow frequency analysis at Bighorn. Table compares the baseline and reallocated conditions. Difference is calculated as reallocated-baseline.

Baseline Computed Probability		Reallocated Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Baseline
0.002	51,460	0.002	55,274	3,814	7.4
0.005	43,617	0.005	46,460	2,843	6.5
0.01	37,962	0.01	40,163	2,201	5.8
0.02	32,535	0.02	34,172	1,637	5.0
0.05	25,685	0.05	26,691	1,006	3.9
0.1	20,714	0.1	21,327	613	3.0
0.2	15,861	0.2	16,155	294	1.9
0.5	9,329	0.5	9,316	-13	0.1
0.8	5,343	0.8	5,239	-104	1.9
0.9	3,950	0.9	3,838	-112	2.8
0.95	3,060	0.95	2,953	-107	3.5
0.99	1,870	0.99	1,782	-88	4.7

Table 50. Annual flow frequency analysis at Miles City. Table compares the baseline and reallocated conditions. Difference is calculated as reallocated-baseline.

Baseline Computed Probability		Reallocated Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Baseline
0.002	119,042	0.002	119,347	305	0.3
0.005	108,239	0.005	108,448	209	0.2
0.01	99,928	0.01	100,067	139	0.1
0.02	91,442	0.02	91,512	70	0.1
0.05	79,817	0.05	79,798	-19	0.0
0.1	70,528	0.1	70,446	-82	0.1
0.2	60,491	0.2	60,347	-144	0.2
0.5	44,582	0.5	44,363	-219	0.5
0.8	32,360	0.8	32,109	-251	0.8
0.9	27,201	0.9	26,946	-255	0.9
0.95	23,490	0.95	23,237	-253	1.1
0.99	17,698	0.99	17,459	-239	1.4

Table 51. Annual flow frequency analysis at Sidney. Table compares the baseline and reallocated conditions. Difference is calculated as reallocated-baseline.

Baseline Computed Probability		Reallocated Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Baseline
0.002	129,513	0.002	128,968	-545	0.4
0.005	118,545	0.005	118,161	-384	0.3
0.01	109,906	0.01	109,619	-287	0.3
0.02	100,904	0.02	100,689	-215	0.2
0.05	88,275	0.05	88,116	-159	0.2
0.1	77,943	0.1	77,793	-150	0.2
0.2	66,549	0.2	66,375	-174	0.3
0.5	48,076	0.5	47,800	-276	0.6
0.8	33,672	0.8	33,293	-379	1.1
0.9	27,601	0.9	27,183	-418	1.5
0.95	23,266	0.95	22,826	-440	1.9
0.99	16,608	0.99	16,155	-453	2.7

Figure 34 shows the pool probability curves comparing the baseline and reallocated simulations. The largest difference between the two curves is caused by the change in reservoir operations required due to raising the joint use pool from elevation 3640 ft msl to elevation 3645 ft msl. At pool elevations below 3640-3645 ft msl, the curves mimic each other. At pool elevations above that interval the reallocated condition tends to achieve higher pool elevations at similar probabilities, but the differences in pool elevations are relatively small.

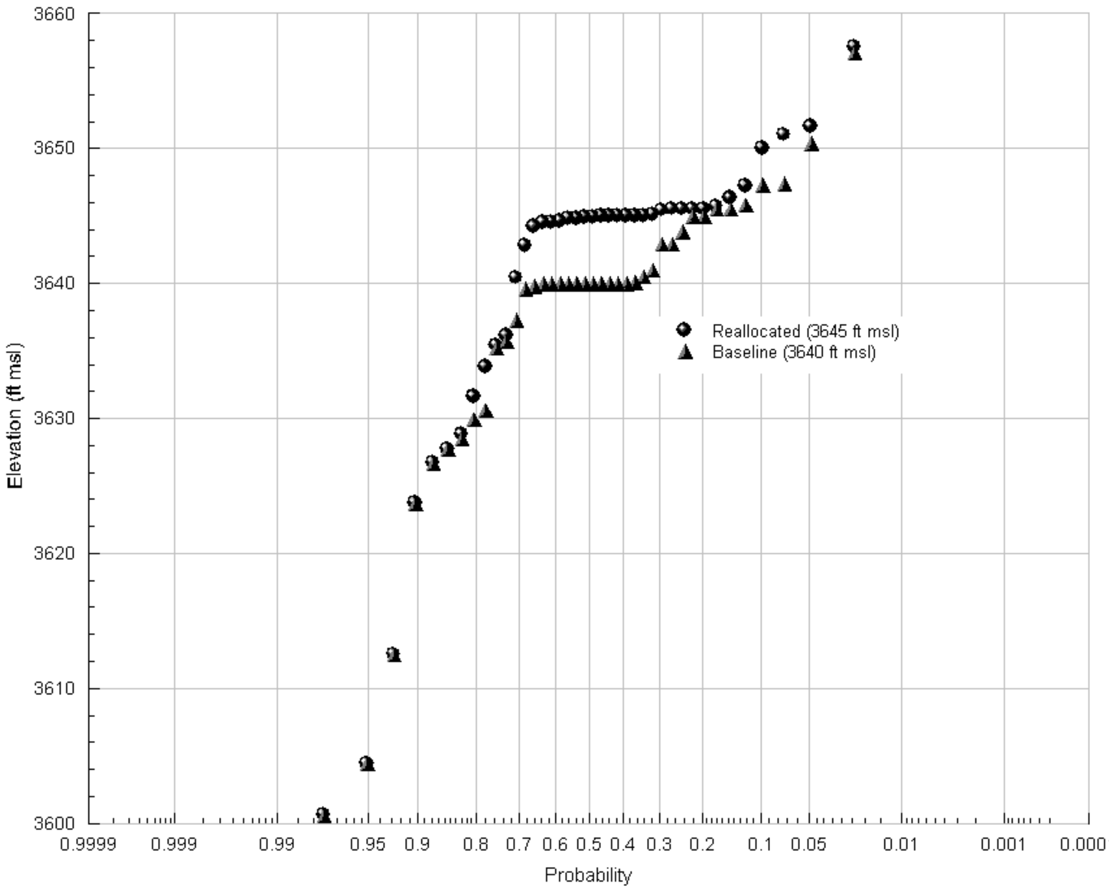

Figure 34. Pool probability plot comparing the baseline and reallocated simulations over the modeled period of record.

Tables 52 through 54 compare the downstream flood damage information for the baseline and reallocated HEC-ResSim simulations. As the discharge/damage curves showed (figures 5-9), the analysis is broken up into reaches with each reach's river flow being represented by the flow at a Yellowstone or Bighorn River location. The locations for the reaches are: reach 1 – Miles City, reach 2 – Miles City, reach 3 – Sidney, reach 5 – Hardin, and reach 6 – Bighorn.

Reach 5 and reach 6 did not show any change in flood damages as a result of the reallocation. Reach 3 did have some modest changes in flood damages. However, the reaches displaying the most impact from the reallocation were reaches 1 and 2 – with reach 1 being the most affected overall. Studying the period of record, reaches 1 and 2 yielded decreases in flood damages while reach 3 had an increase in flood damages.

This analysis shows locations along the Yellowstone River are more affected by the reallocation than locations along the Bighorn River when computing flood damages. During the simulation period, flows on the Bighorn River are generally kept below the limits where damages are incurred. However, these higher flows then combine with flows along the Yellowstone River, often at times when the

Yellowstone River is also experiencing high flows (such as spring snowmelt time). At these river flow levels, the discharge/damage curves along the Yellowstone River can be sensitive to changes in flow. Therefore, if the reallocated simulation models higher, or lower, river flows than the baseline condition at these areas, significant changes to flood damages can occur.

Table 52. Comparison of flood damages for reaches 1 and 2. Difference is calculated as reallocated-baseline.

Year	Reach 1				Reach 2			
	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline
1967	756.3	806.8	50.5	6.7	130.2	138.9	8.7	6.7
1968	56.3	52.1	-4.2	7.5	9.7	8.9	-0.7	7.6
1969	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1970	129.2	127.2	-2.0	1.5	22.2	21.9	-0.3	1.5
1971	116.6	91.9	-24.7	21.2	20.0	15.8	-4.3	21.3
1972	86.9	68.2	-18.7	21.5	14.9	11.7	-3.2	21.6
1973	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1974	733.8	762.6	28.8	3.9	126.3	131.3	5.0	3.9
1975	442.1	485.4	43.3	9.8	76.0	83.5	7.5	9.8
1976	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1977	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1978	1,654.5	1,654.5	0.0	0.0	285.2	285.2	0.0	0.0
1979	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1980	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1981	72.5	35.5	-37.0	51.0	12.4	6.1	-6.4	51.0
1982	290.9	153.8	-137.1	47.1	50.0	26.4	-23.6	47.1
1983	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1984	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1985	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1986	34.8	17.0	-17.8	51.1	6.0	2.9	-3.1	51.2
1987	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1988	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1989	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1990	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1991	201.8	199.5	-2.3	1.1	34.7	34.3	-0.4	1.1
1992	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1993	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1994	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1995	90.6	88.0	-2.6	2.9	15.6	15.1	-0.5	2.9
1996	389.5	377.1	-12.4	3.2	67.0	64.8	-2.1	3.2
1997	1,530.3	1,569.6	39.3	2.6	263.7	270.5	6.8	2.6
1998	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1999	0.0	26.6	26.6	n/a	0.0	4.6	4.6	n/a
2000	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2001	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2002	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2003	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2004	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2005	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2006	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
SUM	6,586.1	6,515.8	-70.3	1.1	1,133.8	1,121.8	-12.0	1.1
Average Annual	164.7	162.9	-1.8	1.1	28.3	28.0	-0.3	1.1

Table 53. Comparison of flood damages for reaches 3 and 5. Difference is calculated as reallocated-baseline.

Year	Reach 3				Reach 5			
	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline
1967	83.2	84.4	1.2	1.4	31.7	31.7	0.0	0.0
1968	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1969	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1970	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1971	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1972	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1973	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1974	48.7	50.7	2.0	4.1	0.0	0.0	0.0	n/a
1975	40.7	45.0	4.2	10.4	0.0	0.0	0.0	n/a
1976	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1977	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1978	450.6	450.2	-0.4	0.1	0.0	0.0	0.0	n/a
1979	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1980	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1981	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1982	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1983	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1984	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1985	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1986	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1987	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1988	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1989	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1990	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1991	5.2	4.3	-0.9	17.7	0.0	0.0	0.0	n/a
1992	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1993	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1994	56.1	56.1	0.0	0.0	0.0	0.0	0.0	n/a
1995	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1996	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1997	139.5	143.6	4.1	3.0	0.0	0.0	0.0	n/a
1998	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1999	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2000	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2001	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2002	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2003	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2004	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2005	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2006	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
SUM	824.1	834.3	10.2	1.2	31.7	31.7	0.0	0.0
Average Annual	20.6	20.9	0.3	1.5	0.8	0.8	0.0	0.0

Table 54. Comparison of flood damages for reach 6. Difference is calculated as reallocated-baseline.

Year	Reach 6			
	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline
1967	204.0	204.0	0.0	0.0
1968	0.0	0.0	0.0	n/a
1969	0.0	0.0	0.0	n/a
1970	0.0	0.0	0.0	n/a
1971	0.0	0.0	0.0	n/a
1972	0.0	0.0	0.0	n/a
1973	0.0	0.0	0.0	n/a
1974	0.0	0.0	0.0	n/a
1975	0.0	0.0	0.0	n/a
1976	0.0	0.0	0.0	n/a
1977	0.0	0.0	0.0	n/a
1978	1,162.2	1,162.2	0.0	0.0
1979	0.0	0.0	0.0	n/a
1980	0.0	0.0	0.0	n/a
1981	0.0	0.0	0.0	n/a
1982	0.0	0.0	0.0	n/a
1983	0.0	0.0	0.0	n/a
1984	0.0	0.0	0.0	n/a
1985	0.0	0.0	0.0	n/a
1986	0.0	0.0	0.0	n/a
1987	0.0	0.0	0.0	n/a
1988	0.0	0.0	0.0	n/a
1989	0.0	0.0	0.0	n/a
1990	0.0	0.0	0.0	n/a
1991	0.0	0.0	0.0	n/a
1992	0.0	0.0	0.0	n/a
1993	0.0	0.0	0.0	n/a
1994	0.0	0.0	0.0	n/a
1995	0.0	0.0	0.0	n/a
1996	0.0	0.0	0.0	n/a
1997	0.0	0.0	0.0	n/a
1998	0.0	0.0	0.0	n/a
1999	0.0	0.0	0.0	n/a
2000	0.0	0.0	0.0	n/a
2001	0.0	0.0	0.0	n/a
2002	0.0	0.0	0.0	n/a
2003	0.0	0.0	0.0	n/a
2004	0.0	0.0	0.0	n/a
2005	0.0	0.0	0.0	n/a
2006	0.0	0.0	0.0	n/a
SUM	1,366.2	1,366.2	0.0	0.0
Average Annual	34.2	34.2	0.0	0.0

Inflow Design Flood

A description of the inflow design flood (USACE, 1974) is provided below. As the write-up is taken directly from the referenced manual, references to paragraphs, plates, or tables could be included in the description. These references apply only to the manual itself, and not to this document.

> "The spillway or inflow design flood as developed by USBR has a peak discharge of 126,000 cfs and a 10-day volume of 1,070,000 acre-feet. The magnitude (volume and peak inflow) of this flood and the Project Design Flood are compared with actual floods as follow:

Flood	Station	Days	Volume (thousand acre-feet)	Peak Inflow (cfs)
SDF	Yellowtail	10	1,070	126,000
PDF	Yellowtail	52	2,044	55,900
1971	Yellowtail	52	1,102	15,600
1967	Yellowtail	52	1,813	29,800
1965	St. Xavier	52	1,467	26,400
1957	St. Xavier	52	1,266	19,400
1947	St. Xavier	52	1,620	28,300
1943	St. Xavier	52	1,667	25,800
1935	St. Xavier	52	1,469	37,400

> Routing of the inflow design flood using regulation curves (Plate 34) is shown on Plate 37. The beginning pool elevation used in the routing (3648.9) was that used by the USBR in designing the spillway capacity. It represents the point where the exclusive flood control zone would be half full. The peak pool and release achieved in the routing were elevation 3659.1 and 99,000 cfs. In the USBR design routing, the peak pool and release achieved were elevation 3659.7 and 86,000 cfs. In the USBR design routing, no releases were made through the outlet works and power plant".

Figures 35 and 36 show how the HEC-ResSim model for the inflow design flood compared to the operations provided in the flood control manual (USACE, 1974). Figure 35 is a plot comparing the Yellowtail outflow data, and figure 36 shows how the elevation data compared. The flood control manual (USACE, 1974) provided a peak outflow from Yellowtail of 99,000 cfs. HEC-ResSim modeled a peak outflow of approximately 98,020 cfs. Both hydrographs reach their peak outflow 84 hours into the simulation. Peak elevation data from the flood control manual (USACE, 1974) and HEC-ResSim were 3,659.1 ft msl and 3,658.6 ft msl, respectively. These peak elevations were achieved 84 hours into the simulation. Appendix E contains the data of figures 35 and 36 in tabular form.

Comparing the results from HEC-ResSim to the flood control manual (USACE, 1974) shows HEC-ResSim's ability to simulate the inflow design flood. HEC-

ResSim does model a lower peak discharge and elevation with the differences being 980 cfs and 0.5 ft, respectively. Figure 35 shows HEC-ResSim released water earlier in the simulation period when compared to the flood control manual (USACE, 1974). This is reflected in the slightly lower peak pool elevation achieved in the HEC-ResSim simulation.

Two reservoir volume balance calculations were completed to ensure the validity of the results. The first calculation provided a percent error between HEC-ResSim and the flood control manual (USACE, 1974) outflow hydrographs of 1.8%. The second calculation compared the peak reservoir volume calculated from the outflow hydrographs to the peak reservoir volume calculated from the peak elevation data. This calculation attempts to confirm the differences in peak elevation are explained by differences in dam operations on the ascending limb of the hydrograph. In this case, a volume difference of 1,450 ac-ft was calculated. In a perfect simulation, both volume balance calculations would yield a value of zero. One possible reason for these differences is imperfections in routing the inflow hydrograph through the dam. Calculations and routing of this storm for the flood control manual (USACE, 1974) were primarily done manually. Consequently, results may not be exact.

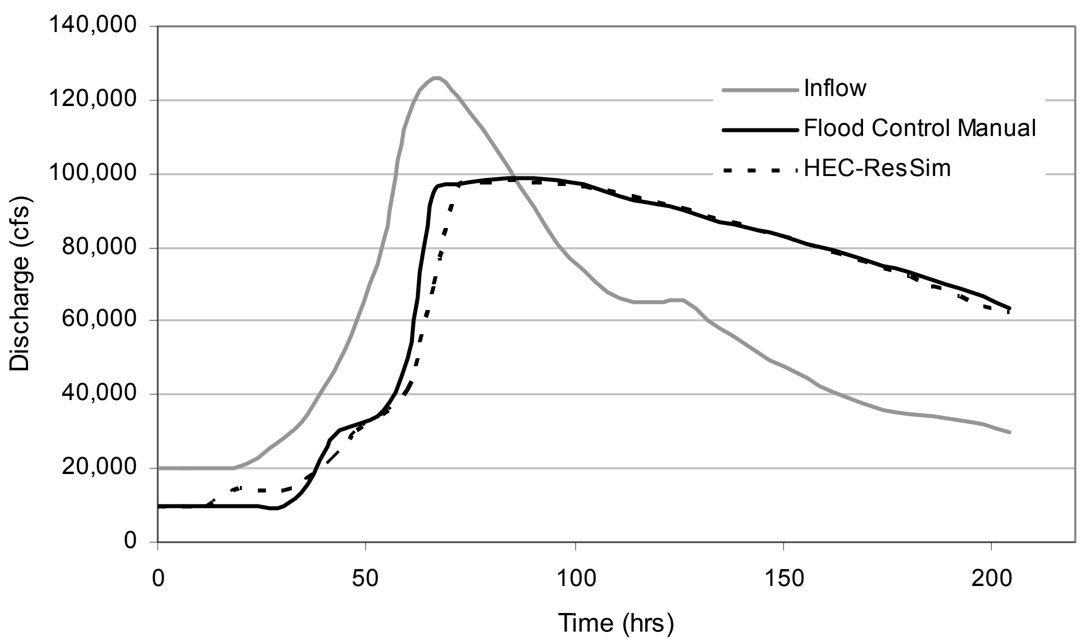

Figure 35. Comparison of the flood control manual and HEC-ResSim outflow data for the inflow design flood. Reservoir inflow is also plotted.

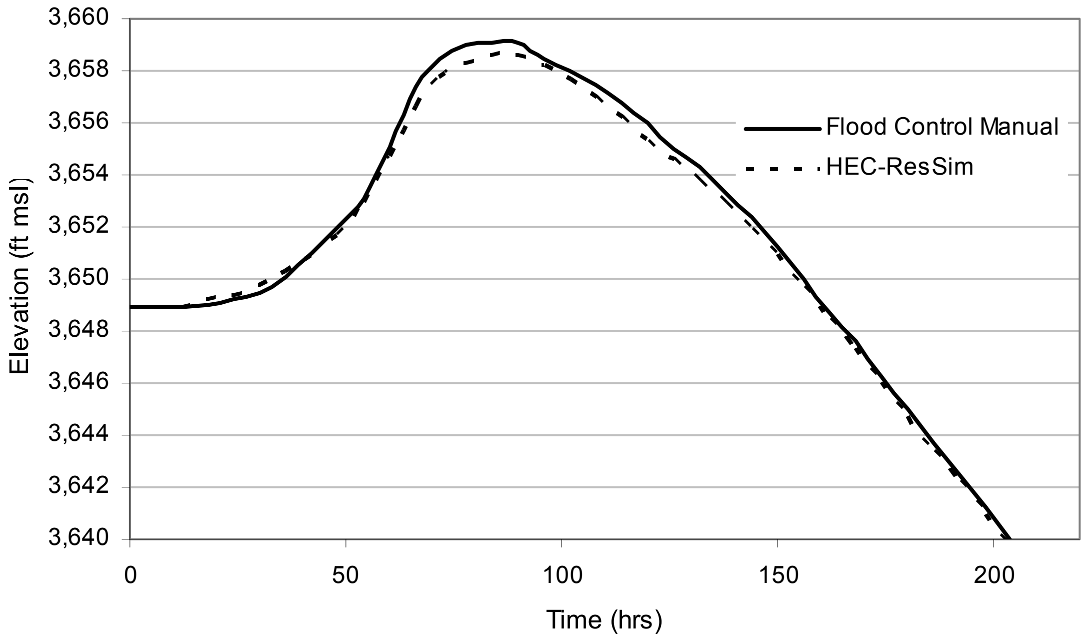

Figure 36. Comparison of the flood control manual and HEC-ResSim elevation data for the inflow design flood.

Figures 37 and 38 compare the baseline HEC-ResSim simulation to the reallocated HEC-ResSim simulation for the inflow design flood. This simulation assumed the top of the joint use pool was raised from 3,640 ft msl to 3,645 ft msl. Figure 37 is a plot comparing the Yellowtail outflow data, and figure 38 shows how the elevation data compared. The baseline simulation yielded a peak outflow from Yellowtail of approximately 98,020 cfs. The reallocated model simulated a peak outflow of approximately 98,350 cfs. As in the calibration simulation, both hydrographs reach their peak outflow 84 hours into the simulation. Peak elevations obtained by the baseline and reallocated simulation were 3,658.6 ft msl and 3,658.9 ft msl, respectively. These elevations were obtained 84 hours into the simulation. Appendix E contains the data of figures 37 and 38 in tabular form.

Comparing the results from the baseline and reallocated condition shows the impact of the joint use pool raise on the reservoir operations as simulated by HEC-ResSim. Both the peak discharge and peak elevation increased as a result of the joint use pool raise. The differences in peak discharge and peak elevation between the two simulations are 330 cfs and 0.3 ft, respectively. The reason the peak discharge and elevation do not increase by a larger amount is because higher releases are made sooner in the simulation period. This can be seen by comparing the two hydrographs in figure 37. This result is not a surprise since the starting pool elevation was increased by calculating a new “half-full” joint use pool elevation – thus requiring HEC-ResSim to make higher releases earlier to remain within the reservoir’s operating constraints.

When comparing the two simulations, the only dam safety concern that has been identified at this time is the increased pool elevation. The reallocated modeled pool elevation is only 1.1 ft from the top of the dam. Since the outflows in both simulations are approaching 100,000 cfs, the increased outflow in the reallocated simulation does not pose additional dam safety concerns. For reference, the listed maximum outflow capacity of Yellowtail Dam is 92,000 cfs (USACE, 1974).

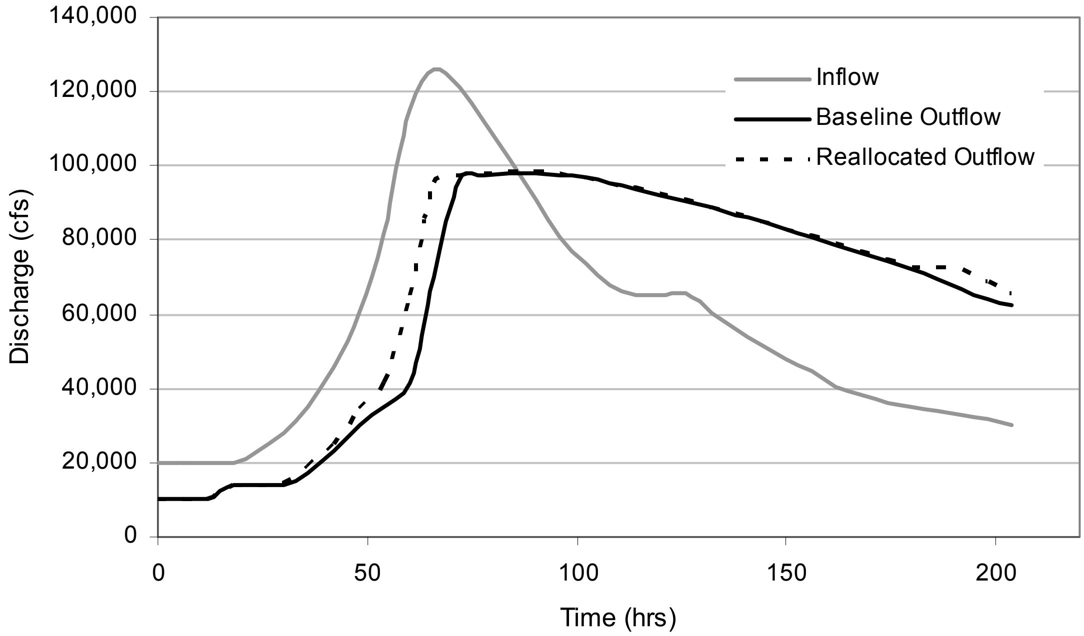

Figure 37. Comparison of the outflow data for the baseline and reallocated HEC-ResSim inflow design flood simulations. Reservoir inflow is also plotted.

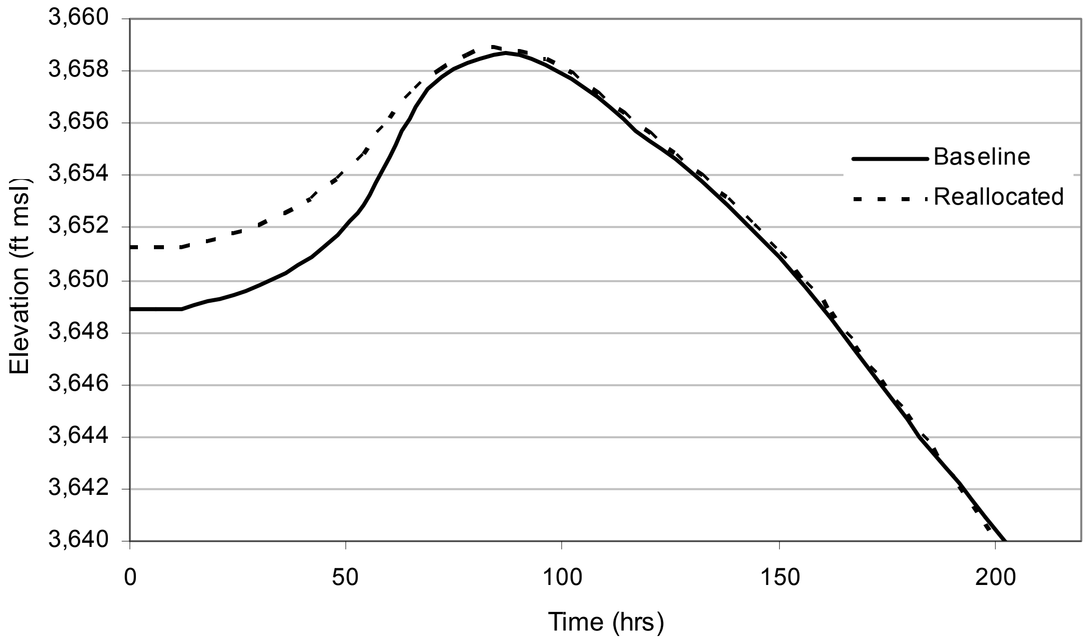

Figure 38. Comparison of the elevation data for the baseline and reallocated HEC-ResSim inflow design flood simulations.

Project Design Flood

A description of the project design flood (USACE, 1974) is provided below. As the write-up is taken directly from the referenced manual, references to paragraphs, plates, or tables could be included in the description. These references apply only to the manual itself, and not to this document.

> "The project flood for Yellowtail was based on an analysis of past floods. The peak discharge was obtained from a curve enveloping a plot of recorded peak discharges versus drainage areas in the Bighorn Basin. The ratios of peak to volume for various periods of time were determined for several floods. The values were plotted on appropriate graph paper and curves were used to determine the shape and volume of the basic flood hydrograph. A hydrograph similar to that of the greatest rainstorm flood of record was super-imposed upon the basic hydrograph so that the desired peak discharge was obtained. A peak flow of 55,900 cfs and a 52-day volume of 2,044,000 acre-feet (580,000 A.F. over 20,000 cfs release) resulted. Routing of this project flood through Yellowtail, using regulation curves described in paragraph 9-04, and after it has been modified to show the effect of the operation of Boysen Reservoir (assuming 50% of the flood volume would come from the area above Boysen Reservoir as indicated from study of past floods), is shown on Plate 36".

Figures 39 and 40 show how the HEC-ResSim model for the project design flood compared to the operations provided in the flood control manual (USACE, 1974). Figure 39 is a plot comparing the Yellowtail outflow data, and figure 40 shows how the elevation data compared. The flood control manual (USACE, 1974) provided a peak outflow from Yellowtail of 21,000 cfs. HEC-ResSim modeled a peak outflow of approximately 20,500 cfs. The flood control manual (USACE, 1974) and HEC-ResSim hydrographs reached an outflow of 20,000 cfs after 19 and 20 days, respectively. Peak elevation data from the flood control manual (USACE, 1974) and HEC-ResSim was 3,656.2 ft msl and 3,655.6 ft msl, respectively. Both of these elevations were achieved during day 35 of the simulation. Appendix E contains the data of figures 39 and 40 in tabular form.

A comparison of the results from HEC-ResSim to the flood control manual (USACE, 1974) shows HEC-ResSim's ability to simulate the project design flood. HEC-ResSim does model a lower peak discharge and pool elevation with the differences being 500 cfs and 0.6 ft, respectively. The major difference between the two outflow hydrographs is the flood control manual (USACE, 1974) has a more gradual increase up to 20,000 cfs than the HEC-ResSim simulation. This gradual increase is probably more realistic to what would occur during actual operations if an event similar to this occurred, and this difference provides the major reason why HEC-ResSim modeled a lower peak pool elevation when compared to the flood control manual (USACE, 1974).

Two reservoir volume balance calculations were completed to ensure the validity of the results. The first calculation provided a percent error between HEC-ResSim and the flood control manual (USACE, 1974) outflow hydrographs of 2.3%. The second calculation compared the peak reservoir volume calculated from the outflow hydrographs to the peak reservoir volume calculated from the peak elevation data. This calculation attempts to confirm the differences in peak elevation are explained by differences in dam operations on the ascending limb of the hydrograph. In this case, a volume difference of 11,070 ac-ft was calculated – showing the difference in volume on the ascending limb of the hydrograph doesn't explain the entire difference in peak elevation. In a perfect simulation, both volume balance calculations would yield a value of zero.

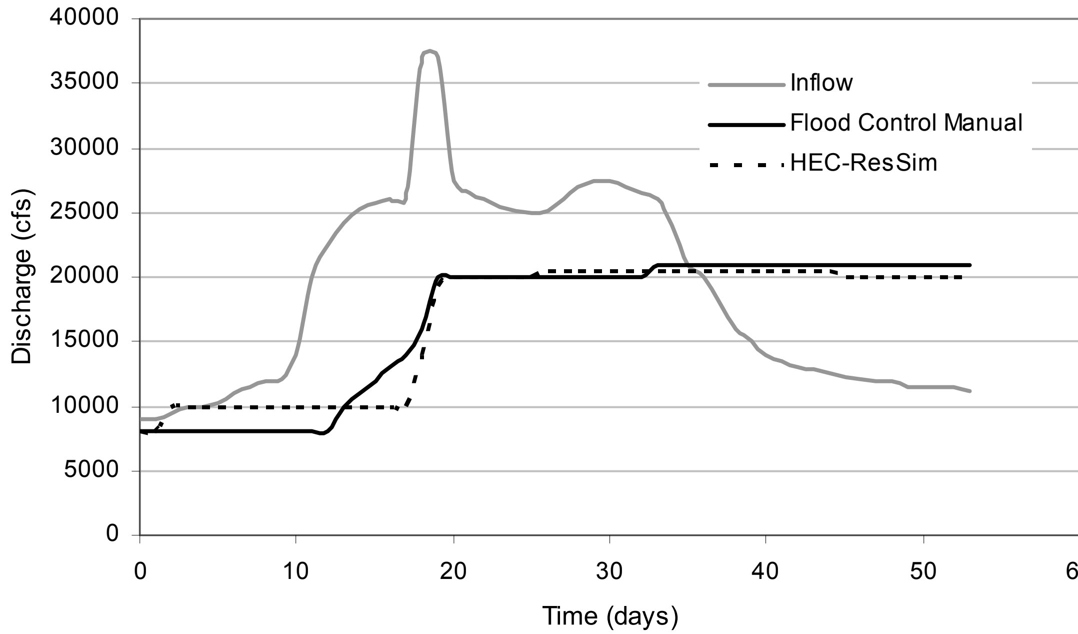

Figure 39. Comparison of the flood control manual and HEC-ResSim outflow data for the project design flood. Reservoir inflow is also plotted.

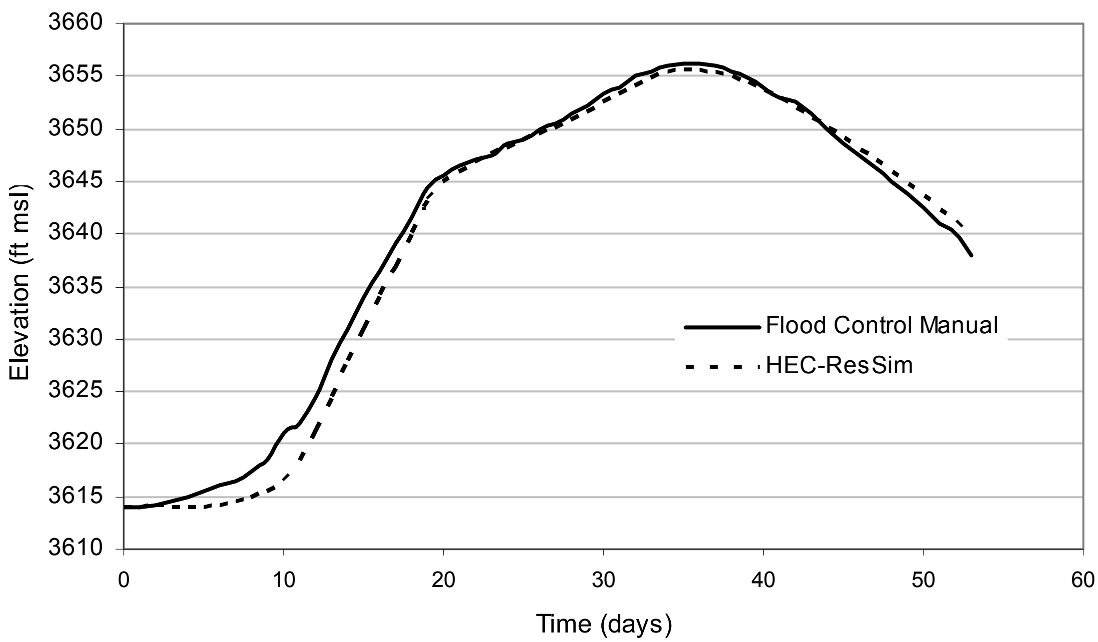

Figure 40. Comparison of the flood control manual and HEC-ResSim elevation data for the project design flood.

Figures 41 and 42 compare the baseline HEC-ResSim simulation to the reallocated HEC-ResSim simulation for the project design flood. This simulation assumed the top of the joint use pool was raised from 3,640 ft msl to 3,645 ft msl. Figure 41 is a plot comparing the Yellowtail outflow data, and figure 42 shows how the elevation data compared. The baseline simulation yielded a peak outflow from Yellowtail of approximately 20,500 cfs and this outflow occurred 26 days into the simulation. The reallocated model simulated a peak outflow of approximately 21,900 cfs, with this outflow occurring 23 days into the simulation. Peak elevations obtained by the baseline and reallocated simulation were 3,655.6 ft msl and 3,655.5 ft msl, respectively. The peak elevations for the baseline and reallocated simulations occurred 35 and 34 days into the simulation, respectively. Appendix E contains the data of figures 41 and 42 in tabular form.

Comparing the results from the baseline and reallocated condition shows the impact of the joint use pool raise on the reservoir operations as simulated by HEC-ResSim. While the peak discharge increased as a result of the joint use pool raise, the peak elevation decreased. The differences in peak discharge and peak elevation between the two simulations are 1,400 cfs and 0.1 ft, respectively. The baseline simulation used a starting elevation of 3,614 ft msl, which is the top of conservation storage. The reallocated simulation used 3,619 ft msl. This represents a value that is 5 ft above the top of conservation storage.

When comparing the two simulations, the increase in peak outflow when studying the reallocated simulation could be categorized as a dam safety concern. The reason for this is the Yellowtail Afterbay outflow capacity (overflow weir, sluiceway, and BIA canal) is listed at 20,750 cfs (USACE, 1974). Although it may be possible to release more than the listed capacity, it should be noted the reallocated simulation has a maximum outflow that is 1,150 cfs above the Yellowtail Afterbay capacity. In practice, it might be possible to reduce the peak outflow below the afterbay capacity by taking advantage of some of the unused reservoir storage – although this would result in a higher peak pool elevation, which could create other dam safety concerns. Furthermore, HEC-ResSim makes every attempt to optimize reservoir operations so it is possible deviating from the model operations would create additional problems.

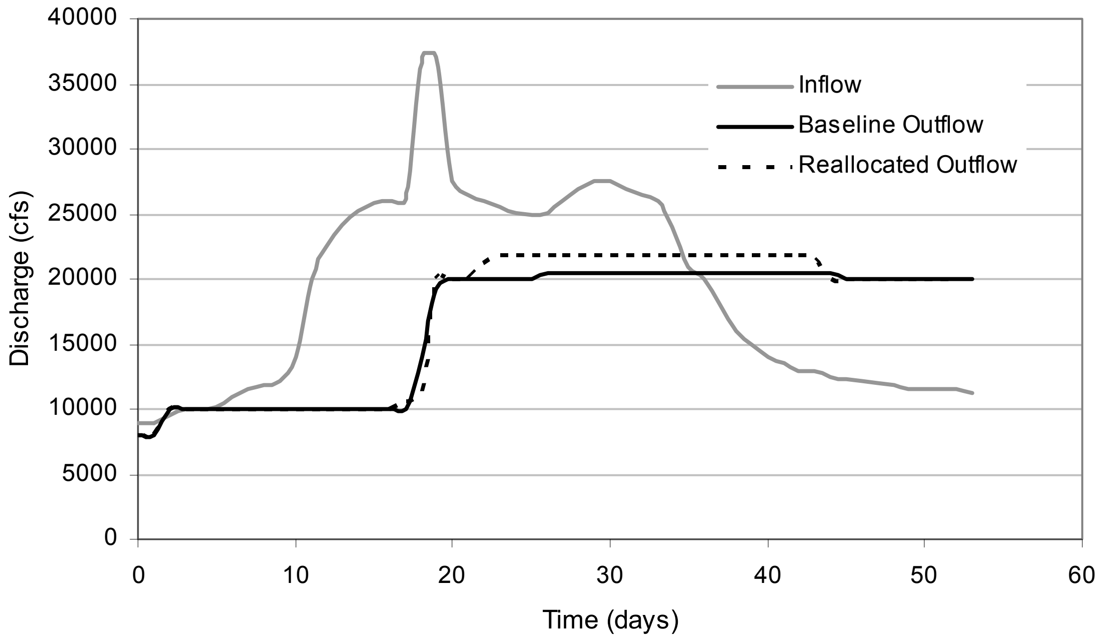

Figure 41. Comparison of the outflow data for the baseline and reallocated HEC-ResSim project design flood simulations. Reservoir inflow is also plotted.

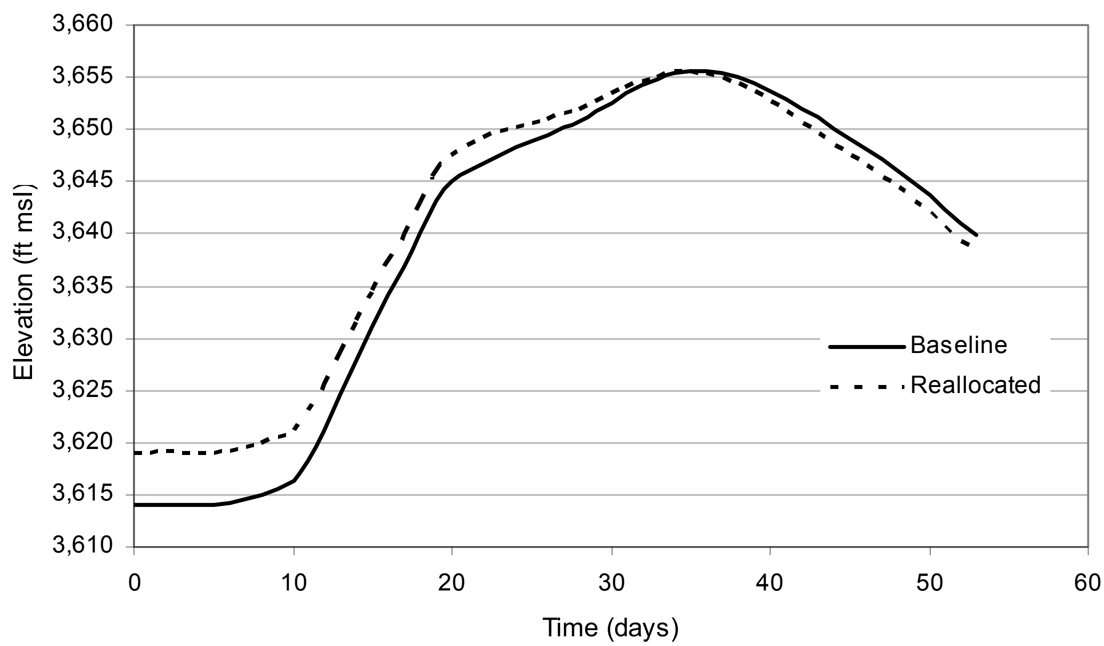

Figure 42. Comparison of the elevation data for the baseline and reallocated HEC-ResSim project design flood simulations.

1923 Flood

A description of the 1923 flood (USACE, 1974) is provided below. As the write-up is taken directly from the referenced manual, references to paragraphs, plates, or tables could be included in the description. These references apply only to the manual itself, and not to this document.

> "The greatest rainfall flood of record on the lower Big Horn River resulted from the storm of September 27 to October 1, 1923. This storm had a total duration of 108 hours starting at 1 am on September 27 and lasting until 1 pm on October 1. However, most of the rainfall occurred in the first two days. Some total rainfall reports from this storm were Basin – 1.50", Buffalo Bill Dam – 3.22", Cody – 2.26", Lander – 3.80", Lovell – 0.74", Riverton – 4.25", and Worland – 2.64". At Hardin, this flood had a peak flow of 42,300 cfs and a 10-day volume of 389,000 acre-feet. Routing of this flood (assuming the joint-use zone filled and Boysen not in place), using regulation curves, is shown on Plate 38".

Figures 42 and 43 show how the HEC-ResSim model for the 1923 flood compared to the operations provided in the flood control manual (USACE, 1974). Figure 42 is a plot comparing the Yellowtail outflow data, and figure 43 shows how the elevation data compared. The flood control manual (USACE, 1974) and HEC-ResSim provided a peak outflow from Yellowtail of 20,000 cfs. The flood control manual (USACE, 1974) and HEC-ResSim hydrographs reached an outflow of 20,000 cfs after 96 and 102 hours, respectively. Peak elevation data from the flood control manual (USACE, 1974) and HEC-ResSim was 3,649.9 ft msl and 3,648.8 ft msl, respectively. These elevations were achieved 132 and 144 hours into the simulation, respectively. Appendix E contains the data of figures 42 and 43 in tabular form.

A comparison of the results from HEC-ResSim to the flood control manual (USACE, 1974) shows HEC-ResSim's ability to simulate the 1923 flood. HEC-ResSim models the same peak discharge and a lower peak pool elevation. The difference in peak pool elevation is 1.1 ft. One difference between the two outflow hydrographs is the ascending limb due to some differences in the decision making process between the flood control manual (USACE, 1974) and HEC-ResSim.

Two reservoir volume balance calculations were completed to ensure the validity of the results. The first calculation provided a percent error between HEC-ResSim and the flood control manual (USACE, 1974) outflow hydrographs of 0.8%. The second calculation compared the peak reservoir volume calculated from the outflow hydrographs to the peak reservoir volume calculated from the peak elevation data. This calculation attempts to confirm the differences in peak elevation are explained by differences in dam operations on the ascending limb of the hydrograph. In this case, a volume difference of 11,100 ac-ft was calculated – showing the difference in volume on the ascending limb of the hydrograph doesn't explain the entire difference in peak elevation. In a perfect simulation, both volume balance calculations would yield a value of zero.

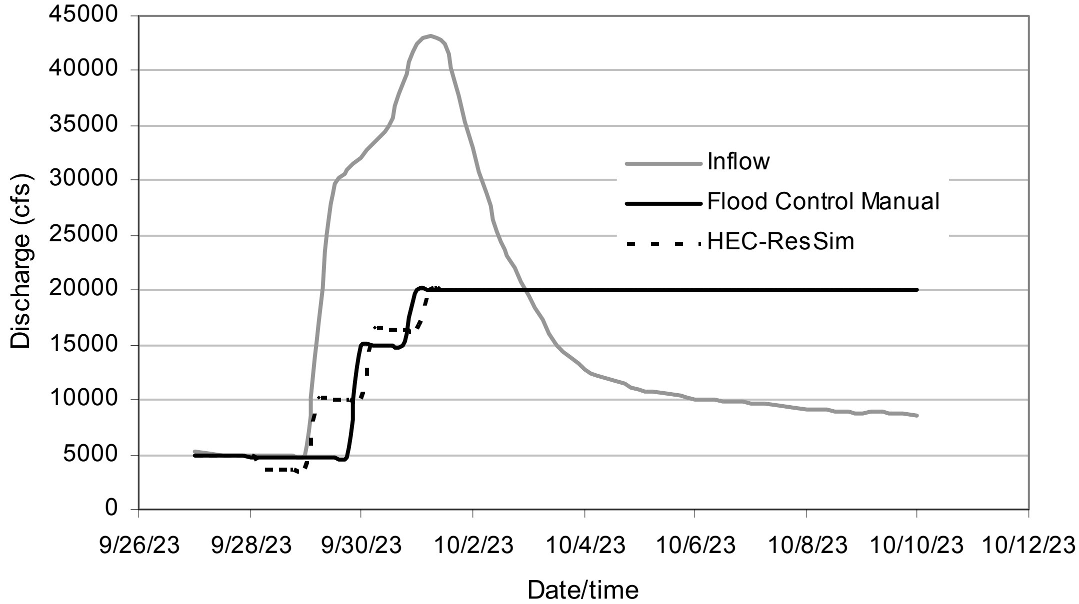

Figure 42. Comparison of the flood control manual and HEC-ResSim outflow data for the 1923 flood. Reservoir inflow is also plotted.

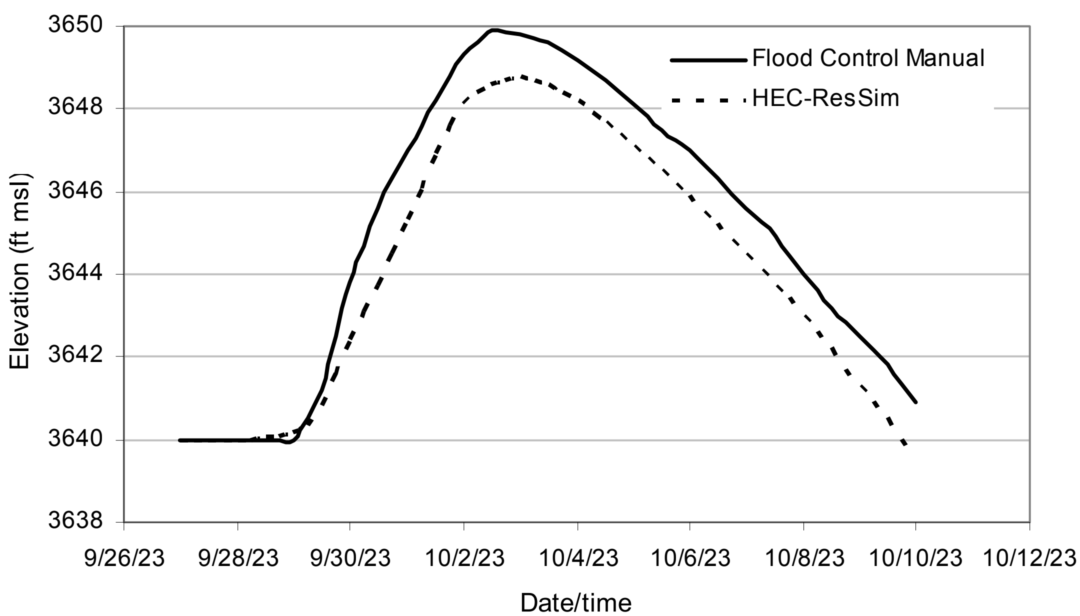

Figure 43. Comparison of the flood control manual and HEC-ResSim elevation data for the 1923 flood.

Figures 44 and 45 compare the baseline HEC-ResSim simulation to the reallocated HEC-ResSim simulation for the 1923 flood. This simulation assumed the top of the joint use pool was raised from 3,640 ft msl to 3,645 ft msl. Figure 44 is a plot comparing the Yellowtail outflow data, and figure 45 shows how the elevation data compared. The baseline simulation yielded a peak outflow from Yellowtail of approximately 20,000 cfs and this outflow occurred 102 hours into the simulation. The reallocated model simulated a peak outflow of approximately 28,800 cfs, with this outflow occurring 120 hours into the simulation. Peak elevations obtained by the baseline and reallocated simulation were 3,648.8 ft msl and 3,651.5 ft msl, respectively. The peak elevations for the baseline and reallocated simulations occurred 144 and 126 hours into the simulation, respectively. Appendix E contains the data of figures 44 and 45 in tabular form.

Comparing the results from the baseline and reallocated condition shows the impact of the joint use pool raise on the reservoir operations as simulated by HEC-ResSim. Both the peak discharge and peak elevation increased as a result of the joint use pool raise. The differences in peak discharge and peak elevation between the two simulations are 8,800 cfs and 2.7 ft, respectively. The baseline simulation used a starting elevation of 3,640 ft msl, which is the top of the joint use storage. The reallocated simulation used 3,645 ft msl. This represents the new elevation of the top of joint use storage assuming the 5 ft reallocation.

When comparing the two simulations, the increase in peak pool elevation has not been identified as a major dam safety concern due to the remaining reservoir storage. However, the increase in peak outflow when studying the reallocated simulation could be categorized as a dam safety concern. The reason for this is the Yellowtail Afterbay outflow capacity (overflow weir, sluiceway, and BIA canal) is listed at 20,750 cfs (USACE, 1974). The reallocated simulation has a maximum outflow that is 8,050 cfs above the Yellowtail Afterbay capacity, and it is very unlikely the afterbay could pass this flow without failure. In practice, it might be possible to reduce the peak outflow below the afterbay capacity by taking advantage of some of the unused reservoir storage – although this would result in a higher peak pool elevation, which could create other dam safety concerns. Furthermore, HEC-ResSim makes every attempt to optimize reservoir operations so it is possible deviating from the model operations would create additional problems.

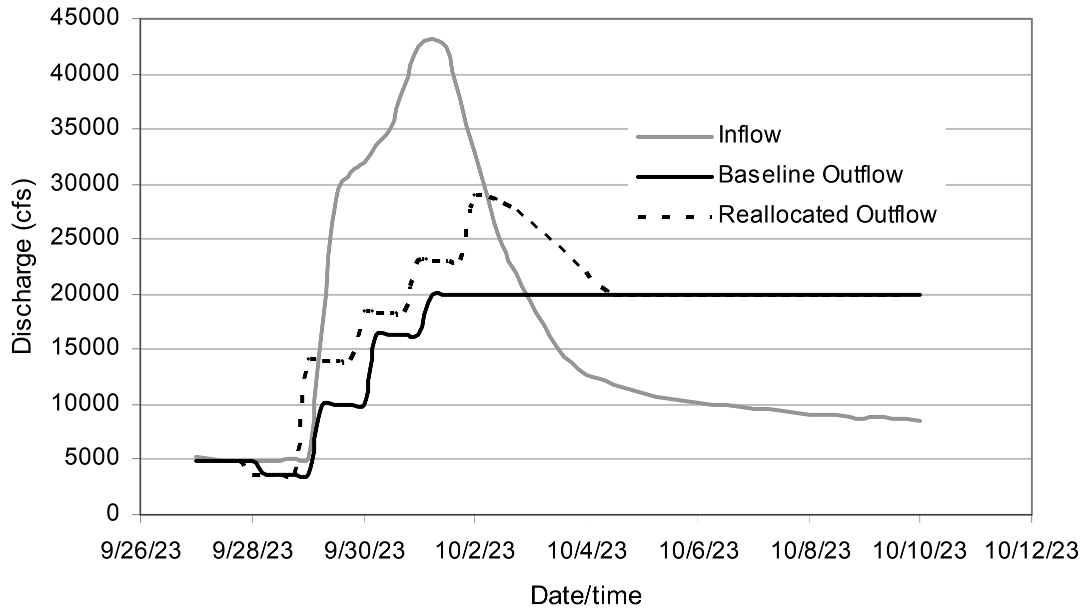

Figure 44. Comparison of the outflow data for the baseline and reallocated HEC-ResSim 1923 flood simulations. Reservoir inflow is also plotted.

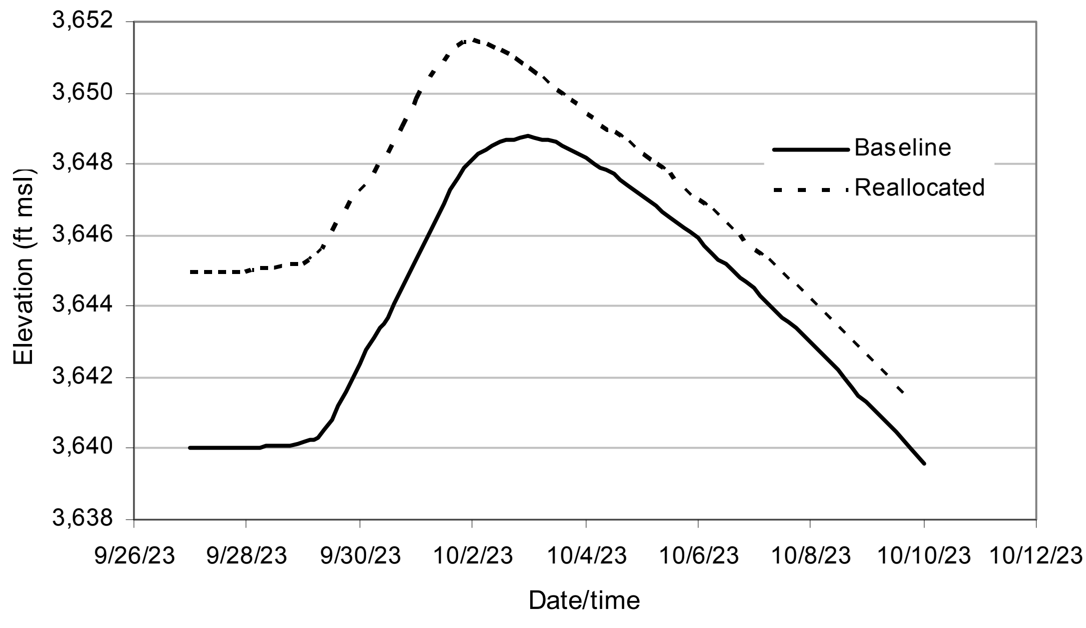

Figure 45. Comparison of the elevation data for the baseline and reallocated HEC-ResSim 1923 flood simulations.

Conclusions

The model HEC-ResSim was used successfully to create several models to evaluate the impacts of the proposed reallocation of exclusive flood control storage to joint use storage. The generated models included: a period of record simulation, the inflow design flood, the project design flood, and the 1923 historic event. These models were calibrated to develop a baseline condition for each simulation. Next, the top of joint use pool was raised from elevation 3640 ft msl to 3645 ft msl and the models were re-run. Finally, results from the baseline and reallocated HEC-ResSim models could be analyzed and compared.

Several different analyses were completed to evaluate the period of record simulation. They included studying the reservoir elevation and outflow data and developing several statistical relationships (pool duration, flow duration, pool probability, and flow frequency). Lastly, flood damages were studied to determine the impact of the reallocation on downstream reaches. Results from the flood damage calculations found that areas downstream of the Bighorn River on the Yellowstone River were more sensitive to the change in outflows as a result of the reallocation. However, when studying the period of record, flood damages did not consistently increase. Some locations reported increases in flood damages, while others saw decreases.

The event based simulations were evaluated only by studying the reservoir elevation and outflow data. There were several issues that will need to be reviewed in relation to operations as a result of the reallocation. These items are listed here:

1. For the inflow design flood, the reallocated condition reaches a peak pool elevation that is only 1.1 ft from the top of Yellowtail Dam.
2. For the project design flood, the reservoir outflow is 1,150 cfs over the capacity of the Yellowtail Afterbay dam.
3. For the 1923 event, the reservoir outflow is 8,050 cfs over the capacity of the Yellowtail Afterbay dam.

The purpose of this particular study was to complete a preliminary assessment on the effects of the proposed reallocation on operations of Yellowtail Dam. Results from this study will provide water managers – as well as other decision makers studying the reallocation – with important information that can be used to aid them in determining the feasibility of the reallocation.

Prior to the adoption of the reallocation, it is recommended that further detailed study of the impacts listed above be completed and appropriate mitigation measures be identified if necessary. Due to changing conditions downstream, an update and sensitivity analysis of the downstream flood damage curves, as well as an analysis of downstream river capacity, should also be included. Furthermore, it will need to be determined if an environmental assessment is needed. Lastly, updates to the flood control manual will need to be made and a new Field Working Agreement approved by both the Bureau of Reclamation and U.S. Army Corps of Engineers.

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Appendix A – Alternative Time Series Simulation

In addition to the previous period of record analysis, an additional analysis was performed to take advantage of HEC-ResSim's ability to model using time series guide curve data. These models were run using information provided by BOR on the potential future operations of Yellowtail Dam. As a result, they cannot be directly compared to the previous period of record simulations or actual data. The analysis was performed because it provides useful information on the effects of the joint use pool reallocation, but it represents only one set of modeling assumptions, and if those change the results would change as well.

HEC-ResSim Model Information

The HEC-ResSim models created for this analysis are based on the previously described period of record models. Therefore, the methodology behind the development of the models is the same other then the exceptions described below.

The first change within the model is changing from the standard guide curves to the time series guide curves. The major advantage of using a time series guide curve is the reservoir can be operated differently from year to year based on certain criteria. In this case, the criteria were determined to be the snowpack and the associated spring runoff volume into the reservoir. Spring draft elevations were changed from year to year based on the amount of runoff expected. This method helped ensure there was sufficient space in the reservoir for the spring snowmelt without releasing an unnecessary amount of water. The draft elevations were determined by classifying each year as an upper quartile, medium or minimum runoff year. Next, the associated guide curve was applied to that year. The result was a time series guide curve that could be placed into the HEC-ResSim period of record simulation. The development of the time series guide curves as well as classifying each year's spring runoff was completed by USBR.

Along with the change of using a time series guide curve, there was another important change made for these simulations. The reallocated joint use pool was raised from a baseline elevation of 3,640 ft msl to a reallocated elevation of 3,643 ft msl – not 3,645 ft msl as was the case in all the other simulations. During the development of the time series guide curves, it was noted that having the top elevation of the joint use pool at 3,645 ft msl might not provide enough storage space within the reservoir for events similar to what occurred in 1967 – particularly if flows are kept below the 20,000 cfs capacity of the Yellowtail Afterbay. As a result, for the reallocated simulation runs, the elevation was set at 3,643 ft msl. Table A.1 and figures A.1 through A.3 provide the annual spring runoff classifications and the guide curves for the baseline and reallocated simulations for the upper quartile, medium, and minimum conditions, respectively.

Table A.1. Annual spring runoff classifications used when developing the time series guide curves (developed by USBR).

Year	*BOR Curve*	*Year*	*BOR Curve*
1967	Upper Quartile	1987	Minimum
1968	Medium	1988	Minimum
1969	Medium	1989	Minimum
1970	Medium	1990	Minimum
1971	Upper Quartile	1991	Upper Quartile
1972	Upper Quartile	1992	Minimum
1973	Medium	1993	Medium
1974	Upper Quartile	1994	Minimum
1975	Upper Quartile	1995	Upper Quartile
1976	Medium	1996	Upper Quartile
1977	Minimum	1997	Upper Quartile
1978	Upper Quartile	1998	Medium
1979	Minimum	1999	Upper Quartile
1980	Medium	2000	Minimum
1981	Medium	2001	Minimum
1982	Medium	2002	Minimum
1983	Upper Quartile	2003	Minimum
1984	Medium	2004	Minimum
1985	Minimum	2005	Medium
1986	Upper Quartile	2006	Minimum

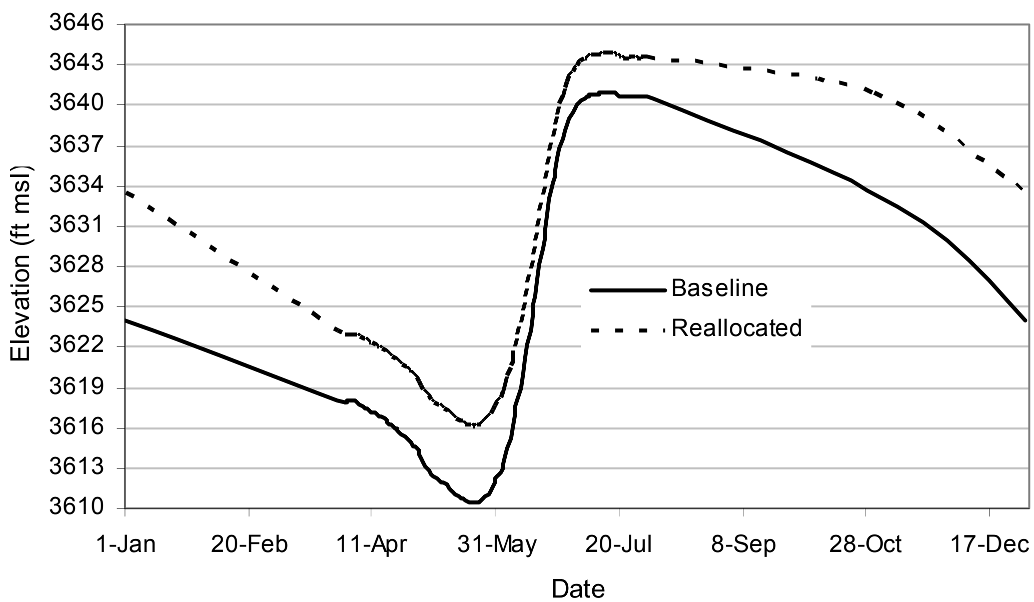

Figure A.1. Baseline and reallocated time series guide curves for the upper quartile spring runoff condition (developed by USBR).

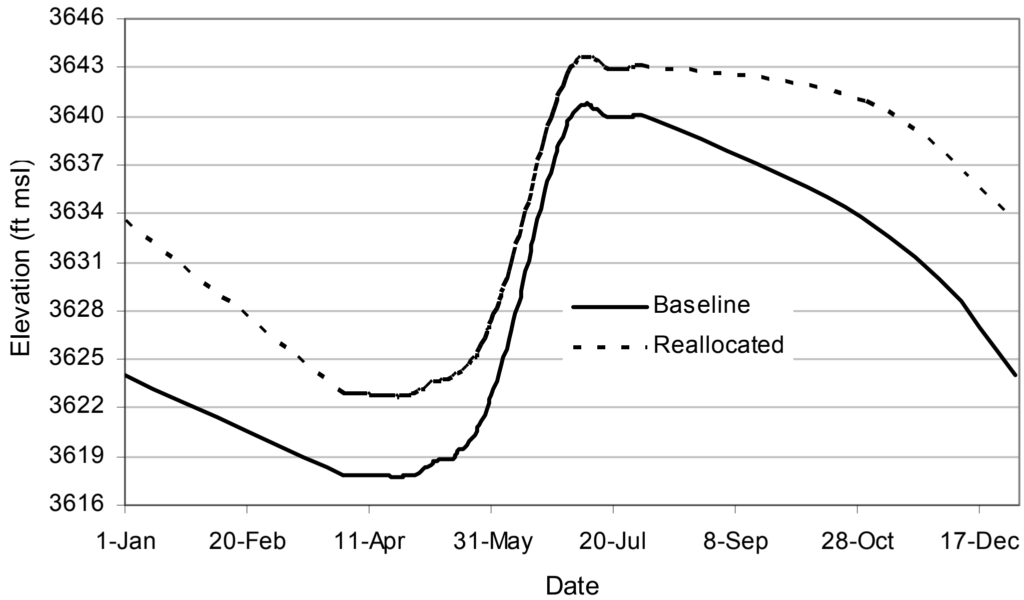

Figure A.2. Baseline and reallocated time series guide curves for the medium spring runoff condition (developed by USBR).

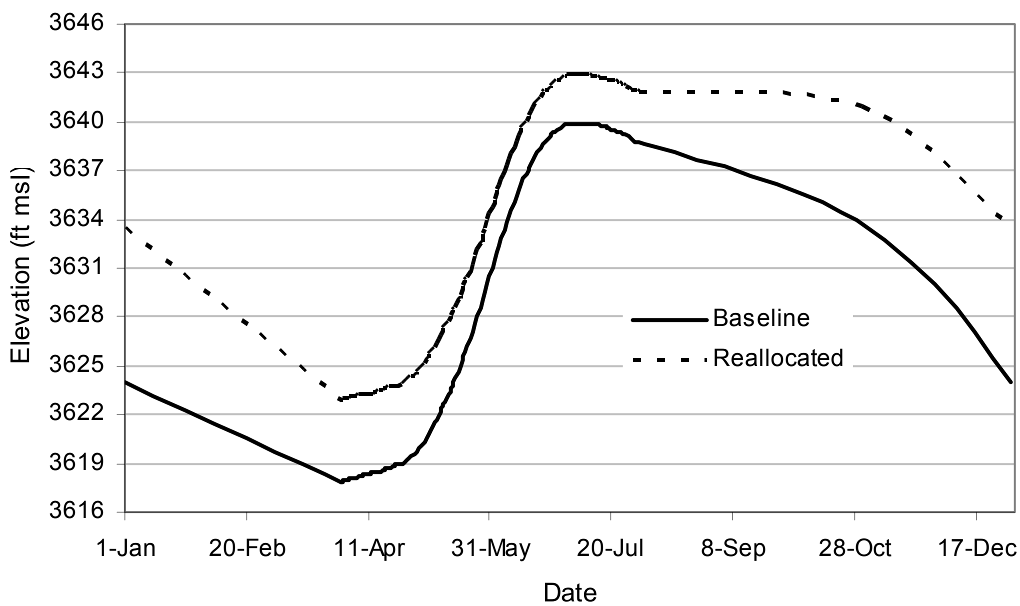

Figure A.3. Baseline and reallocated time series guide curves for the minimum spring runoff condition (developed by USBR).

HEC-ResSim Results

Figures A.4 through A.13 provide a comparison of the baseline and reallocated Yellowtail Dam reservoir elevation and outflow information. Inspecting the elevation data shows the reallocated condition generally maintained a higher elevation than the baseline condition throughout the period of record simulation. Depending on the circumstance, releases from the reallocated condition exceeded the baseline condition, decreased compared to the baseline condition, were initiated earlier or held later with little change to maximum outflow, or were kept close to the same.

A few examples where increases in flow were observed as a result of the reallocation were 1967, 1983, and 1998. The reservoir was able to reach elevation 3,645 ft msl all three years, and in 1967 continued to climb due to the large inflow volume. To evacuate the reservoir storage within the timeframe allocated required peak outflows be increased from baseline outflow levels. These increases were approximately 24,350 cfs to 25,750 cfs, 8,050 cfs to 12,500 cfs, and 9,750 cfs to 13,770 cfs, respectively. These increased releases were made for approximately 19 days, five days, and two days, respectively. These examples show there is the possibility of needing to perform higher releases in order to evacuate extra reservoir storage as a result of the reallocation.

There are also times where the baseline condition released higher annual peak flows than the reallocated condition. Two examples of this are 1971 and 1999. The baseline and reallocated conditions had maximum outflows of approximately 13,030 cfs and 10,230 cfs; and 13,550 cfs and 9,760 cfs, respectively. Once again, the durations of these higher flows were relatively short – three days and six days, respectively. The reason for the differences was the baseline condition was trying to evacuate storage and remain close to the guide curve. This resulted in higher releases. Conversely, for the reallocated condition additional storage allowed the reservoir to hold more water for longer – thus reducing the peak outflow while still maintaining close to the desired guide curve elevations.

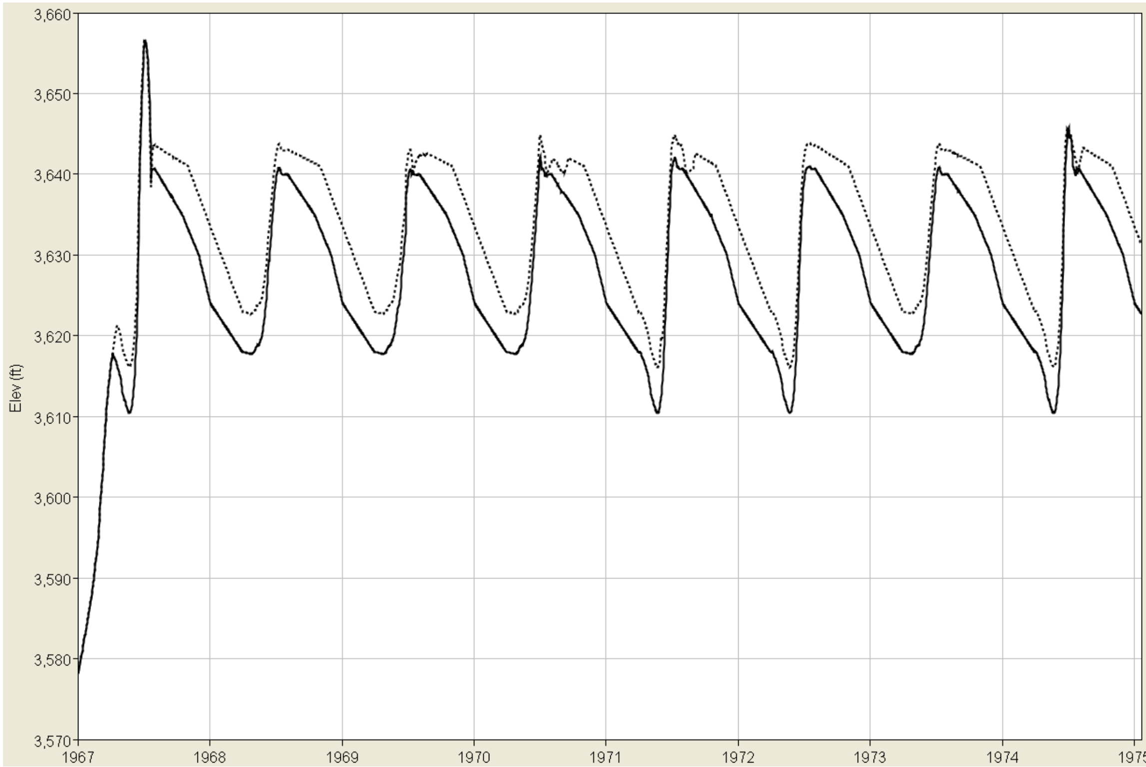

Figure A.4. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1967-1975.

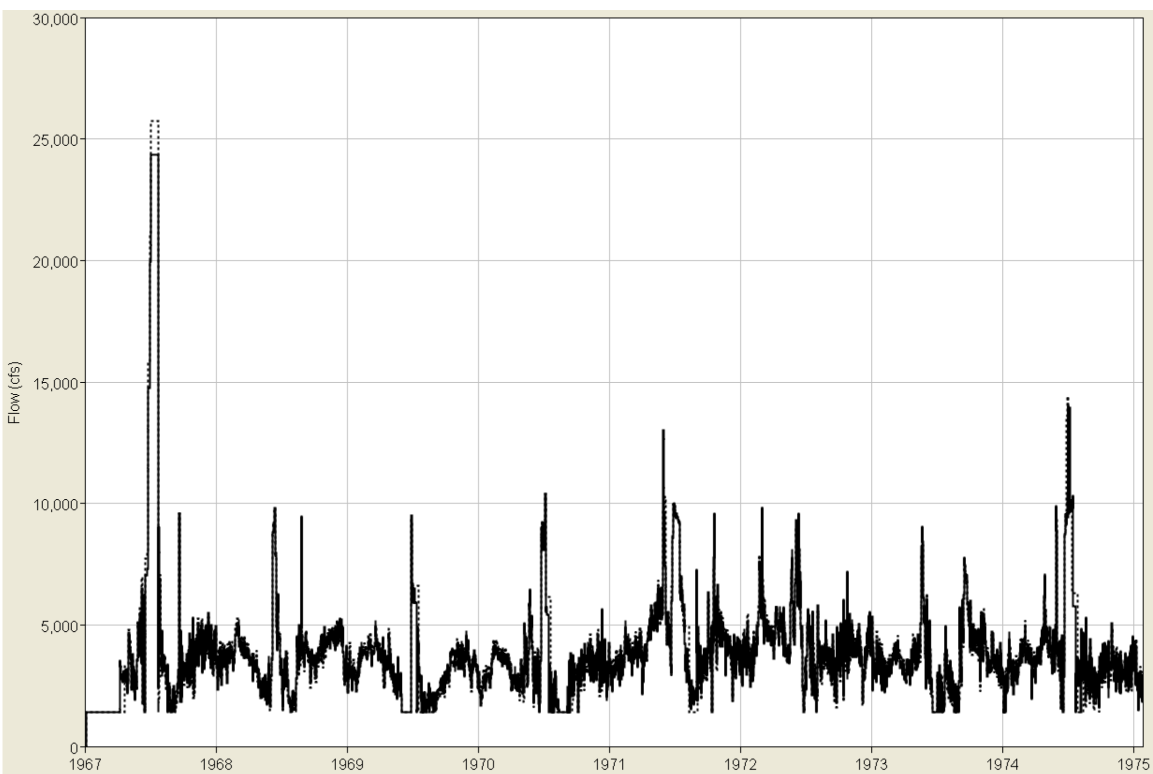

Figure A.5. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1967-1975.

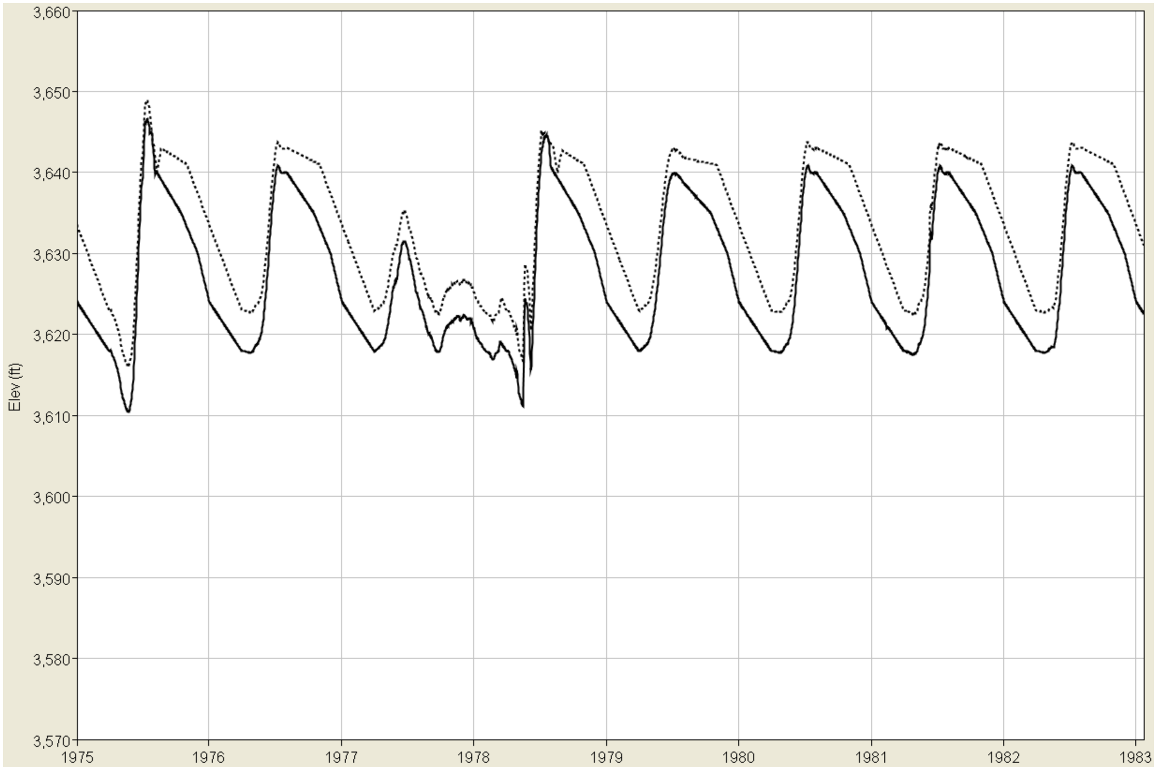

Figure A.6. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1975-1983.

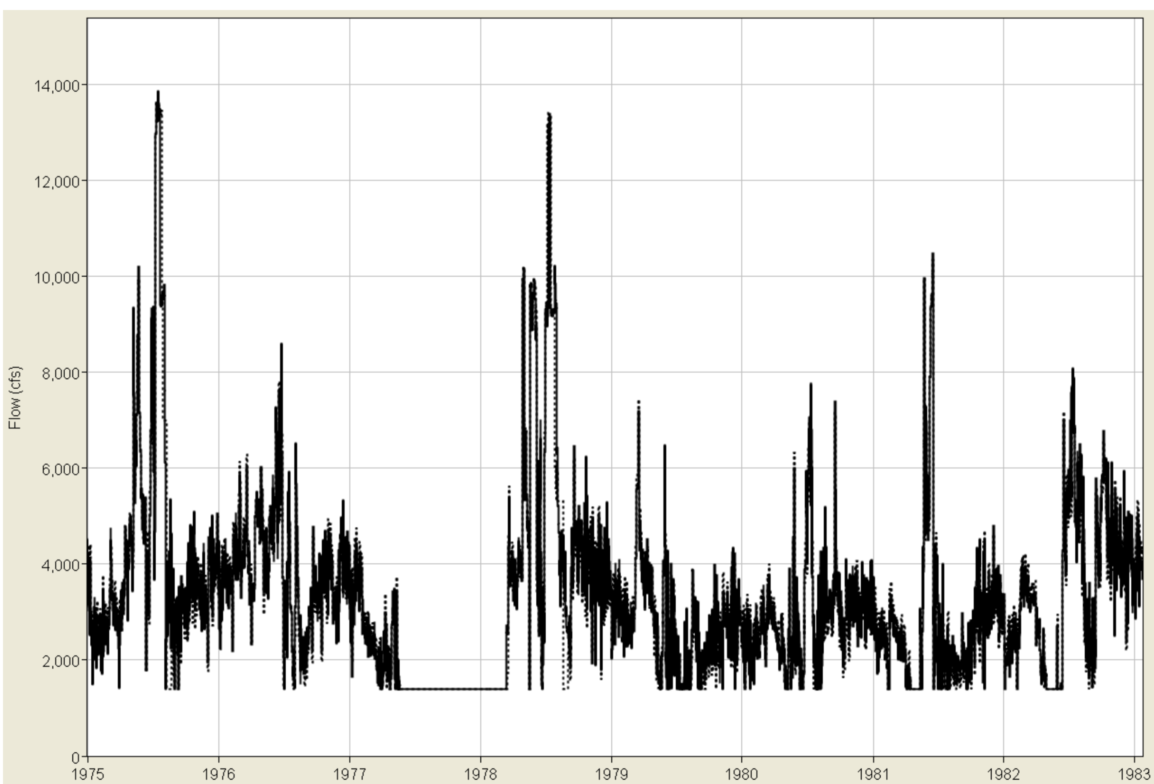

Figure A.7. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1975-1983.

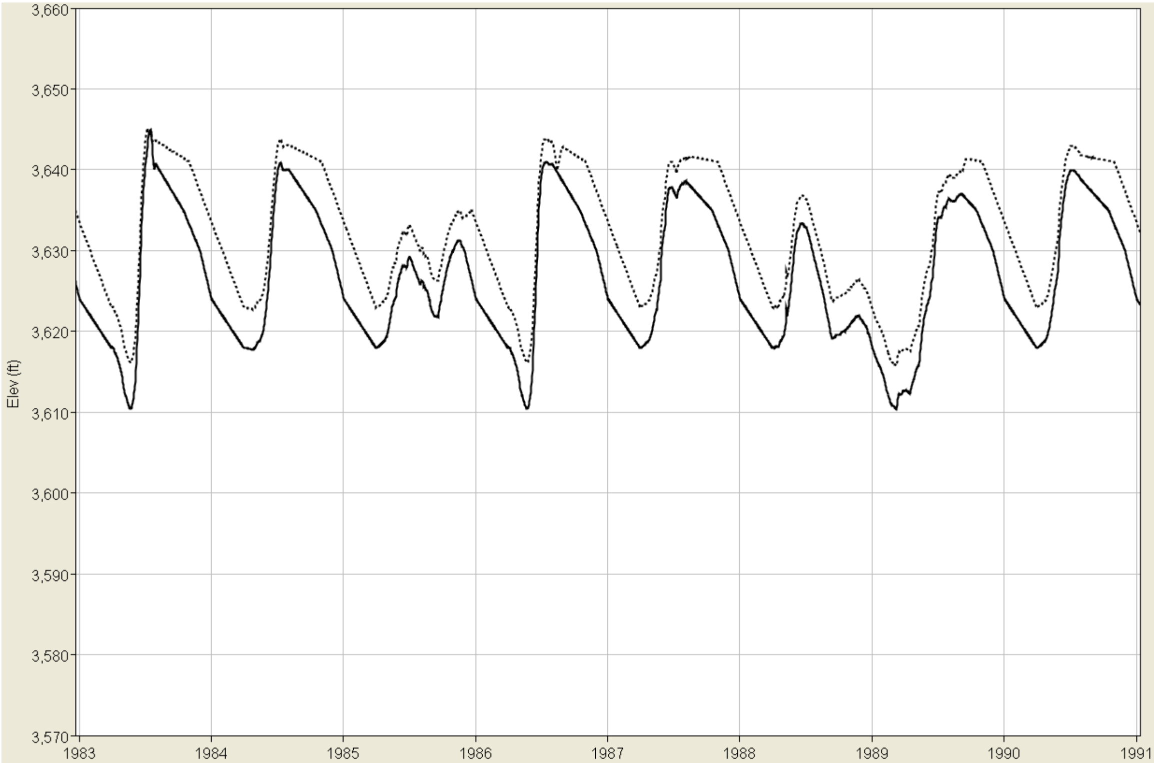

Figure A.8. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1983-1991.

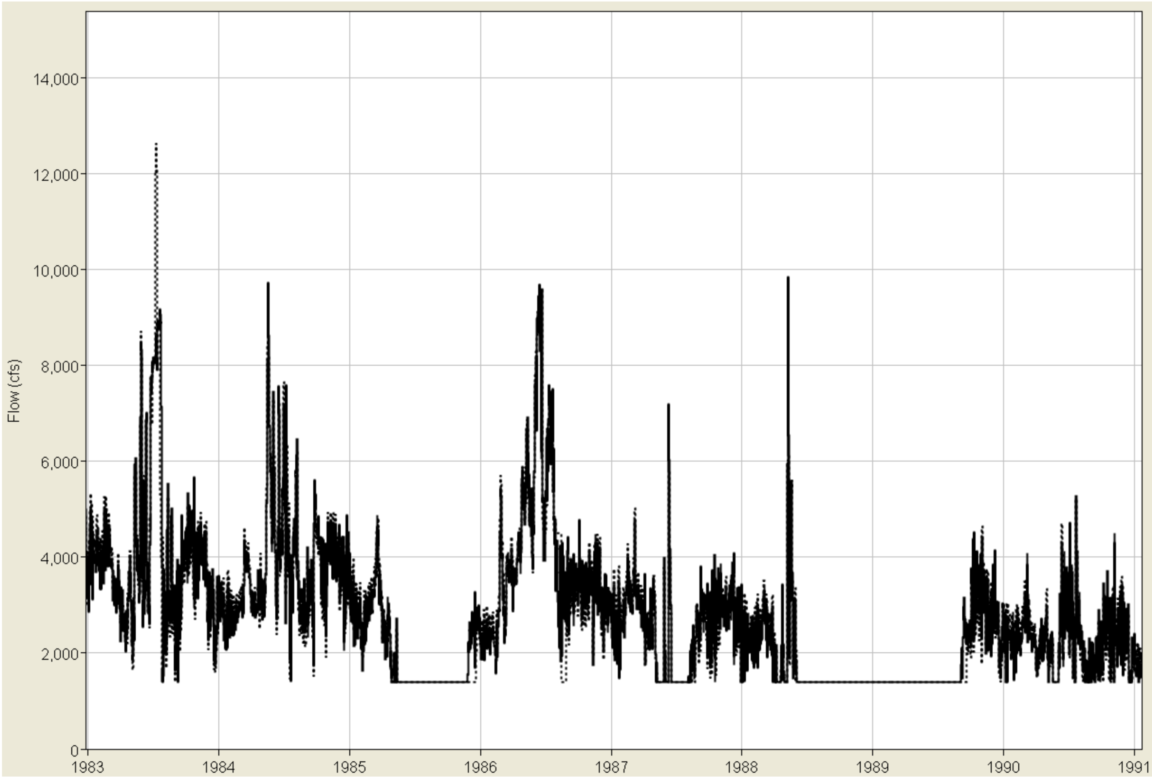

Figure A.9. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1983-1991.

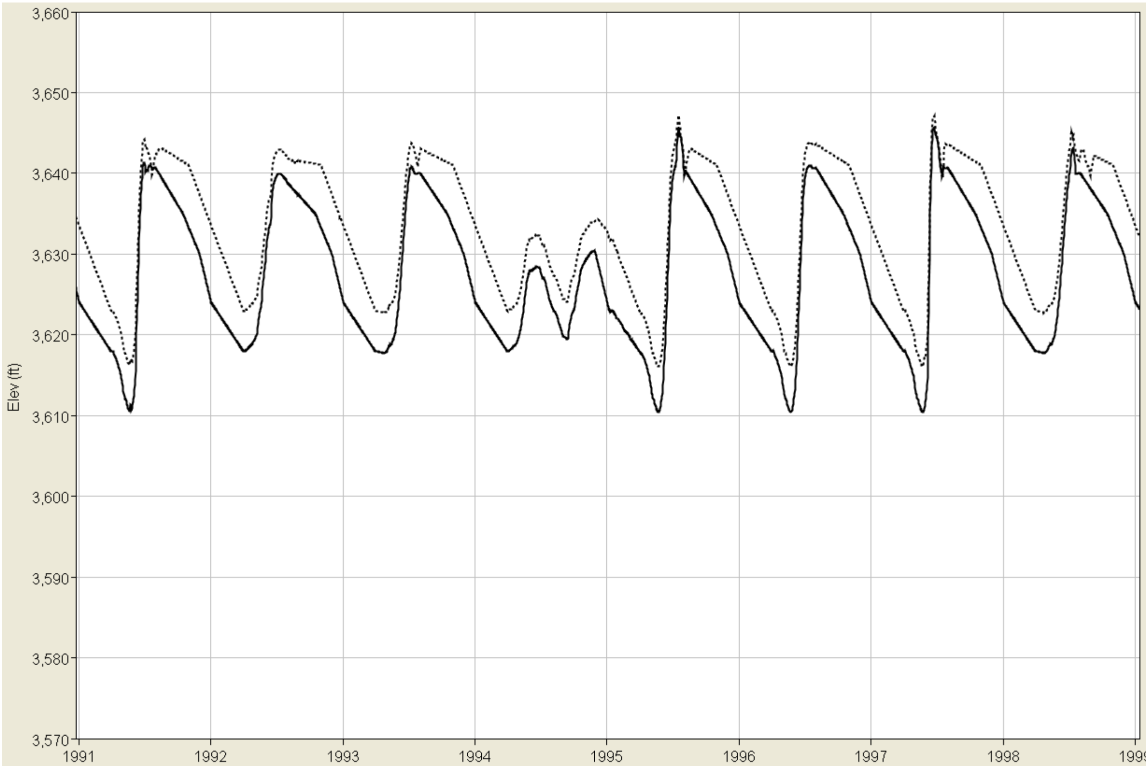

Figure A.10. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1991-1999.

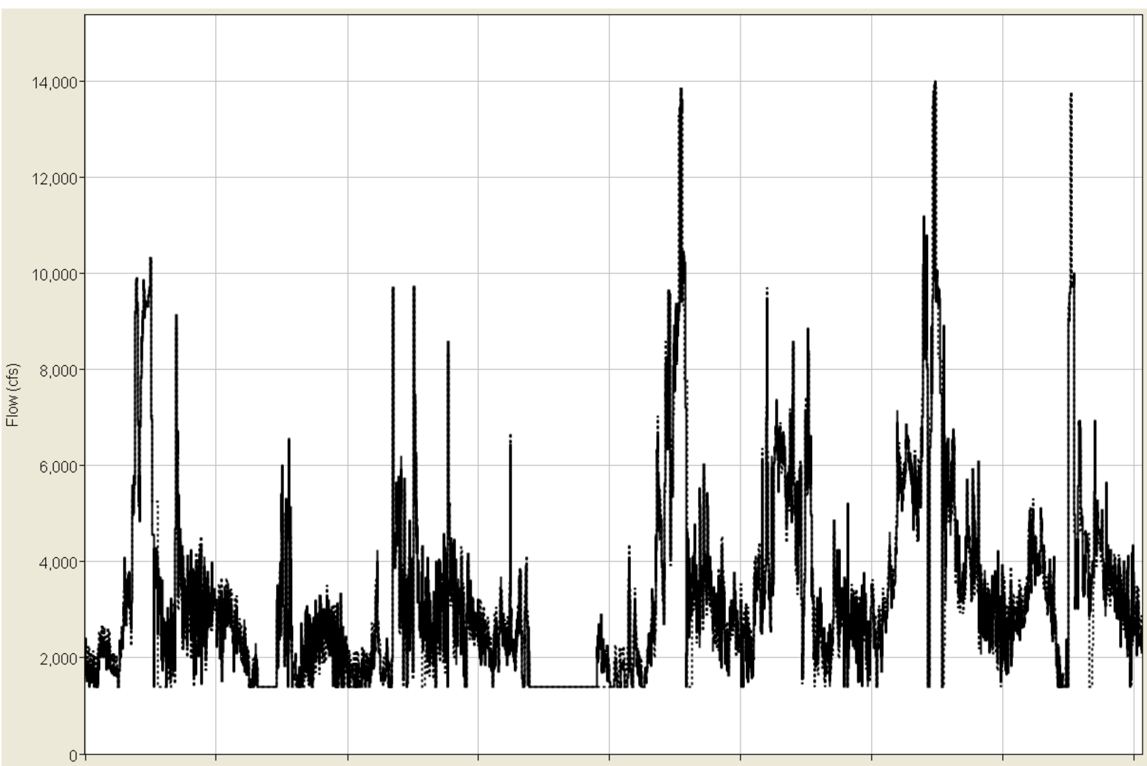

Figure A.11. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1991-1999.

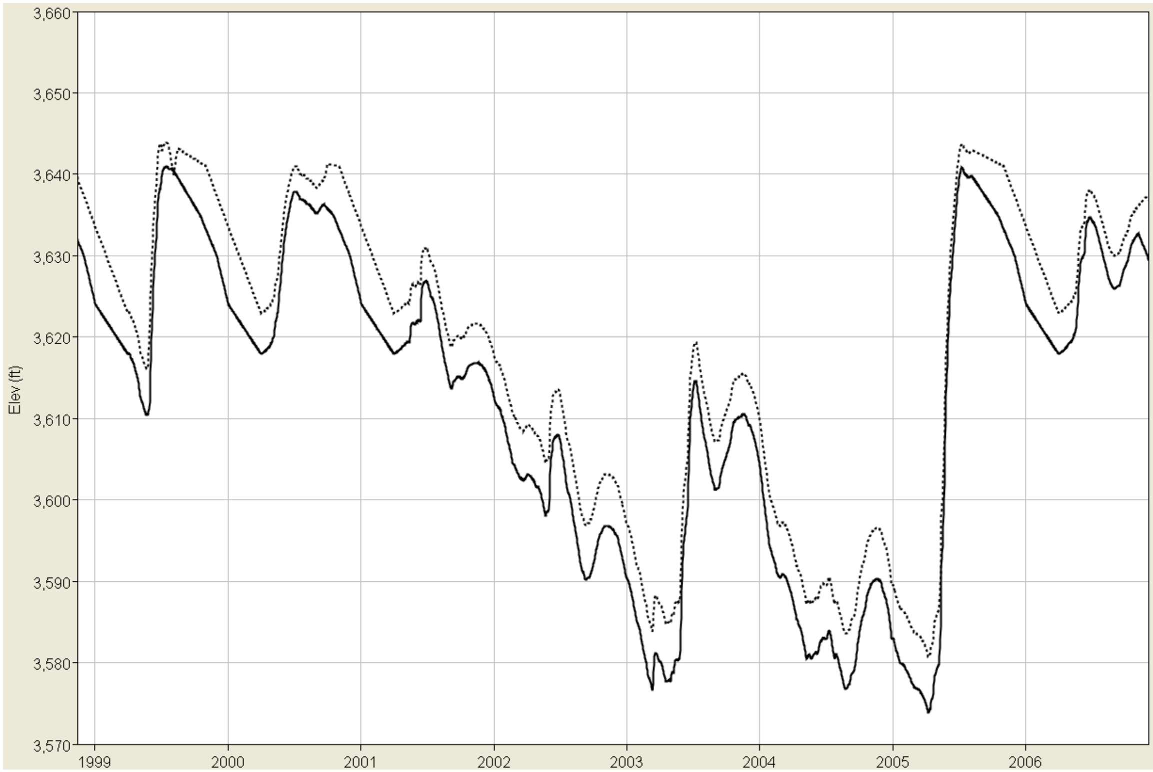

Figure A.12. Baseline and reallocated Yellowtail Dam elevation data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1999-2006.

Figure A.13. Baseline and reallocated Yellowtail Dam outflow data. Baseline data is the solid line, and reallocated data a dashed line. This figure shows the period of 1999-2006.

Tables A.2 through A.4 provide information related to the pool duration analysis that was completed for Yellowtail Dam. These tables provide a comparison between the baseline and reallocated conditions. Five pool duration analyses were conducted. They included annual, winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep), and fall (Oct-Dec) timeframes. The Julian days these timeframes represent are 1-365, 1-90, 91-181, 182-273, and 274-365, respectively. Figures of the pool duration curves can be found in Appendix B. Results from the pool duration analysis show that in all cases specific duration percentages saw increases in elevation as a result of the reallocation. Studying the guide curve elevations in figures A.1 through A.3 show why this is true.

Table A.2. Pool duration analysis for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual			Winter		
Percent exceeded	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)
0.01	3,656.3	3,656.7	0.4	3,624.0	3,633.5	9.5
0.05	3,653.5	3,653.2	-0.3	3,624.0	3,633.5	9.5
0.1	3,651.2	3,651.0	-0.2	3,624.0	3,633.4	9.4
0.2	3,646.7	3,648.8	2.1	3,624.0	3,633.3	9.3
0.5	3,644.8	3,645.5	0.7	3,624.0	3,633.2	9.2
1.0	3,642.7	3,644.2	1.5	3,624.0	3,632.9	8.9
2.0	3,641.2	3,643.6	2.4	3,623.9	3,632.7	8.8
5.0	3,640.2	3,642.9	2.7	3,623.6	3,632.2	8.6
10.0	3,639.0	3,642.4	3.4	3,623.3	3,631.7	8.4
15.0	3,637.5	3,641.9	4.4	3,623.0	3,631.3	8.3
20.0	3,636.3	3,641.3	5.0	3,622.6	3,631.0	8.4
30.0	3,632.9	3,639.5	6.6	3,621.8	3,629.9	8.1
40.0	3,628.8	3,635.4	6.6	3,621.1	3,628.5	7.4
50.0	3,624.0	3,631.9	7.9	3,620.4	3,627.1	6.7
60.0	3,621.7	3,628.3	6.6	3,619.6	3,625.9	6.3
70.0	3,619.6	3,625.1	5.5	3,618.9	3,624.6	5.7
80.0	3,618.1	3,623.1	5.0	3,618.4	3,623.5	5.1
85.0	3,616.5	3,621.5	5.0	3,617.1	3,622.0	4.9
90.0	3,611.2	3,616.8	5.6	3,603.3	3,608.9	5.6
95.0	3,593.3	3,599.2	5.9	3,585.2	3,589.7	4.5
98.0	3,581.0	3,587.6	6.6	3,581.4	3,584.7	3.3
99.0	3,579.0	3,585.1	6.1	3,580.4	3,583.1	2.7
99.5	3,577.3	3,583.7	6.4	3,579.6	3,582.4	2.8
99.8	3,575.7	3,581.9	6.2	3,578.7	3,581.7	3.0
99.9	3,575.0	3,580.8	5.8	3,578.1	3,581.2	3.1
99.95	3,574.8	3,580.1	5.3	3,577.7	3,580.8	3.1
99.99	3,574.4	3,579.4	5.0	3,576.8	3,579.9	3.1

Table A.3. Pool duration analysis for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring			Summer		
Percent exceeded	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)
0.01	3,654.3	3,655.3	1.0	3,656.4	3,656.9	0.5
0.05	3,653.7	3,655.1	1.4	3,656.0	3,656.6	0.6
0.1	3,651.7	3,654.2	2.5	3,654.6	3,655.3	0.7
0.2	3,648.6	3,652.8	4.2	3,652.1	3,653.3	1.2
0.5	3,644.0	3,650.0	6.0	3,646.9	3,649.9	3.0
1.0	3,641.1	3,647.3	6.2	3,645.4	3,646.6	1.2
2.0	3,639.5	3,644.4	4.9	3,644.3	3,644.7	0.4
5.0	3,637.6	3,640.5	2.9	3,641.2	3,643.8	2.6
10.0	3,634.3	3,637.5	3.2	3,640.5	3,643.4	2.9
15.0	3,631.2	3,634.6	3.4	3,640.3	3,643.2	2.9
20.0	3,628.0	3,632.2	4.2	3,640.0	3,643.0	3.0
30.0	3,623.2	3,627.6	4.4	3,639.6	3,642.7	3.1
40.0	3,619.7	3,624.7	5.0	3,638.7	3,642.4	3.7
50.0	3,618.5	3,623.7	5.2	3,637.9	3,642.1	4.2
60.0	3,617.8	3,622.7	4.9	3,637.1	3,641.7	4.6
70.0	3,617.1	3,621.6	4.5	3,636.4	3,640.8	4.4
80.0	3,613.1	3,618.6	5.5	3,628.4	3,632.3	3.9
85.0	3,611.7	3,617.2	5.5	3,624.2	3,628.5	4.3
90.0	3,610.5	3,616.4	5.9	3,619.2	3,624.2	5.0
95.0	3,586.1	3,592.5	6.4	3,602.2	3,608.1	5.9
98.0	3,581.3	3,586.9	5.6	3,584.5	3,591.9	7.4
99.0	3,580.1	3,584.3	4.2	3,583.1	3,586.2	3.1
99.5	3,579.1	3,582.9	3.8	3,582.1	3,584.9	2.8
99.8	3,578.1	3,582.4	4.3	3,581.0	3,584.6	3.6
99.9	3,577.5	3,582.1	4.6	3,580.3	3,584.4	4.1
99.95	3,577.0	3,581.9	4.9	3,579.8	3,584.2	4.4
99.99	3,576.0	3,581.5	5.5	3,578.8	3,584.0	5.2

Table A.4. Pool duration analysis for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall		
Percent exceeded	Baseline (ft msl)	Reallocated (ft msl)	Difference (ft)
0.01	3,636.1	3,641.9	5.8
0.05	3,636.1	3,641.9	5.8
0.1	3,636.1	3,641.9	5.8
0.2	3,636.1	3,641.9	5.8
0.5	3,636.0	3,641.8	5.8
1.0	3,636.0	3,641.7	5.7
2.0	3,635.9	3,641.7	5.8
5.0	3,635.6	3,641.5	5.9
10.0	3,635.2	3,641.4	6.2
15.0	3,634.8	3,641.2	6.4
20.0	3,634.1	3,641.1	7.0
30.0	3,632.8	3,640.7	7.9
40.0	3,631.6	3,639.1	7.5
50.0	3,630.4	3,637.6	7.2
60.0	3,629.0	3,636.3	7.3
70.0	3,627.1	3,635.0	7.9
80.0	3,625.1	3,633.9	8.8
85.0	3,623.0	3,627.0	4.0
90.0	3,618.8	3,622.0	3.2
95.0	3,600.0	3,605.0	5.0
98.0	3,591.2	3,596.7	5.5
99.0	3,587.5	3,594.6	7.1
99.5	3,585.4	3,593.7	8.3
99.8	3,584.7	3,592.9	8.2
99.9	3,584.4	3,592.3	7.9
99.95	3,584.1	3,591.9	7.8
99.99	3,583.7	3,591.0	7.3

Tables A.5 through A.19 display the results of the flow duration analyses for Yellowtail Dam, St. Xavier, Bighorn, Miles City, and Sidney, respectively. Graphical representations of these tables can be found in Appendix C. In most cases, the winter and fall analyses do not show a substantial change between the baseline and reallocated conditions. However, the fall duration analysis does have two exceptions to this. The curves at Yellowtail Dam and Miles City both show noticeable differences. At Yellowtail Dam, the baseline condition shows a higher flow than the reallocated condition at the 0.05% exceedance level. This trend actually exists throughout this particular analysis, but the incremental difference is most noticeable at the exceedance level previously stated. The Miles City fall analysis shows the reallocated condition having higher flows than the baseline condition at the 0.05-1% exceedance level. The rest of this analysis shows the baseline condition having higher flows than the reallocated condition, but the incremental differences are smaller.

The annual flow duration tables for Yellowtail Dam, St. Xavier, and Bighorn show the reallocated condition having a higher flow at the lowest exceedance levels (0.01-0.5% exceedance). Generally, the tables at Miles City and Sidney do not have as large an incremental difference at the lower exceedance levels – though the reallocated condition maintains the higher flow. The annual flow duration analysis at Bighorn has the largest incremental difference of any analysis at the 0.01-0.1% exceedance levels. The reason for this large descrepency is because of the distribution of flow. The baseline condition has two values over 26,000 cfs, while the reallocated condition has 12. In the case of the reallocated simulation, this raises the flow values for the lower exceedance percentages in comparison to the baseline simulation.

When comparing the baseline and reallocated simulations, differences in the spring and summer flow duration tables do exist. Generally speaking, the spring reallocated simulation provides higher flows at exceedance percentages that are approximately less than 0.2%. For the summer analysis, the reallocated simulation provides higher flows at exceedance percentages approximately less than 1%. The Bighorn and Sidney locations were the least sensitive to the reallocation.

Overall, the flow duration analysis shows the reallocation of flood control storage to joint use storage does have an impact on outflows from the dam. Furthermore, river flows at certain downstream locations are also impacted. However, the magnitude of the impact changes seasonally. When studying the seasonal analysis, it appears the spring and summer timeframes show the most sensitivity to the reallocation. This can most likely be attributed to the fact that Yellowtail Dam operations are most affected by the reallocation during those timeframes.

Table A.5. Flow duration analysis at Yellowtail Dam for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	24,258	25,739	1,481	6.1	9,828	9,856	28	0.3
0.05	21,580	25,425	3,845	17.8	9,568	9,619	51	0.5
0.1	19,228	25,137	5,909	30.7	8,710	8,825	115	1.3
0.2	16,106	23,876	7,770	48.2	7,560	7,731	171	2.3
0.5	10,502	14,359	3,857	36.7	6,348	6,482	134	2.1
1.0	9,726	9,757	31	0.3	5,733	5,852	119	2.1
2.0	9,255	9,238	-17	0.2	4,965	5,261	296	6.0
5.0	6,432	6,428	-4	0.1	4,359	4,609	250	5.7
10.0	4,954	4,983	29	0.6	3,968	4,243	275	6.9
15.0	4,350	4,426	76	1.7	3,739	4,009	270	7.2
20.0	3,996	4,044	48	1.2	3,524	3,791	266	7.6
30.0	3,498	3,496	-2	0.1	3,136	3,407	271	8.7
40.0	3,093	3,074	-19	0.6	2,814	3,093	279	9.9
50.0	2,712	2,712	0	0.0	2,550	2,831	280	11.0
60.0	2,333	2,302	-31	1.3	2,292	2,572	280	12.2
70.0	1,824	1,649	-175	9.6	1,994	2,281	287	14.4
80.0	1,490	1,488	-2	0.1	1,499	1,775	276	18.4
85.0	1,482	1,480	-2	0.1	1,490	1,494	4	0.3
90.0	1,473	1,470	-3	0.2	1,479	1,482	4	0.2
95.0	1,460	1,458	-2	0.1	1,465	1,468	3	0.2
98.0	1,448	1,447	-1	0.1	1,452	1,454	2	0.1
99.0	1,442	1,441	-1	0.1	1,444	1,446	2	0.1
99.5	1,436	1,435	-1	0.1	1,438	1,439	1	0.1
99.8	1,430	1,429	-1	0.1	1,432	1,433	1	0.1
99.9	1,426	1,425	-1	0.1	1,427	1,428	1	0.1
99.95	1,423	1,422	-1	0.1	1,424	1,424	1	0.0
99.99	1,416	1,415	-1	0.1	1,417	1,417	0	0.0

Table A.6. Flow duration analysis at Yellowtail Dam for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	19,964	21,158	1,194	6.0	24,351	25,750	1,399	5.7
0.05	19,583	20,867	1,284	6.6	24,107	25,723	1,616	6.7
0.1	18,216	19,709	1,493	8.2	23,158	25,620	2,462	10.6
0.2	15,985	17,525	1,540	9.6	21,373	25,429	4,056	19.0
0.5	12,070	12,718	648	5.4	17,447	25,018	7,571	43.4
1.0	10,005	9,983	-22	0.2	12,987	21,144	8,157	62.8
2.0	9,680	9,682	2	0.0	9,792	10,011	219	2.2
5.0	8,862	8,979	117	1.3	8,803	8,172	-631	7.2
10.0	6,648	6,653	5	0.1	5,936	5,966	30	0.5
15.0	5,687	5,639	-48	0.8	4,834	4,919	85	1.8
20.0	5,006	5,043	37	0.7	4,200	4,284	84	2.0
30.0	3,992	3,991	-1	0.0	3,506	3,268	-238	6.8
40.0	3,320	3,298	-22	0.7	3,038	2,702	-336	11.1
50.0	2,727	2,669	-58	2.1	2,531	2,113	-418	16.5
60.0	2,038	2,030	-8	0.4	2,069	1,499	-570	27.5
70.0	1,497	1,496	-1	0.1	1,497	1,488	-9	0.6
80.0	1,483	1,483	0	0.0	1,484	1,476	-8	0.5
85.0	1,476	1,476	0	0.0	1,476	1,470	-6	0.4
90.0	1,467	1,467	0	0.0	1,468	1,462	-6	0.4
95.0	1,456	1,456	0	0.0	1,456	1,452	-4	0.3
98.0	1,445	1,445	0	0.0	1,446	1,442	-4	0.3
99.0	1,439	1,439	0	0.0	1,439	1,437	-2	0.1
99.5	1,434	1,434	0	0.0	1,434	1,432	-2	0.1
99.8	1,428	1,428	0	0.0	1,429	1,427	-2	0.1
99.9	1,425	1,425	0	0.0	1,425	1,423	-2	0.1
99.95	1,422	1,421	-1	0.1	1,422	1,420	-2	0.1
99.99	1,415	1,415	0	0.0	1,415	1,414	-1	0.1

Table A.7. Flow duration analysis at Yellowtail Dam for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	9,564	9,564	0	0.0
0.05	8,863	7,568	-1,295	14.6
0.1	7,498	6,761	-736	9.8
0.2	6,857	6,219	-638	9.3
0.5	6,188	5,702	-485	7.8
1.0	5,661	5,439	-222	3.9
2.0	5,184	5,031	-153	2.9
5.0	4,682	4,645	-37	0.8
10.0	4,349	4,284	-64	1.5
15.0	4,137	4,026	-111	2.7
20.0	3,925	3,802	-123	3.1
30.0	3,552	3,439	-113	3.2
40.0	3,261	3,147	-114	3.5
50.0	3,001	2,899	-102	3.4
60.0	2,720	2,604	-116	4.3
70.0	2,389	2,225	-164	6.9
80.0	1,500	1,495	-5	0.3
85.0	1,490	1,486	-4	0.3
90.0	1,480	1,476	-3	0.2
95.0	1,465	1,463	-3	0.2
98.0	1,452	1,450	-2	0.1
99.0	1,445	1,443	-2	0.1
99.5	1,438	1,437	-1	0.1
99.8	1,432	1,431	-1	0.1
99.9	1,428	1,427	-1	0.1
99.95	1,424	1,423	-1	0.0
99.99	1,417	1,416	0	0.0

Table A.8. Flow duration analysis at St. Xavier for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	26,097	27,491	1,394	5.3	9,481	9,743	262	2.8
0.05	25,096	26,328	1,232	4.9	9,256	9,555	299	3.2
0.1	23,331	25,350	2,019	8.7	8,507	8,907	400	4.7
0.2	19,175	23,282	4,107	21.4	7,487	7,958	471	6.3
0.5	11,219	15,188	3,969	35.4	6,354	6,663	310	4.9
1.0	10,041	10,059	18	0.2	5,722	5,845	123	2.2
2.0	9,854	9,838	-16	0.2	4,939	5,195	255	5.2
5.0	6,652	6,663	11	0.2	4,420	4,697	277	6.3
10.0	5,140	5,162	22	0.4	4,028	4,300	272	6.8
15.0	4,516	4,554	38	0.8	3,785	4,054	269	7.1
20.0	4,159	4,198	39	0.9	3,588	3,831	244	6.8
30.0	3,675	3,644	-31	0.8	3,182	3,446	264	8.3
40.0	3,271	3,241	-30	0.9	2,868	3,145	277	9.7
50.0	2,898	2,894	-4	0.1	2,617	2,897	280	10.7
60.0	2,538	2,514	-24	0.9	2,367	2,639	272	11.5
70.0	2,144	2,100	-44	2.1	2,108	2,386	278	13.2
80.0	1,832	1,794	-38	2.1	1,784	2,010	227	12.7
85.0	1,658	1,632	-26	1.6	1,631	1,672	42	2.6
90.0	1,525	1,514	-11	0.7	1,531	1,540	9	0.6
95.0	1,421	1,414	-7	0.5	1,454	1,457	4	0.2
98.0	1,329	1,322	-7	0.5	1,385	1,391	6	0.4
99.0	1,269	1,262	-7	0.6	1,334	1,340	6	0.4
99.5	1,213	1,205	-8	0.7	1,280	1,288	8	0.6
99.8	1,127	1,116	-11	1.0	1,202	1,215	13	1.1
99.9	1,057	1,047	-10	0.9	1,150	1,157	7	0.6
99.95	993	945	-48	4.8	1,087	1,087	-1	0.1
99.99	887	566	-321	36.2	916	916	0	0.0

Table A.9. Flow duration analysis at St. Xavier for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	18,226	19,278	1,052	5.8	26,134	27,533	1,399	5.4
0.05	17,889	18,897	1,008	5.6	26,039	27,427	1,388	5.3
0.1	16,709	17,539	830	5.0	25,692	27,034	1,342	5.2
0.2	14,861	15,350	489	3.3	25,090	26,343	1,253	5.0
0.5	11,870	11,589	-281	2.4	22,226	24,959	2,733	12.3
1.0	10,151	10,109	-42	0.4	16,047	21,676	5,629	35.1
2.0	9,996	9,988	-8	0.1	10,103	12,549	2,446	24.2
5.0	9,092	9,244	152	1.7	9,785	9,108	-677	6.9
10.0	6,706	6,705	-1	0.0	6,437	6,443	6	0.1
15.0	5,840	5,827	-13	0.2	5,251	5,287	36	0.7
20.0	5,197	5,189	-8	0.2	4,556	4,597	41	0.9
30.0	4,211	4,223	12	0.3	3,864	3,680	-184	4.8
40.0	3,508	3,497	-11	0.3	3,360	3,042	-318	9.5
50.0	2,902	2,893	-9	0.3	2,894	2,534	-360	12.4
60.0	2,291	2,261	-30	1.3	2,505	2,140	-365	14.6
70.0	1,916	1,913	-3	0.2	2,135	1,984	-151	7.1
80.0	1,695	1,688	-7	0.4	1,953	1,851	-102	5.2
85.0	1,580	1,577	-3	0.2	1,866	1,757	-109	5.8
90.0	1,483	1,482	-1	0.1	1,725	1,626	-99	5.7
95.0	1,392	1,390	-2	0.1	1,498	1,447	-51	3.4
98.0	1,314	1,319	5	0.4	1,358	1,327	-31	2.3
99.0	1,258	1,262	4	0.3	1,297	1,263	-34	2.6
99.5	1,201	1,201	0	0.0	1,238	1,206	-32	2.6
99.8	1,120	1,120	0	0.0	1,170	1,133	-37	3.2
99.9	1,021	1,021	0	0.0	1,120	1,074	-46	4.1
99.95	971	971	0	0.0	1,100	969	-131	11.9
99.99	900	900	0	0.0	1,095	362	-733	66.9

Table A.10. Flow duration analysis at St. Xavier for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	9,262	8,962	-300	3.2
0.05	7,532	7,528	-5	0.1
0.1	6,967	6,886	-81	1.2
0.2	6,609	6,433	-177	2.7
0.5	6,209	5,912	-297	4.8
1.0	5,782	5,488	-294	5.1
2.0	5,187	5,105	-82	1.6
5.0	4,755	4,688	-67	1.4
10.0	4,447	4,399	-48	1.1
15.0	4,227	4,125	-102	2.4
20.0	4,025	3,897	-127	3.2
30.0	3,696	3,571	-125	3.4
40.0	3,427	3,301	-126	3.7
50.0	3,184	3,072	-112	3.5
60.0	2,922	2,834	-88	3.0
70.0	2,604	2,468	-136	5.2
80.0	2,005	1,696	-309	15.4
85.0	1,584	1,555	-28	1.8
90.0	1,479	1,468	-11	0.8
95.0	1,379	1,373	-7	0.5
98.0	1,283	1,278	-4	0.3
99.0	1,228	1,224	-4	0.3
99.5	1,154	1,151	-2	0.2
99.8	1,044	1,045	0	0.0
99.9	998	998	0	0.0
99.95	986	986	0	0.0
99.99	965	965	0	0.0

Table A.11. Flow duration analysis at Bighorn for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	37,146	48,823	11,677	31.4	12,469	12,755	286	2.3
0.05	20,261	30,719	10,458	51.6	12,335	12,625	290	2.4
0.1	17,795	24,770	6,975	39.2	11,837	12,142	305	2.6
0.2	15,701	20,504	4,803	30.6	11,007	11,332	325	3.0
0.5	13,388	15,402	2,014	15.0	9,503	9,851	348	3.7
1.0	11,838	12,411	573	4.8	8,185	8,532	347	4.2
2.0	10,460	10,772	312	3.0	6,895	7,207	312	4.5
5.0	7,874	7,805	-69	0.9	5,415	5,751	336	6.2
10.0	5,986	5,977	-9	0.2	4,591	4,858	267	5.8
15.0	5,092	5,132	40	0.8	4,270	4,521	251	5.9
20.0	4,623	4,672	49	1.1	3,996	4,251	255	6.4
30.0	4,025	4,037	12	0.3	3,535	3,796	261	7.4
40.0	3,589	3,583	-6	0.2	3,216	3,482	266	8.3
50.0	3,181	3,200	19	0.6	2,953	3,213	260	8.8
60.0	2,769	2,744	-25	0.9	2,642	2,908	266	10.1
70.0	2,303	2,222	-81	3.5	2,341	2,626	285	12.2
80.0	1,883	1,819	-64	3.4	1,987	2,141	154	7.8
85.0	1,727	1,690	-37	2.1	1,798	1,857	59	3.3
90.0	1,601	1,576	-25	1.6	1,659	1,686	27	1.6
95.0	1,456	1,442	-14	1.0	1,538	1,557	19	1.2
98.0	1,306	1,286	-20	1.5	1,418	1,447	29	2.0
99.0	1,213	1,184	-29	2.4	1,344	1,374	30	2.2
99.5	1,126	1,097	-29	2.6	1,260	1,292	32	2.5
99.8	1,013	970	-43	4.2	1,149	1,151	2	0.2
99.9	818	769	-49	6.0	485	485	0	0.0
99.95	579	569	-10	1.7	398	398	0	0.0
99.99	364	367	3	0.8	262	262	0	0.0

Table A.12. Flow duration analysis at Bighorn for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	49,837	49,837	0	0.0	25,870	27,269	1,399	5.4
0.05	37,025	37,025	0	0.0	25,741	27,174	1,433	5.6
0.1	23,959	23,958	-1	0.0	25,291	26,823	1,532	6.1
0.2	20,524	20,500	-24	0.1	24,117	26,205	2,088	8.7
0.5	16,695	16,620	-75	0.4	19,028	24,961	5,933	31.2
1.0	14,335	14,235	-100	0.7	14,108	19,974	5,866	41.6
2.0	12,421	12,347	-74	0.6	11,013	12,535	1,522	13.8
5.0	10,551	10,706	155	1.5	9,502	9,496	-6	0.1
10.0	8,234	8,253	19	0.2	6,726	6,628	-98	1.5
15.0	7,097	7,073	-24	0.3	5,438	5,437	-1	0.0
20.0	6,285	6,314	29	0.5	4,686	4,729	43	0.9
30.0	5,258	5,292	34	0.6	3,875	3,726	-149	3.8
40.0	4,351	4,358	7	0.2	3,315	3,029	-286	8.6
50.0	3,646	3,647	1	0.0	2,813	2,422	-391	13.9
60.0	2,886	2,858	-28	1.0	2,361	2,026	-335	14.2
70.0	2,248	2,234	-14	0.6	1,993	1,823	-170	8.5
80.0	1,925	1,915	-10	0.5	1,752	1,660	-92	5.3
85.0	1,786	1,777	-9	0.5	1,650	1,579	-71	4.3
90.0	1,652	1,647	-5	0.3	1,531	1,476	-55	3.6
95.0	1,506	1,505	-1	0.1	1,414	1,362	-52	3.7
98.0	1,385	1,387	2	0.1	1,279	1,230	-49	3.8
99.0	1,298	1,298	0	0.0	1,230	1,160	-70	5.7
99.5	1,194	1,194	0	0.0	1,190	1,090	-100	8.4
99.8	1,068	1,088	20	1.9	1,147	985	-162	14.1
99.9	906	977	71	7.8	1,112	936	-176	15.8
99.95	641	681	40	6.2	1,058	894	-164	15.5
99.99	426	425	-1	0.2	922	812	-110	11.9

Table A.13. Flow duration analysis at Bighorn for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	9,992	9,677	-315	3.2
0.05	9,100	8,517	-584	6.4
0.1	7,489	7,235	-253	3.4
0.2	6,970	6,765	-205	2.9
0.5	6,484	6,282	-202	3.1
1.0	6,145	5,922	-223	3.6
2.0	5,682	5,483	-199	3.5
5.0	5,067	5,012	-54	1.1
10.0	4,759	4,704	-55	1.2
15.0	4,543	4,469	-74	1.6
20.0	4,344	4,219	-124	2.9
30.0	3,974	3,881	-93	2.3
40.0	3,719	3,599	-120	3.2
50.0	3,470	3,349	-121	3.5
60.0	3,178	3,085	-93	2.9
70.0	2,835	2,667	-168	5.9
80.0	2,166	1,885	-282	13.0
85.0	1,707	1,655	-52	3.0
90.0	1,551	1,529	-22	1.4
95.0	1,378	1,372	-6	0.4
98.0	1,187	1,187	0	0.0
99.0	1,083	1,083	0	0.0
99.5	1,006	1,006	0	0.0
99.8	949	949	0	0.0
99.9	913	913	0	0.0
99.95	882	882	0	0.0
99.99	820	820	0	0.0

Table A.14. Flow duration analysis at Miles City for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	86,973	87,658	685	0.8	43,341	43,629	288	0.7
0.05	74,345	75,689	1,344	1.8	41,665	41,884	219	0.5
0.1	70,167	70,620	453	0.6	37,082	37,135	53	0.1
0.2	66,125	66,351	226	0.3	33,036	33,008	-28	0.1
0.5	60,112	60,440	328	0.5	27,909	27,871	-38	0.1
1.0	53,047	53,488	441	0.8	22,972	23,071	99	0.4
2.0	44,931	44,933	2	0.0	17,098	17,186	88	0.5
5.0	34,356	34,472	116	0.3	12,859	13,223	364	2.8
10.0	24,530	24,500	-30	0.1	10,026	10,368	342	3.4
15.0	17,789	17,767	-22	0.1	9,119	9,365	246	2.7
20.0	13,933	13,948	15	0.1	8,466	8,718	252	3.0
30.0	10,634	10,533	-101	0.9	7,498	7,757	259	3.5
40.0	9,039	9,023	-16	0.2	6,754	7,004	250	3.7
50.0	7,999	7,961	-38	0.5	6,138	6,417	279	4.5
60.0	7,162	7,138	-24	0.3	5,614	5,846	232	4.1
70.0	6,337	6,337	0	0.0	5,128	5,336	208	4.1
80.0	5,423	5,464	41	0.8	4,498	4,659	161	3.6
85.0	4,929	4,967	38	0.8	4,187	4,284	97	2.3
90.0	4,393	4,411	18	0.4	3,817	3,893	76	2.0
95.0	3,775	3,787	12	0.3	3,196	3,310	114	3.6
98.0	3,052	3,088	36	1.2	2,553	2,701	148	5.8
99.0	2,614	2,696	82	3.1	2,082	2,284	202	9.7
99.5	2,244	2,370	126	5.6	1,909	1,987	78	4.1
99.8	1,954	2,003	49	2.5	1,766	1,888	122	6.9
99.9	1,816	1,731	-85	4.7	1,678	1,829	151	9.0
99.95	1,699	1,460	-239	14.1	1,603	1,780	177	11.0
99.99	1,482	1,035	-447	30.2	1,466	1,693	227	15.5

Table A.15. Flow duration analysis at Miles City for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	88,663	88,663	0	0.0	68,036	69,181	1,145	1.7
0.05	84,872	86,304	1,432	1.7	67,702	68,819	1,117	1.6
0.1	78,720	80,671	1,951	2.5	66,503	67,519	1,016	1.5
0.2	74,529	75,849	1,320	1.8	64,473	65,322	849	1.3
0.5	68,621	69,009	388	0.6	60,645	61,187	542	0.9
1.0	63,258	63,481	223	0.4	52,767	54,514	1,747	3.3
2.0	57,152	57,293	141	0.2	42,348	42,840	492	1.2
5.0	46,955	46,953	-2	0.0	34,000	34,366	366	1.1
10.0	39,699	39,645	-54	0.1	26,125	26,247	122	0.5
15.0	34,291	34,339	48	0.1	20,557	20,370	-187	0.9
20.0	30,085	30,085	0	0.0	16,506	16,327	-179	1.1
30.0	22,935	22,850	-85	0.4	12,389	12,226	-163	1.3
40.0	17,724	17,733	9	0.1	10,537	10,272	-265	2.5
50.0	14,119	14,127	8	0.1	9,000	8,818	-182	2.0
60.0	11,534	11,530	-4	0.0	7,847	7,510	-337	4.3
70.0	9,366	9,404	38	0.4	6,624	6,323	-301	4.5
80.0	7,611	7,660	49	0.6	5,551	5,387	-164	3.0
85.0	6,939	6,933	-6	0.1	4,960	4,827	-133	2.7
90.0	6,211	6,144	-67	1.1	4,296	4,235	-61	1.4
95.0	5,251	5,280	29	0.6	3,554	3,553	-1	0.0
98.0	4,427	4,425	-2	0.0	2,988	2,988	0	0.0
99.0	4,022	4,021	-1	0.0	2,898	2,898	0	0.0
99.5	3,645	3,645	0	0.0	2,826	2,826	0	0.0
99.8	3,292	3,292	0	0.0	2,750	2,750	0	0.0
99.9	3,090	3,090	0	0.0	2,704	2,704	0	0.0
99.95	2,994	2,994	0	0.0	2,664	2,664	0	0.0
99.99	2,913	2,913	0	0.0	2,590	2,590	0	0.0

Table A.16. Flow duration analysis at Miles City for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	20,045	19,791	-254	1.3
0.05	18,839	19,614	775	4.1
0.1	17,556	18,984	1,428	8.1
0.2	16,353	17,939	1,586	9.7
0.5	14,864	16,034	1,170	7.9
1.0	13,790	14,337	547	4.0
2.0	12,726	12,625	-101	0.8
5.0	11,228	10,943	-285	2.5
10.0	10,348	10,197	-151	1.5
15.0	9,808	9,681	-127	1.3
20.0	9,299	9,214	-85	0.9
30.0	8,540	8,427	-113	1.3
40.0	7,904	7,806	-98	1.2
50.0	7,429	7,346	-83	1.1
60.0	7,021	6,933	-88	1.3
70.0	6,424	6,257	-167	2.6
80.0	5,470	5,341	-129	2.4
85.0	4,882	4,812	-70	1.4
90.0	4,462	4,431	-31	0.7
95.0	4,015	3,952	-63	1.6
98.0	3,385	3,263	-122	3.6
99.0	2,881	2,762	-119	4.1
99.5	2,426	2,368	-58	2.4
99.8	2,013	1,892	-121	6.0
99.9	1,860	1,476	-384	20.6
99.95	1,731	1,132	-599	34.6
99.99	1,498	964	-534	35.6

Table A.17. Flow duration analysis at Sidney for the annual and winter timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Annual				Winter			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	104,326	104,336	10	0.0	74,751	75,017	266	0.4
0.05	78,494	78,536	42	0.1	73,067	73,315	248	0.3
0.1	74,466	74,647	181	0.2	67,193	67,378	185	0.3
0.2	70,645	71,034	389	0.6	58,393	58,493	100	0.2
0.5	62,639	63,042	403	0.6	45,669	45,672	3	0.0
1.0	55,999	56,139	140	0.3	36,561	36,573	12	0.0
2.0	49,108	49,174	66	0.1	25,000	24,823	-177	0.7
5.0	36,557	36,599	42	0.1	15,771	15,819	48	0.3
10.0	25,498	25,445	-53	0.2	11,953	12,278	325	2.7
15.0	18,473	18,427	-46	0.2	10,398	10,682	284	2.7
20.0	14,467	14,435	-32	0.2	9,534	9,782	248	2.6
30.0	11,031	11,006	-25	0.2	8,377	8,601	224	2.7
40.0	9,444	9,408	-36	0.4	7,463	7,695	232	3.1
50.0	8,272	8,290	18	0.2	6,753	6,989	236	3.5
60.0	7,355	7,326	-29	0.4	6,082	6,368	286	4.7
70.0	6,424	6,439	15	0.2	5,545	5,739	194	3.5
80.0	5,441	5,419	-22	0.4	4,812	4,940	128	2.7
85.0	4,876	4,849	-27	0.6	4,441	4,531	90	2.0
90.0	4,313	4,279	-34	0.8	4,076	4,136	60	1.5
95.0	3,460	3,453	-7	0.2	3,343	3,451	108	3.2
98.0	2,502	2,481	-21	0.8	2,638	2,745	107	4.1
99.0	1,886	1,871	-15	0.8	2,270	2,312	42	1.9
99.5	1,477	1,461	-16	1.1	1,929	2,000	71	3.7
99.8	1,093	1,084	-9	0.8	1,082	1,083	1	0.1
99.9	915	926	11	1.2	868	898	30	3.5
99.95	771	803	32	4.2	717	783	66	9.2
99.99	505	580	75	14.9	455	589	134	29.5

Table A.18. Flow duration analysis at Sidney for the spring and summer timeframes. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Spring				Summer			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	106,597	106,622	25	0.0	72,712	72,939	227	0.3
0.05	101,374	101,371	-3	0.0	72,350	72,612	262	0.4
0.1	87,832	87,791	-41	0.0	71,170	71,517	347	0.5
0.2	78,336	78,372	36	0.0	69,342	69,859	517	0.7
0.5	72,358	72,585	227	0.3	63,634	64,420	786	1.2
1.0	66,275	66,642	367	0.6	56,983	57,706	723	1.3
2.0	58,937	59,054	117	0.2	47,084	47,762	678	1.4
5.0	50,705	50,601	-104	0.2	36,363	36,414	51	0.1
10.0	41,742	41,695	-47	0.1	26,824	27,034	210	0.8
15.0	35,596	35,568	-28	0.1	21,453	21,130	-323	1.5
20.0	30,468	30,449	-19	0.1	16,699	16,501	-198	1.2
30.0	22,746	22,705	-41	0.2	12,307	12,084	-223	1.8
40.0	17,832	17,834	2	0.0	10,155	9,793	-362	3.6
50.0	14,403	14,405	2	0.0	8,439	8,285	-154	1.8
60.0	11,850	11,847	-3	0.0	6,972	6,702	-270	3.9
70.0	9,670	9,720	50	0.5	5,776	5,525	-251	4.3
80.0	8,022	8,008	-14	0.2	4,584	4,397	-187	4.1
85.0	7,334	7,286	-48	0.7	4,015	3,900	-115	2.9
90.0	6,326	6,372	46	0.7	3,437	3,370	-67	1.9
95.0	5,322	5,355	33	0.6	2,539	2,488	-51	2.0
98.0	4,665	4,666	1	0.0	1,707	1,711	4	0.2
99.0	4,059	4,059	0	0.0	1,355	1,359	4	0.3
99.5	3,550	3,550	0	0.0	1,117	1,119	2	0.2
99.8	2,756	2,756	0	0.0	998	998	0	0.0
99.9	1,911	1,911	0	0.0	982	982	0	0.0
99.95	1,280	1,280	0	0.0	970	970	0	0.0
99.99	901	901	0	0.0	950	950	0	0.0

Table A.19. Flow duration analysis at Sidney for the fall timeframe. Table compares the baseline and reallocated simulations. Difference is calculated as reallocated-baseline.

	Fall			
Percent exceeded	Baseline (cfs)	Reallocated (cfs)	Difference (cfs)	% of Baseline
0.01	30,454	30,200	-254	0.8
0.05	27,691	27,517	-174	0.6
0.1	21,625	21,606	-19	0.1
0.2	18,975	18,961	-14	0.1
0.5	16,716	16,680	-36	0.2
1.0	15,164	15,117	-47	0.3
2.0	13,735	13,676	-59	0.4
5.0	11,994	11,900	-94	0.8
10.0	10,793	10,678	-115	1.1
15.0	10,216	10,083	-133	1.3
20.0	9,753	9,648	-105	1.1
30.0	8,991	8,867	-124	1.4
40.0	8,267	8,215	-52	0.6
50.0	7,666	7,543	-123	1.6
60.0	7,180	7,039	-141	2.0
70.0	6,505	6,376	-129	2.0
80.0	5,559	5,448	-111	2.0
85.0	5,020	4,942	-78	1.6
90.0	4,508	4,470	-38	0.8
95.0	3,917	3,800	-117	3.0
98.0	2,887	2,776	-111	3.8
99.0	2,148	1,996	-152	7.1
99.5	1,589	1,498	-91	5.7
99.8	1,057	1,054	-3	0.3
99.9	905	900	-5	0.6
99.95	791	778	-13	1.6
99.99	591	561	-30	5.1

Comparing the flow frequency analyses developed at St. Xavier, Bighorn, Miles City, and Sidney yielded little differences between the baseline and reallocated conditions. The reallocated condition usually posted higher flows at specific probabilities, but the relative difference between the two at these probabilities was never over 1,000 cfs. Tables A.20 through A.23 provide the flow frequency data, and the data is plotted graphically in Appendix D.

Table A.20. Annual flow frequency analysis at St. Xavier. Table compares the baseline and reallocated conditions. Difference is calculated as reallocated-baseline.

Baseline Computed Probability		Reallocated Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Baseline
0.002	24,450	0.002	25,152	702	2.9
0.005	22,817	0.005	23,411	594	2.6
0.01	21,406	0.01	21,918	512	2.4
0.02	19,815	0.02	20,247	432	2.2
0.05	17,377	0.05	17,706	329	1.9
0.1	15,208	0.1	15,464	256	1.7
0.2	12,656	0.2	12,844	188	1.5
0.5	8,277	0.5	8,389	112	1.4
0.8	4,878	0.8	4,955	77	1.6
0.9	3,541	0.9	3,606	65	1.8
0.95	2,654	0.95	2,710	56	2.1
0.99	1,455	0.99	1,498	43	3.0

Table A.21. Annual flow frequency analysis at Bighorn. Table compares the baseline and reallocated conditions. Difference is calculated as reallocated-baseline.

Baseline Computed Probability		Reallocated Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Baseline
0.002	48,919	0.002	48,970	51	0.1
0.005	41,683	0.005	41,768	85	0.2
0.01	36,425	0.01	36,528	103	0.3
0.02	31,344	0.02	31,459	115	0.4
0.05	24,877	0.05	25,000	123	0.5
0.1	20,142	0.1	20,264	122	0.6
0.2	15,484	0.2	15,596	112	0.7
0.5	9,148	0.5	9,236	88	1.0
0.8	5,242	0.8	5,303	61	1.2
0.9	3,870	0.9	3,918	48	1.2
0.95	2,993	0.95	3,032	39	1.3
0.99	1,818	0.99	1,844	26	1.4

Table A.22. Annual flow frequency analysis at Miles City. Table compares the baseline and reallocated conditions. Difference is calculated as reallocated-baseline.

Baseline Computed Probability		Reallocated Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Baseline
0.002	117,044	0.002	117,173	129	0.1
0.005	106,480	0.005	106,622	142	0.1
0.01	98,358	0.01	98,506	148	0.2
0.02	90,069	0.02	90,220	151	0.2
0.05	78,718	0.05	78,867	149	0.2
0.1	69,652	0.1	69,793	141	0.2
0.2	59,855	0.2	59,983	128	0.2
0.5	44,315	0.5	44,413	98	0.2
0.8	32,352	0.8	32,418	66	0.2
0.9	27,289	0.9	27,339	50	0.2
0.95	23,641	0.95	23,679	38	0.2
0.99	17,928	0.99	17,948	20	0.1

Table A.23. Annual flow frequency analysis at Sidney. Table compares the baseline and reallocated conditions. Difference is calculated as reallocated-baseline.

Baseline Computed Probability		Reallocated Computed Probability			
Probability	Flow (cfs)	Probability	Flow (cfs)	Difference (cfs)	% of Baseline
0.002	128,834	0.002	128,696	-138	0.1
0.005	117,747	0.005	117,708	-39	0.0
0.01	109,052	0.01	109,077	25	0.0
0.02	100,026	0.02	100,102	76	0.1
0.05	87,420	0.05	87,544	124	0.1
0.1	77,153	0.1	77,297	144	0.2
0.2	65,877	0.2	66,022	145	0.2
0.5	47,682	0.5	47,787	105	0.2
0.8	33,548	0.8	33,592	44	0.1
0.9	27,595	0.9	27,608	13	0.0
0.95	23,341	0.95	23,332	-9	0.0
0.99	16,795	0.99	16,752	-43	0.3

Figure A.14 shows the pool probability curves comparing the baseline and reallocated simulations. The baseline curve tends to track below the reallocated curve. At the lowest probability value of 0.024, the reallocated condition reaches an elevation that is 0.5 ft higher than the baseline condition.

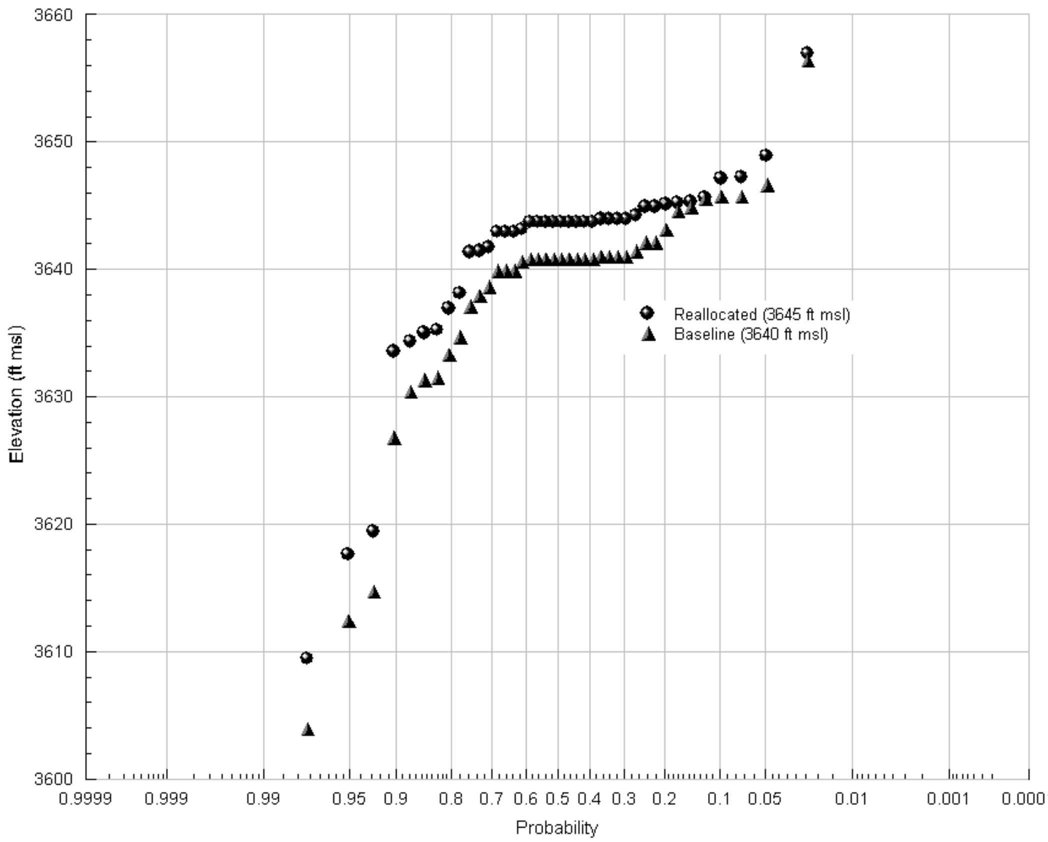

Figure A.14. Pool probability plot comparing the baseline and reallocated simulations over the modeled period of record.

Tables A.24 through A.26 compare the downstream flood damage information for the baseline and reallocated HEC-ResSim simulations. As the discharge/damage curves showed (figures 5-9), the analysis is broken up into reaches with each reach's river flow being represented by the flow at a Yellowstone or Bighorn River location. The locations for the reaches are: reach 1 – Miles City, reach 2 – Miles City, reach 3 – Sidney, reach 5 – Hardin, and reach 6 – Bighorn.

Reach 5 and reach 6 only showed a change in flood damages in one year – 1967. For that year, the reallocated simulation resulted in increased damages of $8,500 and $24,700, respectively. In certain years, Reach 3 did show some increases to flood damages as a result of the reallocation. The reallocation affected reaches 1 and 2 in three ways. Flood damages remained the same, increased, or decreased depending on the year. The reach displaying the most impact from the reallocation was reach 1. Over the course of the period of record, all reaches saw an increase in flood damages as a result of the reallocation.

Table A.24. Comparison of flood damages for reaches 1 and 2. Difference is calculated as reallocated-baseline.

Year	Reach 1				Reach 2			
	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline
1967	663.5	699.6	36.1	5.4	114.2	120.4	6.2	5.5
1968	56.3	56.3	0.0	0.0	9.7	9.7	0.0	0.0
1969	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1970	127.2	127.2	0.0	0.0	21.9	21.9	0.0	0.0
1971	1.4	2.8	1.4	100.0	0.3	0.5	0.2	92.0
1972	72.2	71.7	-0.5	0.7	12.4	12.3	-0.1	0.7
1973	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1974	716.9	720.0	3.1	0.4	123.4	123.9	0.5	0.4
1975	437.1	457.6	20.5	4.7	75.2	78.7	3.5	4.7
1976	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1977	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1978	1655.6	1655.6	0.0	0.0	285.4	285.4	0.0	0.0
1979	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1980	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1981	64.8	66.4	1.6	2.5	11.1	11.4	0.3	2.4
1982	300.5	292.5	-8.0	2.7	51.7	50.3	-1.4	2.7
1983	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1984	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1985	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1986	29.4	27.8	-1.6	5.4	5.0	4.8	-0.3	5.4
1987	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1988	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1989	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1990	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1991	200.1	200.7	0.6	0.3	34.4	34.5	0.1	0.3
1992	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1993	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1994	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1995	73.2	72.6	-0.6	0.8	12.6	12.5	-0.1	1.0
1996	338.9	339.5	0.6	0.2	58.3	58.4	0.1	0.2
1997	1414.4	1449.5	35.1	2.5	243.7	249.8	6.1	2.5
1998	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1999	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2000	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2001	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2002	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2003	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2004	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2005	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2006	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
SUM	6151.5	6239.8	88.3	1.4	1059.0	1074.2	15.2	1.4
Average Annual	153.8	156.0	2.2	1.4	26.5	26.9	0.4	1.5

Table A.25. Comparison of flood damages for reaches 3 and 5. Difference is calculated as reallocated-baseline.

Year	Reach 3				Reach 5			
	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline
1967	78.6	78.7	0.1	0.2	14.6	23.1	8.5	57.8
1968	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1969	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1970	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1971	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1972	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1973	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1974	46.6	46.7	0.1	0.3	0.0	0.0	0.0	n/a
1975	40.4	41.8	1.4	3.4	0.0	0.0	0.0	n/a
1976	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1977	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1978	453.3	453.8	0.5	0.1	0.0	0.0	0.0	n/a
1979	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1980	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1981	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1982	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1983	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1984	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1985	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1986	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1987	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1988	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1989	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1990	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1991	4.7	4.8	0.1	2.1	0.0	0.0	0.0	n/a
1992	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1993	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1994	52.7	54.3	1.6	3.1	0.0	0.0	0.0	n/a
1995	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1996	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1997	127.3	131.0	3.7	2.9	0.0	0.0	0.0	n/a
1998	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
1999	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2000	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2001	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2002	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2003	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2004	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2005	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
2006	0.0	0.0	0.0	n/a	0.0	0.0	0.0	n/a
SUM	803.5	811.0	7.5	1.0	14.6	23.1	8.5	58.2
Average Annual	20.1	20.3	0.2	1.0	0.4	0.6	0.2	50.0

Table A.26. Comparison of flood damages for reach 6. Difference is calculated as reallocated-baseline.

Year	Reach 6			
	Baseline ($1000)	Reallocated ($1000)	Difference ($1000)	% of Baseline
1967	103.5	128.2	24.7	23.9
1968	0.0	0.0	0.0	n/a
1969	0.0	0.0	0.0	n/a
1970	0.0	0.0	0.0	n/a
1971	0.0	0.0	0.0	n/a
1972	0.0	0.0	0.0	n/a
1973	0.0	0.0	0.0	n/a
1974	0.0	0.0	0.0	n/a
1975	0.0	0.0	0.0	n/a
1976	0.0	0.0	0.0	n/a
1977	0.0	0.0	0.0	n/a
1978	1164.0	1164.0	0.0	0.0
1979	0.0	0.0	0.0	n/a
1980	0.0	0.0	0.0	n/a
1981	0.0	0.0	0.0	n/a
1982	0.0	0.0	0.0	n/a
1983	0.0	0.0	0.0	n/a
1984	0.0	0.0	0.0	n/a
1985	0.0	0.0	0.0	n/a
1986	0.0	0.0	0.0	n/a
1987	0.0	0.0	0.0	n/a
1988	0.0	0.0	0.0	n/a
1989	0.0	0.0	0.0	n/a
1990	0.0	0.0	0.0	n/a
1991	0.0	0.0	0.0	n/a
1992	0.0	0.0	0.0	n/a
1993	0.0	0.0	0.0	n/a
1994	0.0	0.0	0.0	n/a
1995	0.0	0.0	0.0	n/a
1996	0.0	0.0	0.0	n/a
1997	0.0	0.0	0.0	n/a
1998	0.0	0.0	0.0	n/a
1999	0.0	0.0	0.0	n/a
2000	0.0	0.0	0.0	n/a
2001	0.0	0.0	0.0	n/a
2002	0.0	0.0	0.0	n/a
2003	0.0	0.0	0.0	n/a
2004	0.0	0.0	0.0	n/a
2005	0.0	0.0	0.0	n/a
2006	0.0	0.0	0.0	n/a
SUM	1267.5	1292.2	24.7	1.9
Average Annual	31.7	32.3	0.6	1.9

Conclusions

HEC-ResSim models were successfully constructed using time-series guide curves to model the baseline and reallocated operating conditions at Yellowtail Dam. The time-series guide curves allowed the draft elevation to be changed each year based on the estimated snowmelt runoff instead of being maintained at a constant elevation each year no matter the inflow conditions. The models were based on information provided by BOR on potential future operations of the dam, so conclusions cannot be compared to the other period of record simulations. Nevertheless, the results do provide an example of how the reallocation might impact operations at Yellowtail Dam. They also could provide water managers with useful information when/if further development of guide curves occur.

Pool elevation and outflow results show the dam maintains a higher pool elevation throughout the simulation period as a result of the reallocation. Outflow conditions vary when comparing the two simulations, with periods of similar flows, periods where the reallocated condition exceeds the baseline, and vice versa. Flow and pool duration analyses were performed on the data. The flow duration analysis showed the spring and summer timeframe to be the most sensitive to the reallocation. The pool duration analysis reflected the comparison in pool elevation data in that the reallocated condition consistently posted higher elevation values at specific duration percentages.

Pool probability curves were also developed to compare the baseline and reallocated condition. These curves also reflected the pool elevation data and showed peak annual pool elevations increased as a result of the reallocation. A flow frequency analysis was performed at all downstream locations. This analysis showed the reallocated condition posted higher flows than the baseline condition – though the relative difference between the two was never greater than 1,000 cfs. Lastly, flood damages were calculated for downstream reaches. On an annual basis, the reallocated condition posted flood damages similar, higher, and lower than the baseline condition. Studying the period of record, flood damages increased at all reaches as a result of the reallocation.

Appendix B – Additional Pool Duration Information

This appendix contains the pool duration figures for all the HEC-ResSim period of record simulations. This same information was presented earlier in the report in tabular form. Each figure caption provides information about the HEC-ResSim simulation it is from. Any figure caption that references “standard guide curve” corresponds to the HEC-ResSim baseline simulation. This simulation compared the HEC-ResSim model with the actual Yellowtail operations. Figures with a caption referencing “reallocated standard guide curve” correspond to the HEC-ResSim reallocated simulation. This simulation compared the baseline condition with the reallocated condition where the top of joint use pool was increased to 3,645 ft msl. Figure captions referencing “time series guide curve” correspond to the time series simulations described in Appendix A. These simulations compared the time series baseline condition to a time series reallocated condition where the joint use pool was raised a maximum of 3 ft to 3,643 ft msl.

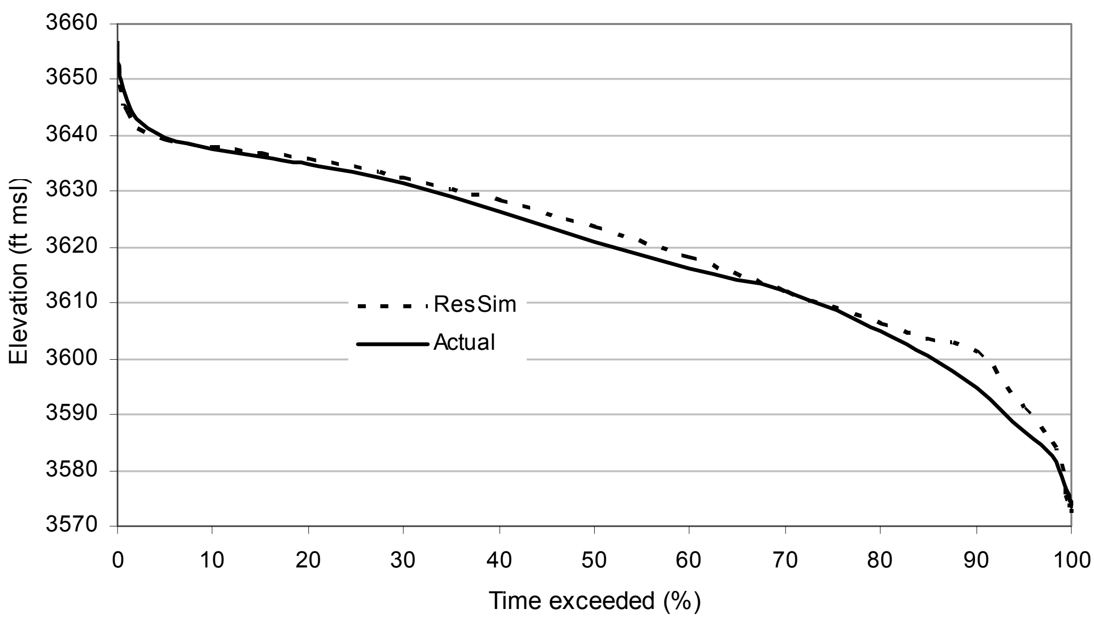

Figure B.1. Annual Yellowtail pool duration curve for the HEC-ResSim standard guide curve simulation.

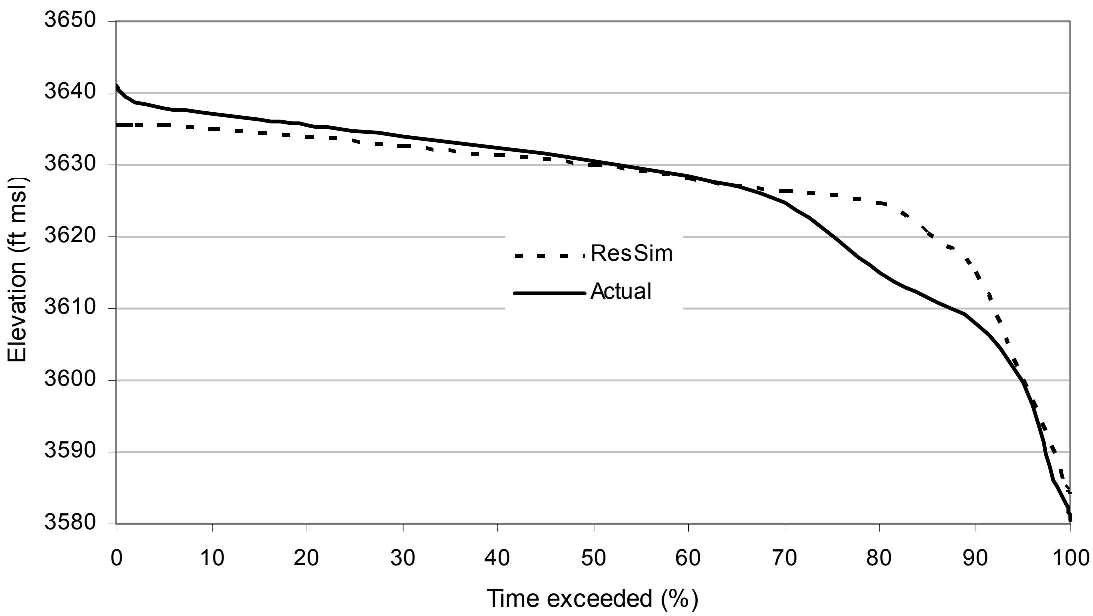

Figure B.2. Fall Yellowtail pool duration curve for the HEC-ResSim standard guide curve simulation.

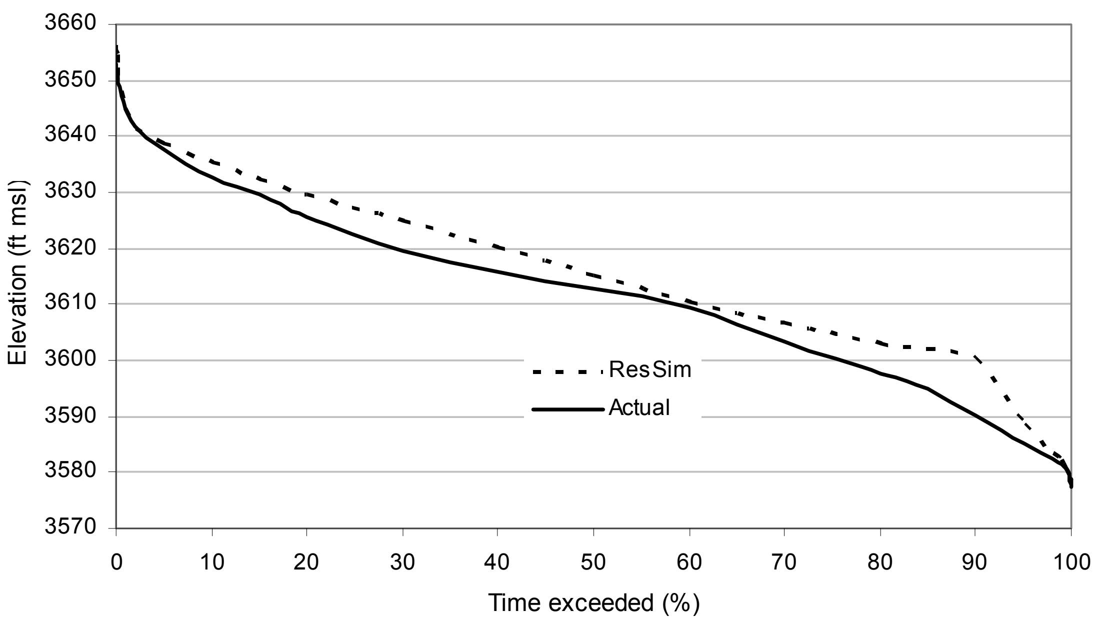

Figure B.3. Spring Yellowtail pool duration curve for the HEC-ResSim standard guide curve simulation.

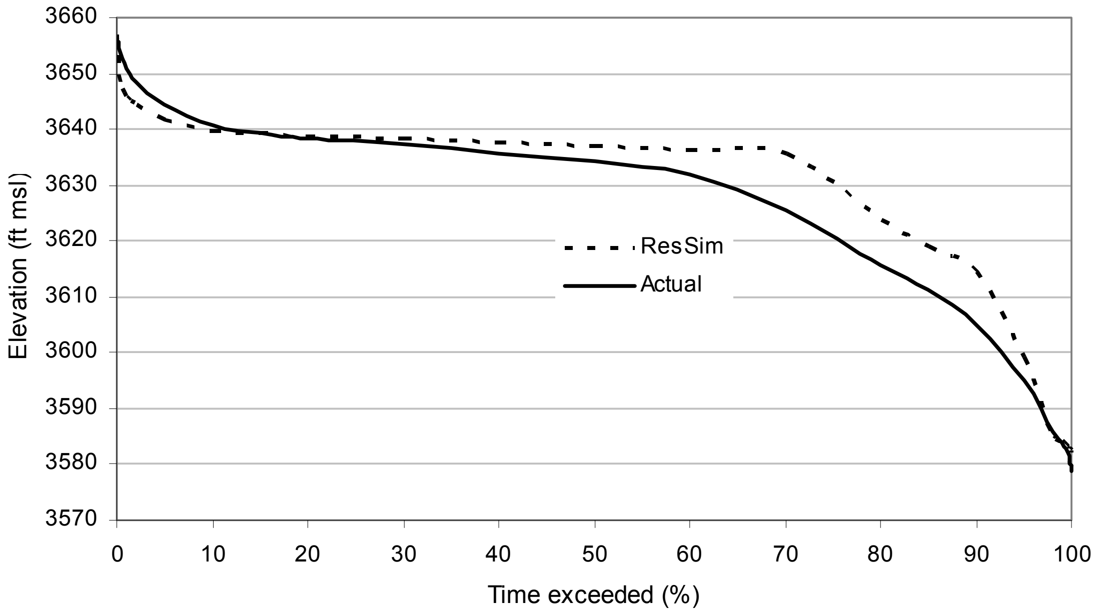

Figure B.4. Summer Yellowtail pool duration curve for the HEC-ResSim standard guide curve simulation.

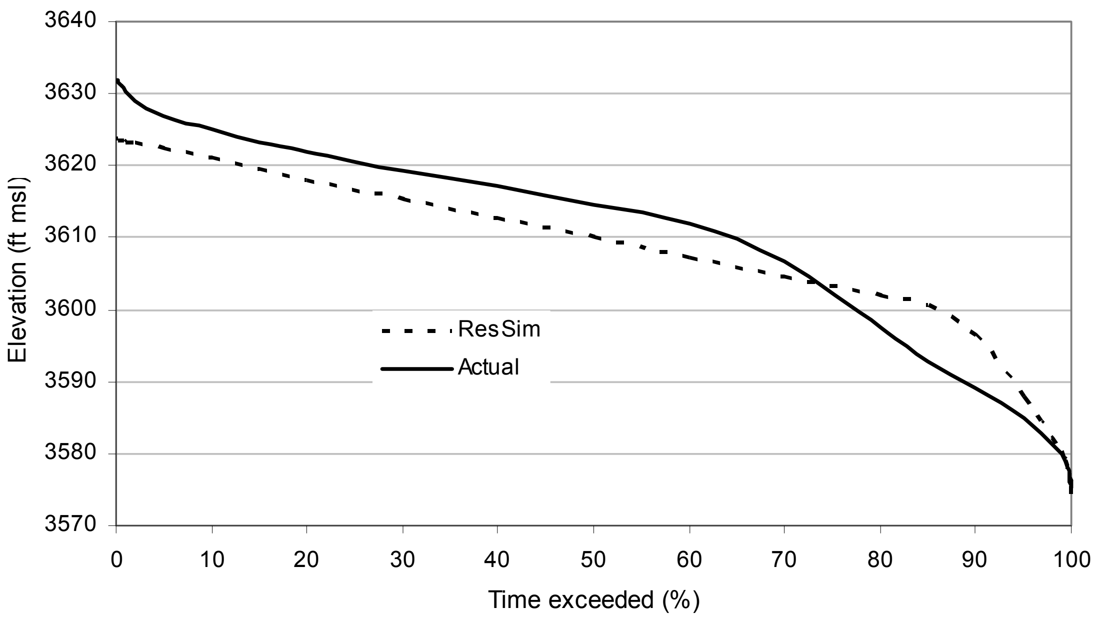

Figure B.5. Winter Yellowtail pool duration curve for the HEC-ResSim standard guide curve simulation.

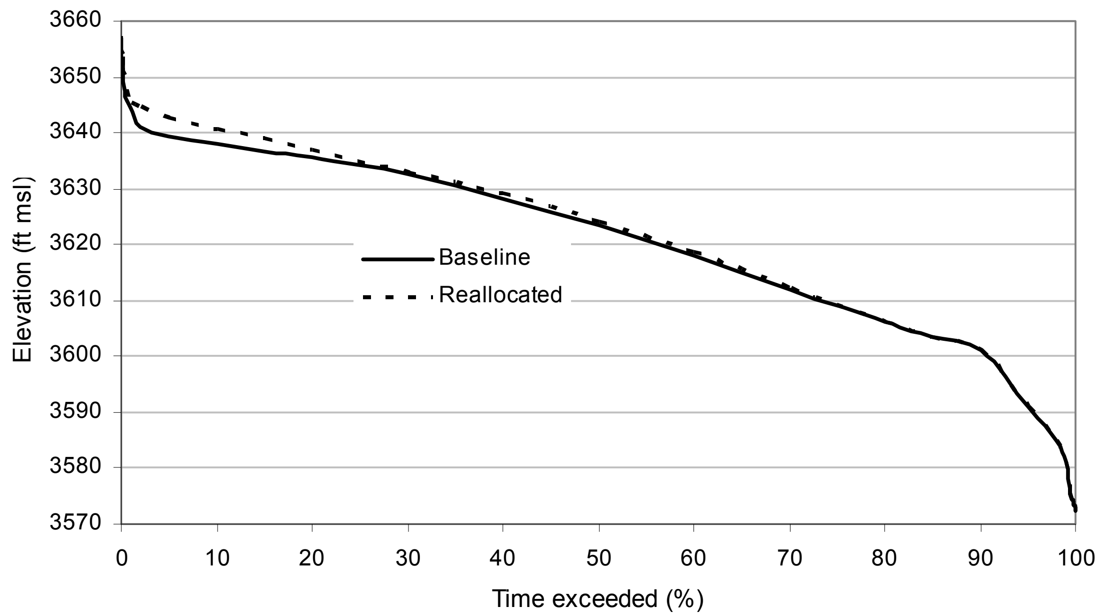

Figure B.6. Annual Yellowtail pool duration curve for the HEC-ResSim reallocated standard guide curve simulation.

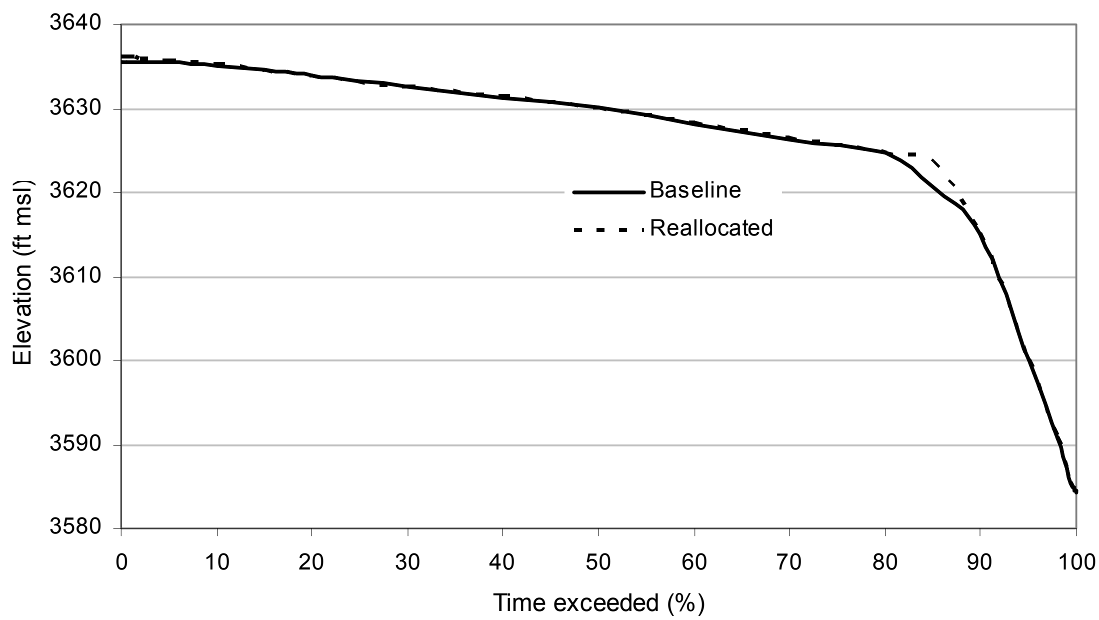

Figure B.7. Fall Yellowtail pool duration curve for the HEC-ResSim reallocated standard guide curve simulation.

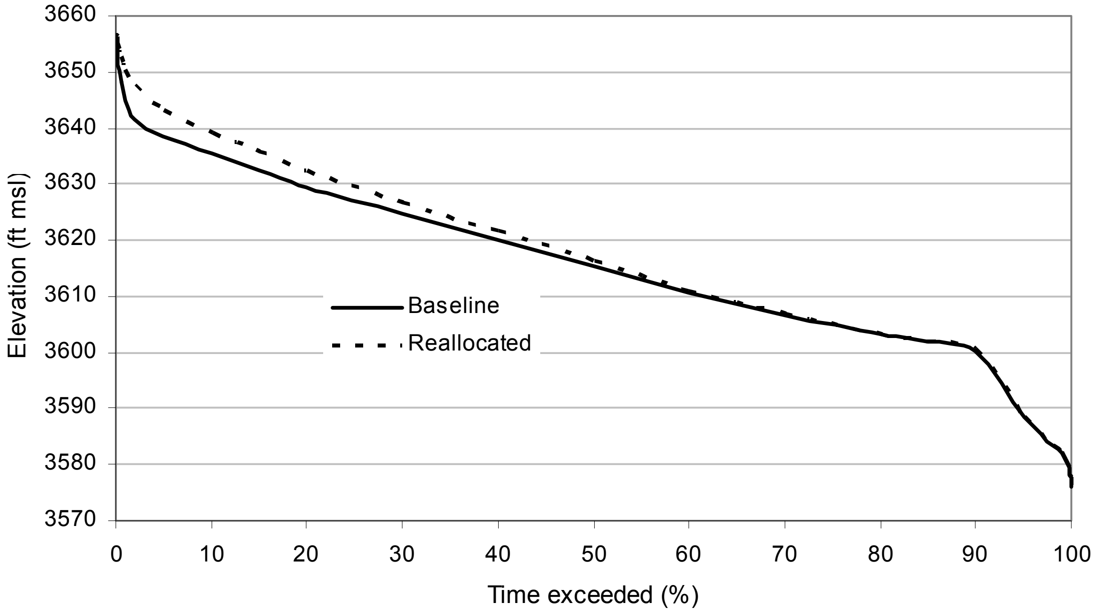

Figure B.8. Spring Yellowtail pool duration curve for the HEC-ResSim reallocated standard guide curve simulation.

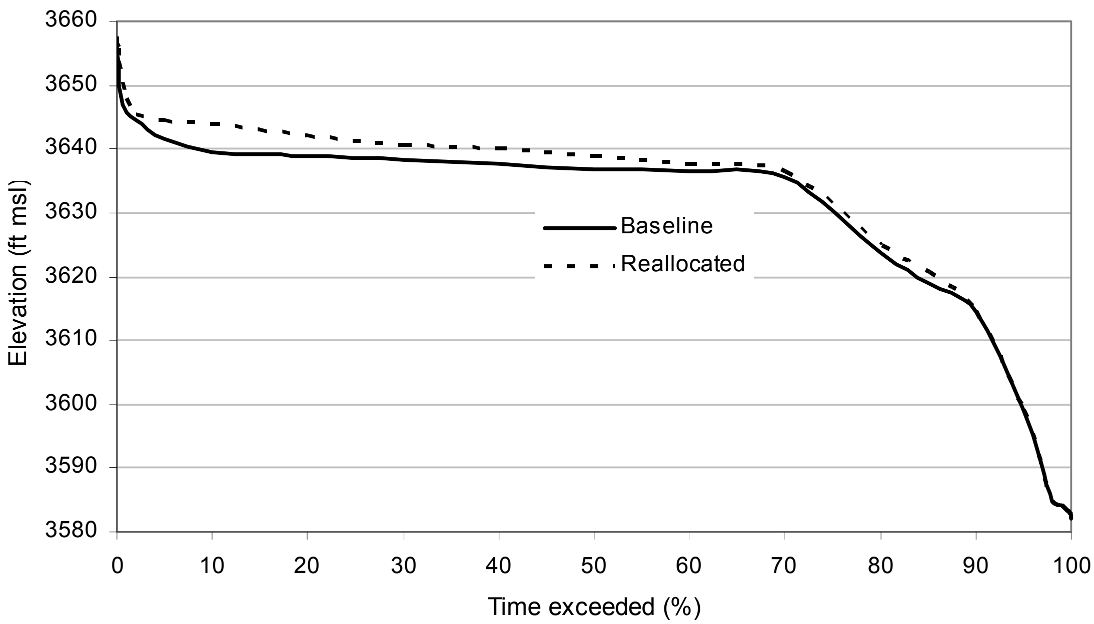

Figure B.9. Summer Yellowtail pool duration curve for the HEC-ResSim reallocated standard guide curve simulation.

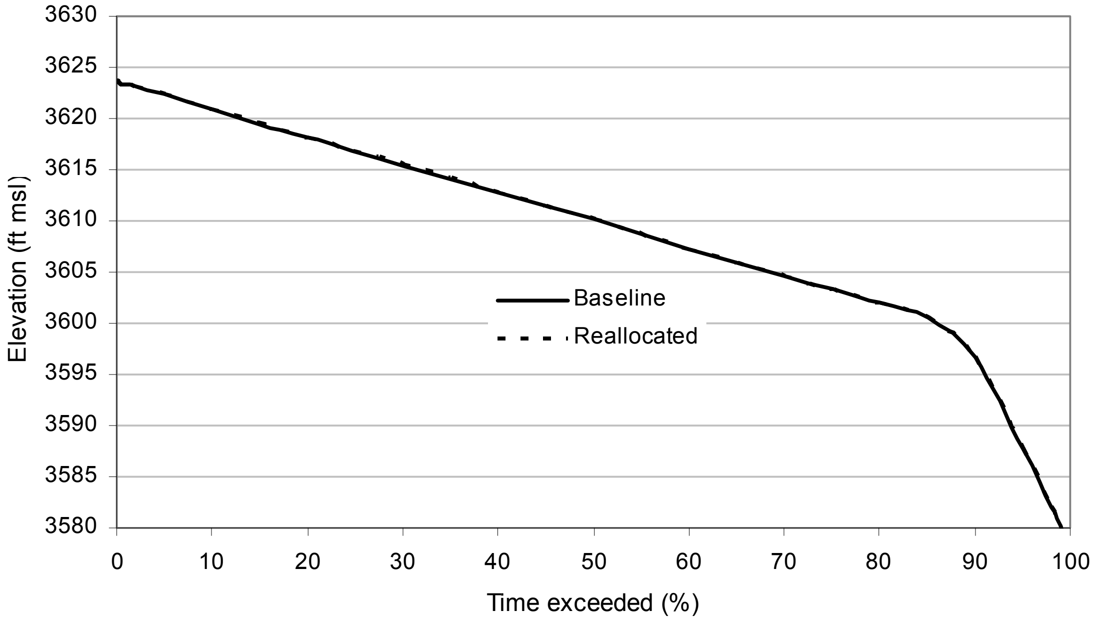

Figure B.10. Winter Yellowtail pool duration curve for the HEC-ResSim reallocated standard guide curve simulation.

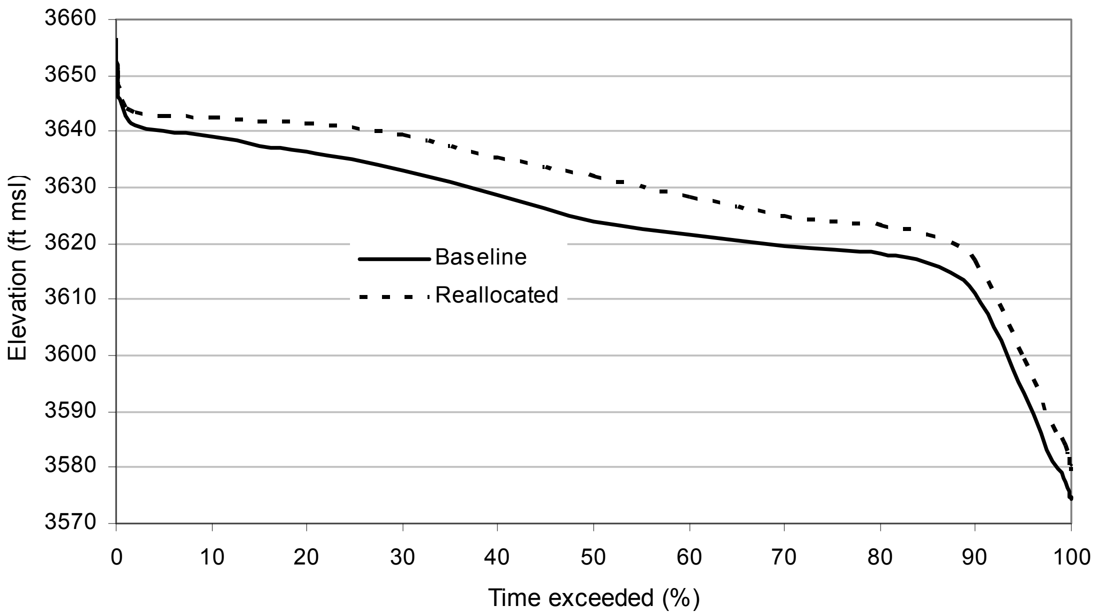

Figure B.11. Annual Yellowtail pool duration curve for the HEC-ResSim time series guide curve simulation.

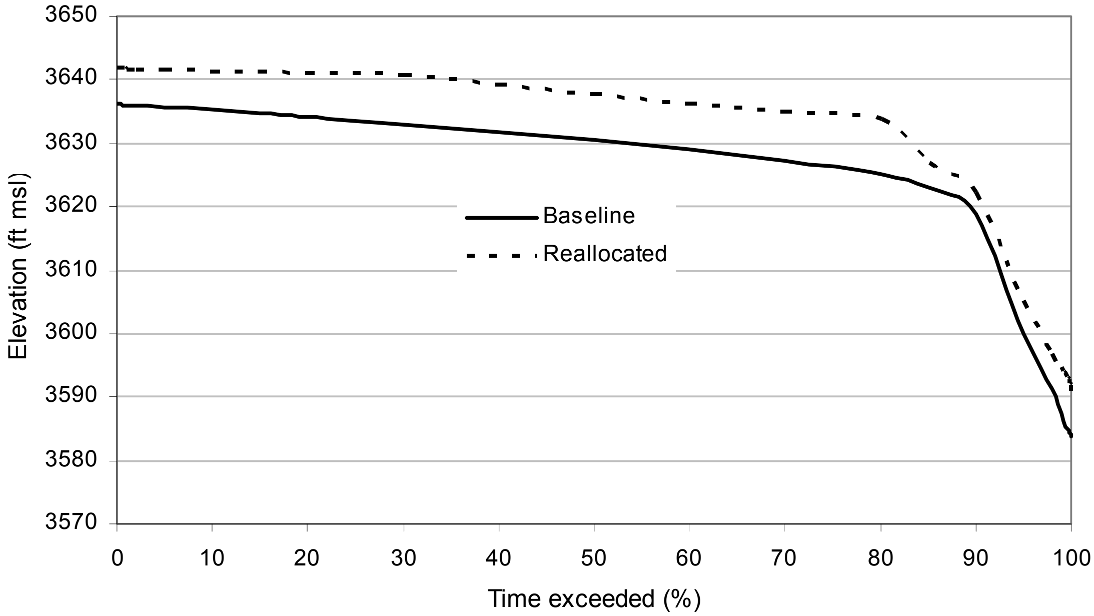

Figure B.12. Fall Yellowtail pool duration curve for the HEC-ResSim time series guide curve simulation.

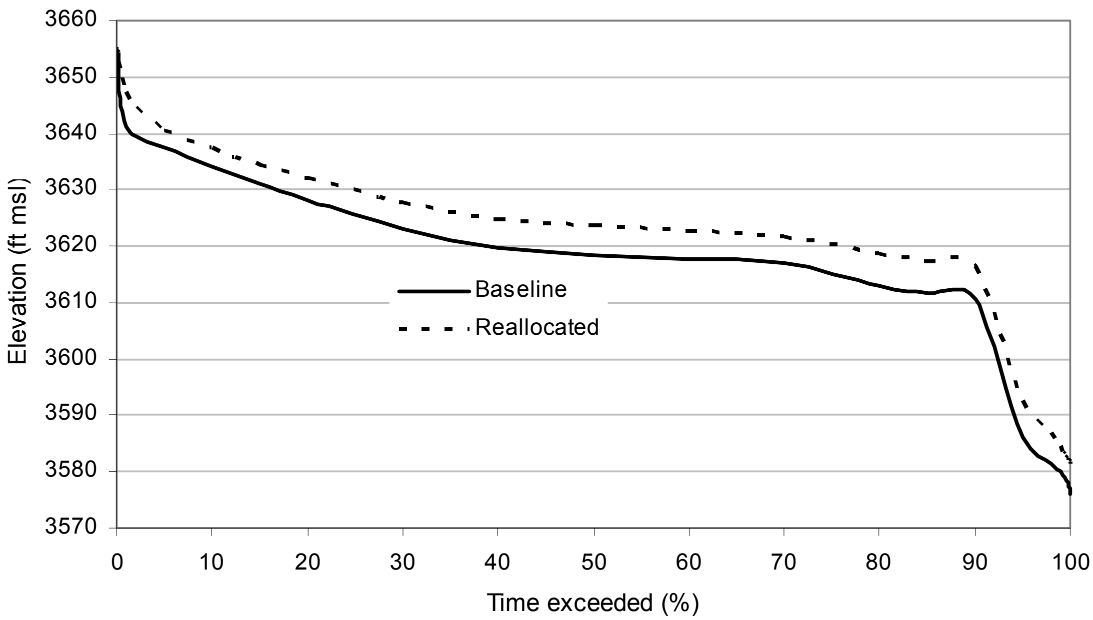

Figure B.13. Spring Yellowtail pool duration curve for the HEC-ResSim time series guide curve simulation.

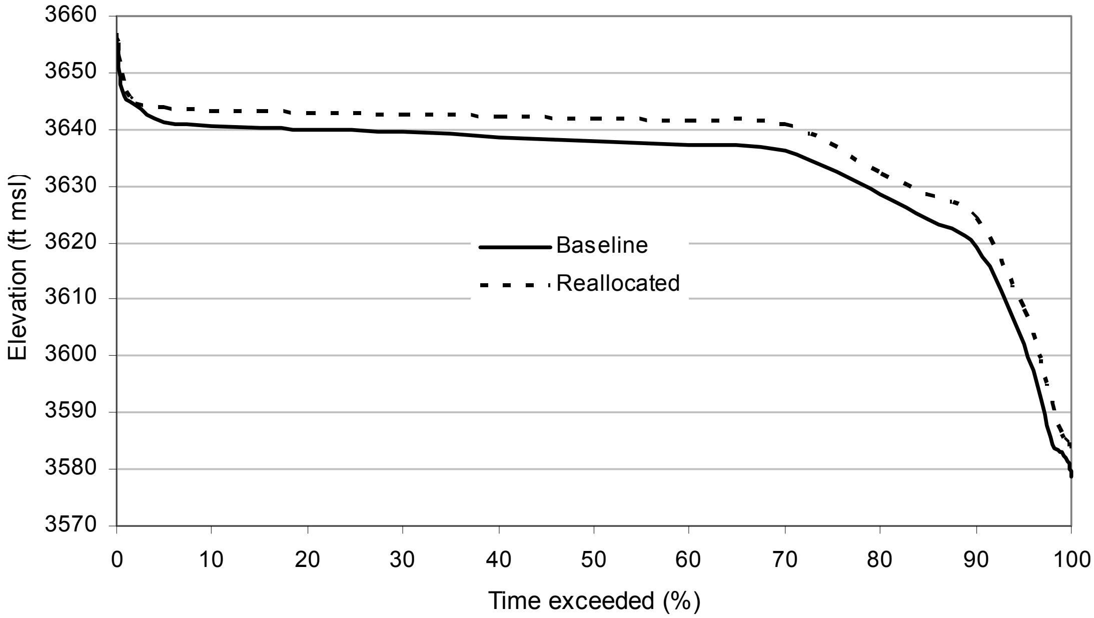

Figure B.14. Summer Yellowtail pool duration curve for the HEC-ResSim time series guide curve simulation.

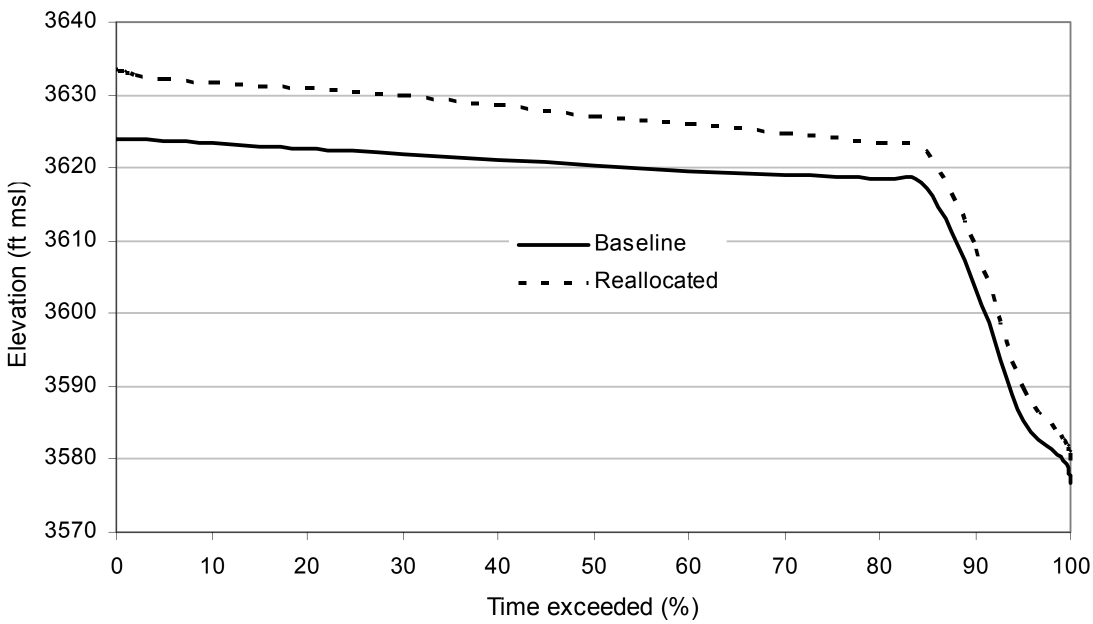

Figure B.15. Winter Yellowtail pool duration curve for the HEC-ResSim time series guide curve simulation.

Appendix C – Additional Flow Duration Information

This appendix contains the flow duration figures for all the HEC-ResSim period of record simulations. This same information was presented earlier in the report in tabular form. Each figure caption provides information about the HEC-ResSim simulation it is from. Any figure caption that references “standard guide curve” corresponds to the HEC-ResSim baseline simulation. This simulation compared the HEC-ResSim model with the actual Yellowtail operations. Figures with a caption referencing “reallocated standard guide curve” correspond to the HEC-ResSim reallocated simulation. This simulation compared the baseline condition with the reallocated condition where the top of joint use pool was increased to 3,645 ft msl. Figure captions referencing “time series guide curve” correspond to the time series simulations described in Appendix A. These simulations compared the time series baseline condition to a time series reallocated condition where the joint use pool was raised a maximum of 3 ft to 3,643 ft msl.

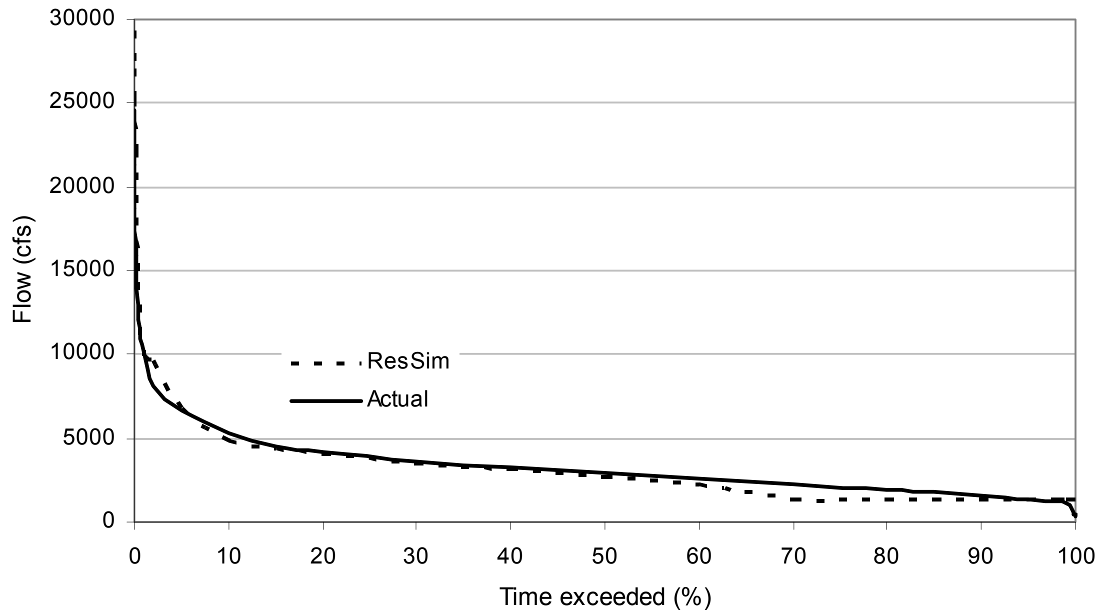

Figure C.1. Annual Yellowtail flow duration curve for the HEC-ResSim standard guide curve simulation.

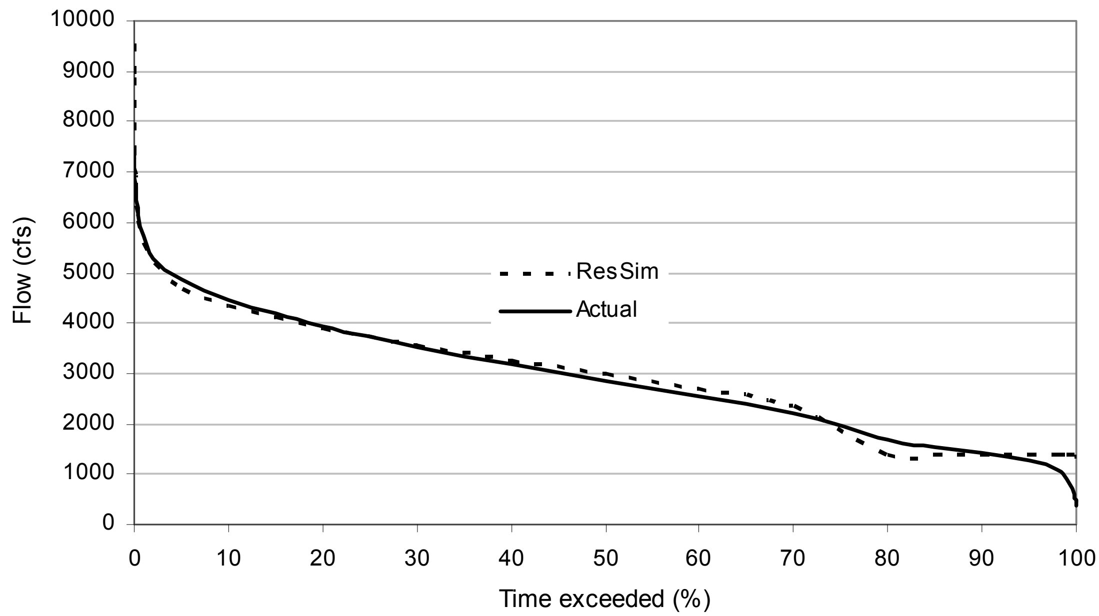

Figure C.2. Fall Yellowtail flow duration curve for the HEC-ResSim standard guide curve simulation.

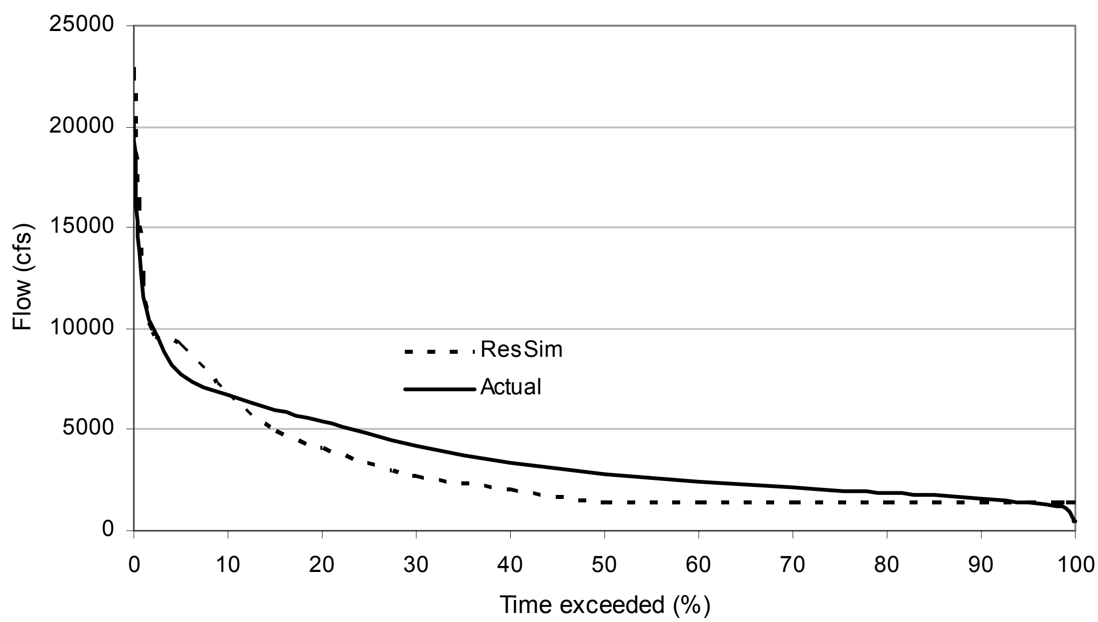

Figure C.3. Spring Yellowtail flow duration curve for the HEC-ResSim standard guide curve simulation.

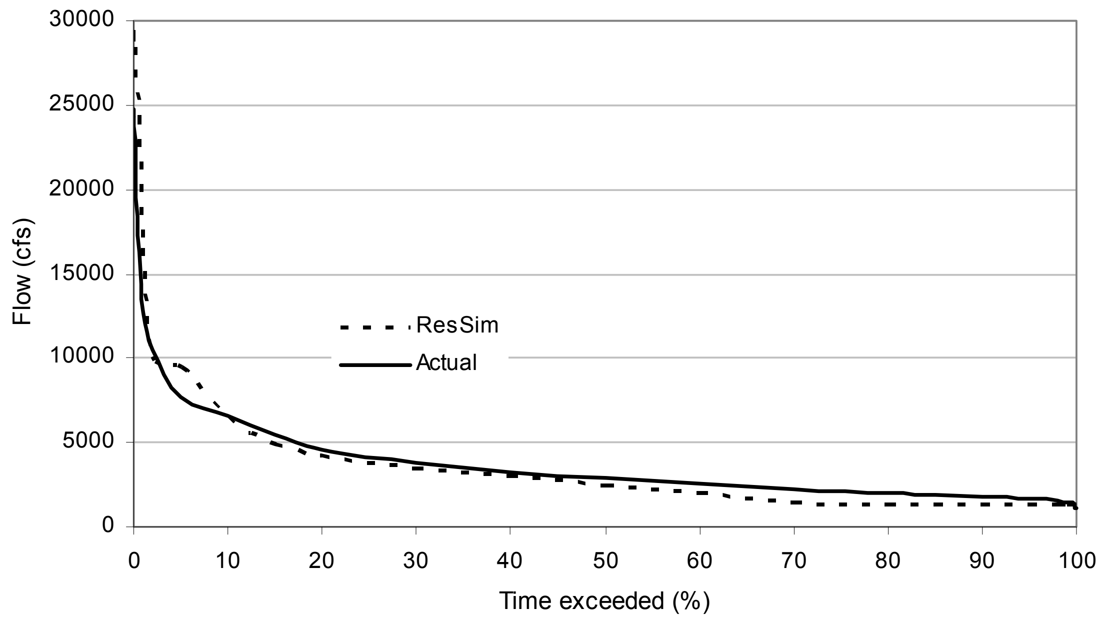

Figure C.4. Summer Yellowtail flow duration curve for the HEC-ResSim standard guide curve simulation.

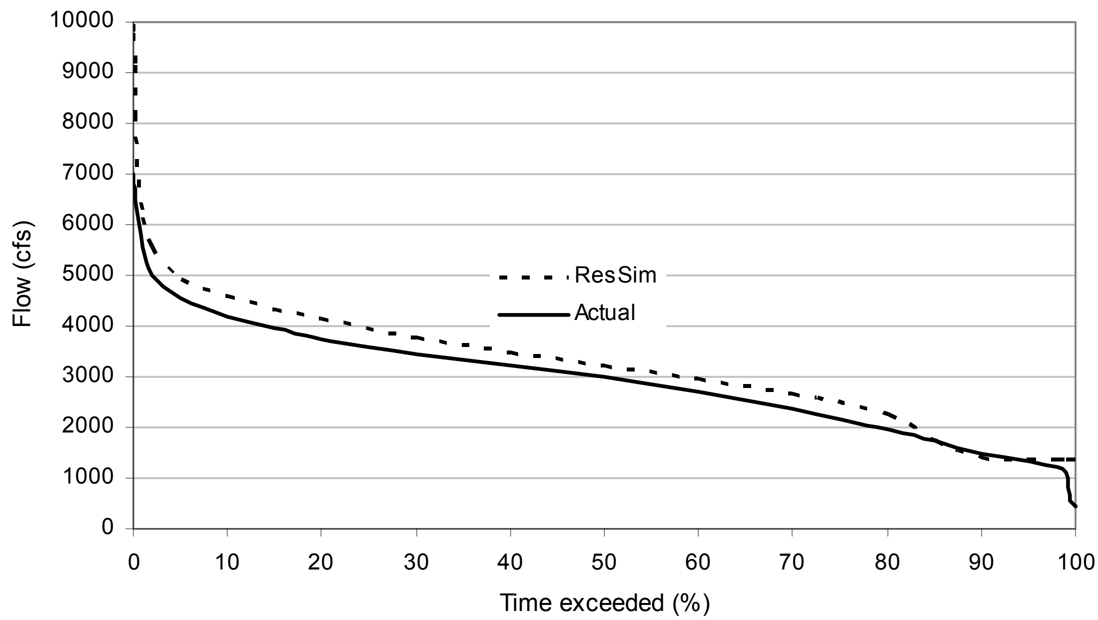

Figure C.5. Winter Yellowtail flow duration curve for the HEC-ResSim standard guide curve simulation.

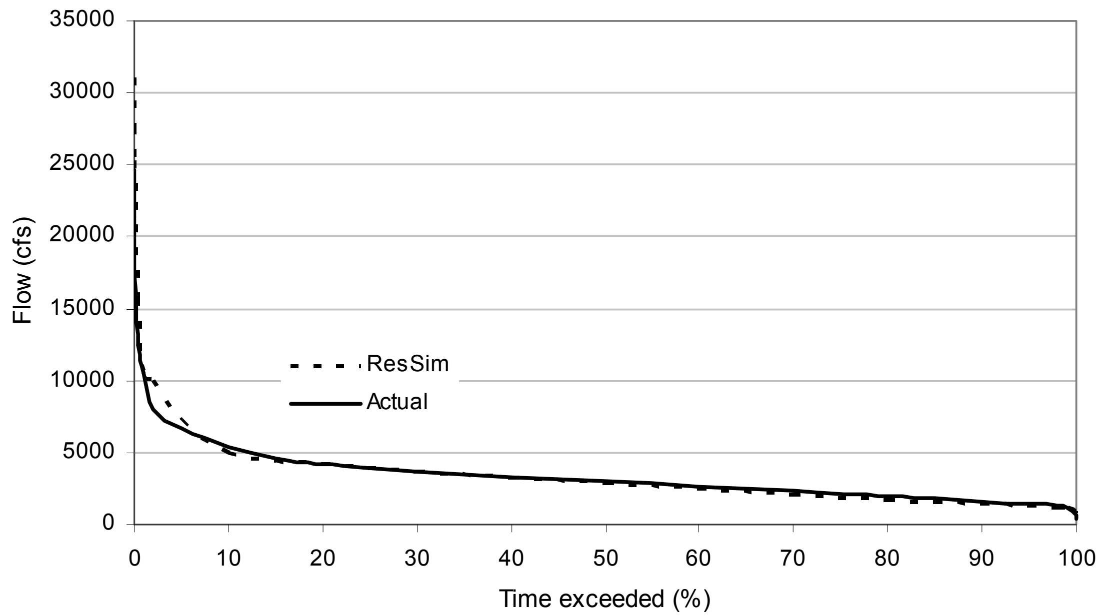

Figure C.6. Annual St. Xavier flow duration curve for the HEC-ResSim standard guide curve simulation.

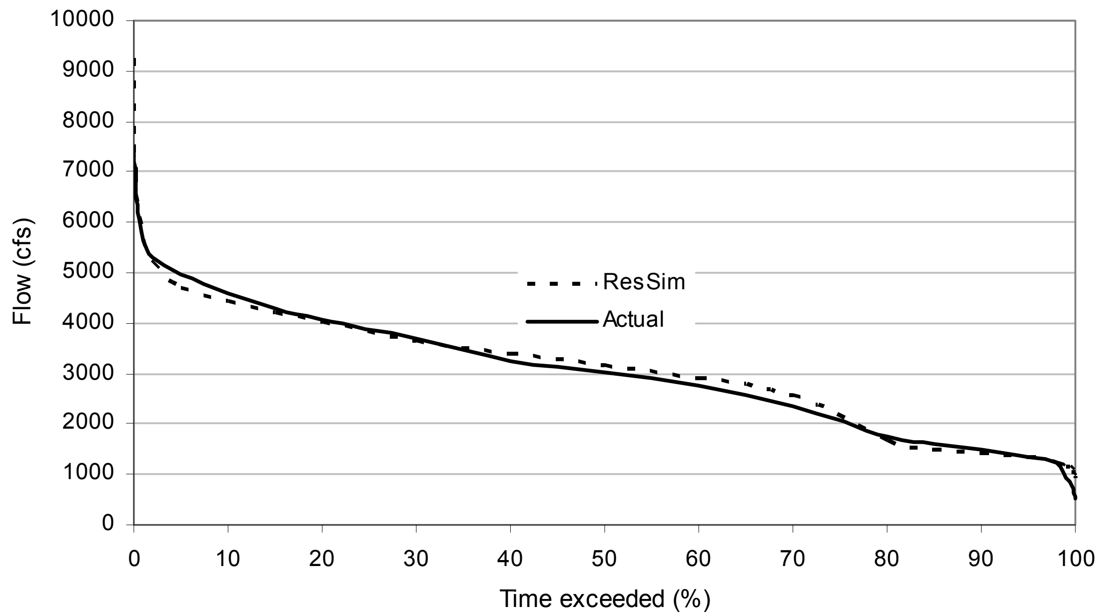

Figure C.7. Fall St. Xavier flow duration curve for the HEC-ResSim standard guide curve simulation.

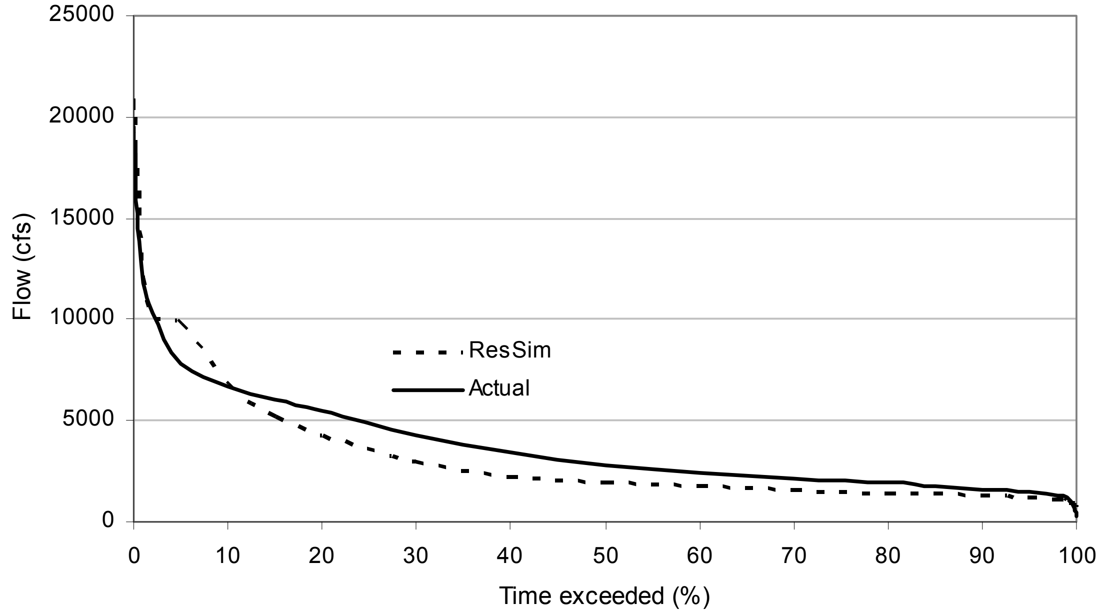

Figure C.8. Spring St. Xavier flow duration curve for the HEC-ResSim standard guide curve simulation.

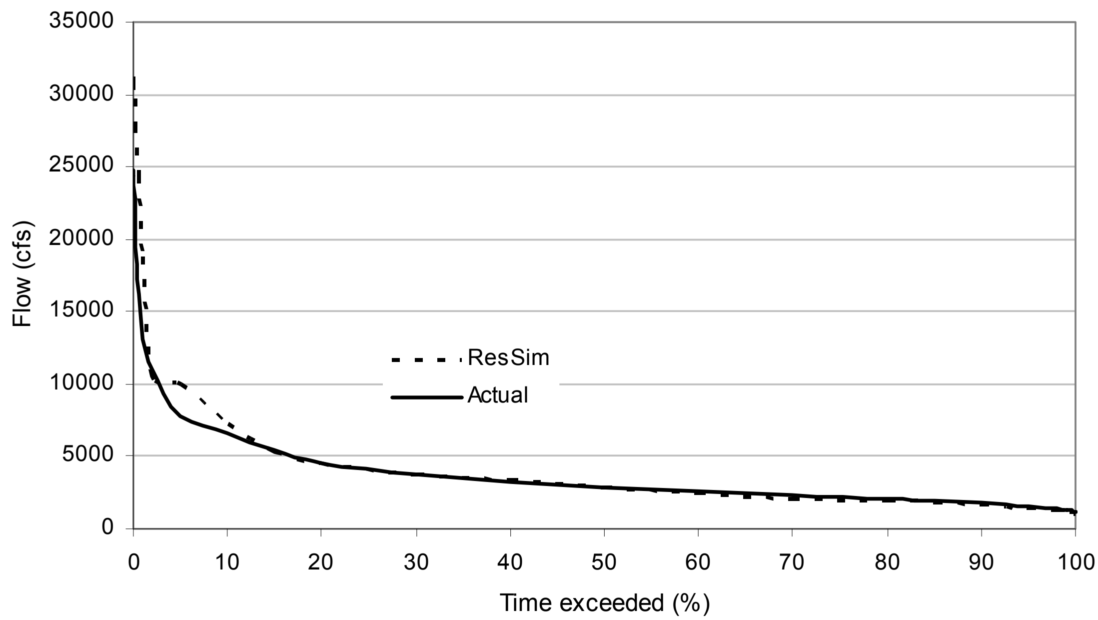

Figure C.9. Summer St. Xavier flow duration curve for the HEC-ResSim standard guide curve simulation.

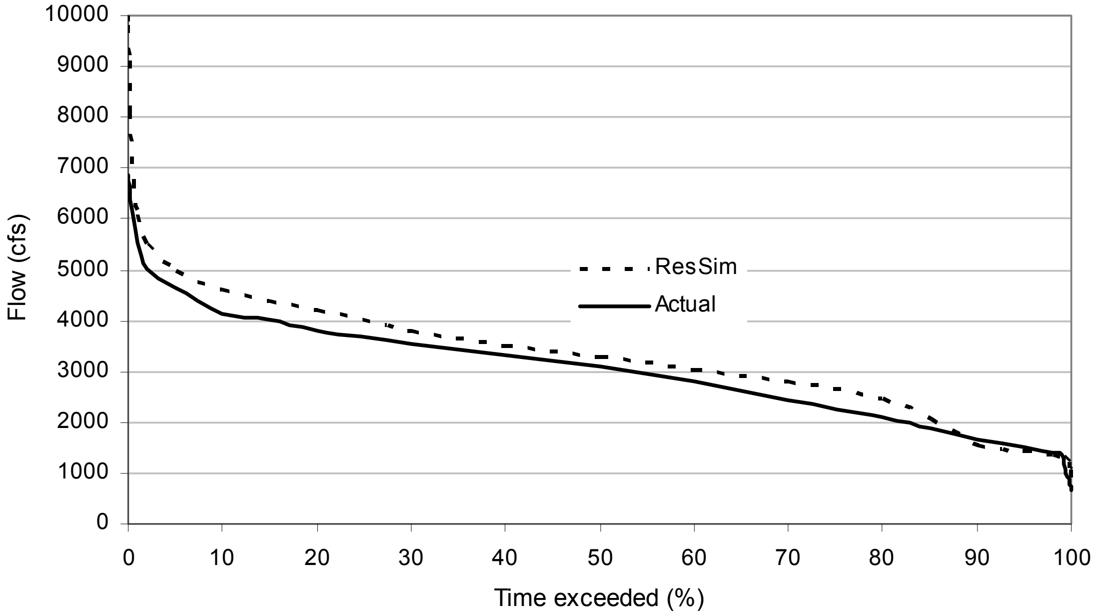

Figure C.10. Winter St. Xavier flow duration curve for the HEC-ResSim standard guide curve simulation.

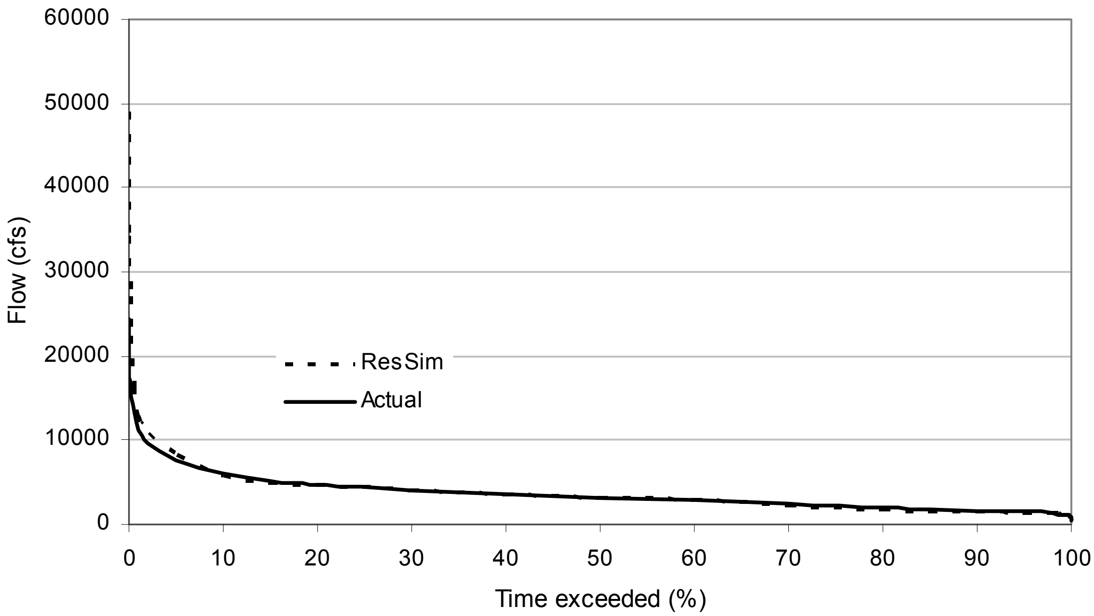

Figure C.11. Annual Bighorn flow duration curve for the HEC-ResSim standard guide curve simulation.

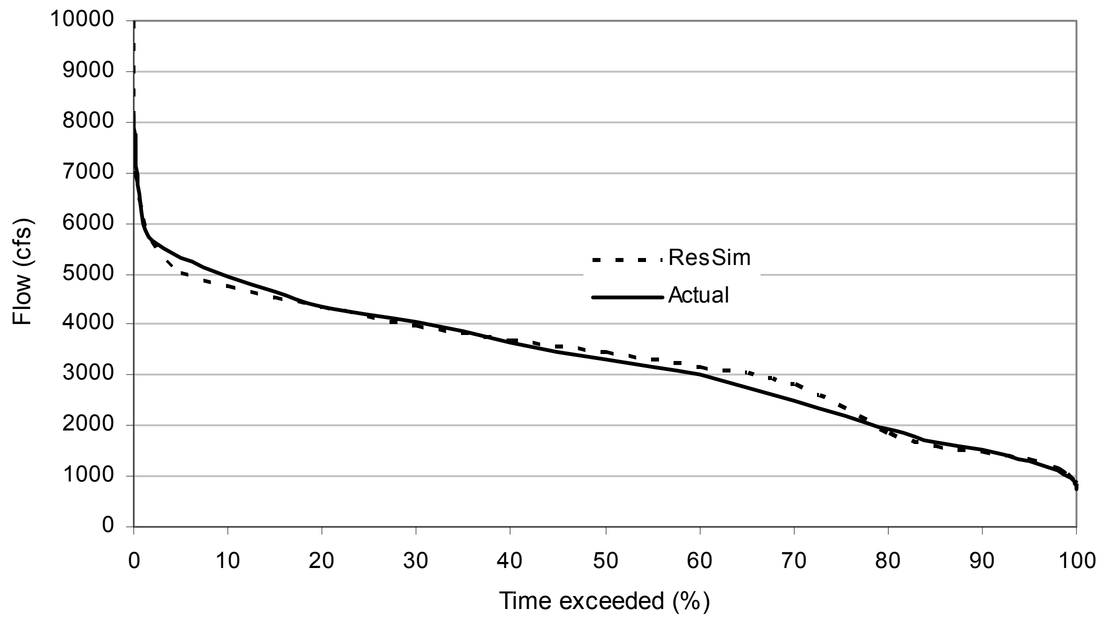

Figure C.12. Fall Bighorn flow duration curve for the HEC-ResSim standard guide curve simulation.

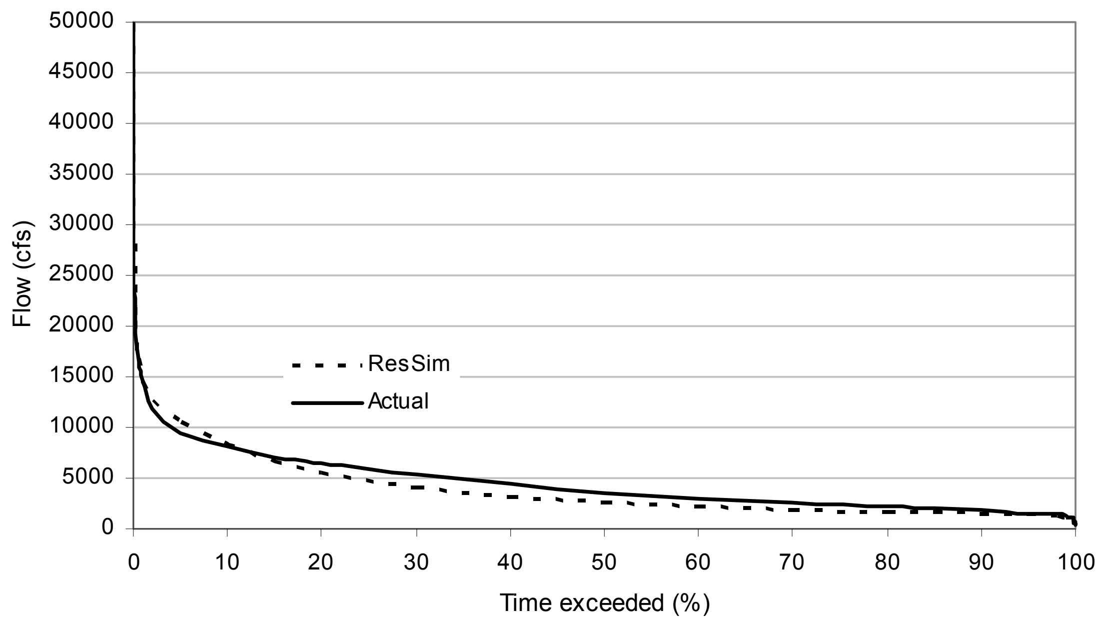

Figure C.13. Spring Bighorn flow duration curve for the HEC-ResSim standard guide curve simulation.

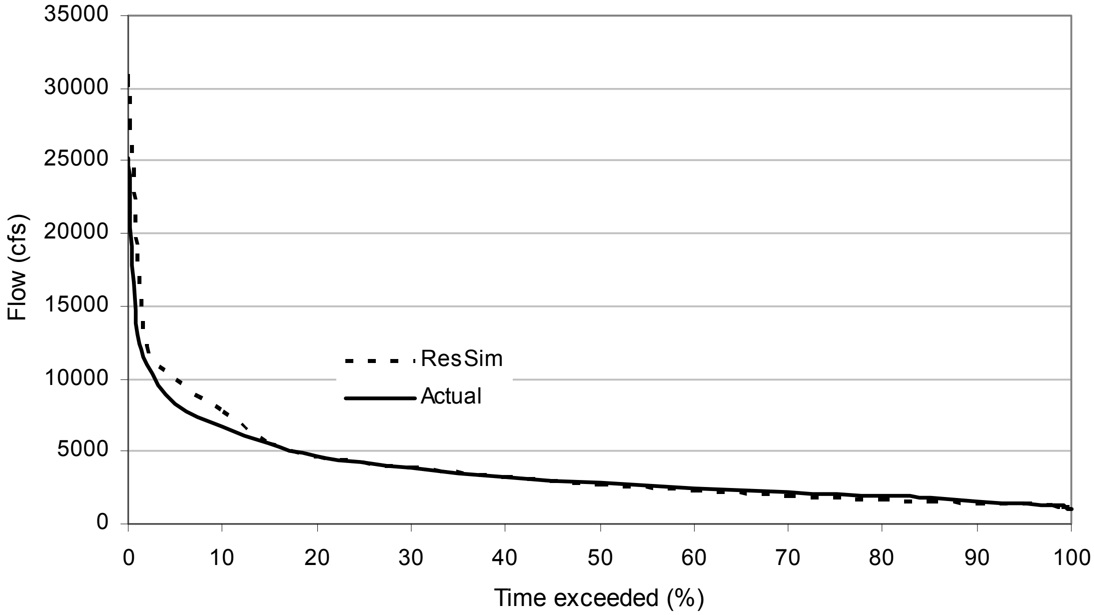

Figure C.14. Summer Bighorn flow duration curve for the HEC-ResSim standard guide curve simulation.

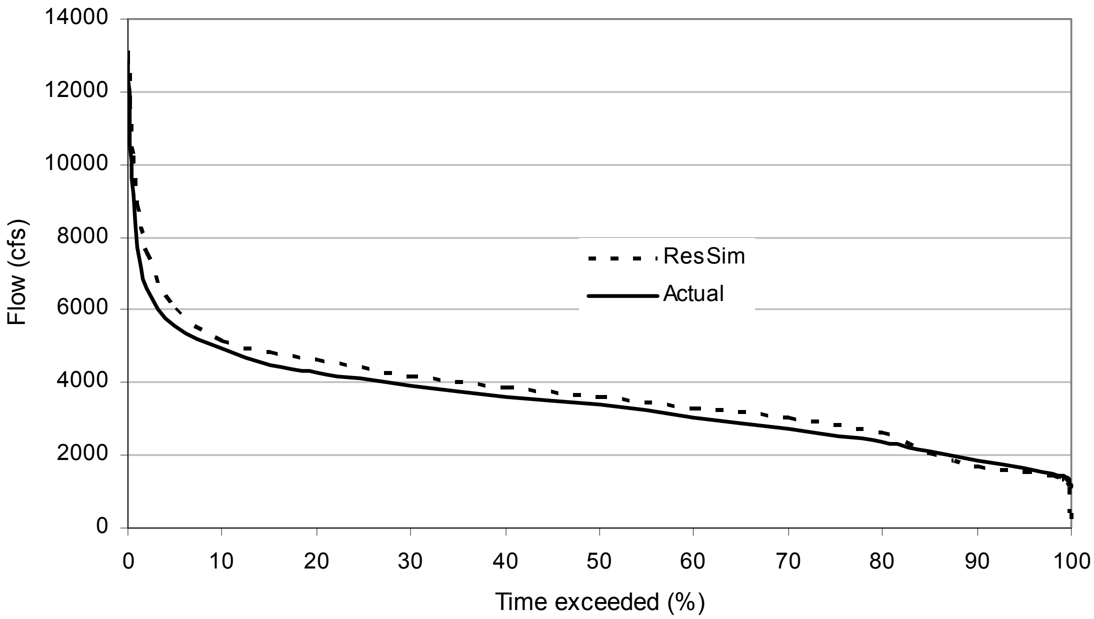

Figure C.15. Winter Bighorn flow duration curve for the HEC-ResSim standard guide curve simulation.

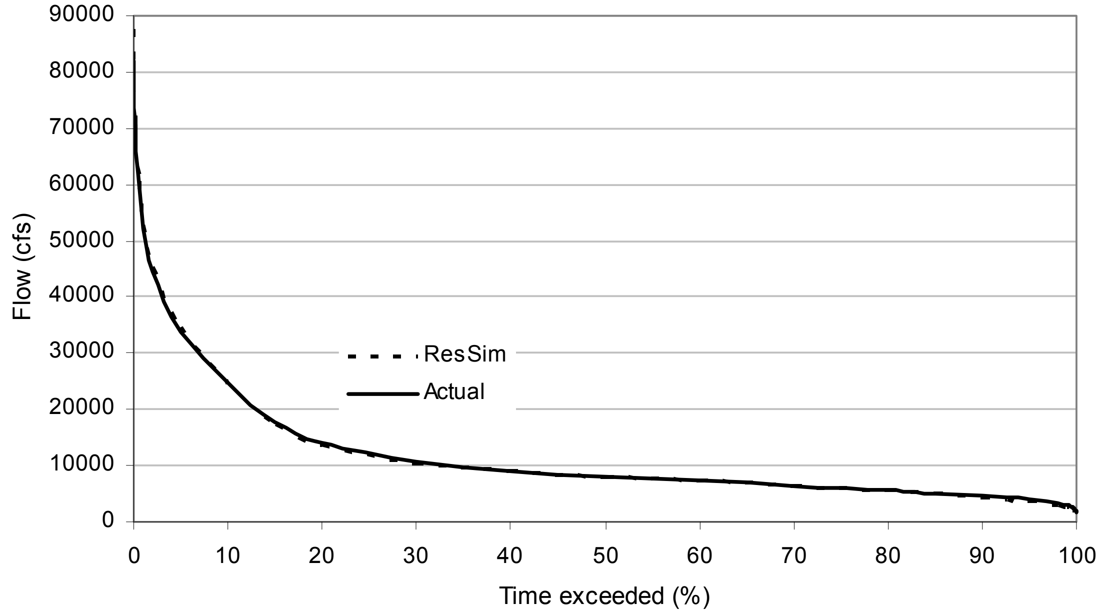

Figure C.16. Annual Miles City flow duration curve for the HEC-ResSim standard guide curve simulation.

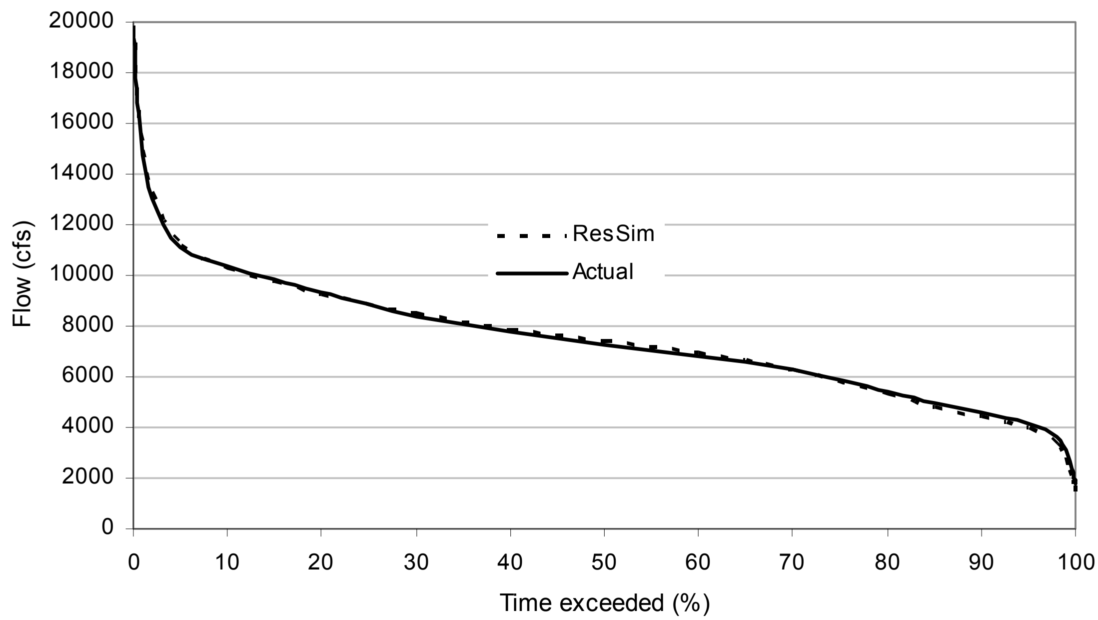

Figure C.17. Fall Miles City flow duration curve for the HEC-ResSim standard guide curve simulation.

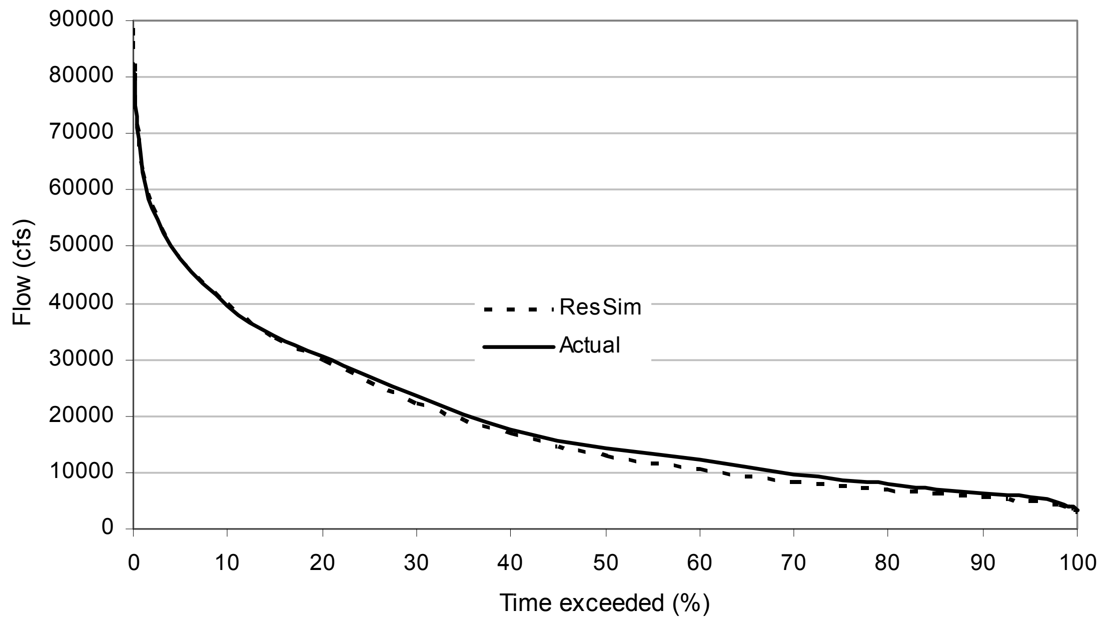

Figure C.18. Spring Miles City flow duration curve for the HEC-ResSim standard guide curve simulation.

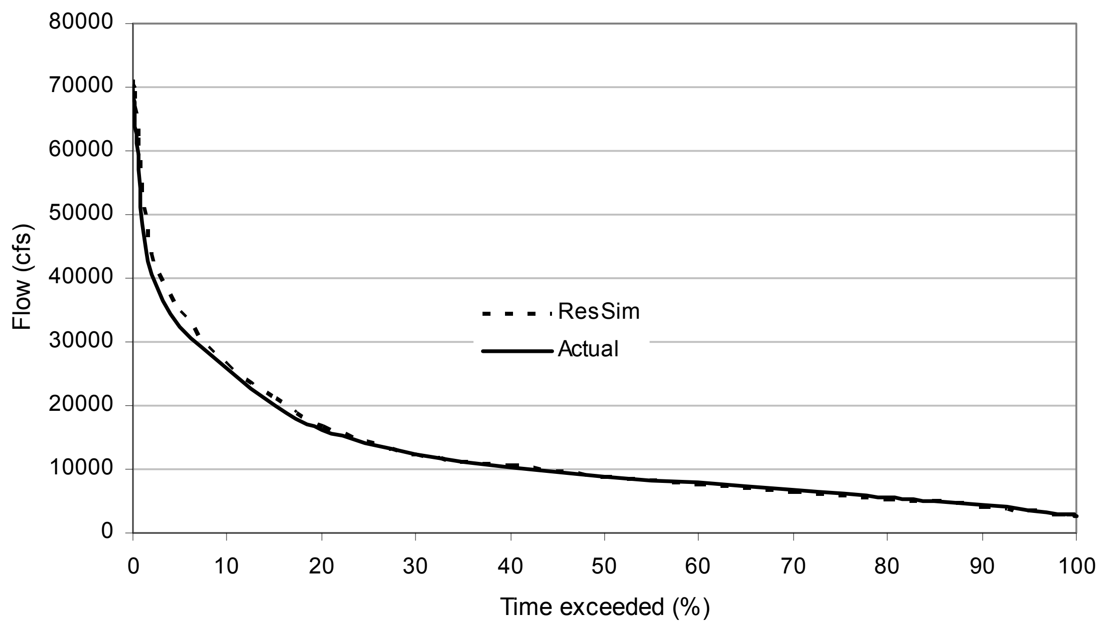

Figure C.19. Summer Miles City flow duration curve for the HEC-ResSim standard guide curve simulation.

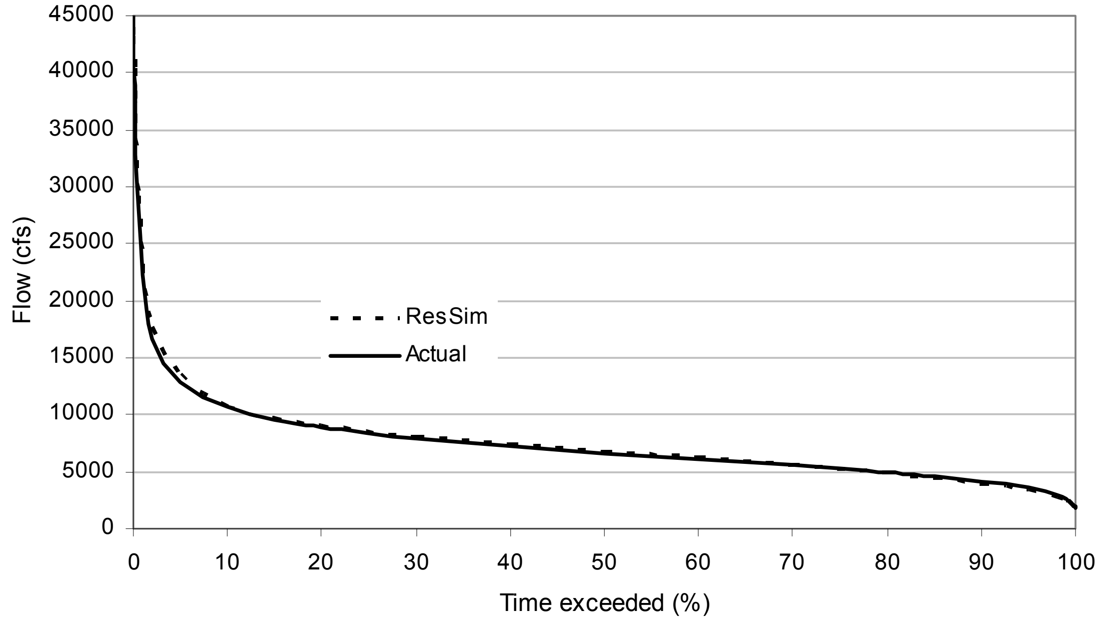

Figure C.20. Winter Miles City flow duration curve for the HEC-ResSim standard guide curve simulation.

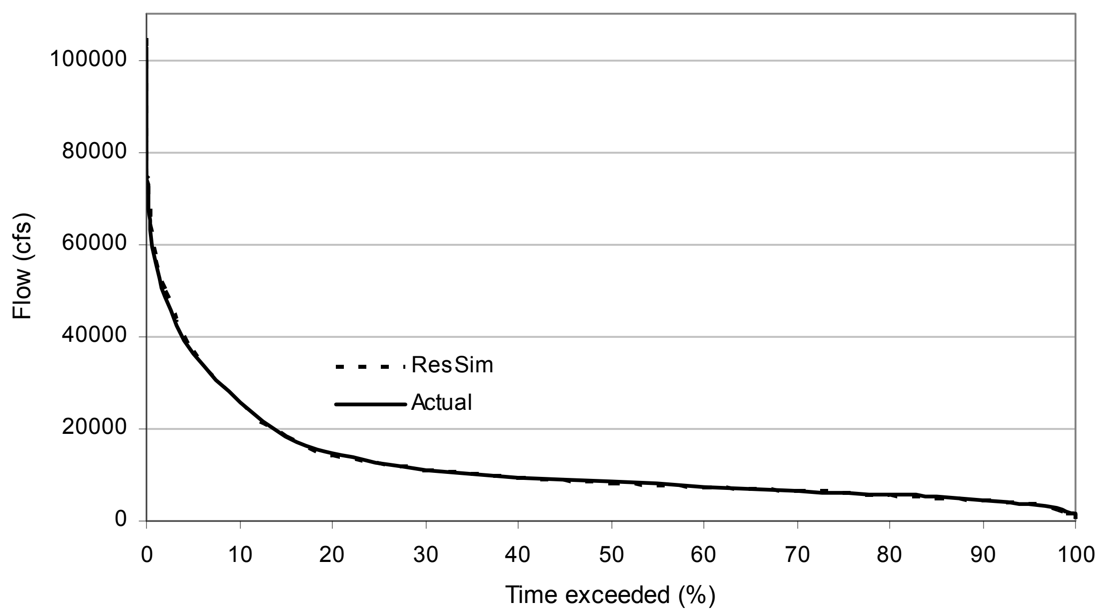

Figure C.21. Annual Sidney flow duration curve for the HEC-ResSim standard guide curve simulation.

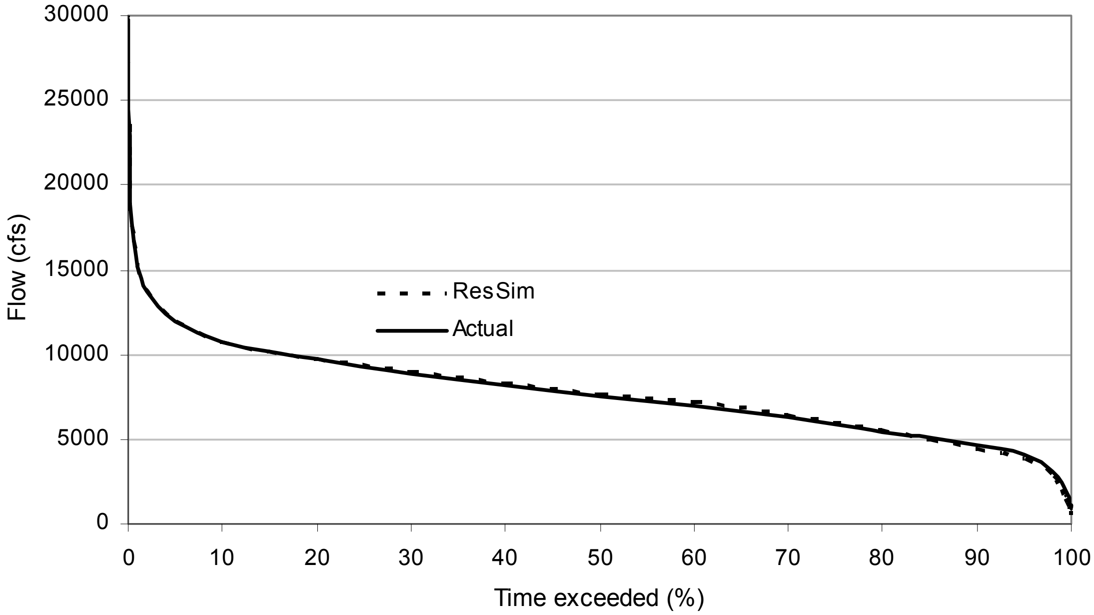

Figure C.22. Fall Sidney flow duration curve for the HEC-ResSim standard guide curve simulation.

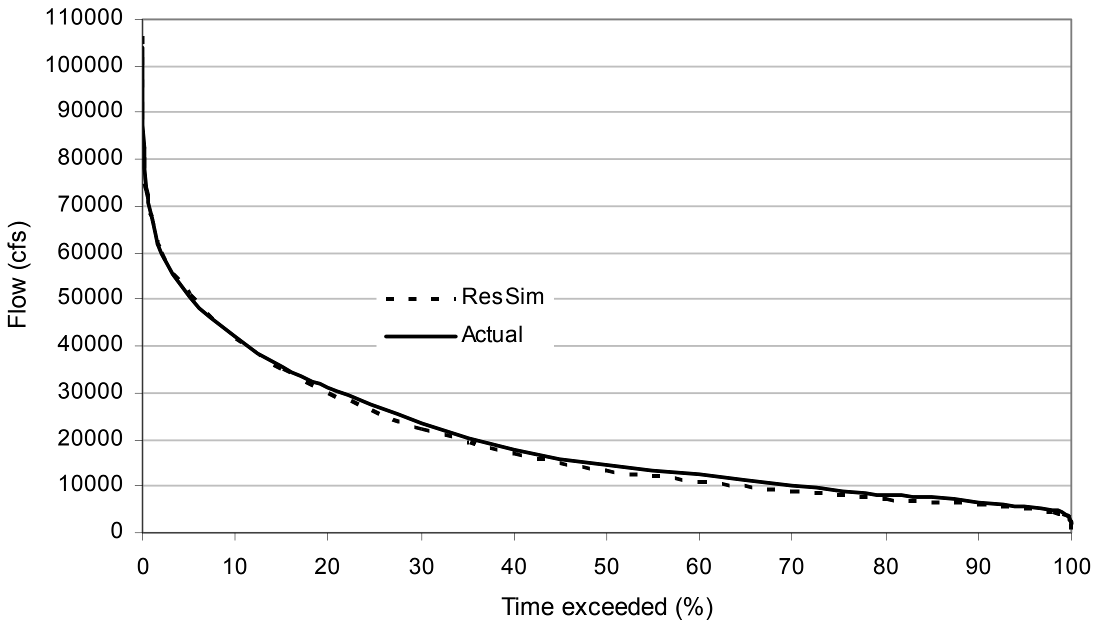

Figure C.23. Spring Sidney flow duration curve for the HEC-ResSim standard guide curve simulation.

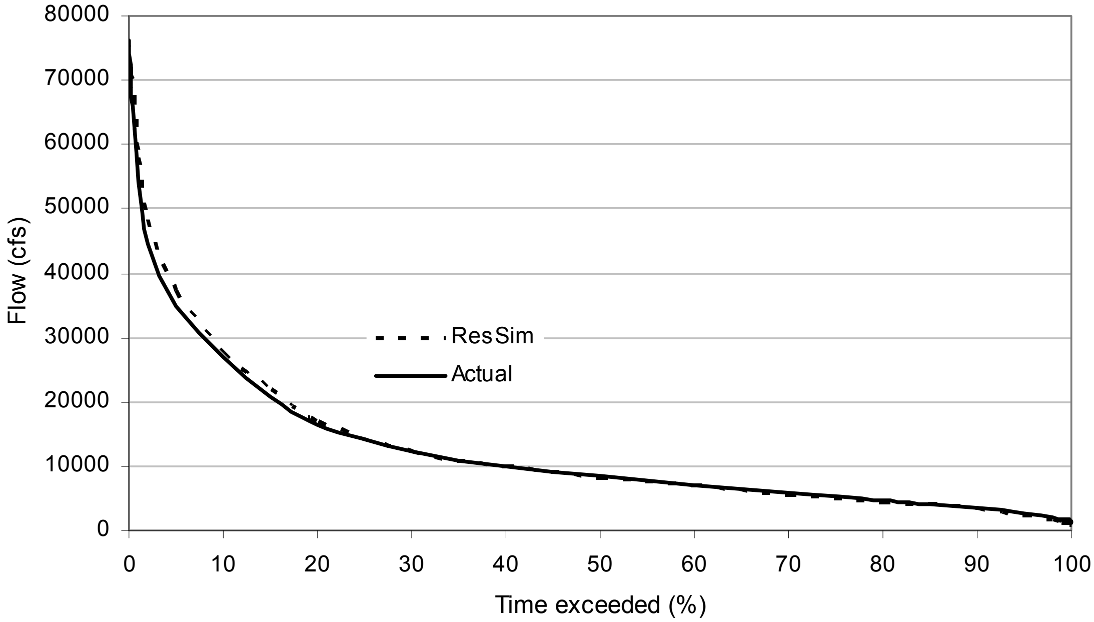

Figure C.24. Summer Sidney flow duration curve for the HEC-ResSim standard guide curve simulation.

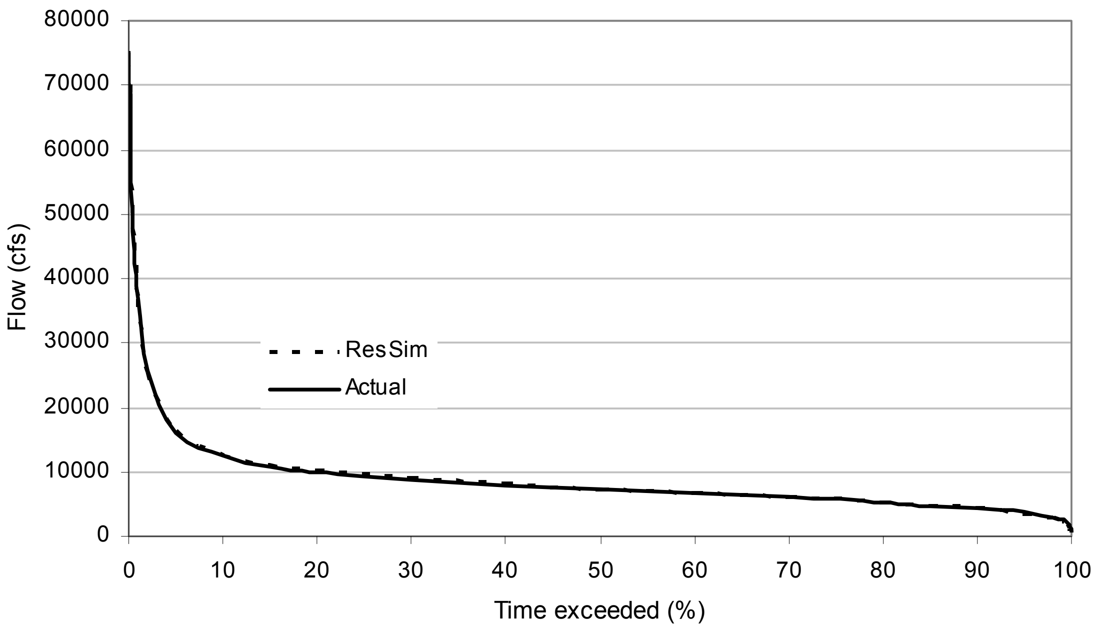

Figure C.25. Winter Sidney flow duration curve for the HEC-ResSim standard guide curve simulation.

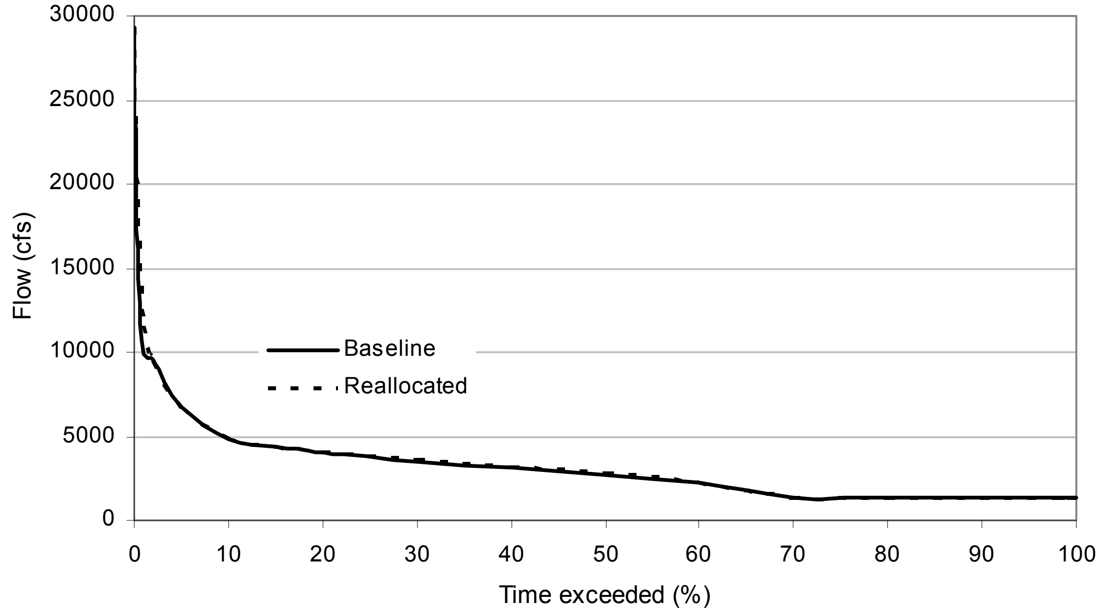

Figure C.26. Annual Yellowtail flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

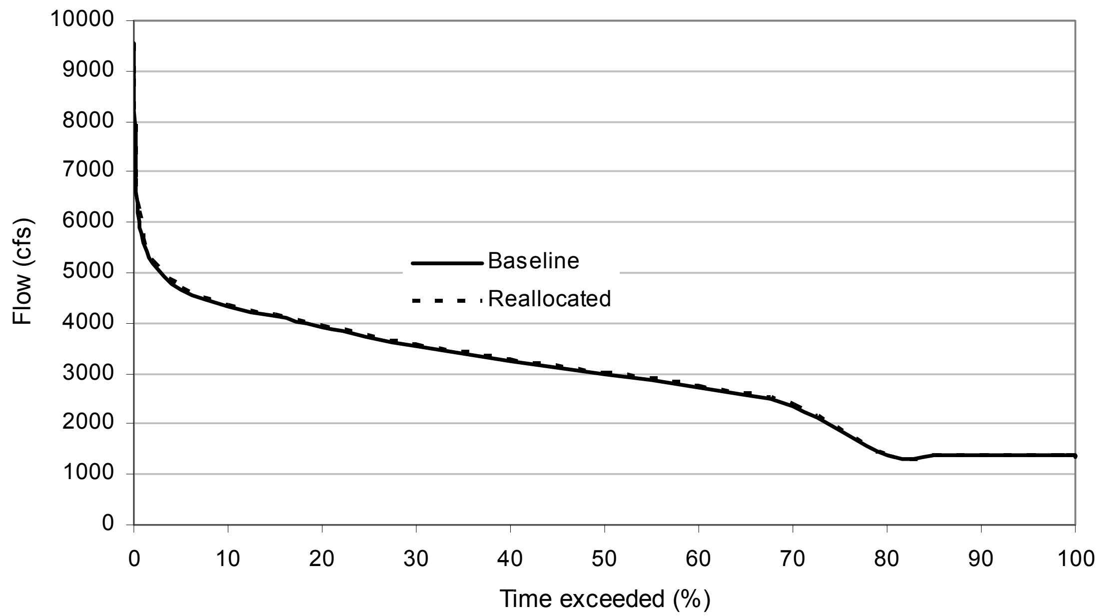

Figure C.27. Fall Yellowtail flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

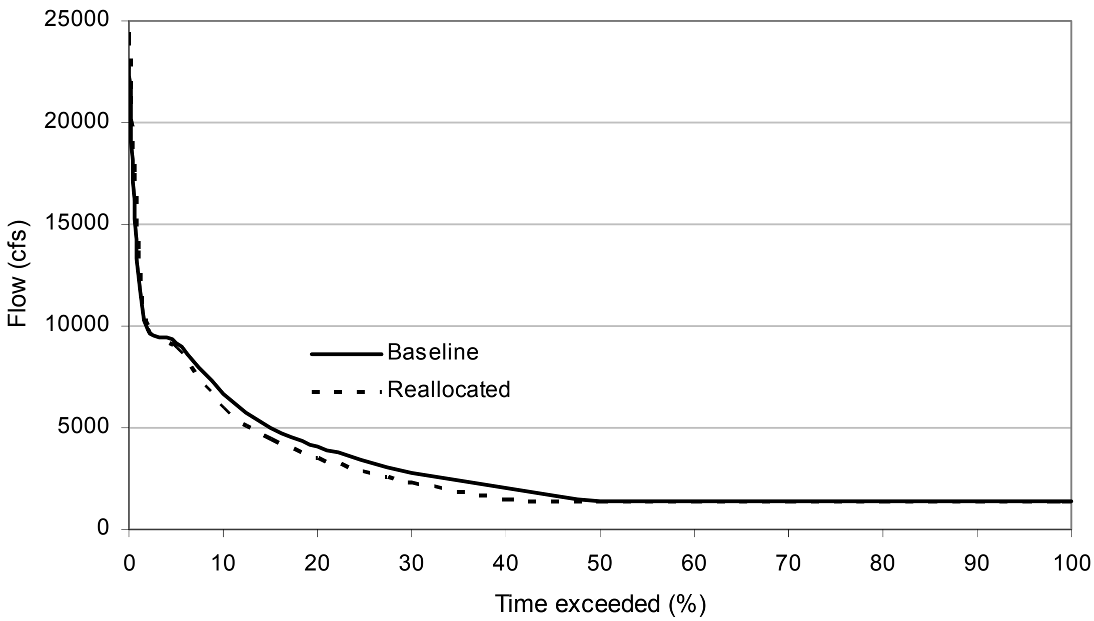

Figure C.28. Spring Yellowtail flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

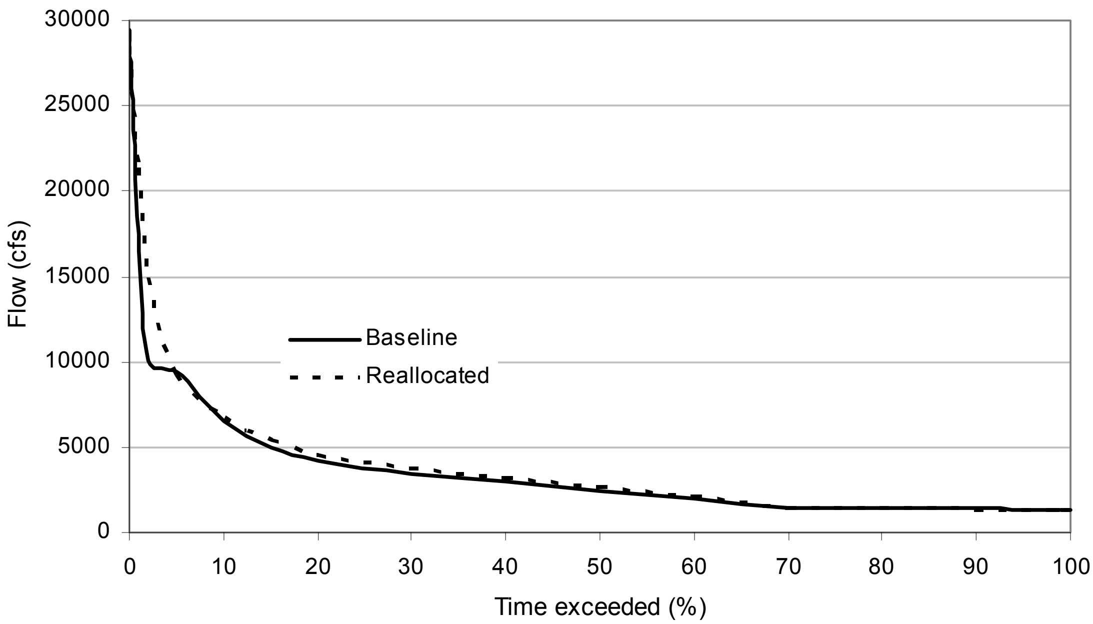

Figure C.29. Summer Yellowtail flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

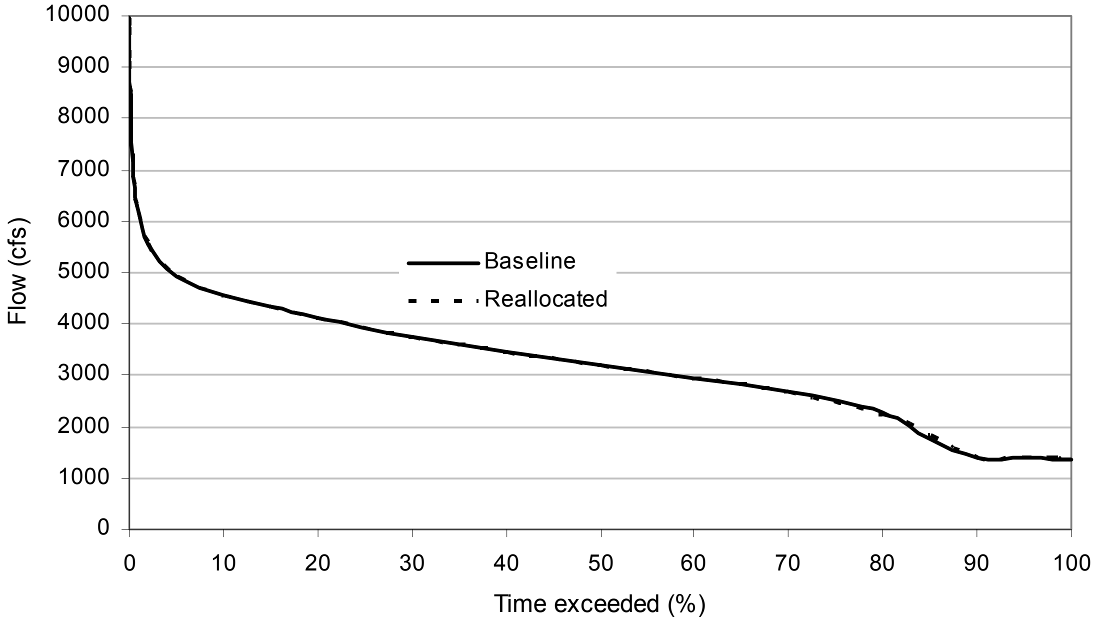

Figure C.30. Winter Yellowtail flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

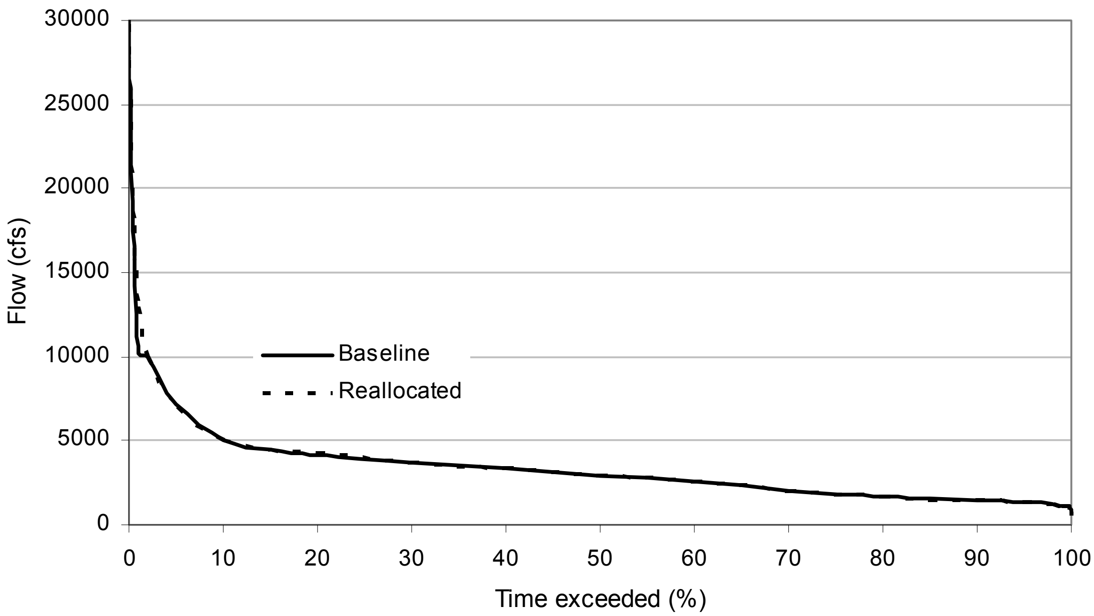

Figure C.31. Annual St. Xavier flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

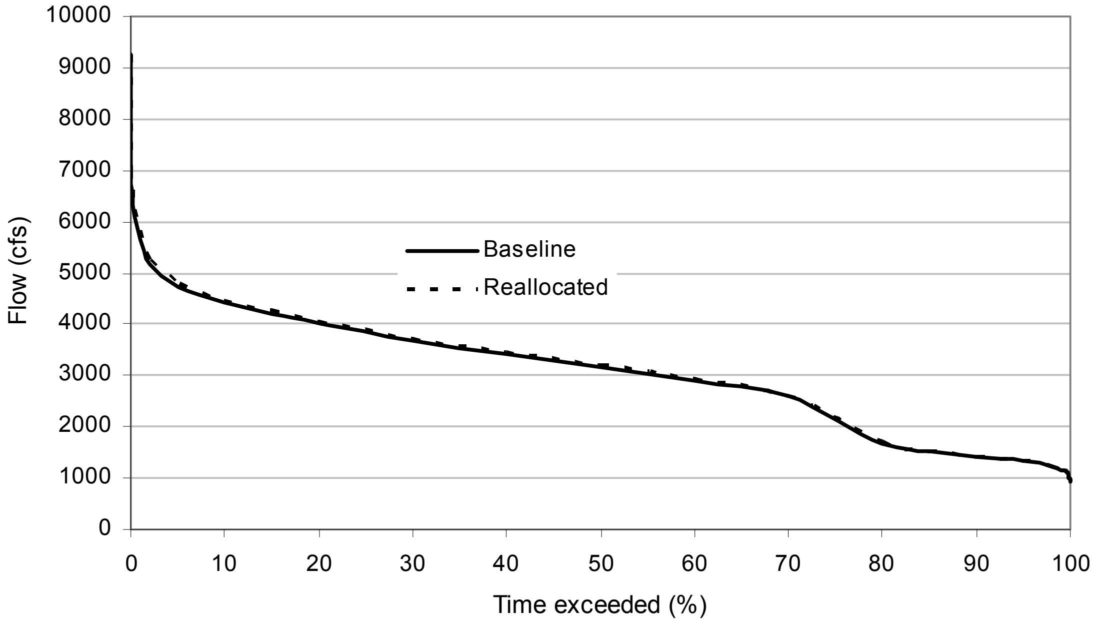

Figure C.32. Fall St. Xavier flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

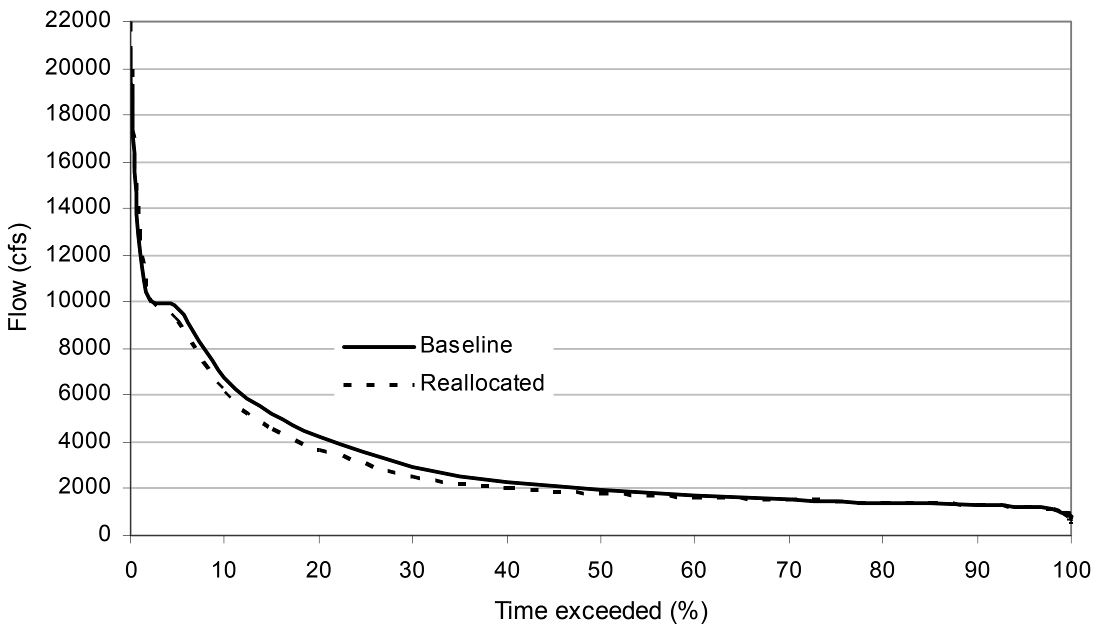

Figure C.33. Spring St. Xavier flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

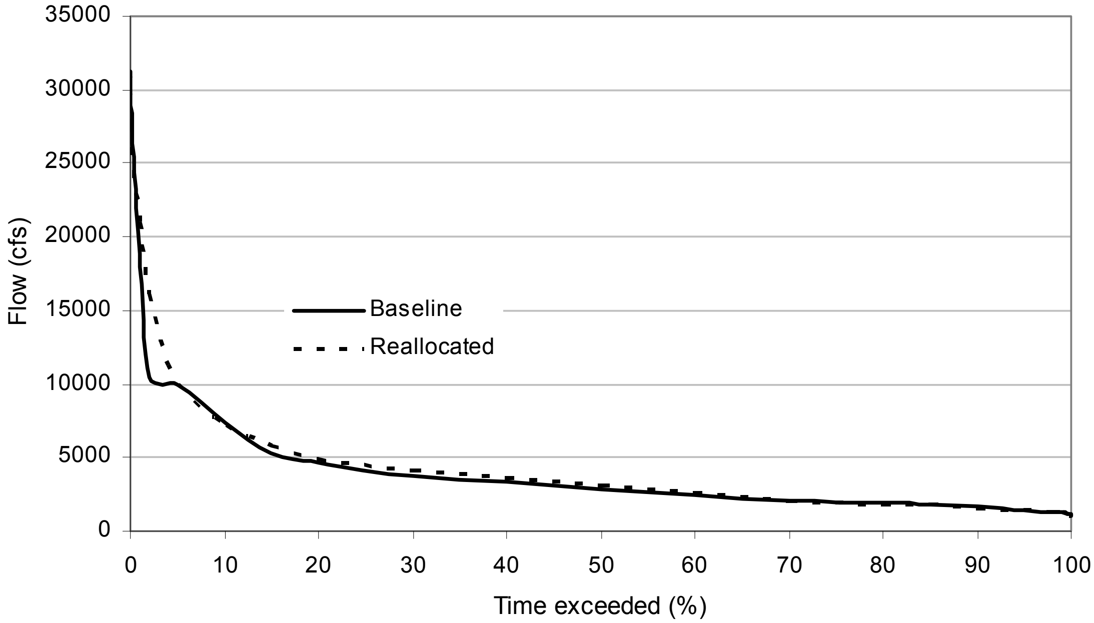

Figure C.34. Summer St. Xavier flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

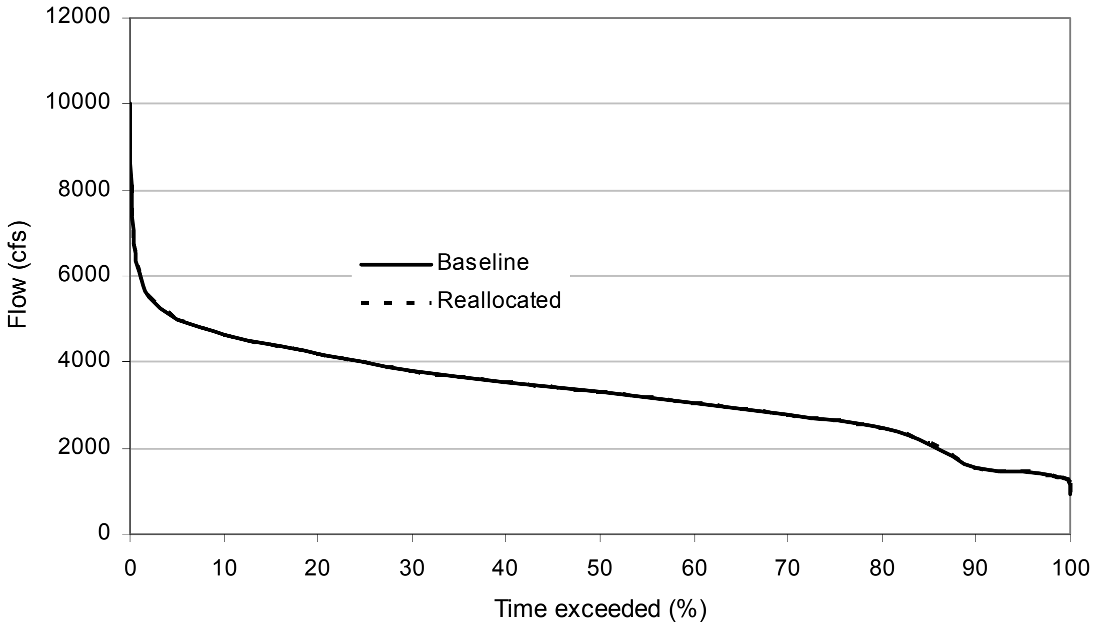

Figure C.35. Winter St. Xavier flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

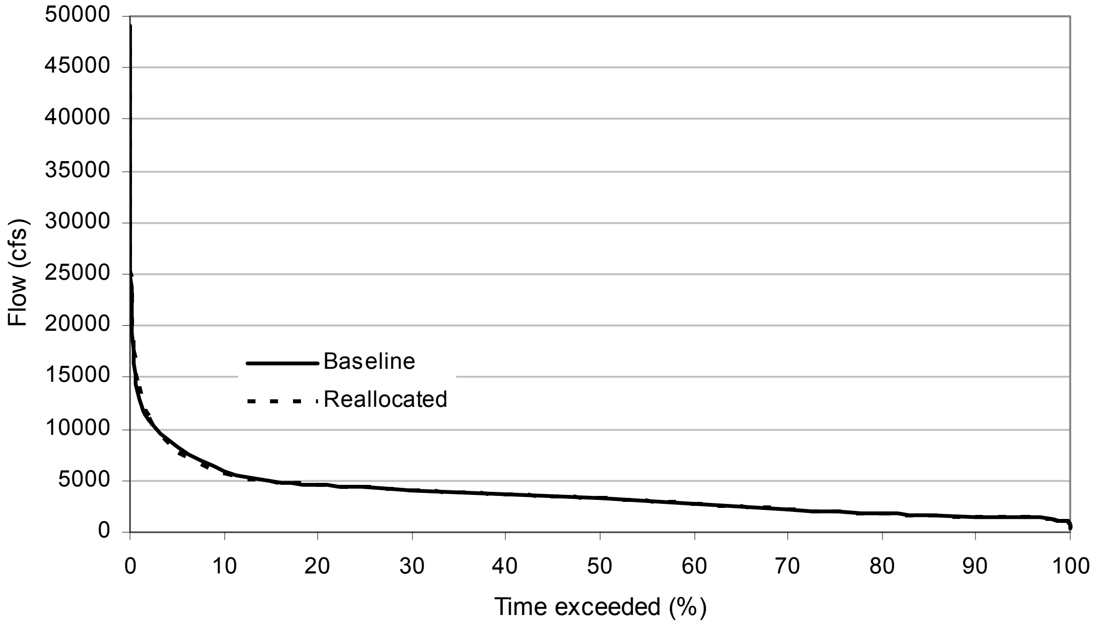

Figure C.36. Annual Bighorn flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

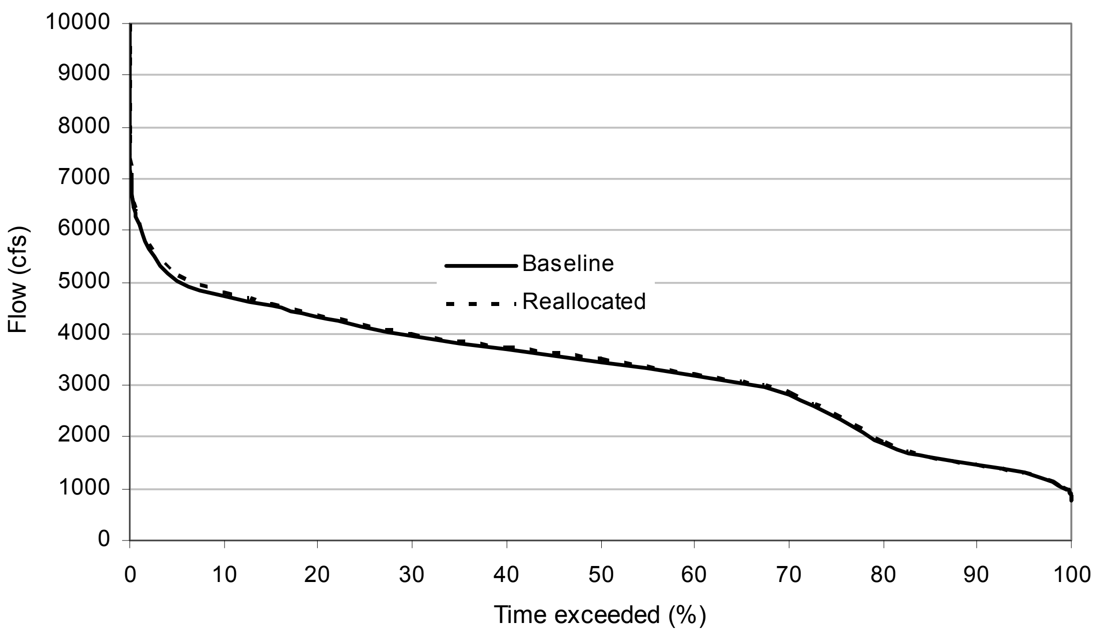

Figure C.37. Fall Bighorn flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

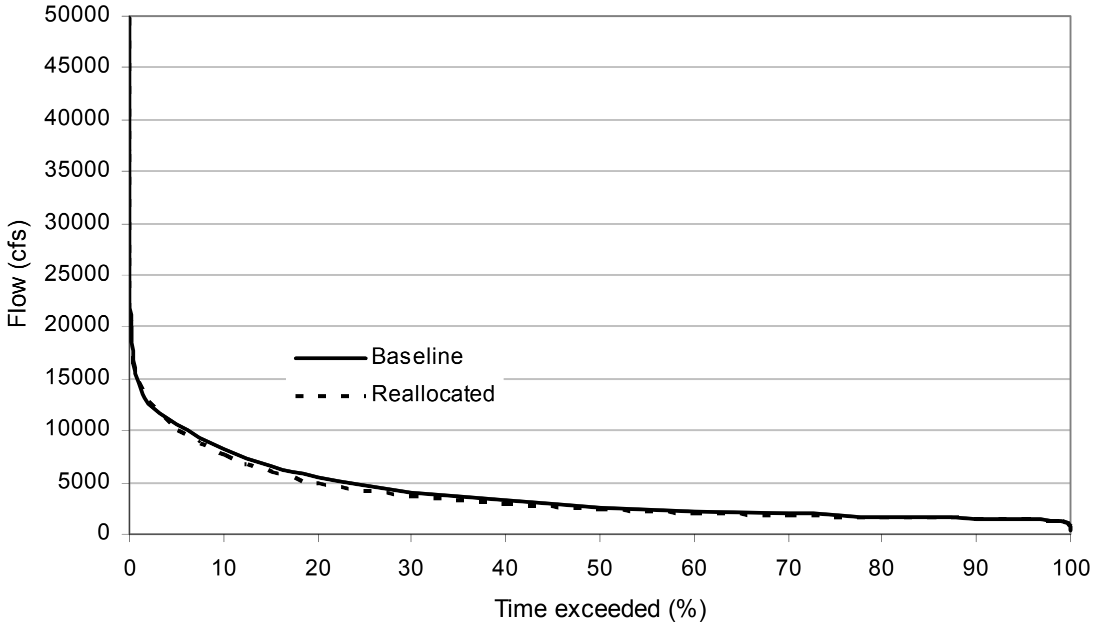

Figure C.38. Spring Bighorn flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

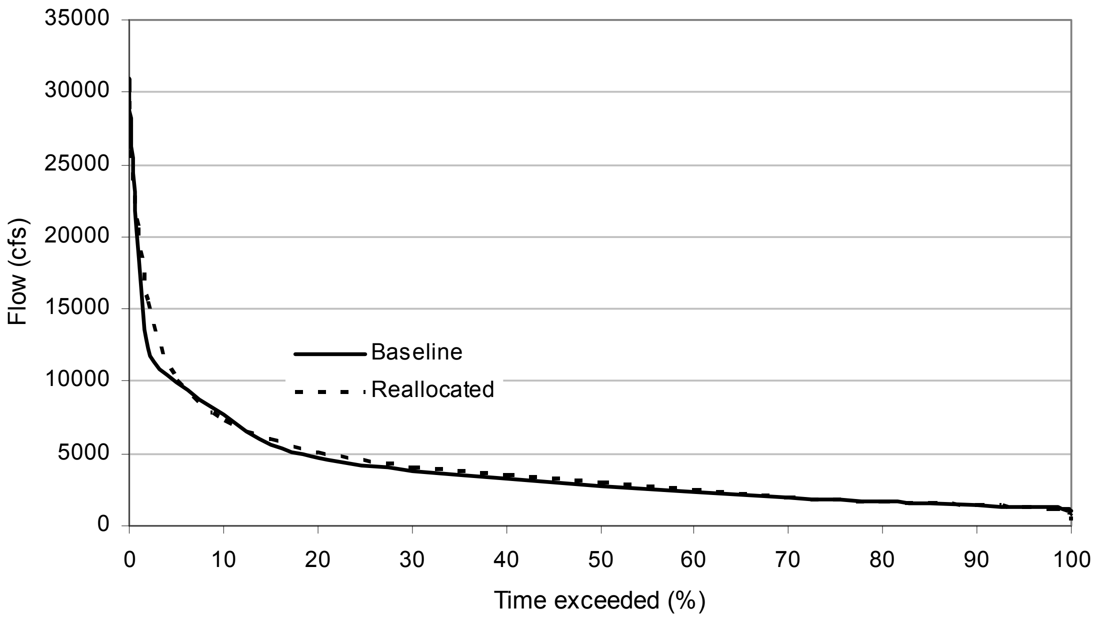

Figure C.39. Summer Bighorn flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

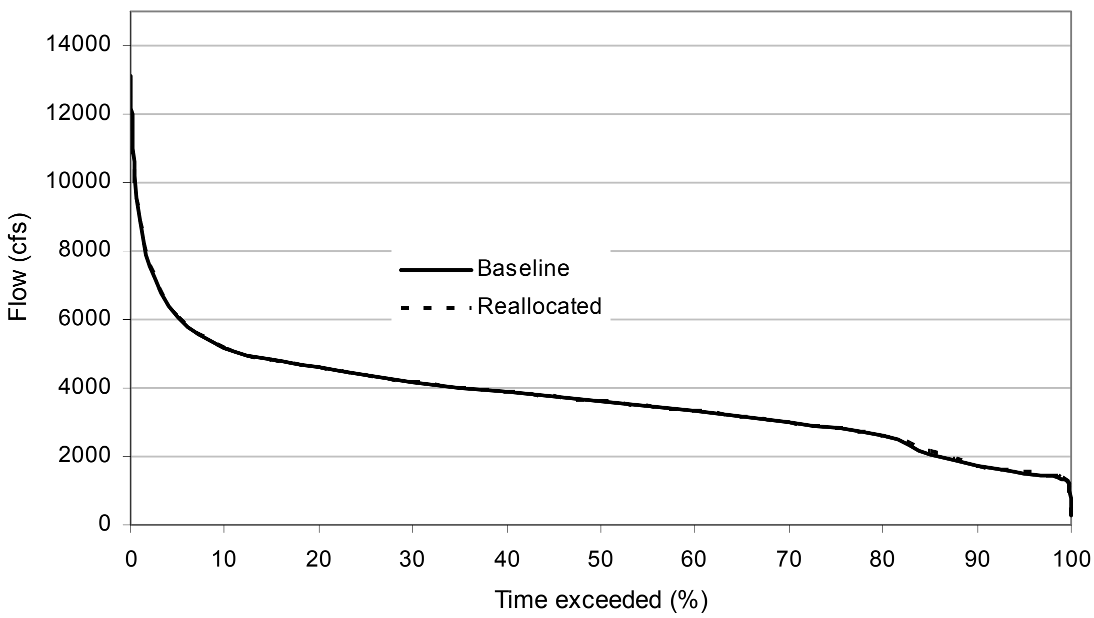

Figure C.40. Winter Bighorn flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

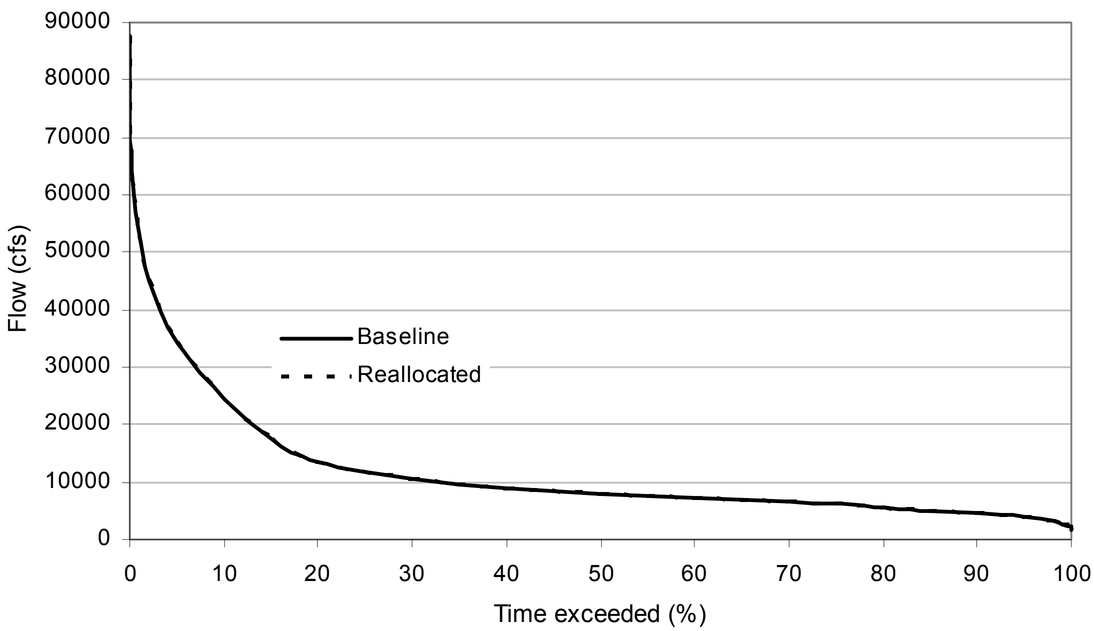

Figure C.41. Annual Miles City flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

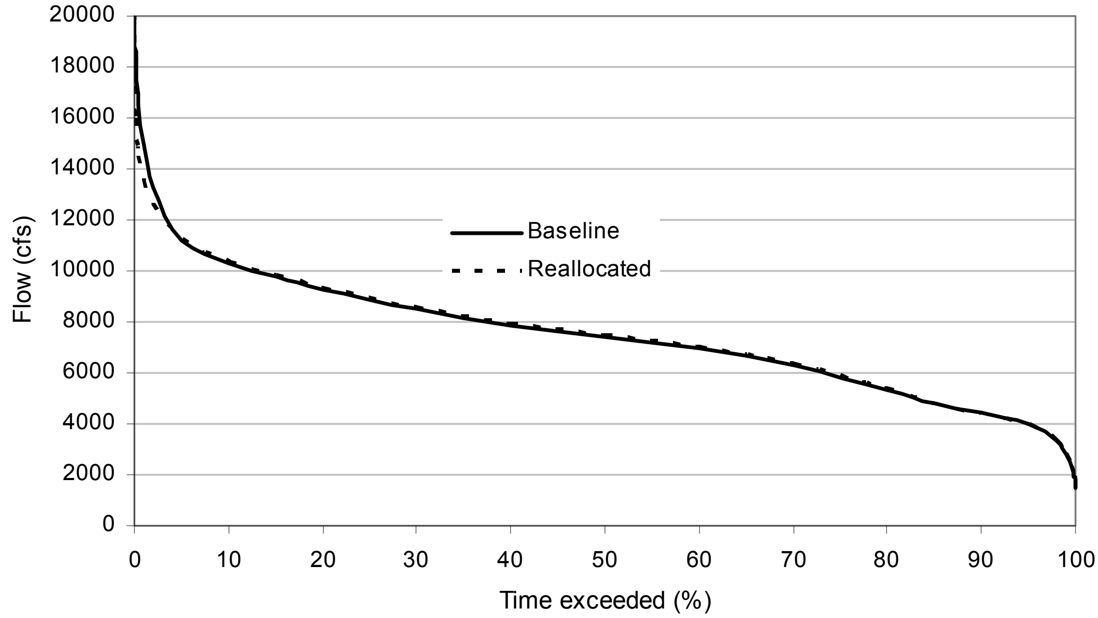

Figure C.42. Fall Miles City flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

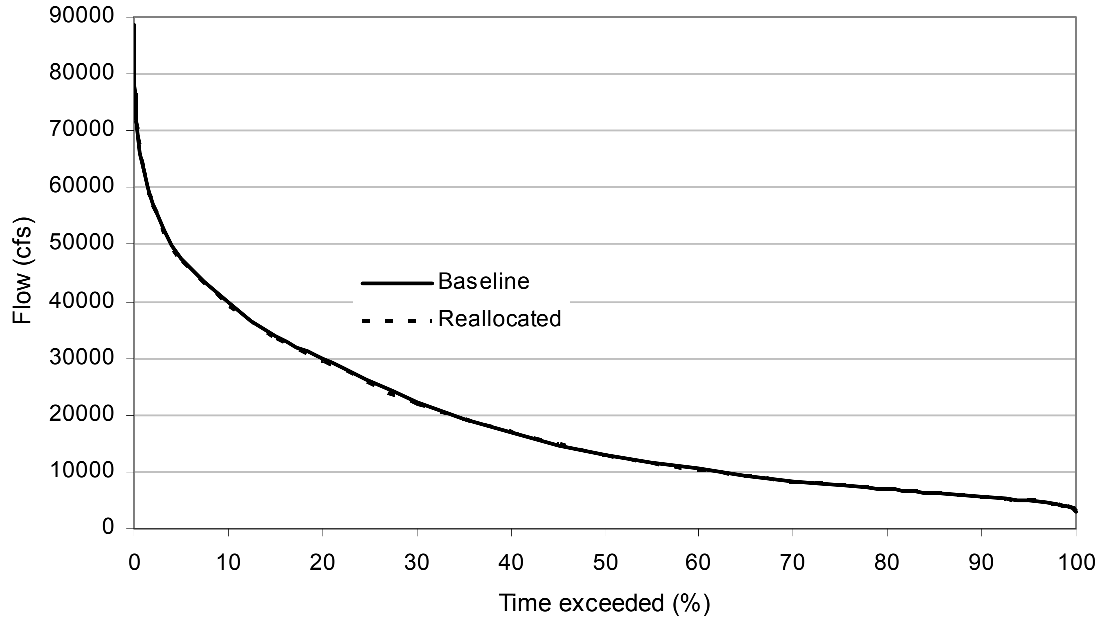

Figure C.43. Spring Miles City flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

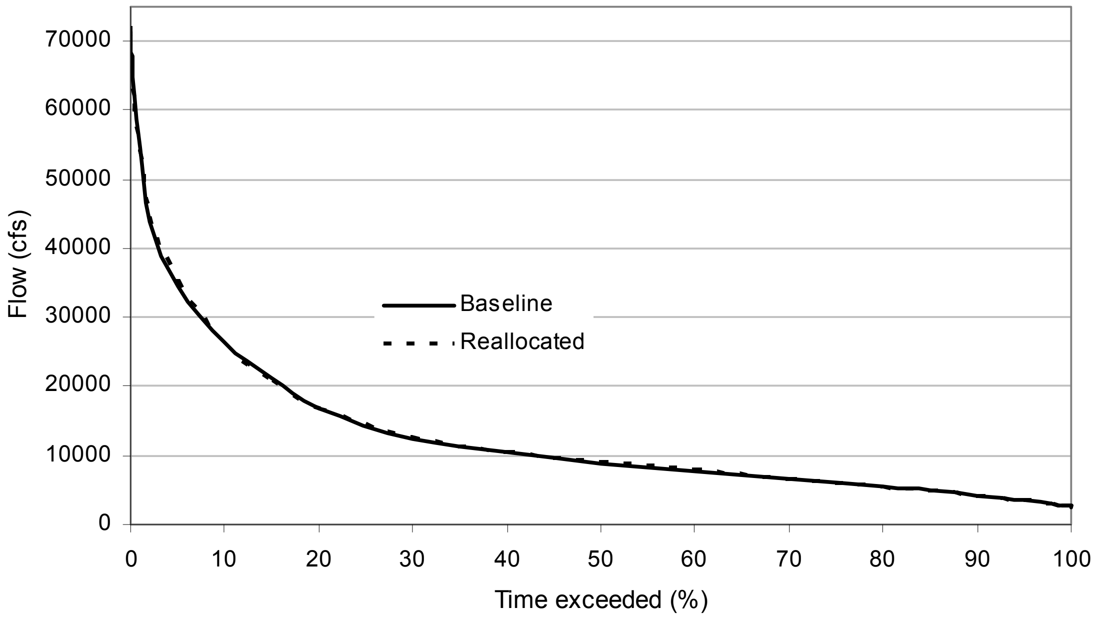

Figure C.44. Summer Miles City flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

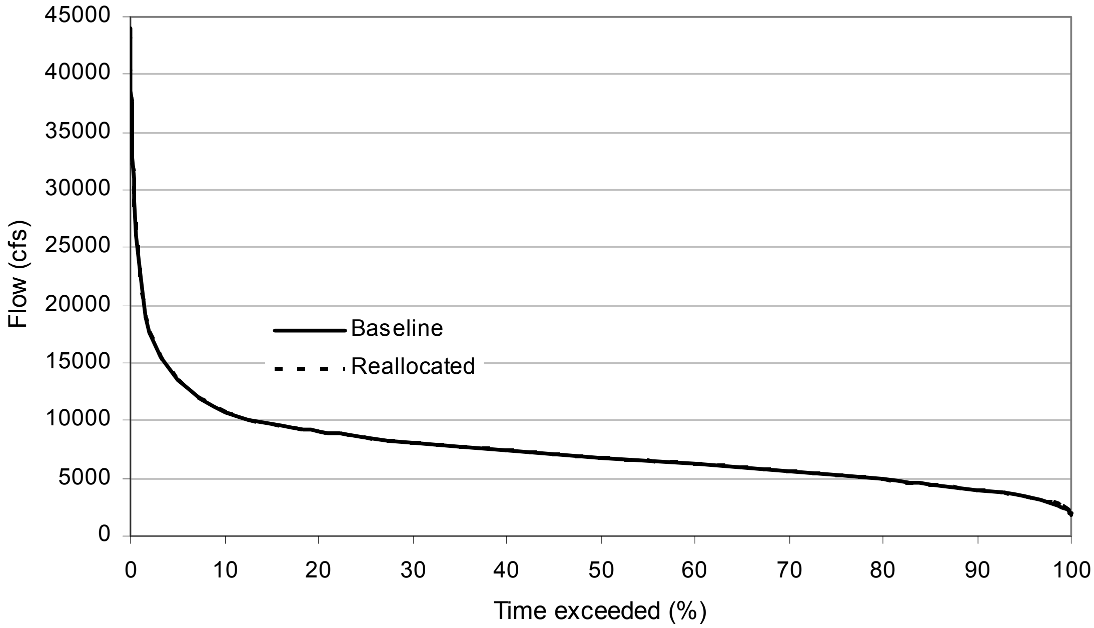

Figure C.45. Winter Miles City flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

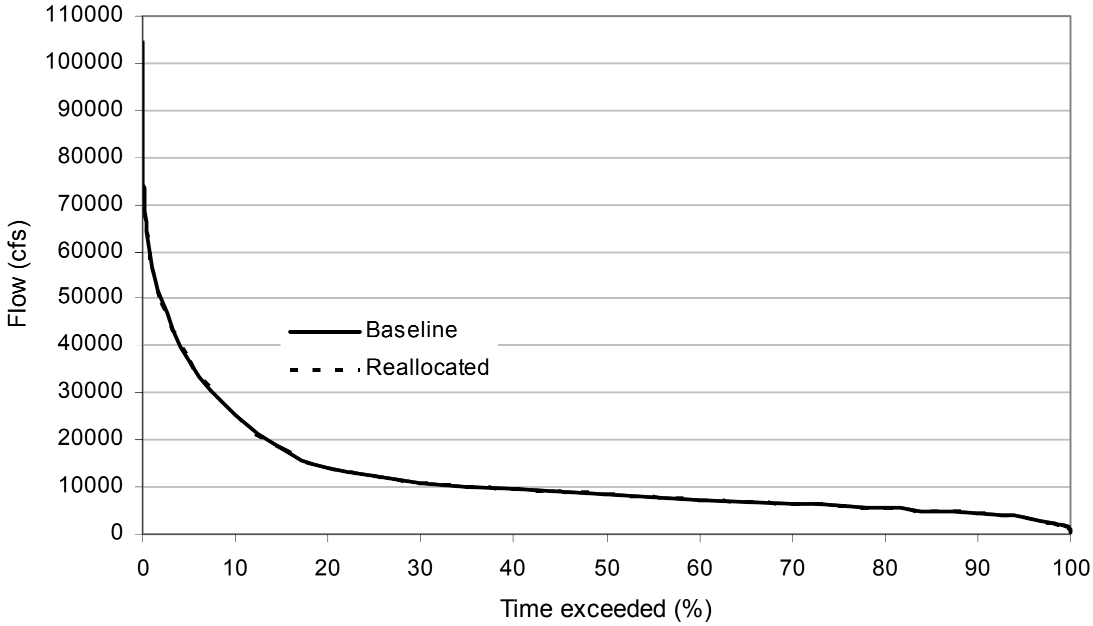

Figure C.46. Annual Sidney flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

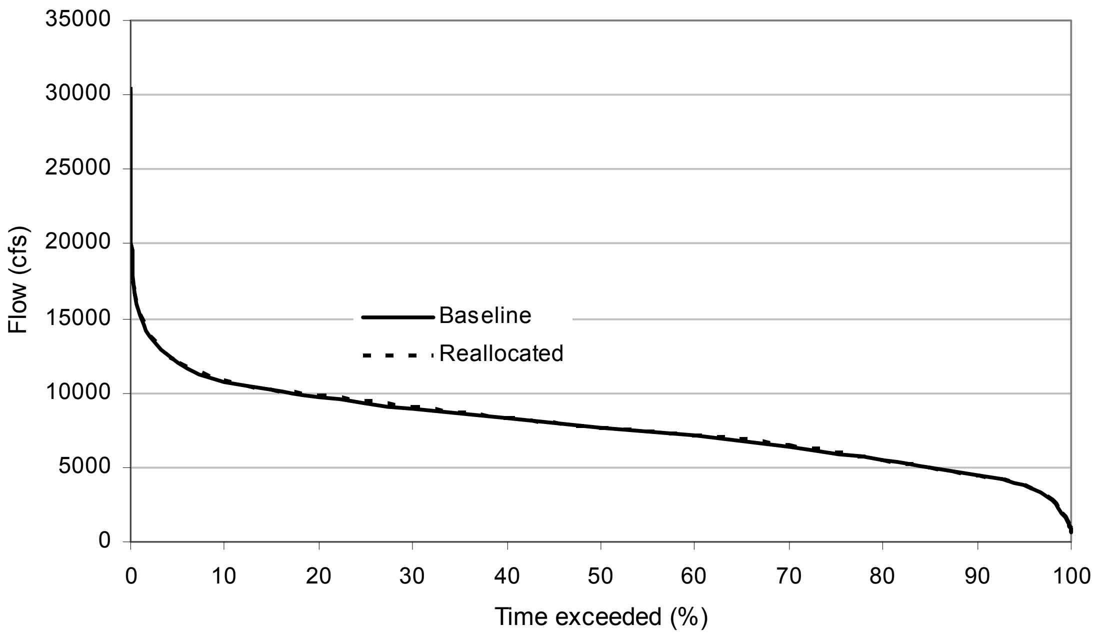

Figure C.47. Fall Sidney flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

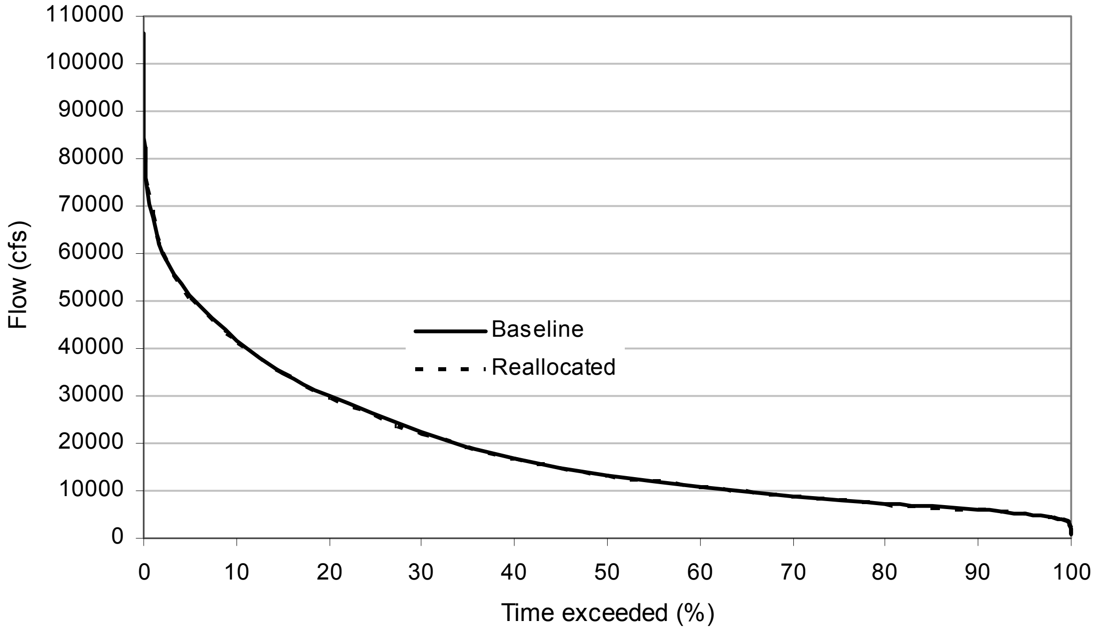

Figure C.48. Spring Sidney flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

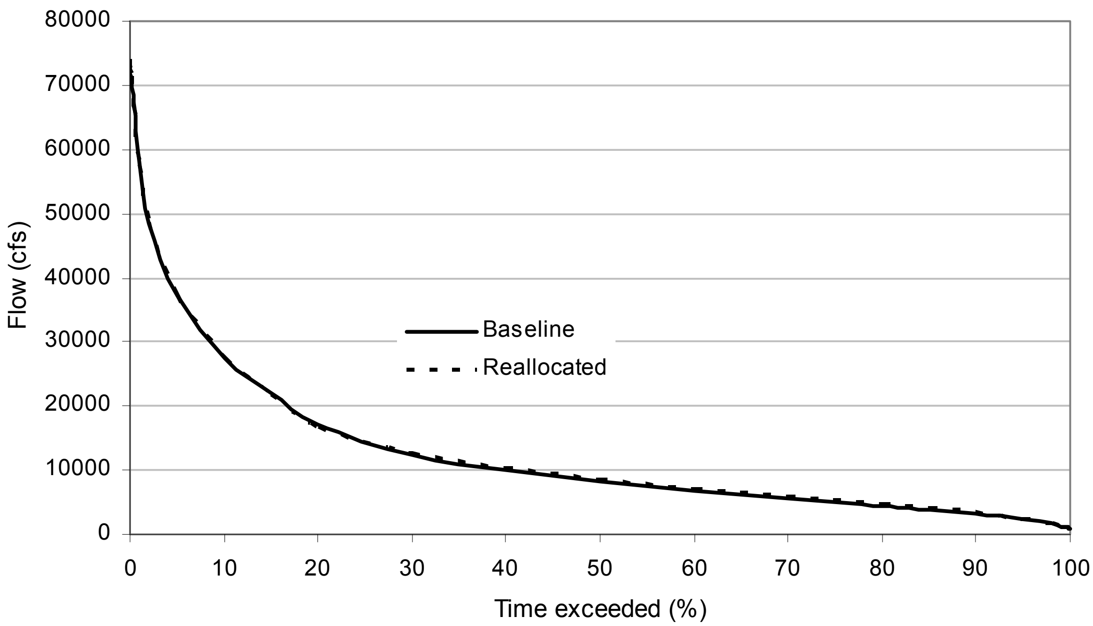

Figure C.49. Summer Sidney flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

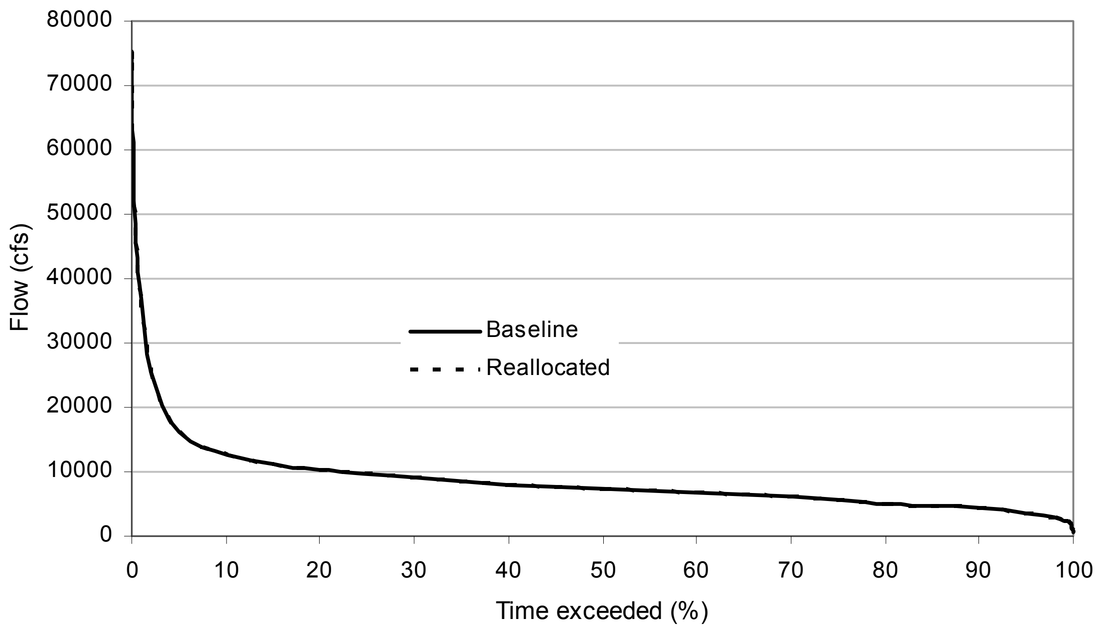

Figure C.50. Winter Sidney flow duration curve for the HEC-ResSim reallocated standard guide curve simulation.

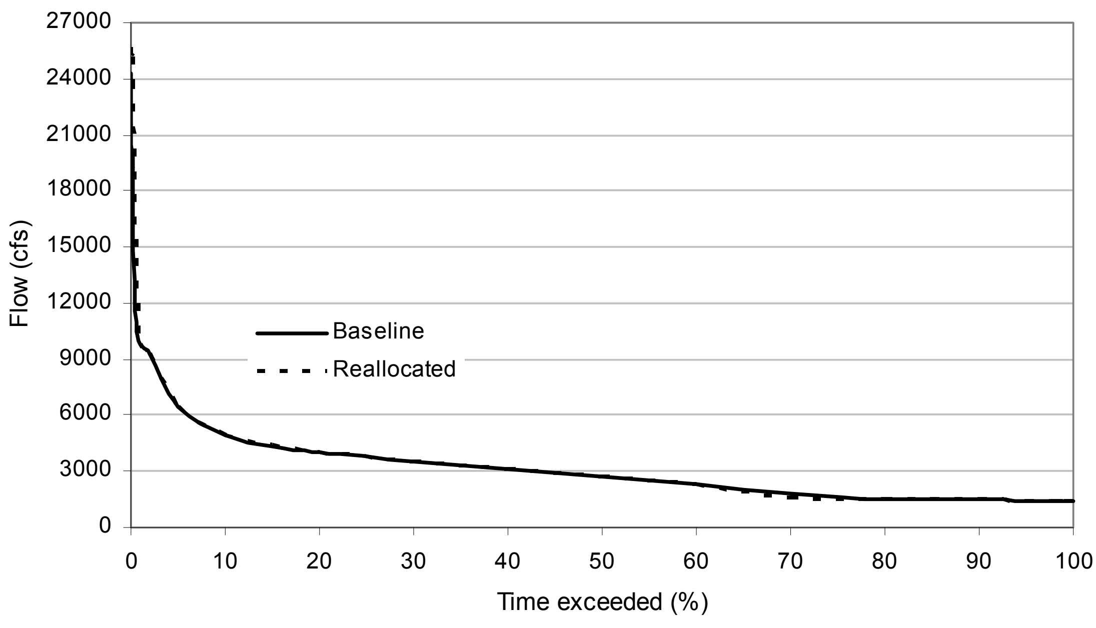

Figure C.51. Annual Yellowtail flow duration curve for the HEC-ResSim time series guide curve simulation.

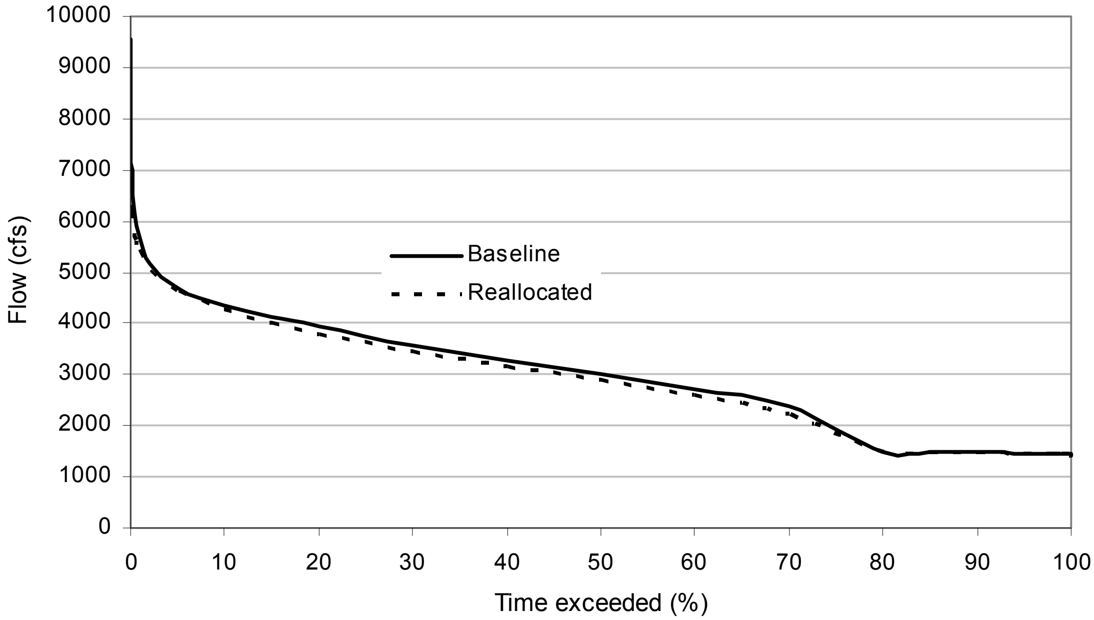

Figure C.52. Fall Yellowtail flow duration curve for the HEC-ResSim time series guide curve simulation.

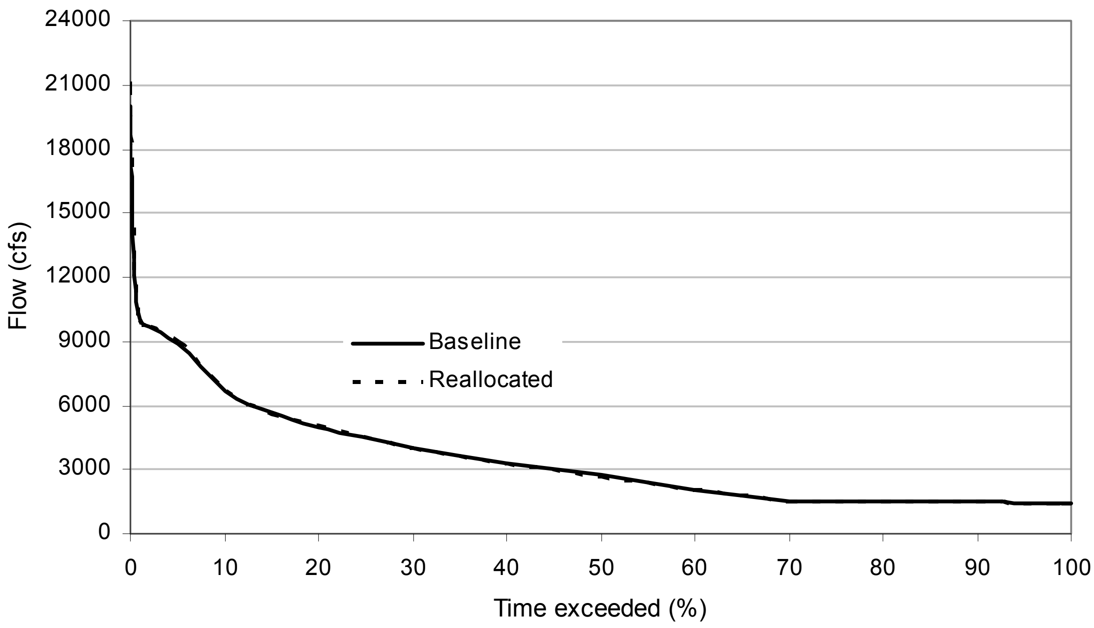

Figure C.53. Spring Yellowtail flow duration curve for the HEC-ResSim time series guide curve simulation.

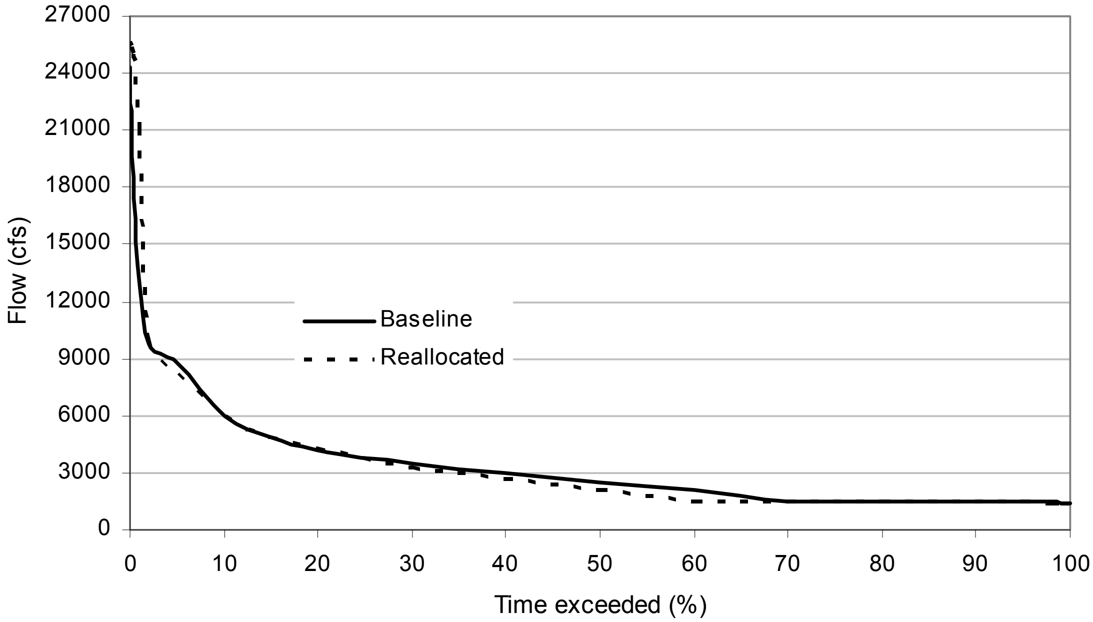

Figure C.54. Summer Yellowtail flow duration curve for the HEC-ResSim time series guide curve simulation.

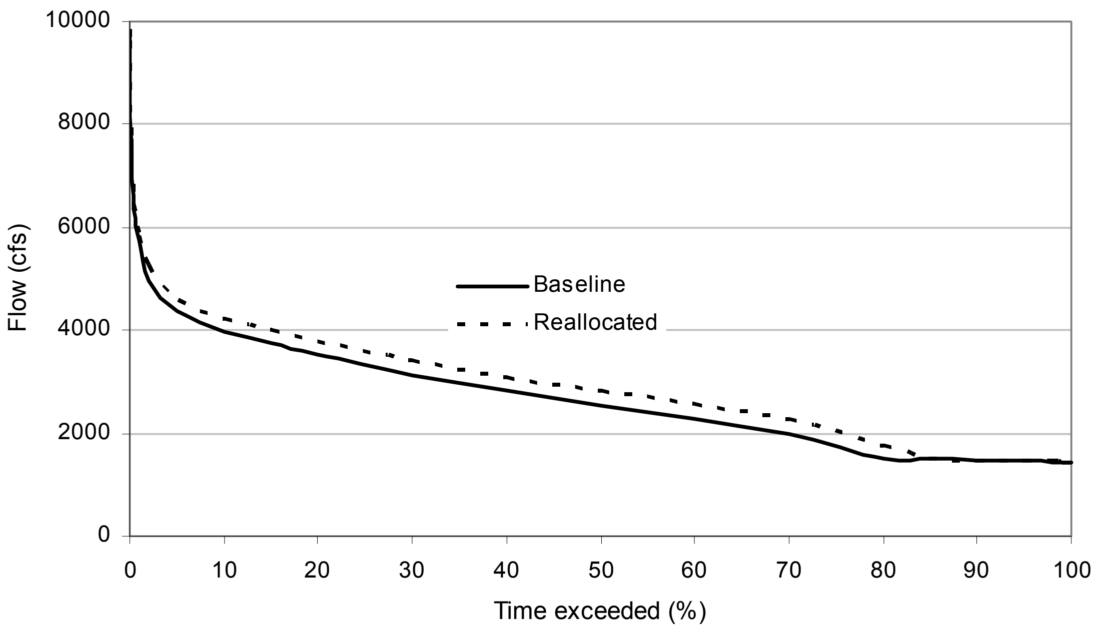

Figure C.55. Winter Yellowtail flow duration curve for the HEC-ResSim time series guide curve simulation.

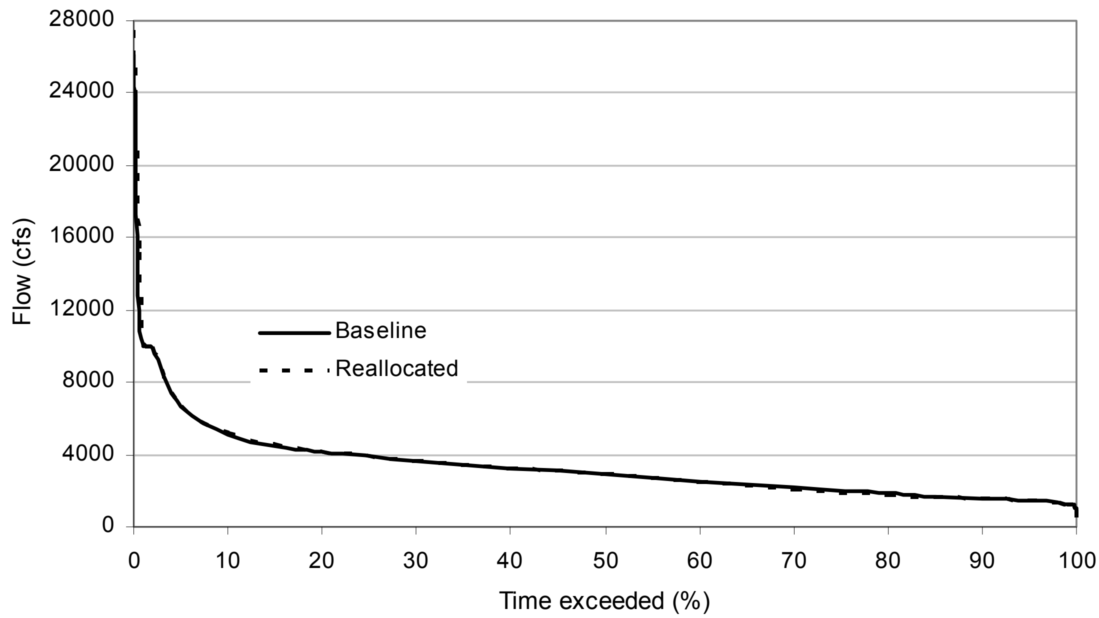

Figure C.56. Annual St. Xavier flow duration curve for the HEC-ResSim time series guide curve simulation.

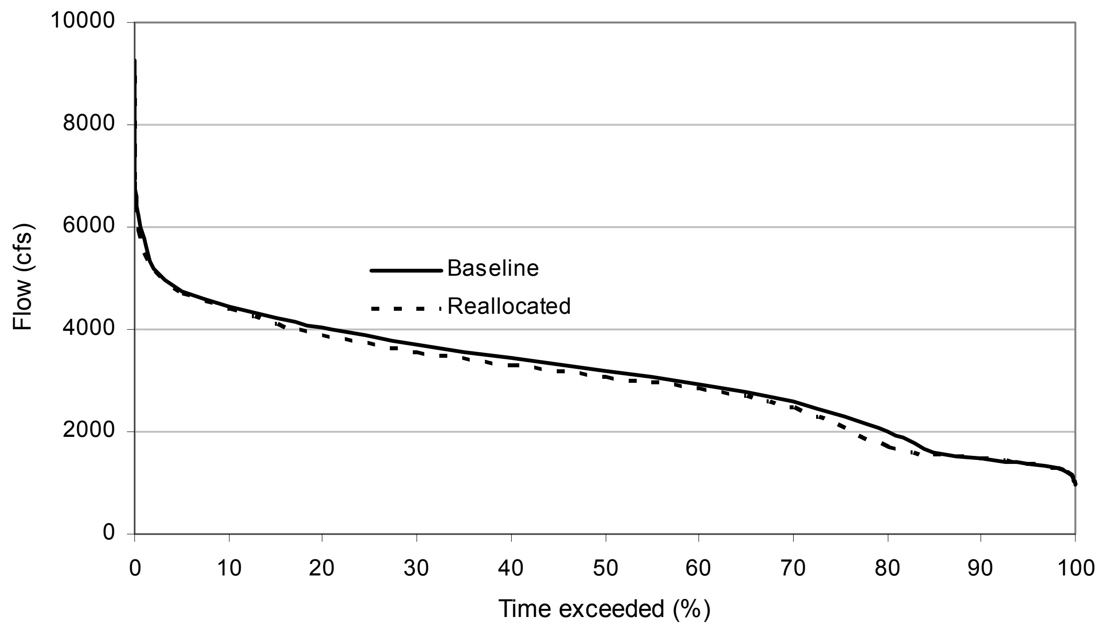

Figure C.57. Fall St. Xavier flow duration curve for the HEC-ResSim time series guide curve simulation.

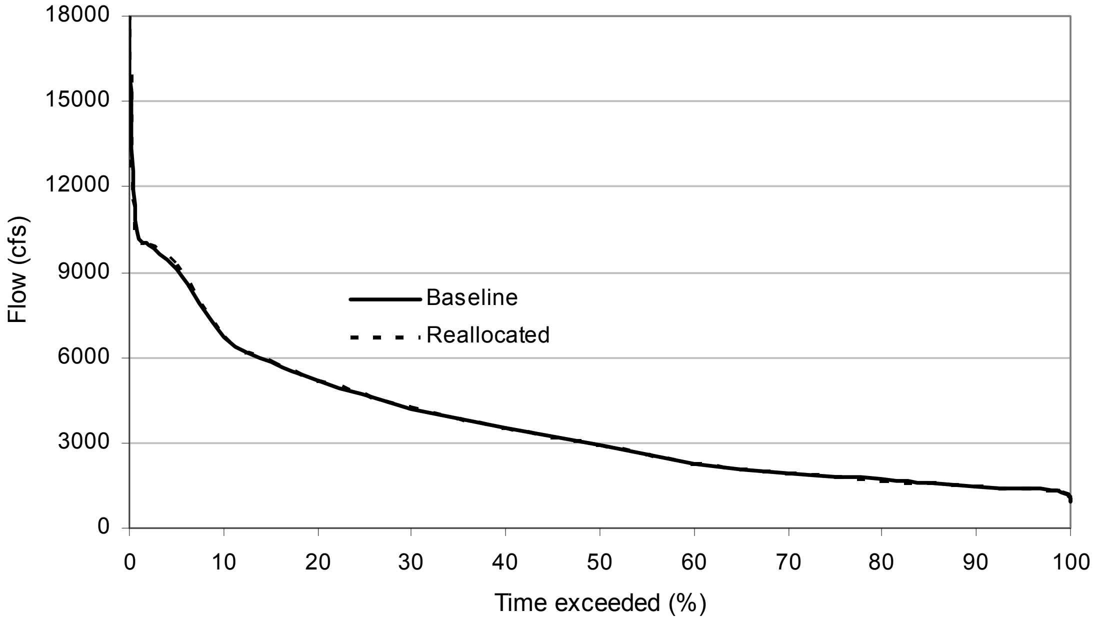

Figure C.58. Spring St. Xavier flow duration curve for the HEC-ResSim time series guide curve simulation.

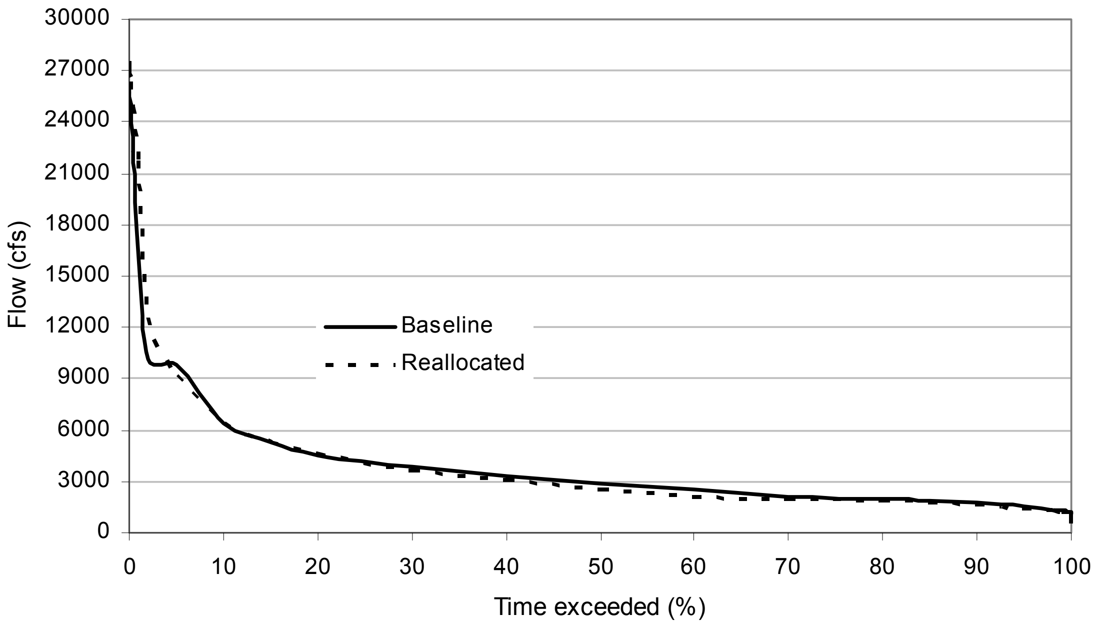

Figure C.59. Summer St. Xavier flow duration curve for the HEC-ResSim time series guide curve simulation.

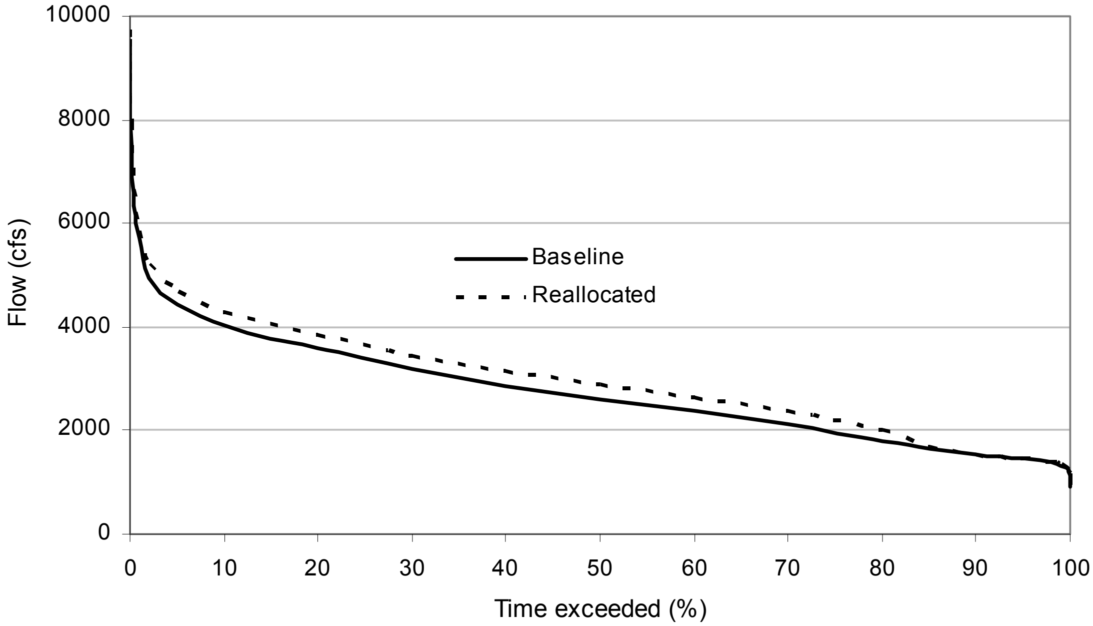

Figure C.60. Winter St. Xavier flow duration curve for the HEC-ResSim time series guide curve simulation.

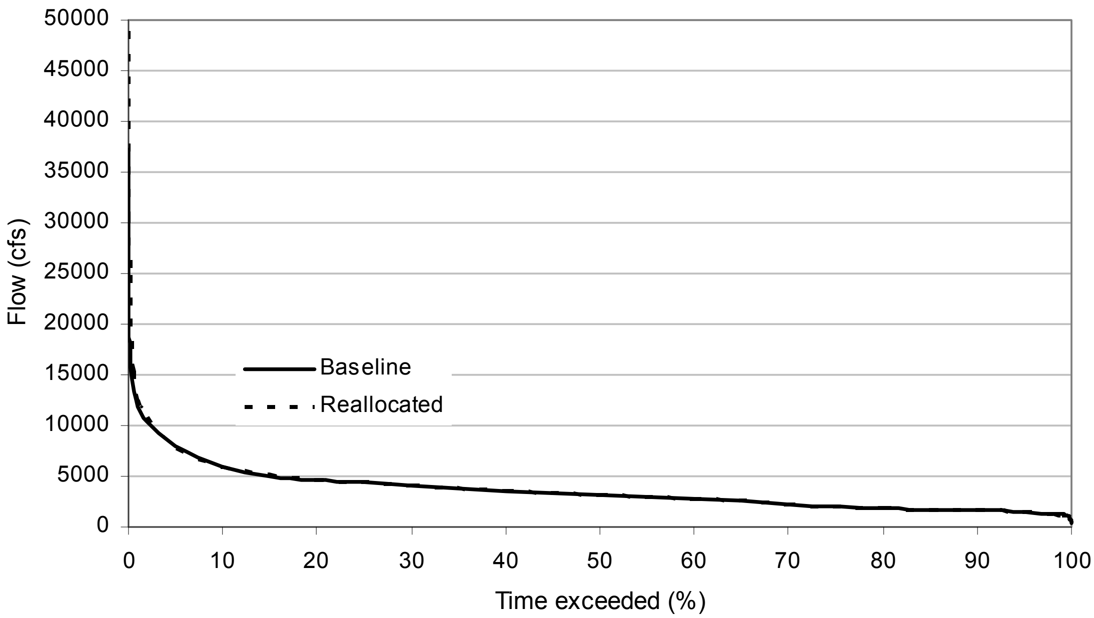

Figure C.61. Annual Bighorn flow duration curve for the HEC-ResSim time series guide curve simulation.

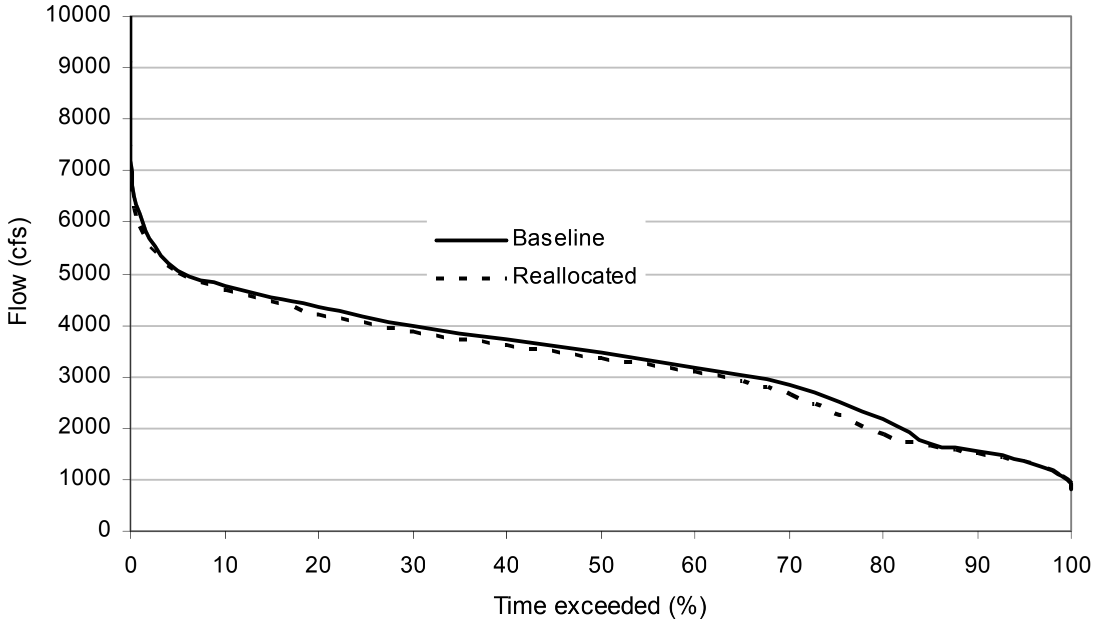

Figure C.62. Fall Bighorn flow duration curve for the HEC-ResSim time series guide curve simulation.

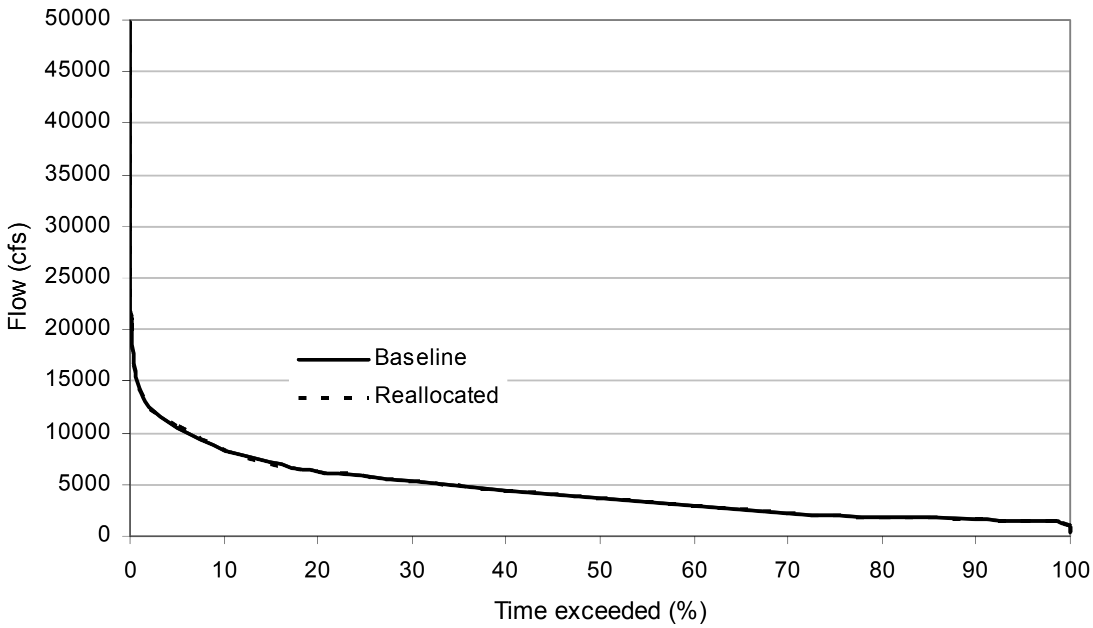

Figure C.63. Spring Bighorn flow duration curve for the HEC-ResSim time series guide curve simulation.

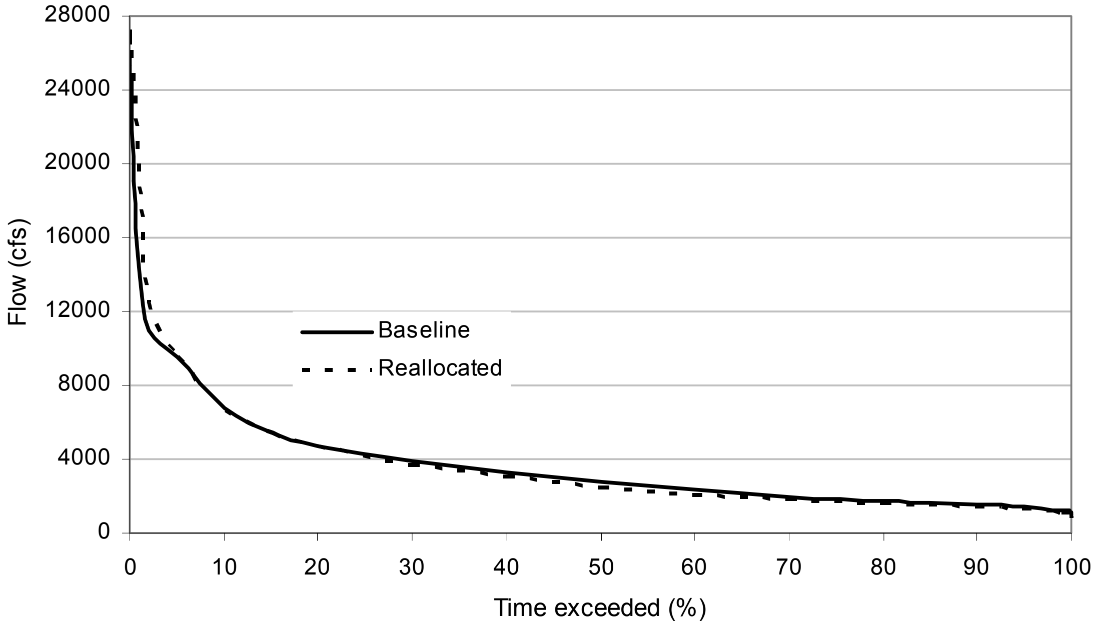

Figure C.64. Summer Bighorn flow duration curve for the HEC-ResSim time series guide curve simulation.

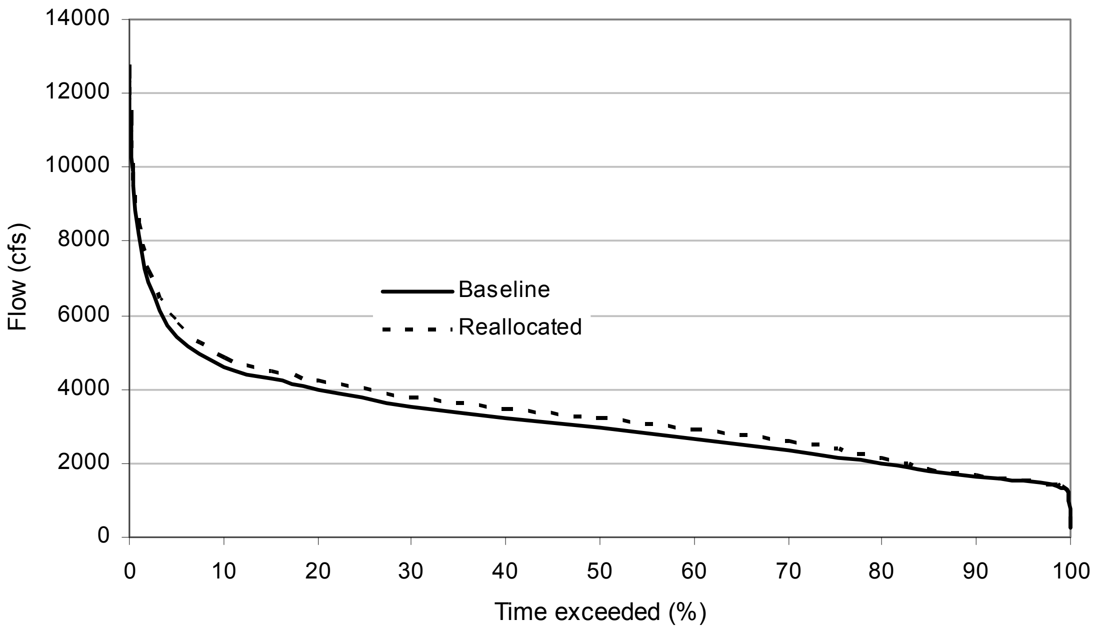

Figure C.65. Winter Bighorn flow duration curve for the HEC-ResSim time series guide curve simulation.

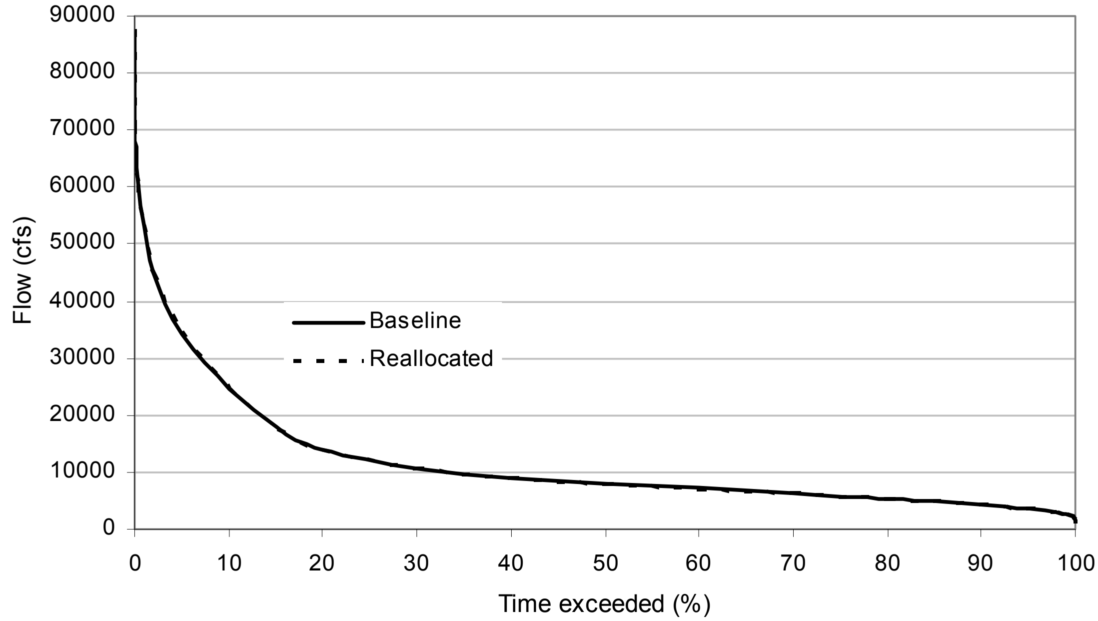

Figure C.66. Annual Miles City flow duration curve for the HEC-ResSim time series guide curve simulation.

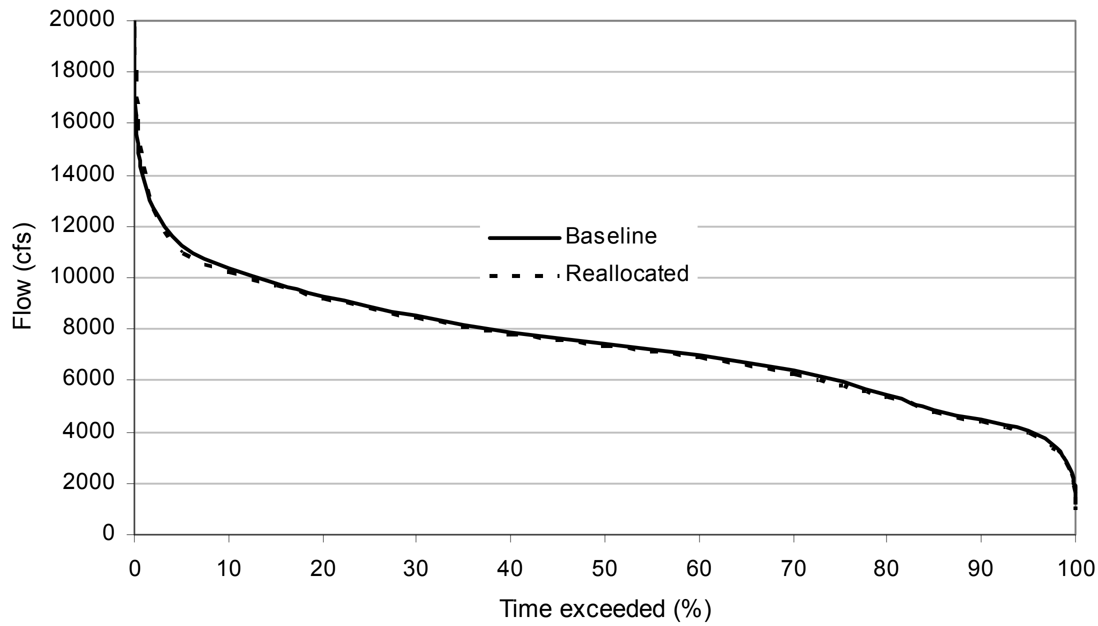

Figure C.67. Fall Miles City flow duration curve for the HEC-ResSim time series guide curve simulation.

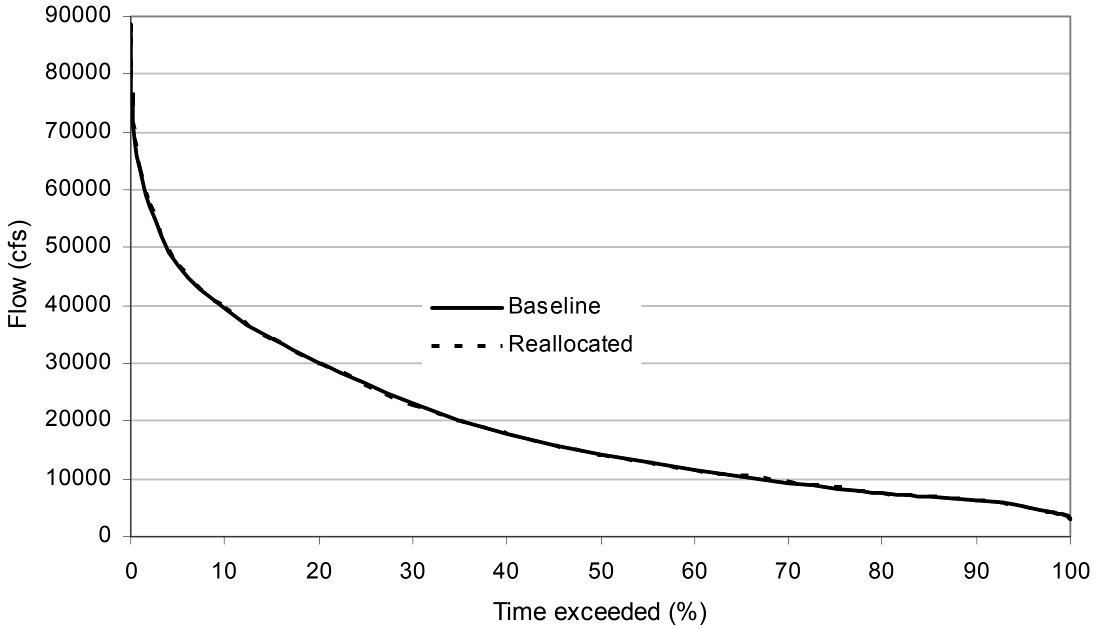

Figure C.68. Spring Miles City flow duration curve for the HEC-ResSim time series guide curve simulation.

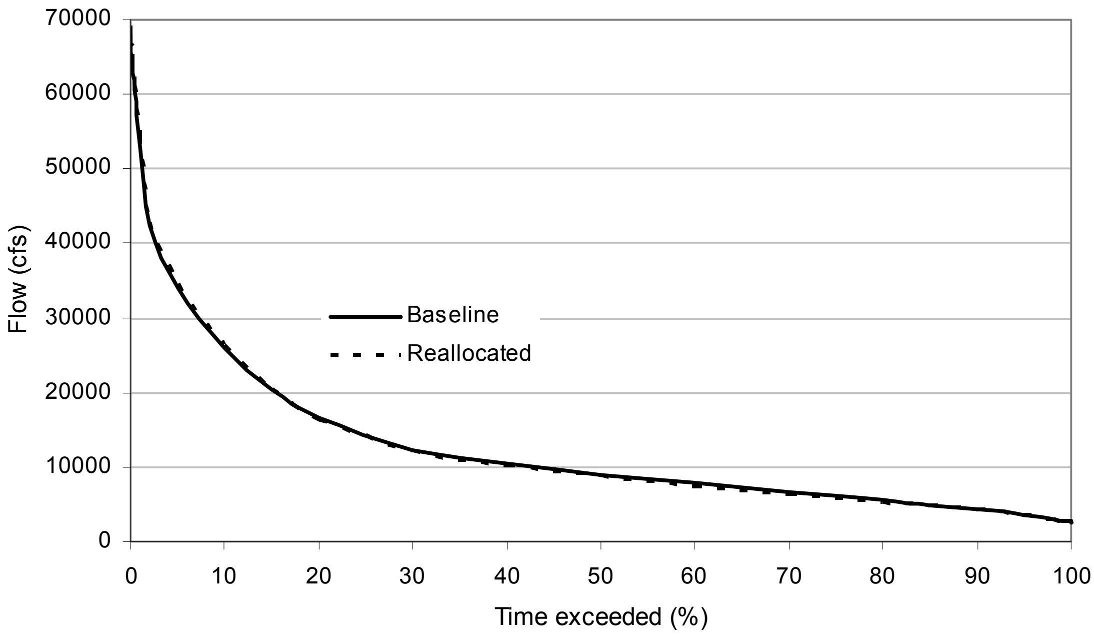

Figure C.69. Summer Miles City flow duration curve for the HEC-ResSim time series guide curve simulation.

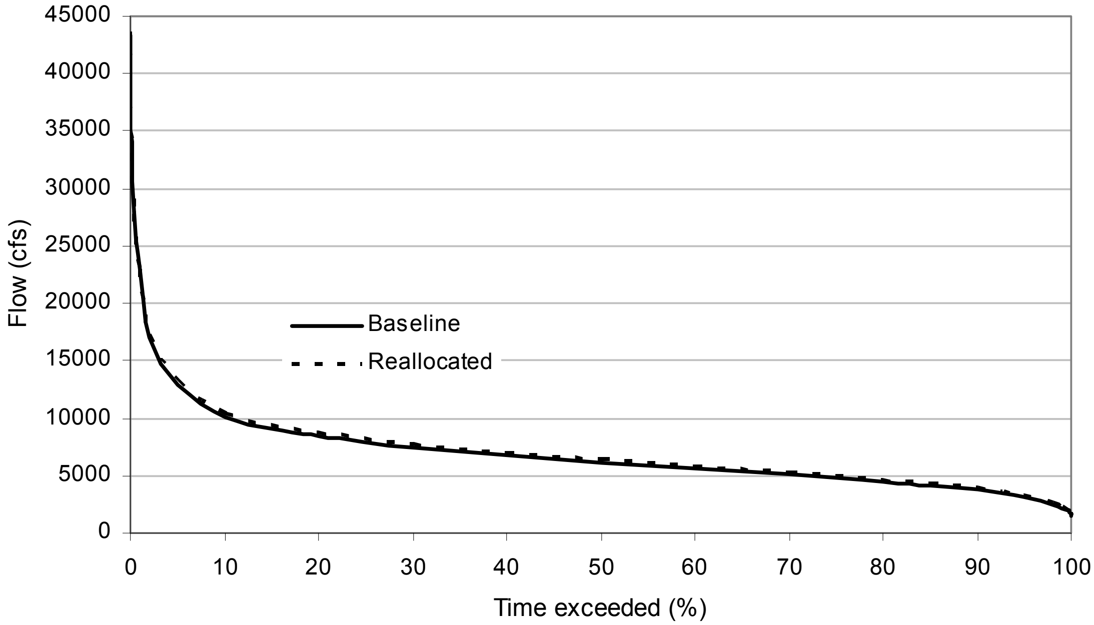

Figure C.70. Winter Miles City flow duration curve for the HEC-ResSim time series guide curve simulation.

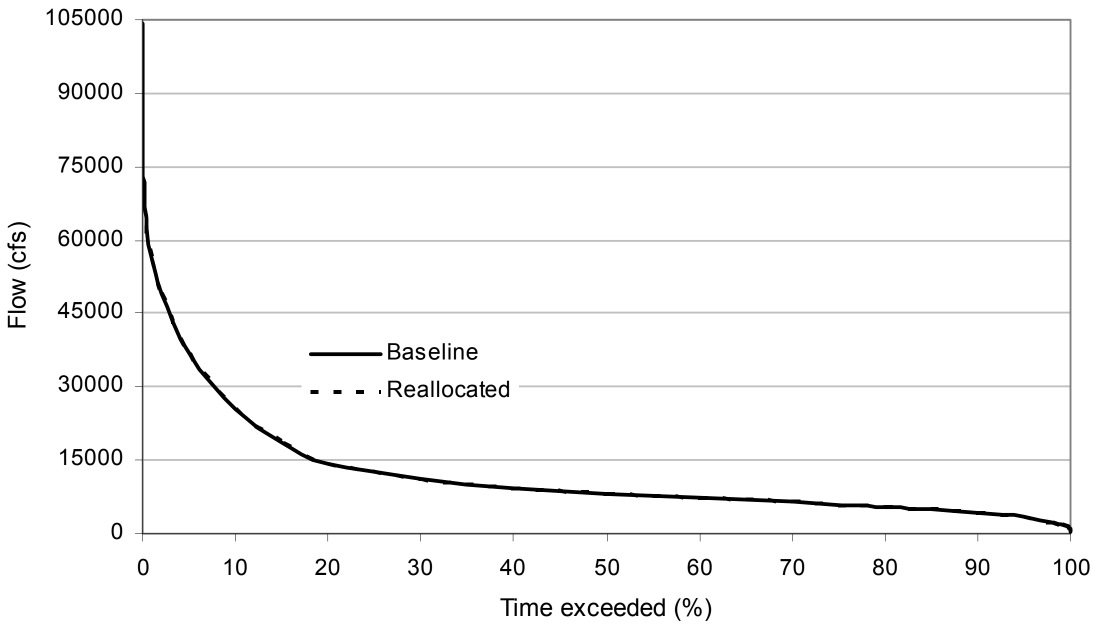

Figure C.71. Annual Sidney flow duration curve for the HEC-ResSim time series guide curve simulation.

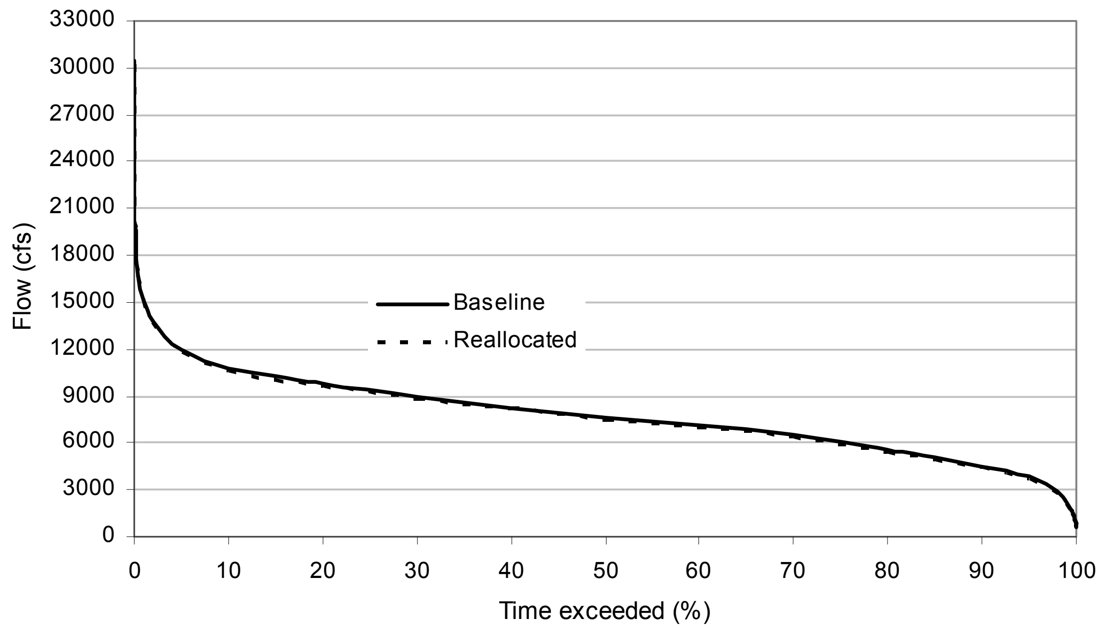

Figure C.72. Fall Sidney flow duration curve for the HEC-ResSim time series guide curve simulation.

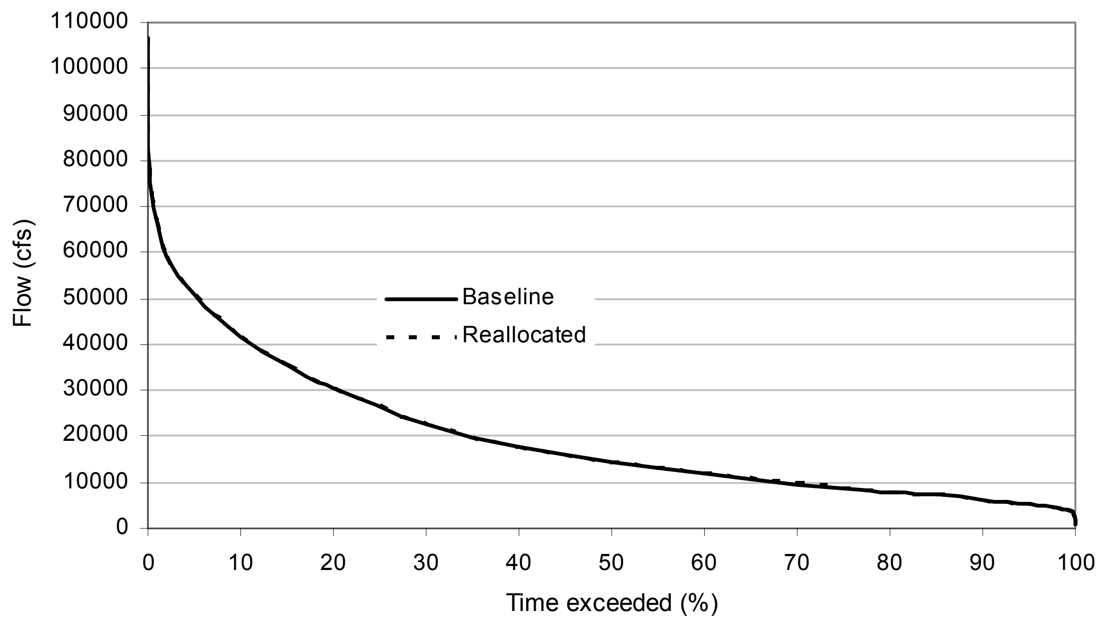

Figure C.73. Spring Sidney flow duration curve for the HEC-ResSim time series guide curve simulation.

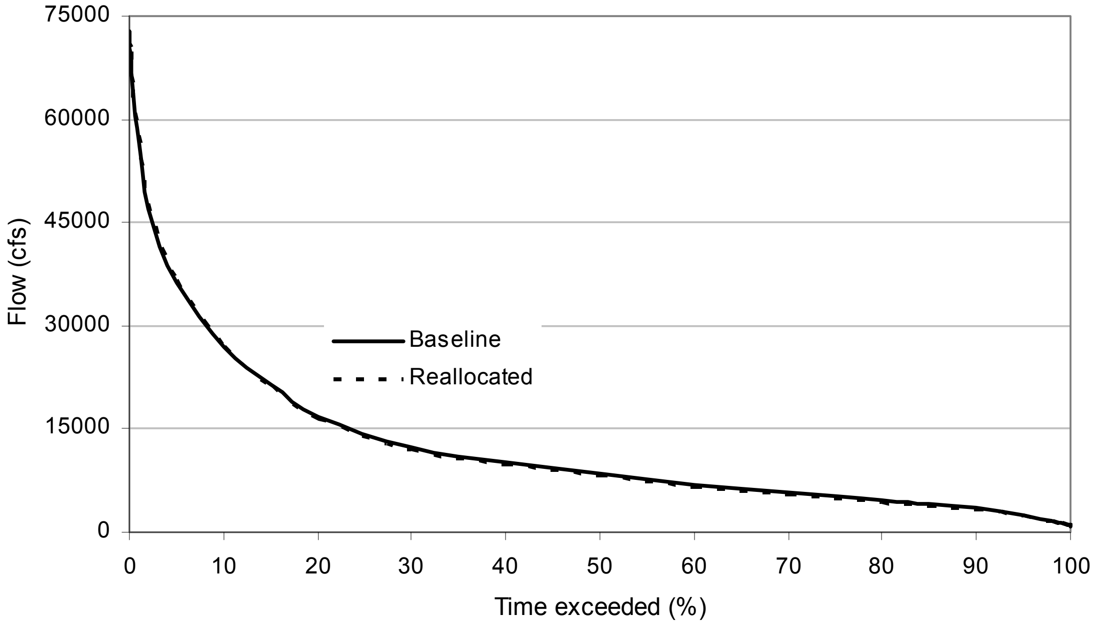

Figure C.74. Summer Sidney flow duration curve for the HEC-ResSim time series guide curve simulation.

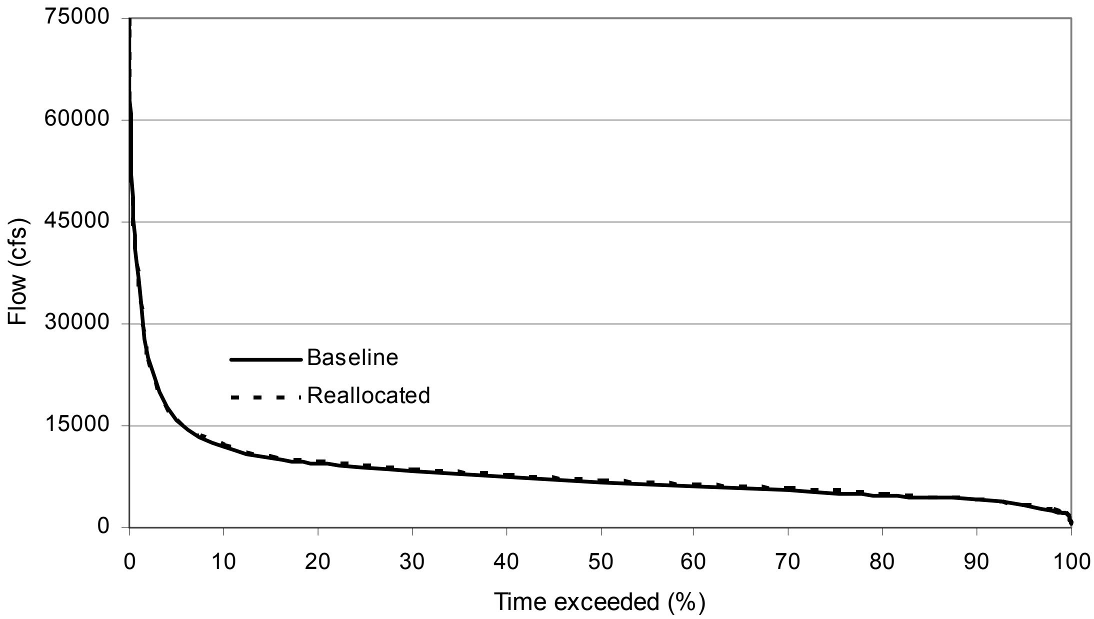

Figure C.75. Winter Sidney flow duration curve for the HEC-ResSim time series guide curve simulation.

Appendix D – Additional Flow Frequency Information

This appendix contains additional flow frequency tables and figures for all the HEC-ResSim period of record simulations. The tabular information supplements information presented earlier in the report and the figures were presented earlier in tabular form. Each table or figure caption provides information about the HEC-ResSim simulation it is from. Any caption that references "standard guide curve" corresponds to the HEC-ResSim baseline simulation. This simulation compared the HEC-ResSim model with the actual Yellowtail operations. Captions referencing "reallocated standard guide curve" correspond to the HEC-ResSim reallocated simulation. This simulation compared the baseline condition with the reallocated condition where the top of joint use pool was increased to 3,645 ft msl. Captions referencing "time series guide curve" correspond to the time series simulations described in appendix A. These simulations compared the time series baseline condition to a time series reallocated condition where the joint use pool was raised a maximum of 3 ft to 3,643 ft msl.

Table D.1. Bulletin 17B pertinent statistics at the Bighorn River at St. Xavier and Bighorn for the HEC-ResSim standard guide curve simulation.

	St. Xavier		*Bighorn*	
	HEC-ResSim	*Actual*	*HEC-ResSim*	*Actual*
Mean	3.90	3.80	3.96	3.89
Standard Deviation	0.26	0.27	0.28	0.29
Adopted Skew	-0.67	-0.17	-0.17	0.28
Systematic Events	40	40	40	40
High Outliers	0	0	0	1

Table D.2. Bulletin 17B pertinent statistics at the Yellowstone River at Miles City and Sidney for the HEC-ResSim standard guide curve simulation.

	Miles City		*Sidney*	
	HEC-ResSim	*Actual*	*HEC-ResSim*	*Actual*
Mean	4.64	4.65	4.67	4.68
Standard Deviation	0.16	0.15	0.18	0.16
Adopted Skew	-0.17	-0.12	-0.32	-0.21
Systematic Events	40	40	40	40
High Outliers	0	0	0	0

Table D.3. Bulletin 17B pertinent statistics at the Bighorn River at St. Xavier and Bighorn for the HEC-ResSim reallocated standard guide curve simulation.

	St. Xavier		*Bighorn*	
	Baseline	*Reallocated*	*Baseline*	*Reallocated*
Mean	3.90	3.90	3.96	3.96
Standard Deviation	0.26	0.27	0.28	0.29
Adopted Skew	-0.67	-0.54	-0.17	-0.16
Systematic Events	40	40	40	40
High Outliers	0	0	0	0

Table D.4. Bulletin 17B pertinent statistics at the Yellowstone River at Miles City and Sidney for the HEC-ResSim reallocated standard guide curve simulation.

	Miles City		*Sidney*	
	Baseline	*Reallocated*	*Baseline*	*Reallocated*
Mean	4.64	4.64	4.67	4.67
Standard Deviation	0.16	0.16	0.18	0.18
Adopted Skew	-0.17	-0.18	-0.32	-0.34
Systematic Events	40	40	40	40
High Outliers	0	0	0	0

Table D.5. Bulletin 17B pertinent statistics at the Bighorn River at St. Xavier and Bighorn for the HEC-ResSim time series guide curve simulation.

	St. Xavier		*Bighorn*	
	Baseline	*Reallocated*	*Baseline*	*Reallocated*
Mean	3.89	3.89	3.95	3.96
Standard Deviation	0.25	0.25	0.28	0.28
Adopted Skew	-0.76	-0.74	-0.20	-0.20
Systematic Events	40	40	40	40
High Outliers	0	0	0	0

Table D.6. Bulletin 17B pertinent statistics at the Yellowstone River at Miles City and Sidney for the HEC-ResSim time series guide curve simulation.

	Miles City		*Sidney*	
	Baseline	*Reallocated*	*Baseline*	*Reallocated*
Mean	4.64	4.64	4.67	4.67
Standard Deviation	0.16	0.16	0.17	0.18
Adopted Skew	-0.16	-0.17	-0.30	-0.31
Systematic Events	40	40	40	40
High Outliers	0	0	0	0

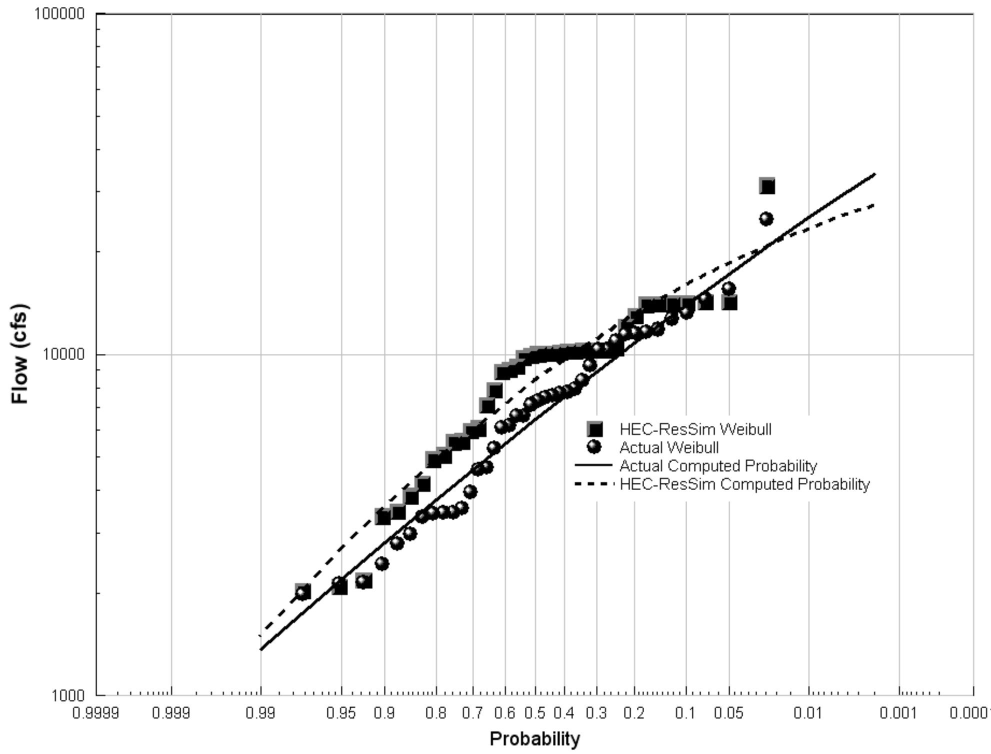

Figure D.1. St. Xavier flow frequency analysis for the HEC-ResSim standard guide curve simulation.

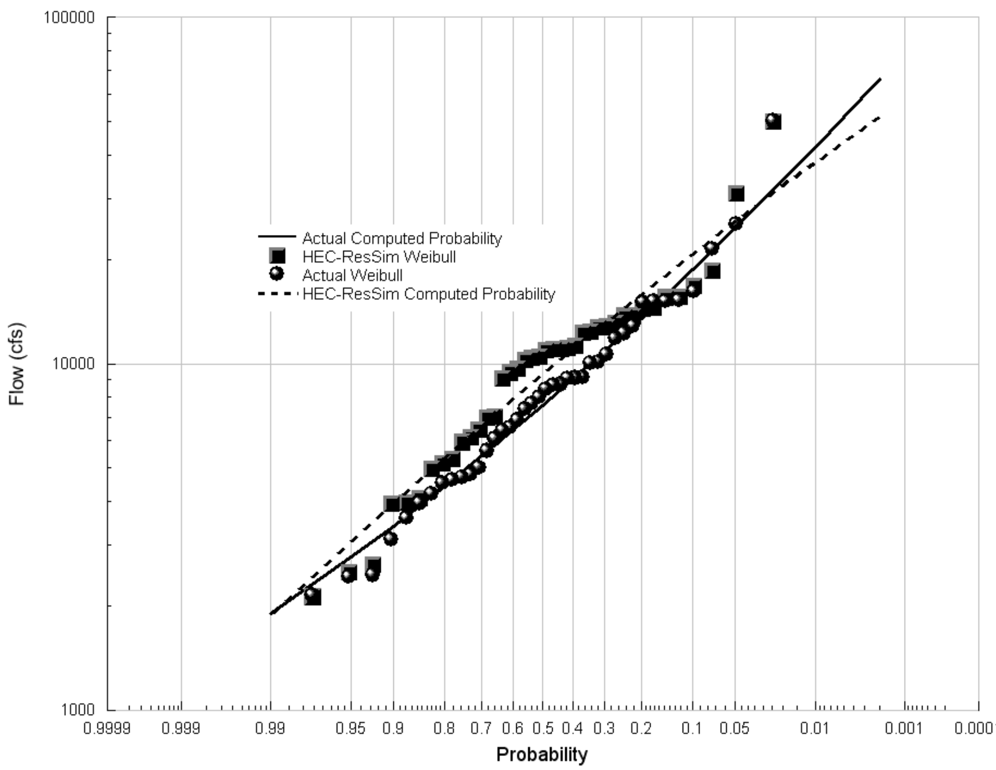

Figure D.2. Bighorn flow frequency analysis for the HEC-ResSim standard guide curve simulation.

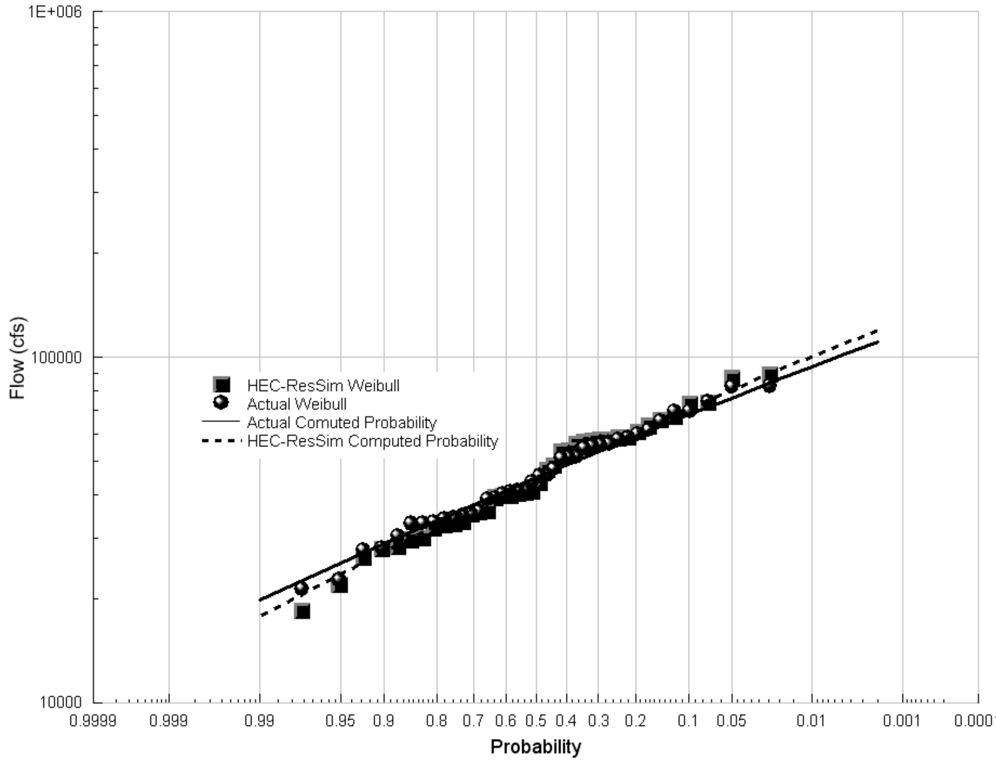

Figure D.3. Miles City flow frequency analysis for the HEC-ResSim standard guide curve simulation.

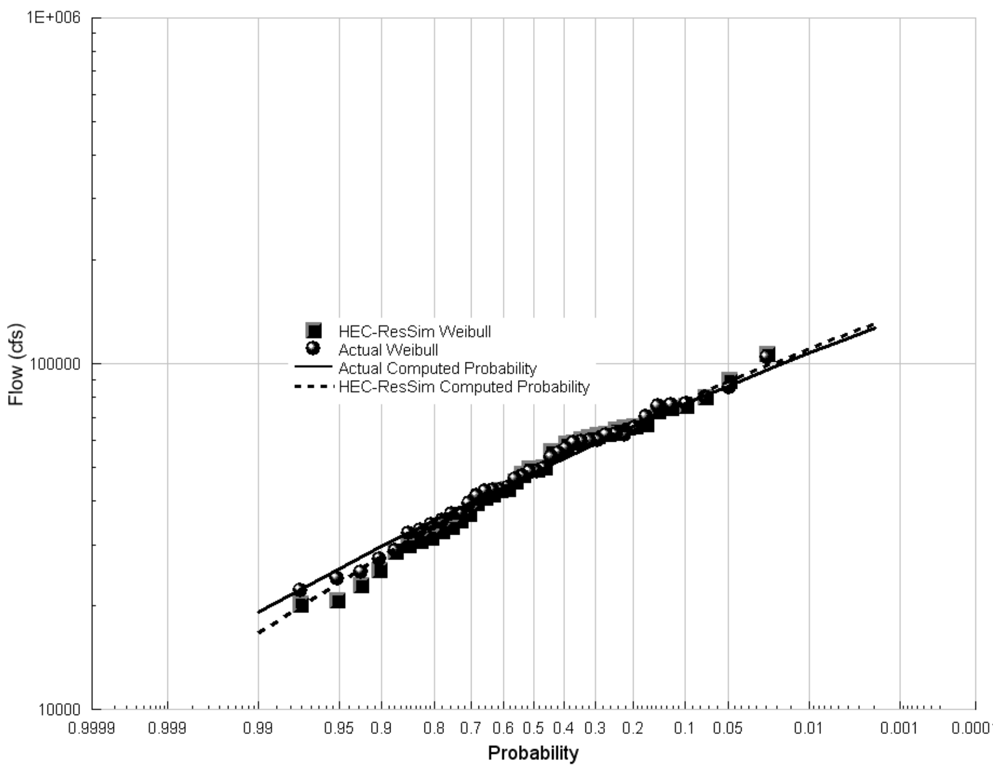

Figure D.4. Sidney flow frequency analysis for the HEC-ResSim standard guide curve simulation.

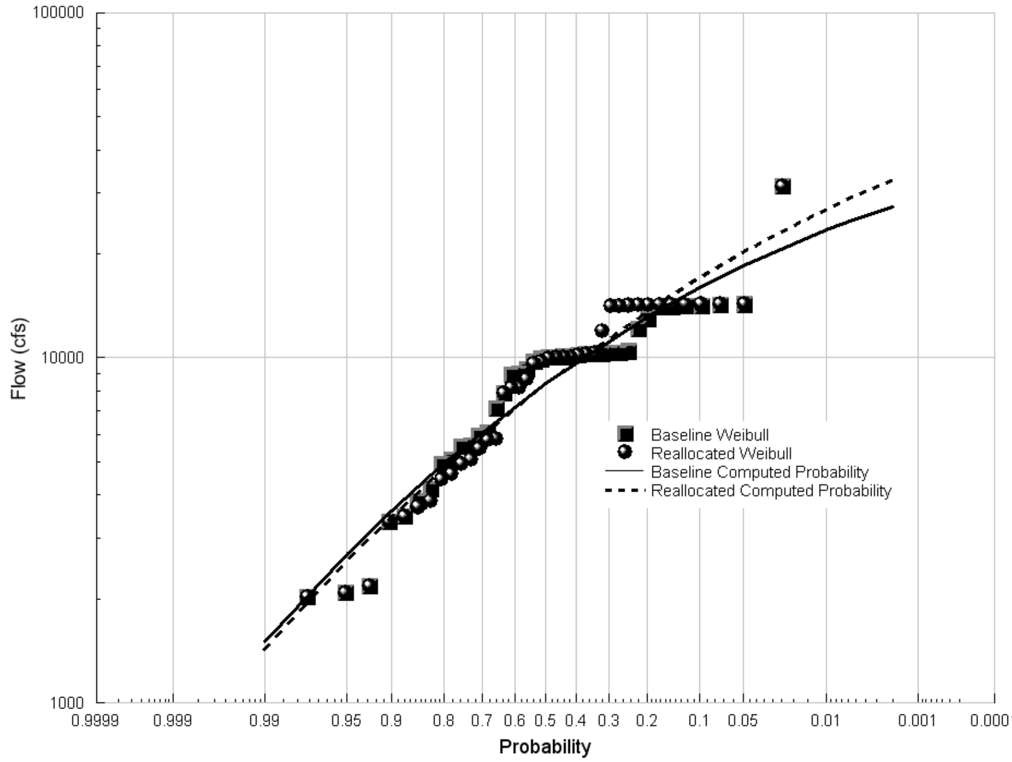

Figure D.5. St. Xavier flow frequency analysis for the HEC-ResSim reallocated standard guide curve simulation.

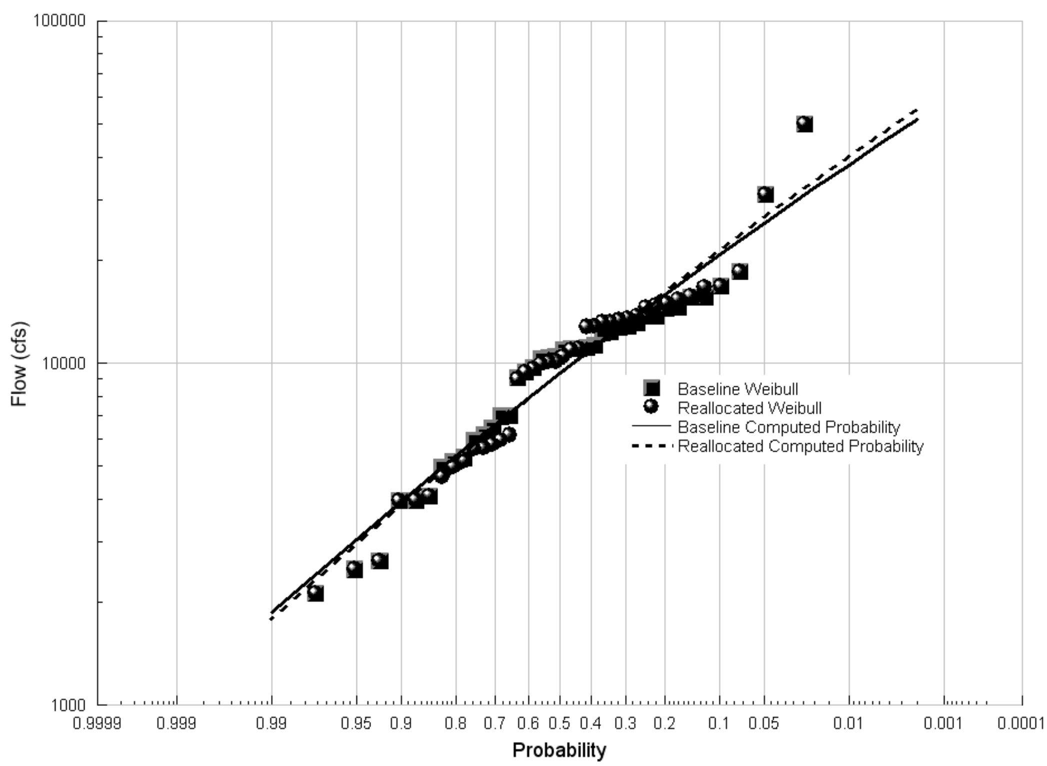

Figure D.6. Bighorn flow frequency analysis for the HEC-ResSim reallocated standard guide curve simulation.

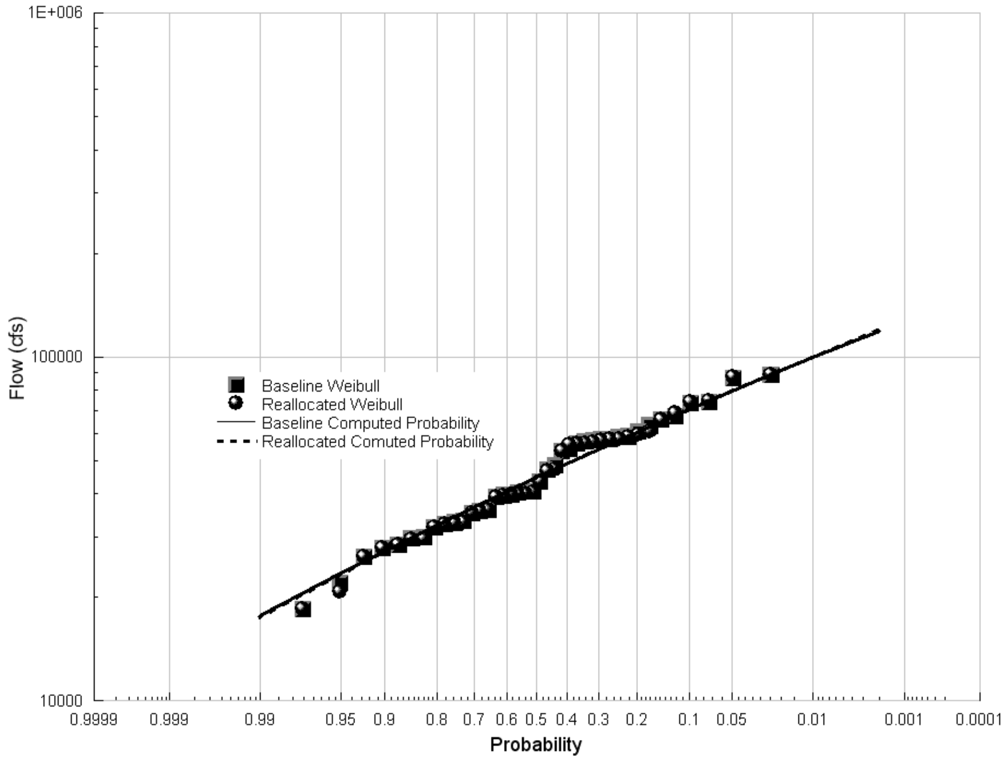

Figure D.7. Miles City flow frequency analysis for the HEC-ResSim reallocated standard guide curve simulation.

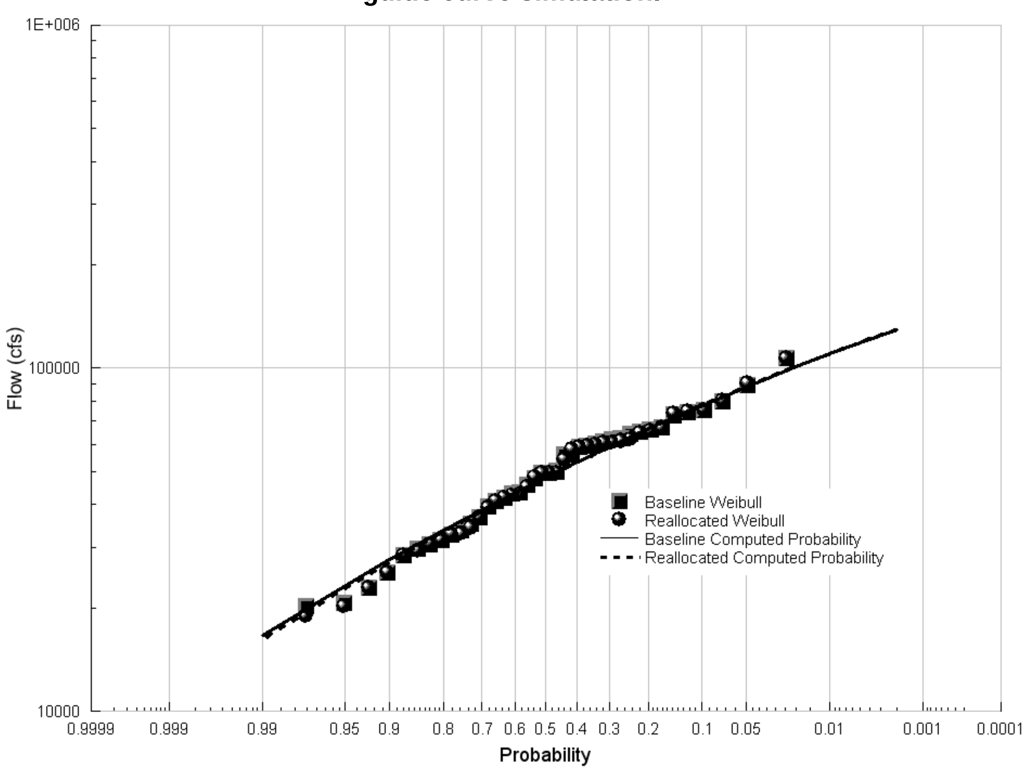

Figure D.8. Sidney flow frequency analysis for the HEC-ResSim reallocated standard guide curve simulation.

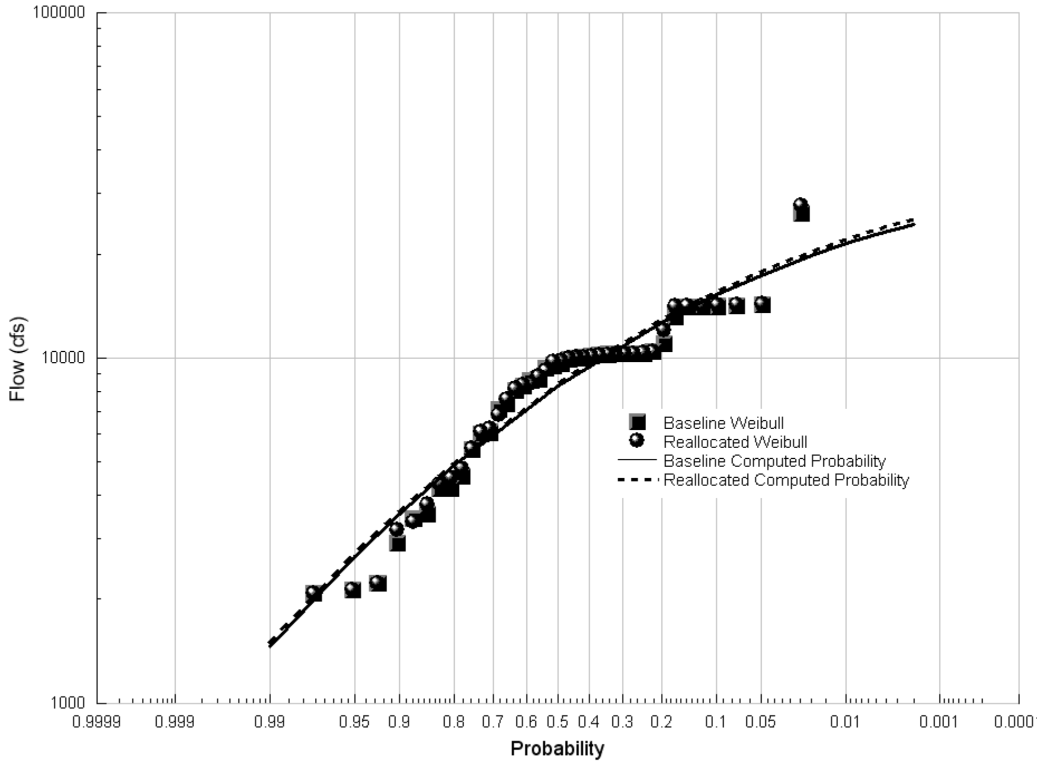

Figure D.9. St. Xavier flow frequency analysis for the HEC-ResSim time series guide curve simulation.

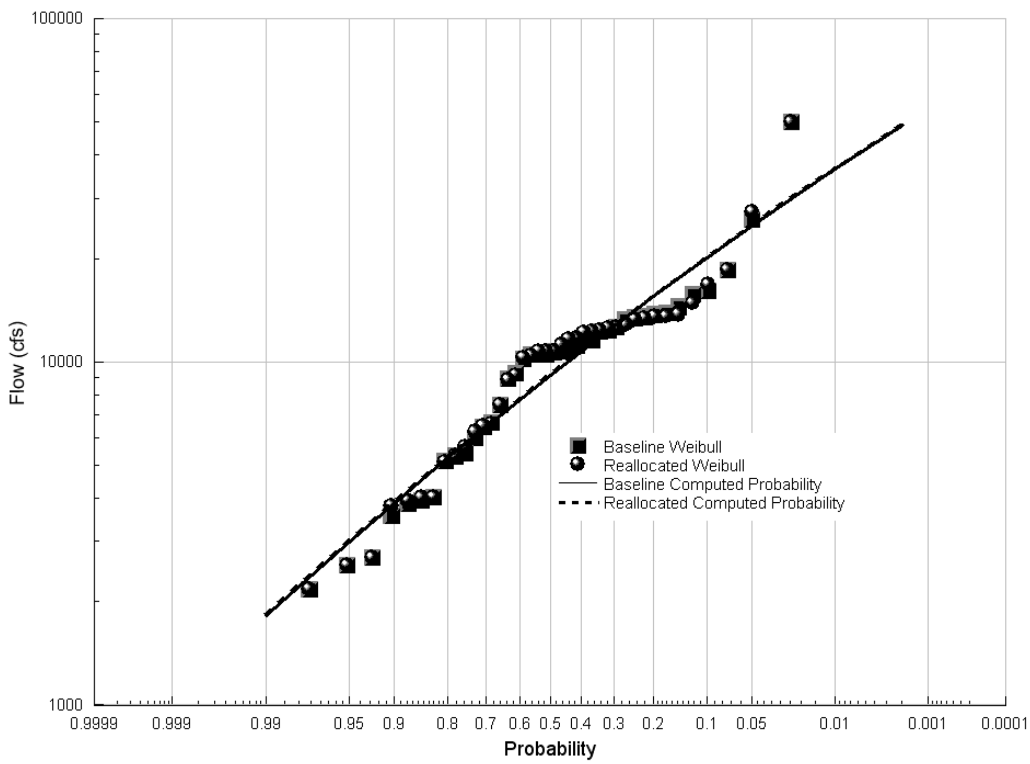

Figure D.10. Bighorn flow frequency analysis for the HEC-ResSim time series guide curve simulation.

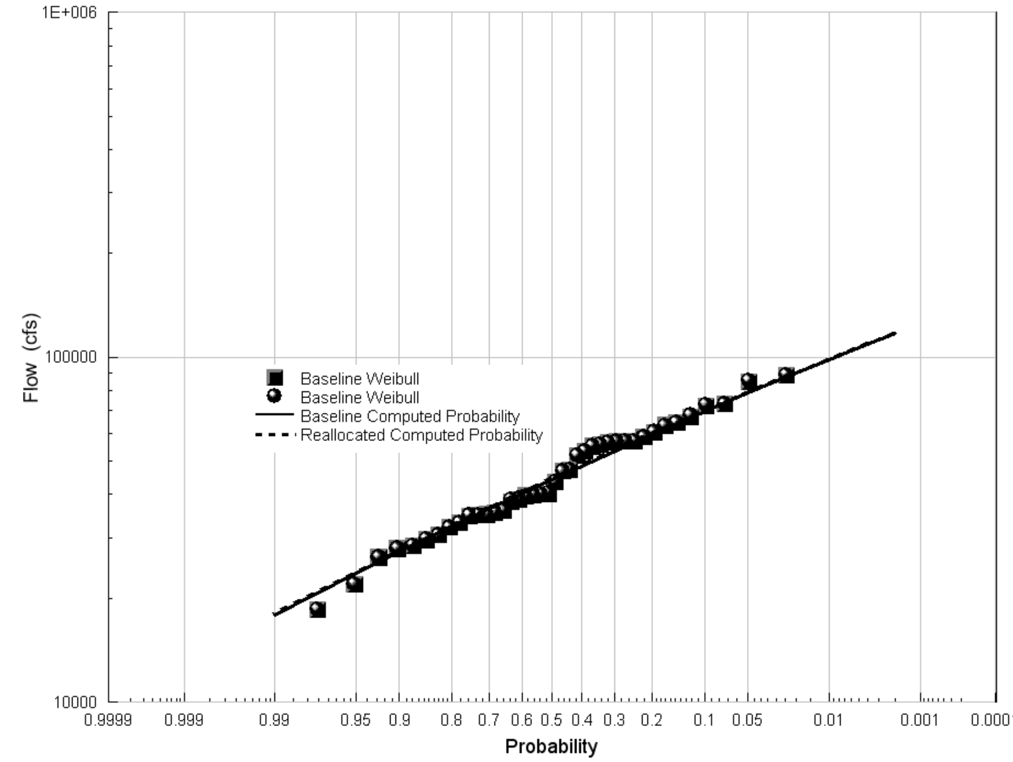

Figure D.11. Miles City flow frequency analysis for the HEC-ResSim time series guide curve simulation.

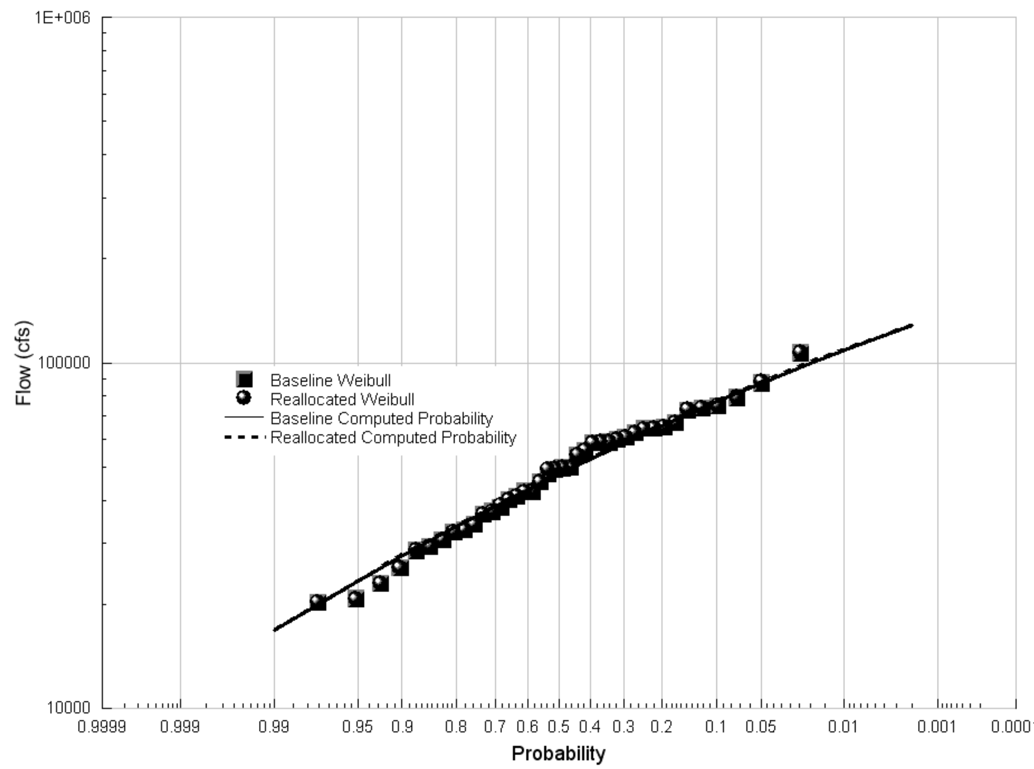

Figure D.12. Sidney flow frequency analysis for the HEC-ResSim time series guide curve simulation.

Appendix E – Elevation/outflow Tables

This section contains elevation/outflow tables for the inflow design flood, project design flood, and 1923 flood. For each flood event, there are tables comparing the flood control manual (USACE, 1974) to the calibrated HEC-ResSim baseline model. There are also tables comparing the baseline HEC-ResSim model to the reallocated HEC-ResSim model. Information was presented earlier graphically.

Table E.1. Elevation/outflow table comparing the flood control manual to the HEC-ResSim baseline condition for the inflow design flood.

Time (hr)	Discharge (cfs)		Elevation (ft msl)	Discharge (cfs)		Elevation (ft msl)
	Inflow	Outflow		Inflow	Outflow	
	Flood Control Manual			HEC-ResSim		
0	20,000	10,000	3,648.90	20,000	10,000	3,648.90
6	20,000	10,000	3,648.90	20,000	10,000	3,648.90
12	20,000	10,000	3,648.90	20,000	10,000	3,648.90
18	20,000	10,000	3,649.00	20,000	14,000	3,649.20
24	23,000	10,000	3,649.20	23,000	14,000	3,649.40
30	28,000	10,000	3,649.50	28,000	14,000	3,649.80
36	35,000	16,000	3,650.10	35,000	17,125	3,650.30
42	46,000	29,000	3,651.00	46,000	22,978	3,650.90
48	61,000	32,000	3,652.00	61,000	30,340	3,651.70
54	82,000	36,000	3,653.10	82,000	34,761	3,652.90
60	115,000	50,000	3,655.10	115,000	41,232	3,654.70
66	126,000	95,000	3,657.40	126,000	69,922	3,656.60
72	121,000	97,000	3,658.50	121,000	96,230	3,657.80
78	112,000	98,000	3,659.00	112,000	97,565	3,658.30
84	102,000	99,000	3,659.10	102,000	98,018	3,658.60
90	91,000	99,000	3,659.10	91,000	97,919	3,658.60
96	81,000	98,000	3,658.50	81,000	97,351	3,658.20
102	74,000	97,000	3,658.00	74,000	96,689	3,657.70
108	68,000	95,000	3,657.50	68,000	95,262	3,657.00
114	65,000	93,000	3,656.80	65,000	93,708	3,656.20
120	65,000	91,500	3,656.00	65,000	92,097	3,655.30
126	65,500	90,000	3,655.00	65,500	90,608	3,654.60
132	60,500	88,000	3,654.30	60,500	88,703	3,653.80
138	56,000	86,500	3,653.30	56,000	86,919	3,652.90
144	51,500	84,500	3,652.40	51,500	84,880	3,651.90
150	48,000	83,000	3,651.20	48,000	82,770	3,650.90
156	44,500	81,000	3,650.00	44,500	80,764	3,649.70
162	40,500	79,000	3,648.70	40,500	78,802	3,648.50
168	38,000	77,000	3,647.60	38,000	76,651	3,647.30
174	36,000	75,000	3,646.20	36,000	74,500	3,646.00
180	35,000	73,000	3,645.00	35,000	72,176	3,644.70
186	34,000	71,000	3,643.70	34,000	69,338	3,643.40
192	33,000	69,000	3,642.50	33,000	66,762	3,642.20
198	32,000	66,500	3,641.20	32,000	64,081	3,640.90
204	30,000	63,500	3,640.00	30,000	62,220	3,639.70

Table E.2. Elevation/outflow table comparing the HEC-ResSim baseline condition to the HEC-ResSim reallocated condition for the inflow design flood.

Time (hr)	Discharge (cfs)		Elevation (ft msl)	Discharge (cfs)		Elevation (ft msl)
	Inflow	Outflow		Inflow	Outflow	
	HEC-ResSim Baseline			HEC-ResSim Reallocated		
0	20,000	10,000	3,648.90	20,000	10,000	3,651.30
6	20,000	10,000	3,648.90	20,000	10,000	3,651.30
12	20,000	10,000	3,648.90	20,000	10,000	3,651.30
18	20,000	14,000	3,649.20	20,000	14,000	3,651.50
24	23,000	14,000	3,649.40	23,000	14,000	3,651.80
30	28,000	14,000	3,649.80	28,000	14,559	3,652.10
36	35,000	17,125	3,650.30	35,000	18,796	3,652.60
42	46,000	22,978	3,650.90	46,000	24,896	3,653.10
48	61,000	30,340	3,651.70	61,000	34,574	3,653.90
54	82,000	34,761	3,652.90	82,000	41,669	3,654.80
60	115,000	41,232	3,654.70	115,000	65,017	3,656.20
66	126,000	69,922	3,656.60	126,000	95,540	3,657.30
72	121,000	96,230	3,657.80	121,000	97,224	3,658.10
78	112,000	97,565	3,658.30	112,000	98,098	3,658.60
84	102,000	98,018	3,658.60	102,000	98,354	3,658.90
90	91,000	97,919	3,658.60	91,000	98,283	3,658.80
96	81,000	97,351	3,658.20	81,000	97,811	3,658.50
102	74,000	96,689	3,657.70	74,000	96,984	3,657.90
108	68,000	95,262	3,657.00	68,000	95,565	3,657.20
114	65,000	93,708	3,656.20	65,000	94,129	3,656.40
120	65,000	92,097	3,655.30	65,000	92,565	3,655.60
126	65,500	90,608	3,654.60	65,500	91,076	3,654.80
132	60,500	88,703	3,653.80	60,500	89,107	3,654.00
138	56,000	86,919	3,652.90	56,000	87,340	3,653.10
144	51,500	84,880	3,651.90	51,500	85,212	3,652.10
150	48,000	82,770	3,650.90	48,000	83,088	3,651.00
156	44,500	80,764	3,649.70	44,500	81,058	3,649.90
162	40,500	78,802	3,648.50	40,500	79,086	3,648.70
168	38,000	76,651	3,647.30	38,000	76,880	3,647.40
174	36,000	74,500	3,646.00	36,000	74,766	3,646.10
180	35,000	72,176	3,644.70	35,000	72,765	3,644.80
186	34,000	69,338	3,643.40	34,000	72,765	3,643.50
192	33,000	66,762	3,642.20	33,000	72,120	3,642.10
198	32,000	64,081	3,640.90	32,000	68,983	3,640.60
204	30,000	62,220	3,639.70	30,000	65,940	3,639.20

Table E.3. Elevation/outflow table comparing the flood control manual to the HEC-ResSim baseline condition for the project design flood.

Time (days)	Discharge (cfs)		Elevation (ft msl)	Discharge (cfs)		Elevation (ft msl)
	Inflow	Outflow		Inflow	Outflow	
	Flood Control Manual			HEC-ResSim		
0	9000	8000	3614.0	9,000	8,000	3,614.00
1	9000	8000	3614.0	9,000	8,000	3,614.00
2	9500	8000	3614.2	9,500	10,000	3,614.10
3	10000	8000	3614.6	10,000	10,000	3,614.00
4	10000	8000	3615.0	10,000	10,000	3,614.00
5	10200	8000	3615.5	10,200	10,000	3,614.00
6	11000	8000	3616.0	11,000	10,000	3,614.20
7	11500	8000	3616.5	11,500	10,000	3,614.60
8	11900	8000	3617.5	11,900	10,000	3,615.00
9	12100	8000	3618.5	12,100	10,000	3,615.60
10	14000	8000	3621.0	14,000	10,000	3,616.40
11	20000	8000	3622.0	20,000	10,000	3,618.30
12	22500	8000	3624.5	22,500	10,000	3,621.20
13	24200	10000	3628.0	24,200	10,000	3,624.50
14	25200	11000	3631.0	25,200	10,000	3,627.80
15	25800	12000	3634.0	25,800	10,000	3,631.00
16	26000	13000	3636.5	26,000	10,000	3,634.10
17	26100	14000	3639.0	26,100	10,000	3,636.90
18	37100	16000	3641.5	37,100	14,000	3,640.10
19	37100	20000	3644.5	37,100	19,212	3,643.20
20	27500	20000	3645.5	27,500	20,000	3,645.00
21	26500	20000	3646.5	26,500	20,000	3,646.00
22	26000	20000	3647.0	26,000	20,000	3,646.80
23	25500	20000	3647.5	25,500	20,000	3,647.60
24	25100	20000	3648.5	25,100	20,000	3,648.30
25	25000	20000	3649.0	25,000	20,000	3,648.90
26	25100	20000	3650.0	25,100	20,504	3,649.50
27	26000	20000	3650.5	26,000	20,504	3,650.20
28	27000	20000	3651.5	27,000	20,504	3,650.90
29	27500	20000	3652.3	27,500	20,504	3,651.70
30	27500	20000	3653.3	27,500	20,504	3,652.60
31	27000	20000	3654.0	27,000	20,504	3,653.40
32	26500	20000	3655.0	26,500	20,504	3,654.20
33	26000	21000	3655.5	26,000	20,504	3,654.80
34	24000	21000	3656.0	24,000	20,504	3,655.40
35	21000	21000	3656.2	21,000	20,504	3,655.60
36	20000	21000	3656.2	20,000	20,504	3,655.60
37	18000	21000	3656.0	18,000	20,504	3,655.40
38	16000	21000	3655.5	16,000	20,504	3,655.00
39	15000	21000	3654.9	15,000	20,504	3,654.40
40	14000	21000	3654.0	14,000	20,504	3,653.70
41	13500	21000	3653.0	13,500	20,504	3,652.90
42	13000	21000	3652.5	13,000	20,504	3,652.00

43	12900	21000	3651.5	12,900	20,504	3,651.10
44	12500	21000	3650.0	12,500	20,504	3,650.10
45	12300	21000	3648.5	12,300	20,000	3,649.10
46	12100	21000	3647.5	12,100	20,000	3,648.10
47	12000	21000	3646.4	12,000	20,000	3,647.10
48	11900	21000	3645.0	11,900	20,000	3,646.00
49	11500	21000	3643.9	11,500	20,000	3,644.80
50	11500	21000	3642.5	11,500	20,000	3,643.70
51	11500	21000	3641.0	11,500	20,000	3,642.40
52	11500	21000	3640.0	11,500	20,000	3,641.10
53	11200	21000	3638.0	11,200	20,000	3,639.80

Table E.4. Elevation/outflow table comparing the HEC-ResSim baseline condition to the HEC-ResSim reallocated condition for the project design flood.

Time (days)	Discharge (cfs)		Elevation (ft msl)	Discharge (cfs)		Elevation (ft msl)
	Inflow	Outflow		Inflow	Outflow	
	HEC-ResSim Baseline			HEC-ResSim Reallocated		
0	9,000	8,000	3,614.00	9,000	8,000	3,619.00
1	9,000	8,000	3,614.00	9,000	8,000	3,619.00
2	9,500	10,000	3,614.10	9,500	10,000	3,619.10
3	10,000	10,000	3,614.00	10,000	10,000	3,619.00
4	10,000	10,000	3,614.00	10,000	10,000	3,619.00
5	10,200	10,000	3,614.00	10,200	10,000	3,619.00
6	11,000	10,000	3,614.20	11,000	10,000	3,619.20
7	11,500	10,000	3,614.60	11,500	10,000	3,619.50
8	11,900	10,000	3,615.00	11,900	10,000	3,619.90
9	12,100	10,000	3,615.60	12,100	10,000	3,620.50
10	14,000	10,000	3,616.40	14,000	10,000	3,621.20
11	20,000	10,000	3,618.30	20,000	10,000	3,623.00
12	22,500	10,000	3,621.20	22,500	10,000	3,625.60
13	24,200	10,000	3,624.50	24,200	10,000	3,628.60
14	25,200	10,000	3,627.80	25,200	10,000	3,631.60
15	25,800	10,000	3,631.00	25,800	10,000	3,634.50
16	26,000	10,000	3,634.10	26,000	10,000	3,637.30
17	26,100	10,000	3,636.90	26,100	10,622	3,639.90
18	37,100	14,000	3,640.10	37,100	11,421	3,643.00
19	37,100	19,212	3,643.20	37,100	20,000	3,646.00
20	27,500	20,000	3,645.00	27,500	20,000	3,647.60
21	26,500	20,000	3,646.00	26,500	20,000	3,648.50
22	26,000	20,000	3,646.80	26,000	21,244	3,649.30
23	25,500	20,000	3,647.60	25,500	21,898	3,649.80
24	25,100	20,000	3,648.30	25,100	21,898	3,650.20
25	25,000	20,000	3,648.90	25,000	21,898	3,650.60
26	25,100	20,504	3,649.50	25,100	21,898	3,651.00
27	26,000	20,504	3,650.20	26,000	21,898	3,651.50
28	27,000	20,504	3,650.90	27,000	21,898	3,652.00
29	27,500	20,504	3,651.70	27,500	21,898	3,652.70

30	27,500	20,504	3,652.60	27,500	21,898	3,653.40
31	27,000	20,504	3,653.40	27,000	21,898	3,654.00
32	26,500	20,504	3,654.20	26,500	21,898	3,654.60
33	26,000	20,504	3,654.80	26,000	21,898	3,655.10
34	24,000	20,504	3,655.40	24,000	21,898	3,655.50
35	21,000	20,504	3,655.60	21,000	21,898	3,655.50
36	20,000	20,504	3,655.60	20,000	21,898	3,655.40
37	18,000	20,504	3,655.40	18,000	21,898	3,655.00
38	16,000	20,504	3,655.00	16,000	21,898	3,654.40
39	15,000	20,504	3,654.40	15,000	21,898	3,653.70
40	14,000	20,504	3,653.70	14,000	21,898	3,652.80
41	13,500	20,504	3,652.90	13,500	21,898	3,651.80
42	13,000	20,504	3,652.00	13,000	21,898	3,650.70
43	12,900	20,504	3,651.10	12,900	21,482	3,649.60
44	12,500	20,504	3,650.10	12,500	20,000	3,648.60
45	12,300	20,000	3,649.10	12,300	20,000	3,647.60
46	12,100	20,000	3,648.10	12,100	20,000	3,646.60
47	12,000	20,000	3,647.10	12,000	20,000	3,645.50
48	11,900	20,000	3,646.00	11,900	20,000	3,644.40
49	11,500	20,000	3,644.80	11,500	20,000	3,643.20
50	11,500	20,000	3,643.70	11,500	20,000	3,642.00
51	11,500	20,000	3,642.40	11,500	20,000	3,640.70
52	11,500	20,000	3,641.10	11,500	20,000	3,639.30
53	11,200	20,000	3,639.80	11,200	10,000	3,638.70

Table E.5. Elevation/outflow table comparing the flood control manual to the HEC-ResSim baseline condition for the 1923 flood.

Time (days)	Discharge (cfs)		Elevation (ft msl)	Discharge (cfs)		Elevation (ft msl)
	Inflow	Outflow		Inflow	Outflow	
	Flood Control Manual			HEC-ResSim		
9/27/1923 0:00	5200	4900	3640.0	5200	4,900	3,640.00
9/27/1923 6:00	5100	4900	3640.0	5100	4,900	3,640.00
9/27/1923 12:00	4900	4900	3640.0	4900	4,900	3,640.00
9/27/1923 18:00	4900	4900	3640.0	4900	4,900	3,640.00
9/28/1923 0:00	4900	4800	3640.0	4900	4,900	3,640.00
9/28/1923 6:00	4900	4800	3640.0	4900	3,688	3,640.00
9/28/1923 12:00	4900	4800	3640.0	4900	3,688	3,640.10
9/28/1923 18:00	5000	4800	3640.0	5000	3,688	3,640.10
9/29/1923 0:00	5000	4800	3640.0	5000	3,688	3,640.20
9/29/1923 6:00	17100	4800	3640.5	17100	10,000	3,640.30
9/29/1923 12:00	28700	4800	3641.2	28700	10,000	3,640.80
9/29/1923 18:00	31000	4800	3642.5	31000	10,000	3,641.60
9/30/1923 0:00	32000	15000	3643.8	32000	10,000	3,642.40
9/30/1923 6:00	33500	15000	3644.7	33500	16,420	3,643.10
9/30/1923 12:00	35000	15000	3645.6	35000	16,420	3,643.70
9/30/1923 18:00	38750	15000	3646.3	38750	16,420	3,644.50
10/1/1923 0:00	42500	20000	3647.0	42500	16,420	3,645.30

10/1/1923 6:00	43200	20000	3647.6	43200	20,000	3,646.10
10/1/1923 12:00	42500	20000	3648.2	42500	20,000	3,646.90
10/1/1923 18:00	37750	20000	3648.8	37750	20,000	3,647.60
10/2/1923 0:00	33000	20000	3649.3	33000	20,000	3,648.10
10/2/1923 6:00	28750	20000	3649.6	28750	20,000	3,648.40
10/2/1923 12:00	24500	20000	3649.9	24500	20,000	3,648.60
10/2/1923 18:00	22000	20000	3649.9	22000	20,000	3,648.70
10/3/1923 0:00	19500	20000	3649.8	19500	20,000	3,648.80
10/3/1923 6:00	17250	20000	3649.7	17250	20,000	3,648.70
10/3/1923 12:00	15000	20000	3649.6	15000	20,000	3,648.60
10/3/1923 18:00	13850	20000	3649.4	13850	20,000	3,648.40
10/4/1923 0:00	12700	20000	3649.2	12700	20,000	3,648.20
10/4/1923 6:00	12250	20000	3649.0	12250	20,000	3,647.90
10/4/1923 12:00	11800	20000	3648.7	11800	20,000	3,647.70
10/4/1923 18:00	11400	20000	3648.4	11400	20,000	3,647.40
10/5/1923 0:00	11000	20000	3648.1	11000	20,000	3,647.10
10/5/1923 6:00	10750	20000	3647.8	10750	20,000	3,646.80
10/5/1923 12:00	10500	20000	3647.5	10500	20,000	3,646.50
10/5/1923 18:00	10325	20000	3647.3	10325	20,000	3,646.20
10/6/1923 0:00	10100	20000	3647.0	10100	20,000	3,645.90
10/6/1923 6:00	10000	20000	3646.7	10000	20,000	3,645.50
10/6/1923 12:00	9900	20000	3646.3	9900	20,000	3,645.20
10/6/1923 18:00	9800	20000	3646.0	9800	20,000	3,644.80
10/7/1923 0:00	9700	20000	3645.6	9700	20,000	3,644.50
10/7/1923 6:00	9600	20000	3645.3	9600	20,000	3,644.10
10/7/1923 12:00	9500	20000	3644.9	9500	20,000	3,643.70
10/7/1923 18:00	9325	20000	3644.5	9325	20,000	3,643.40
10/8/1923 0:00	9150	20000	3644.0	9150	20,000	3,643.00
10/8/1923 6:00	9075	20000	3643.6	9075	20,000	3,642.60
10/8/1923 12:00	9000	20000	3643.2	9000	20,000	3,642.20
10/8/1923 18:00	8900	20000	3642.9	8900	20,000	3,641.70
10/9/1923 0:00	8800	20000	3642.5	8800	20,000	3,641.30
10/9/1923 6:00	8850	20000	3642.2	8850	20,000	3,640.90
10/9/1923 12:00	8700	20000	3641.8	8700	20,000	3,640.50
10/9/1923 18:00	8750	20000	3641.4	8750	20,000	3,640.00

Table E.6. Elevation/outflow table comparing the HEC-ResSim baseline condition to the HEC-ResSim reallocated condition for the 1923 flood.

Time (days)	Discharge (cfs)		Elevation (ft msl)	Discharge (cfs)		Elevation (ft msl)
	Inflow	Outflow		Inflow	Outflow	
	HEC-ResSim Baseline			HEC-ResSim Reallocated		
9/27/1923 0:00	5200	4,900	3,640.00	5200	4,900	3,645.00
9/27/1923 6:00	5100	4,900	3,640.00	5100	4,900	3,645.00
9/27/1923 12:00	4900	4,900	3,640.00	4900	4,900	3,645.00
9/27/1923 18:00	4900	4,900	3,640.00	4900	4,900	3,645.00
9/28/1923 0:00	4900	4,900	3,640.00	4900	3,688	3,645.00
9/28/1923 6:00	4900	3,688	3,640.00	4900	3,688	3,645.10

9/28/1923 12:00	4900	3,688	3,640.10	4900	3,688	3,645.10
9/28/1923 18:00	5000	3,688	3,640.10	5000	3,688	3,645.20
9/29/1923 0:00	5000	3,688	3,640.20	5000	14,000	3,645.20
9/29/1923 6:00	17100	10,000	3,640.30	17100	14,000	3,645.50
9/29/1923 12:00	28700	10,000	3,640.80	28700	14,000	3,646.10
9/29/1923 18:00	31000	10,000	3,641.60	31000	14,000	3,646.70
9/30/1923 0:00	32000	10,000	3,642.40	32000	18,392	3,647.20
9/30/1923 6:00	33500	16,420	3,643.10	33500	18,392	3,647.70
9/30/1923 12:00	35000	16,420	3,643.70	35000	18,392	3,648.30
9/30/1923 18:00	38750	16,420	3,644.50	38750	18,392	3,649.00
10/1/1923 0:00	42500	16,420	3,645.30	42500	22,996	3,649.80
10/1/1923 6:00	43200	20,000	3,646.10	43200	22,996	3,650.40
10/1/1923 12:00	42500	20,000	3,646.90	42500	22,996	3,650.90
10/1/1923 18:00	37750	20,000	3,647.60	37750	22,996	3,651.30
10/2/1923 0:00	33000	20,000	3,648.10	33000	28,823	3,651.50
10/2/1923 6:00	28750	20,000	3,648.40	28750	28,823	3,651.40
10/2/1923 12:00	24500	20,000	3,648.60	24500	28,373	3,651.20
10/2/1923 18:00	22000	20,000	3,648.70	22000	27,551	3,651.00
10/3/1923 0:00	19500	20,000	3,648.80	19500	26,559	3,650.70
10/3/1923 6:00	17250	20,000	3,648.70	17250	25,414	3,650.40
10/3/1923 12:00	15000	20,000	3,648.60	15000	24,262	3,650.10
10/3/1923 18:00	13850	20,000	3,648.40	13850	23,035	3,649.80
10/4/1923 0:00	12700	20,000	3,648.20	12700	21,885	3,649.40
10/4/1923 6:00	12250	20,000	3,647.90	12250	20,759	3,649.10
10/4/1923 12:00	11800	20,000	3,647.70	11800	20,000	3,648.90
10/4/1923 18:00	11400	20,000	3,647.40	11400	20,000	3,648.60
10/5/1923 0:00	11000	20,000	3,647.10	11000	20,000	3,648.30
10/5/1923 6:00	10750	20,000	3,646.80	10750	20,000	3,648.00
10/5/1923 12:00	10500	20,000	3,646.50	10500	20,000	3,647.70
10/5/1923 18:00	10325	20,000	3,646.20	10325	20,000	3,647.30
10/6/1923 0:00	10100	20,000	3,645.90	10100	20,000	3,647.00
10/6/1923 6:00	10000	20,000	3,645.50	10000	20,000	3,646.70
10/6/1923 12:00	9900	20,000	3,645.20	9900	20,000	3,646.30
10/6/1923 18:00	9800	20,000	3,644.80	9800	20,000	3,646.00
10/7/1923 0:00	9700	20,000	3,644.50	9700	20,000	3,645.60
10/7/1923 6:00	9600	20,000	3,644.10	9600	20,000	3,645.30
10/7/1923 12:00	9500	20,000	3,643.70	9500	20,000	3,644.90
10/7/1923 18:00	9325	20,000	3,643.40	9325	20,000	3,644.60
10/8/1923 0:00	9150	20,000	3,643.00	9150	20,000	3,644.20
10/8/1923 6:00	9075	20,000	3,642.60	9075	20,000	3,643.80
10/8/1923 12:00	9000	20,000	3,642.20	9000	20,000	3,643.40
10/8/1923 18:00	8900	20,000	3,641.70	8900	20,000	3,643.00
10/9/1923 0:00	8800	20,000	3,641.30	8800	20,000	3,642.60
10/9/1923 6:00	8850	20,000	3,640.90	8850	20,000	3,642.20
10/9/1923 12:00	8700	20,000	3,640.50	8700	20,000	3,641.70
10/9/1923 18:00	8750	20,000	3,640.00	8750	20,000	3,641.30

Appendix F – Additional Tables

This appendix contains several additional tables pertaining to the Yellowtail Dam reallocation study. All of the information can be found in previous sections of the report in graphical form, but the tabular data was provided for anyone interested.

Table F.1. Elevation vs. area and elevation vs. capacity tables used in the Yellowtail Dam HEC-ResSim model. Data is from the 1982 re-survey of the reservoir (USBR, 2000).

Elevation	Area (ac)	Capacity (ac-ft)	Elevation	Area (ac)	Capacity (ac-ft)	Elevation	Area (ac)	Capacity (ac-ft)
3211.20	0	0	3566.00	576008	4602	3599.00	739092	5468
3220.00	224	51	3567.00	580553	4623	3599.50	741832	5490
3240.00	2064	133	3568.00	585121	4645	3600.00	744582	5511
3260.00	5474	208	3569.00	589712	4666	3600.50	747345	5541
3280.00	10464	291	3570.00	594324	4688	3601.00	750123	5572
3300.00	17374	400	3571.00	598959	4709	3601.50	752917	5602
3320.00	26684	531	3572.00	603616	4731	3602.00	755725	5632
3340.00	38784	679	3573.00	608295	4753	3602.50	758549	5662
3360.00	54074	850	3574.00	612996	4774	3603.00	761388	5693
3380.00	73024	1045	3575.00	617719	4796	3603.50	764242	5723
3400.00	96974	1350	3576.00	622467	4817	3604.00	767111	5753
3420.00	127144	1667	3577.00	627243	4839	3604.50	769995	5794
3440.00	164134	2032	3578.00	632046	4860	3605.00	772894	5834
3460.00	207964	2351	3579.00	636878	4882	3605.50	775814	5875
3480.00	259424	2795	3580.00	641737	4903	3606.00	778759	5915
3500.00	319814	3244	3581.00	646619	4925	3606.50	781729	5965
3520.00	388564	3631	3582.00	651519	4946	3607.00	784724	6016
3540.00	465034	4016	3583.00	656437	4968	3607.50	787744	6066
3545.00	485332	4103	3584.00	661373	4989	3608.00	790789	6116
3547.00	493584	4192	3585.00	666327	5011	3608.50	793860	6166
3548.00	497744	4214	3586.00	671305	5033	3609.00	796955	6217
3549.00	501928	4236	3587.00	676315	5054	3609.50	800076	6267
3550.00	506134	4257	3588.00	681355	5076	3610.00	803222	6317
3551.00	510362	4279	3589.00	686427	5097	3610.50	806399	6392
3552.00	514608	4300	3590.00	691529	5118	3611.00	809614	6467
3553.00	518874	4322	3591.00	696665	5154	3611.50	812866	6541
3554.00	523158	4343	3592.00	701837	5189	3612.00	816155	6616
3555.00	527462	4365	3593.00	707044	5225	3612.50	819482	6691
3556.00	531783	4386	3594.00	712286	5260	3613.00	822846	6766
3557.00	536119	4408	3594.50	714921	5280	3613.50	826248	6840
3558.00	540472	4430	3595.00	717564	5300	3614.00	829687	6915
3559.00	544840	4451	3595.50	720218	5319	3614.50	833163	6984
3560.00	549224	4473	3596.00	722882	5339	3615.00	836677	7054
3561.00	553628	4494	3596.50	725557	5361	3615.50	840225	7123
3562.00	558056	4516	3597.00	728242	5382	3616.00	843805	7192
3563.00	562508	4537	3597.50	730939	5404	3616.50	847417	7255
3564.00	566984	4559	3598.00	733646	5425	3617.00	851060	7319
3565.00	571484	4580	3598.50	736364	5447	3617.50	854736	7382

Elevation	Area (ac)	Capacity (ac-ft)	Elevation	Area (ac)	Capacity (ac-ft)
3618.00	858442	7445	3639.50	1063770	12438
3618.50	862181	7509	3640.00	1070029	12598
3619.00	865951	7572	3640.50	1076373	12778
3619.50	869753	7636	3641.00	1082807	12958
3620.00	873587	7699	3641.50	1089331	13137
3620.50	877457	7784	3642.00	1095945	13317
3621.00	881369	7869	3642.50	1102648	13497
3621.50	885323	7953	3643.00	1109442	13677
3622.00	889318	8038	3643.50	1116325	13856
3622.50	893355	8137	3644.00	1123298	14036
3623.00	897434	8236	3644.50	1130361	14193
3623.50	901554	8334	3645.00	1137514	14349
3624.00	905716	8433	3645.50	1144746	14506
3624.50	909919	8532	3646.00	1152044	14662
3625.00	914164	8631	3646.50	1159408	14795
3625.50	918457	8729	3647.00	1166839	14929
3626.00	922804	8828	3647.50	1174337	15062
3626.50	927205	8927	3648.00	1181901	15195
3627.00	931660	9025	3648.50	1189532	15328
3627.50	936169	9124	3649.00	1197230	15462
3628.00	940731	9222	3649.50	1204994	15595
3628.50	945348	9321	3650.00	1212824	15728
3629.00	950019	9420	3650.50	1220716	15840
3629.50	954743	9518	3651.00	1228663	15951
3630.00	959522	9617	3651.50	1236666	16063
3630.50	964362	9754	3652.00	1244725	16174
3631.00	969271	9891	3652.50	1252839	16286
3631.50	974250	10028	3653.00	1261008	16397
3632.00	979298	10165	3653.50	1269233	16509
3632.50	984416	10304	3654.00	1277514	16620
3633.00	989602	10422	3654.50	1285850	16732
3633.50	994858	10581	3655.00	1294242	16843
3634.00	1000183	10720	3655.50	1302689	16955
3634.50	1005578	10869	3656.00	1311191	17066
3635.00	1011042	11019	3656.50	1319748	17178
3635.50	1016580	11168	3657.00	1328360	17289
3636.00	1022199	11317	3657.50	1337028	17401
3636.50	1027898	11477	3658.00	1345750	17512
3637.00	1033676	11638	3658.50	1354527	17624
3637.50	1039535	11798	3659.00	1363359	17735
3638.00	1045474	11958	3659.50	1372247	17847
3638.50	1051493	12118	3660.00	1381189	17958
3639.00	1057591	12278			

Table F.2. Discharge vs. damage table for Reach 1 (developed by Omaha District USACE). Reach 1 represents the Yellowstone River from Bighorn to Miles City and is evaluated by obtaining the annual peak flows at Miles City.

Flow (cfs)	Damage ($1000)
55000	0
56000	36.2
70000	543.1
90000	1735.3
130000	10335.3
150000	13332

Table F.3. Discharge vs. damage table for Reach 2 (developed by Omaha District USACE). Reach 2 represents the Yellowstone River from Miles City to Glendive, MT and is evaluated by obtaining the annual peak flows at Miles City.

55000	0
56000	6.2
70000	93.4
90000	299.1
130000	1523.6
162800	3965.3

Table F.3. Discharge vs. damage table for Reach 3 (developed by Omaha District USACE). Reach 3 represents the Yellowstone River from Glendive to Sidney and is evaluated by obtaining the annual peak flows at Sidney.

Flow (cfs)	Damage ($1000)
66000	0
67000	6
90000	144.5
108000	479.4
120000	1168.5
140000	2796.8
162000	3449.1

Table F.4. Discharge vs. damage table for Reach 5 (developed by Omaha District USACE). Reach 5 represents the Bighorn River from Yellowtail Dam to Hardin and is evaluated by obtaining the annual peak flows at Hardin.

Flow (cfs)	Damage ($1000)
10000	0
20000	0
21000	3.4
30000	33.6
40000	492.9
50000	2304.3
56500	2840.1

Table F.5. Discharge vs. damage table for Reach 6 (developed by Omaha District USACE). Reach 6 represents the Bighorn River from Hardin to Bighorn and is evaluated by obtaining the annual peak flows at Hardin.

Flow (cfs)	Damage ($1000)
10000	0
20000	0
21000	17.6
30000	176.4
40000	463
50000	1175.6
57500	1805

Table F.6. Baseline and reallocated time series guide curves (in tabular form) for the upper quartile spring runoff condition (developed by BOR).

Baseline		Reallocated	
Date	Elevation (ft msl)	Date	Elevation (ft msl)
1/1/2009	3624.0	1/1/2009	3633.5
3/31/2009	3617.9	3/31/2009	3622.9
4/1/2009	3618.0	4/1/2009	3623.0
4/2/2009	3618.1	4/2/2009	3623.0
4/3/2009	3618.0	4/3/2009	3623.0
4/4/2009	3618.0	4/4/2009	3623.0
4/5/2009	3617.9	4/5/2009	3622.9
4/6/2009	3617.8	4/6/2009	3622.8
4/7/2009	3617.6	4/7/2009	3622.7
4/8/2009	3617.5	4/8/2009	3622.6
4/9/2009	3617.4	4/9/2009	3622.5
4/10/2009	3617.3	4/10/2009	3622.4
4/11/2009	3617.2	4/11/2009	3622.3
4/12/2009	3617.1	4/12/2009	3622.2
4/13/2009	3617.0	4/13/2009	3622.1
4/14/2009	3616.9	4/14/2009	3622.0
4/15/2009	3616.8	4/15/2009	3621.9
4/16/2009	3616.7	4/16/2009	3621.8
4/17/2009	3616.5	4/17/2009	3621.6
4/18/2009	3616.3	4/18/2009	3621.5
4/19/2009	3616.2	4/19/2009	3621.3
4/20/2009	3616.0	4/20/2009	3621.2
4/21/2009	3615.9	4/21/2009	3621.0
4/22/2009	3615.7	4/22/2009	3620.9
4/23/2009	3615.5	4/23/2009	3620.7
4/24/2009	3615.4	4/24/2009	3620.6
4/25/2009	3615.2	4/25/2009	3620.5
4/26/2009	3615.0	4/26/2009	3620.3
4/27/2009	3614.9	4/27/2009	3620.2
4/28/2009	3614.6	4/28/2009	3619.9
4/29/2009	3614.4	4/29/2009	3619.7

4/30/2009	3614.0	4/30/2009	3619.4
5/1/2009	3613.7	5/1/2009	3619.1
5/2/2009	3613.4	5/2/2009	3618.8
5/3/2009	3613.0	5/3/2009	3618.5
5/4/2009	3612.8	5/4/2009	3618.3
5/5/2009	3612.6	5/5/2009	3618.0
5/6/2009	3612.4	5/6/2009	3617.9
5/7/2009	3612.2	5/7/2009	3617.7
5/8/2009	3612.1	5/8/2009	3617.7
5/9/2009	3612.0	5/9/2009	3617.6
5/10/2009	3611.9	5/10/2009	3617.5
5/11/2009	3611.8	5/11/2009	3617.3
5/12/2009	3611.5	5/12/2009	3617.1
5/13/2009	3611.4	5/13/2009	3617.0
5/14/2009	3611.2	5/14/2009	3616.9
5/15/2009	3611.1	5/15/2009	3616.7
5/16/2009	3610.9	5/16/2009	3616.6
5/17/2009	3610.8	5/17/2009	3616.5
5/18/2009	3610.8	5/18/2009	3616.5
5/19/2009	3610.6	5/19/2009	3616.3
5/20/2009	3610.5	5/20/2009	3616.2
5/21/2009	3610.4	5/21/2009	3616.2
5/22/2009	3610.4	5/22/2009	3616.1
5/23/2009	3610.4	5/23/2009	3616.1
5/24/2009	3610.5	5/24/2009	3616.2
5/25/2009	3610.6	5/25/2009	3616.3
5/26/2009	3610.7	5/26/2009	3616.4
5/27/2009	3610.9	5/27/2009	3616.6
5/28/2009	3611.1	5/28/2009	3616.8
5/29/2009	3611.4	5/29/2009	3617.0
5/30/2009	3611.7	5/30/2009	3617.3
5/31/2009	3612.0	5/31/2009	3617.6
6/1/2009	3612.4	6/1/2009	3617.9
6/2/2009	3612.7	6/2/2009	3618.2
6/3/2009	3613.2	6/3/2009	3618.6
6/4/2009	3613.8	6/4/2009	3619.2
6/5/2009	3614.5	6/5/2009	3619.8
6/6/2009	3615.2	6/6/2009	3620.5
6/7/2009	3616.1	6/7/2009	3621.2
6/8/2009	3617.0	6/8/2009	3622.1
6/9/2009	3618.0	6/9/2009	3623.0
6/10/2009	3619.0	6/10/2009	3623.9
6/11/2009	3620.0	6/11/2009	3624.8
6/12/2009	3621.1	6/12/2009	3625.8
6/13/2009	3622.2	6/13/2009	3626.8
6/14/2009	3623.3	6/14/2009	3627.8
6/15/2009	3624.5	6/15/2009	3628.9
6/16/2009	3625.7	6/16/2009	3629.9

6/17/2009	3626.9	6/17/2009	3631.0
6/18/2009	3628.1	6/18/2009	3632.1
6/19/2009	3629.4	6/19/2009	3633.3
6/20/2009	3630.7	6/20/2009	3634.5
6/21/2009	3631.9	6/21/2009	3635.6
6/22/2009	3633.1	6/22/2009	3636.7
6/23/2009	3634.2	6/23/2009	3637.6
6/24/2009	3635.1	6/24/2009	3638.5
6/25/2009	3636.0	6/25/2009	3639.3
6/26/2009	3636.8	6/26/2009	3640.0
6/27/2009	3637.5	6/27/2009	3640.6
6/28/2009	3638.1	6/28/2009	3641.3
6/29/2009	3638.6	6/29/2009	3641.7
6/30/2009	3639.0	6/30/2009	3642.1
7/1/2009	3639.4	7/1/2009	3642.4
7/2/2009	3639.7	7/2/2009	3642.7
7/3/2009	3640.0	7/3/2009	3642.9
7/4/2009	3640.2	7/4/2009	3643.1
7/5/2009	3640.4	7/5/2009	3643.3
7/6/2009	3640.5	7/6/2009	3643.4
7/7/2009	3640.6	7/7/2009	3643.5
7/8/2009	3640.7	7/8/2009	3643.6
7/9/2009	3640.8	7/9/2009	3643.7
7/10/2009	3640.8	7/10/2009	3643.7
7/11/2009	3640.8	7/11/2009	3643.7
7/12/2009	3640.8	7/12/2009	3643.7
7/13/2009	3640.9	7/13/2009	3643.8
7/14/2009	3641.0	7/14/2009	3643.9
7/15/2009	3641.0	7/15/2009	3643.9
7/16/2009	3641.0	7/16/2009	3643.9
7/17/2009	3641.0	7/17/2009	3643.9
7/18/2009	3640.9	7/18/2009	3643.8
7/19/2009	3640.8	7/19/2009	3643.7
7/20/2009	3640.7	7/20/2009	3643.6
7/21/2009	3640.6	7/21/2009	3643.6
7/22/2009	3640.6	7/22/2009	3643.5
7/23/2009	3640.6	7/23/2009	3643.5
7/24/2009	3640.6	7/24/2009	3643.5
7/25/2009	3640.6	7/25/2009	3643.6
7/26/2009	3640.6	7/26/2009	3643.6
7/27/2009	3640.6	7/27/2009	3643.5
7/28/2009	3640.6	7/28/2009	3643.5
7/29/2009	3640.6	7/29/2009	3643.5
7/30/2009	3640.7	7/30/2009	3643.6
7/31/2009	3640.7	7/31/2009	3643.6
10/15/2009	3635.0	10/31/2009	3641.0
11/30/2009	3630.0	12/31/2009	3633.5
12/31/2009	3624.0		

Table F.7. Baseline and reallocated time series guide curves (in tabular form) for the medium spring runoff condition (developed by BOR).

Baseline		Reallocated	
Date	Elevation (ft msl)	Date	Elevation (ft msl)
1/1/2009	3624.0	1/1/2009	3633.5
3/31/2009	3617.9	3/31/2009	3622.9
4/1/2009	3617.9	4/1/2009	3622.9
4/2/2009	3617.9	4/2/2009	3622.9
4/3/2009	3617.9	4/3/2009	3622.9
4/4/2009	3617.9	4/4/2009	3622.9
4/5/2009	3617.9	4/5/2009	3622.9
4/6/2009	3617.9	4/6/2009	3622.9
4/7/2009	3617.9	4/7/2009	3622.9
4/8/2009	3617.9	4/8/2009	3622.9
4/9/2009	3617.9	4/9/2009	3622.9
4/10/2009	3617.8	4/10/2009	3622.9
4/11/2009	3617.8	4/11/2009	3622.8
4/12/2009	3617.8	4/12/2009	3622.8
4/13/2009	3617.8	4/13/2009	3622.8
4/14/2009	3617.8	4/14/2009	3622.8
4/15/2009	3617.8	4/15/2009	3622.8
4/16/2009	3617.8	4/16/2009	3622.8
4/17/2009	3617.8	4/17/2009	3622.8
4/18/2009	3617.8	4/18/2009	3622.8
4/19/2009	3617.8	4/19/2009	3622.8
4/20/2009	3617.7	4/20/2009	3622.8
4/21/2009	3617.7	4/21/2009	3622.8
4/22/2009	3617.7	4/22/2009	3622.7
4/23/2009	3617.7	4/23/2009	3622.7
4/24/2009	3617.7	4/24/2009	3622.8
4/25/2009	3617.7	4/25/2009	3622.8
4/26/2009	3617.8	4/26/2009	3622.8
4/27/2009	3617.8	4/27/2009	3622.8
4/28/2009	3617.8	4/28/2009	3622.8
4/29/2009	3617.9	4/29/2009	3622.9
4/30/2009	3617.9	4/30/2009	3622.9
5/1/2009	3618.0	5/1/2009	3623.0
5/2/2009	3618.1	5/2/2009	3623.1
5/3/2009	3618.2	5/3/2009	3623.1
5/4/2009	3618.3	5/4/2009	3623.2
5/5/2009	3618.4	5/5/2009	3623.3
5/6/2009	3618.5	5/6/2009	3623.5
5/7/2009	3618.7	5/7/2009	3623.6
5/8/2009	3618.7	5/8/2009	3623.6
5/9/2009	3618.7	5/9/2009	3623.7
5/10/2009	3618.8	5/10/2009	3623.7
5/11/2009	3618.9	5/11/2009	3623.8

5/12/2009	3618.8	5/12/2009	3623.8
5/13/2009	3618.8	5/13/2009	3623.8
5/14/2009	3618.9	5/14/2009	3623.8
5/15/2009	3618.9	5/15/2009	3623.9
5/16/2009	3619.1	5/16/2009	3624.0
5/17/2009	3619.2	5/17/2009	3624.1
5/18/2009	3619.4	5/18/2009	3624.2
5/19/2009	3619.4	5/19/2009	3624.3
5/20/2009	3619.6	5/20/2009	3624.4
5/21/2009	3619.7	5/21/2009	3624.5
5/22/2009	3619.9	5/22/2009	3624.7
5/23/2009	3620.1	5/23/2009	3624.9
5/24/2009	3620.3	5/24/2009	3625.1
5/25/2009	3620.6	5/25/2009	3625.3
5/26/2009	3620.9	5/26/2009	3625.6
5/27/2009	3621.2	5/27/2009	3625.9
5/28/2009	3621.5	5/28/2009	3626.2
5/29/2009	3621.9	5/29/2009	3626.6
5/30/2009	3622.3	5/30/2009	3626.9
5/31/2009	3622.8	5/31/2009	3627.3
6/1/2009	3623.2	6/1/2009	3627.7
6/2/2009	3623.6	6/2/2009	3628.1
6/3/2009	3624.1	6/3/2009	3628.5
6/4/2009	3624.6	6/4/2009	3628.9
6/5/2009	3625.1	6/5/2009	3629.4
6/6/2009	3625.6	6/6/2009	3629.9
6/7/2009	3626.2	6/7/2009	3630.4
6/8/2009	3626.7	6/8/2009	3630.9
6/9/2009	3627.3	6/9/2009	3631.4
6/10/2009	3627.9	6/10/2009	3632.0
6/11/2009	3628.5	6/11/2009	3632.5
6/12/2009	3629.2	6/12/2009	3633.1
6/13/2009	3629.8	6/13/2009	3633.7
6/14/2009	3630.4	6/14/2009	3634.2
6/15/2009	3631.1	6/15/2009	3634.8
6/16/2009	3631.7	6/16/2009	3635.4
6/17/2009	3632.4	6/17/2009	3636.0
6/18/2009	3633.0	6/18/2009	3636.6
6/19/2009	3633.7	6/19/2009	3637.2
6/20/2009	3634.3	6/20/2009	3637.8
6/21/2009	3634.9	6/21/2009	3638.3
6/22/2009	3635.5	6/22/2009	3638.8
6/23/2009	3636.0	6/23/2009	3639.3
6/24/2009	3636.5	6/24/2009	3639.8
6/25/2009	3637.0	6/25/2009	3640.2
6/26/2009	3637.5	6/26/2009	3640.6
6/27/2009	3637.9	6/27/2009	3641.0
6/28/2009	3638.3	6/28/2009	3641.4

6/29/2009	3638.7	6/29/2009	3641.8
6/30/2009	3639.1	6/30/2009	3642.2
7/1/2009	3639.5	7/1/2009	3642.5
7/2/2009	3639.8	7/2/2009	3642.8
7/3/2009	3640.0	7/3/2009	3643.0
7/4/2009	3640.3	7/4/2009	3643.2
7/5/2009	3640.4	7/5/2009	3643.4
7/6/2009	3640.6	7/6/2009	3643.5
7/7/2009	3640.7	7/7/2009	3643.6
7/8/2009	3640.7	7/8/2009	3643.7
7/9/2009	3640.8	7/9/2009	3643.7
7/10/2009	3640.7	7/10/2009	3643.6
7/11/2009	3640.7	7/11/2009	3643.6
7/12/2009	3640.5	7/12/2009	3643.5
7/13/2009	3640.5	7/13/2009	3643.4
7/14/2009	3640.3	7/14/2009	3643.3
7/15/2009	3640.2	7/15/2009	3643.1
7/16/2009	3640.1	7/16/2009	3643.0
7/17/2009	3640.0	7/17/2009	3642.9
7/18/2009	3639.9	7/18/2009	3642.9
7/19/2009	3639.9	7/19/2009	3642.9
7/20/2009	3639.9	7/20/2009	3642.9
7/21/2009	3639.9	7/21/2009	3642.9
7/22/2009	3639.9	7/22/2009	3642.9
7/23/2009	3639.9	7/23/2009	3642.9
7/24/2009	3639.9	7/24/2009	3642.9
7/25/2009	3639.9	7/25/2009	3642.9
7/26/2009	3640.0	7/26/2009	3642.9
7/27/2009	3640.0	7/27/2009	3643.0
7/28/2009	3640.0	7/28/2009	3643.0
7/29/2009	3640.1	7/29/2009	3643.0
7/30/2009	3640.1	7/30/2009	3643.1
7/31/2009	3640.1	7/31/2009	3643.1
10/15/2009	3635.0	10/31/2009	3641.0
11/30/2009	3630.0	12/31/2009	3633.5
12/31/2009	3624.0		

Table F.8. Baseline and reallocated time series guide curves (in tabular form) for the minimum fill spring runoff condition (developed by BOR).

Baseline		Reallocated	
Date	Elevation (ft msl)	Date	Elevation (ft msl)
1/1/2009	3624.0	1/1/2009	3633.5
3/31/2009	3617.9	3/31/2009	3622.9
4/1/2009	3618.0	4/1/2009	3623.0
4/2/2009	3618.0	4/2/2009	3623.0
4/3/2009	3618.0	4/3/2009	3623.0
4/4/2009	3618.1	4/4/2009	3623.1

4/5/2009	3618.1	4/5/2009	3623.1
4/6/2009	3618.1	4/6/2009	3623.1
4/7/2009	3618.2	4/7/2009	3623.2
4/8/2009	3618.2	4/8/2009	3623.2
4/9/2009	3618.2	4/9/2009	3623.2
4/10/2009	3618.3	4/10/2009	3623.2
4/11/2009	3618.3	4/11/2009	3623.3
4/12/2009	3618.3	4/12/2009	3623.3
4/13/2009	3618.4	4/13/2009	3623.3
4/14/2009	3618.4	4/14/2009	3623.4
4/15/2009	3618.5	4/15/2009	3623.4
4/16/2009	3618.5	4/16/2009	3623.5
4/17/2009	3618.6	4/17/2009	3623.5
4/18/2009	3618.6	4/18/2009	3623.6
4/19/2009	3618.7	4/19/2009	3623.6
4/20/2009	3618.7	4/20/2009	3623.7
4/21/2009	3618.8	4/21/2009	3623.7
4/22/2009	3618.8	4/22/2009	3623.7
4/23/2009	3618.9	4/23/2009	3623.8
4/24/2009	3618.9	4/24/2009	3623.8
4/25/2009	3619.0	4/25/2009	3623.9
4/26/2009	3619.1	4/26/2009	3624.0
4/27/2009	3619.2	4/27/2009	3624.1
4/28/2009	3619.3	4/28/2009	3624.2
4/29/2009	3619.4	4/29/2009	3624.3
4/30/2009	3619.6	4/30/2009	3624.4
5/1/2009	3619.7	5/1/2009	3624.6
5/2/2009	3619.9	5/2/2009	3624.7
5/3/2009	3620.1	5/3/2009	3624.9
5/4/2009	3620.3	5/4/2009	3625.1
5/5/2009	3620.5	5/5/2009	3625.3
5/6/2009	3620.8	5/6/2009	3625.5
5/7/2009	3621.1	5/7/2009	3625.8
5/8/2009	3621.3	5/8/2009	3626.0
5/9/2009	3621.6	5/9/2009	3626.3
5/10/2009	3621.9	5/10/2009	3626.6
5/11/2009	3622.2	5/11/2009	3626.8
5/12/2009	3622.5	5/12/2009	3627.1
5/13/2009	3622.8	5/13/2009	3627.4
5/14/2009	3623.2	5/14/2009	3627.7
5/15/2009	3623.5	5/15/2009	3628.0
5/16/2009	3623.8	5/16/2009	3628.3
5/17/2009	3624.2	5/17/2009	3628.6
5/18/2009	3624.6	5/18/2009	3629.0
5/19/2009	3625.0	5/19/2009	3629.3
5/20/2009	3625.4	5/20/2009	3629.7
5/21/2009	3625.8	5/21/2009	3630.1
5/22/2009	3626.2	5/22/2009	3630.4
5/23/2009	3626.7	5/23/2009	3630.8
5/24/2009	3627.1	5/24/2009	3631.2
5/25/2009	3627.6	5/25/2009	3631.7

5/26/2009	3628.0	5/26/2009	3632.1
5/27/2009	3628.5	5/27/2009	3632.5
5/28/2009	3629.0	5/28/2009	3632.9
5/29/2009	3629.5	5/29/2009	3633.4
5/30/2009	3630.0	5/30/2009	3633.9
5/31/2009	3630.5	5/31/2009	3634.3
6/1/2009	3631.0	6/1/2009	3634.7
6/2/2009	3631.5	6/2/2009	3635.2
6/3/2009	3632.0	6/3/2009	3635.6
6/4/2009	3632.4	6/4/2009	3636.0
6/5/2009	3632.9	6/5/2009	3636.4
6/6/2009	3633.3	6/6/2009	3636.9
6/7/2009	3633.8	6/7/2009	3637.3
6/8/2009	3634.2	6/8/2009	3637.7
6/9/2009	3634.6	6/9/2009	3638.0
6/10/2009	3635.0	6/10/2009	3638.4
6/11/2009	3635.4	6/11/2009	3638.8
6/12/2009	3635.8	6/12/2009	3639.1
6/13/2009	3636.2	6/13/2009	3639.4
6/14/2009	3636.5	6/14/2009	3639.7
6/15/2009	3636.8	6/15/2009	3640.0
6/16/2009	3637.1	6/16/2009	3640.3
6/17/2009	3637.4	6/17/2009	3640.6
6/18/2009	3637.7	6/18/2009	3640.8
6/19/2009	3637.9	6/19/2009	3641.1
6/20/2009	3638.2	6/20/2009	3641.3
6/21/2009	3638.4	6/21/2009	3641.5
6/22/2009	3638.6	6/22/2009	3641.7
6/23/2009	3638.8	6/23/2009	3641.9
6/24/2009	3639.0	6/24/2009	3642.0
6/25/2009	3639.1	6/25/2009	3642.2
6/26/2009	3639.3	6/26/2009	3642.3
6/27/2009	3639.4	6/27/2009	3642.4
6/28/2009	3639.5	6/28/2009	3642.5
6/29/2009	3639.6	6/29/2009	3642.6
6/30/2009	3639.7	6/30/2009	3642.7
7/1/2009	3639.8	7/1/2009	3642.8
7/2/2009	3639.8	7/2/2009	3642.8
7/3/2009	3639.9	7/3/2009	3642.9
7/4/2009	3639.9	7/4/2009	3642.9
7/5/2009	3639.9	7/5/2009	3642.9
7/6/2009	3639.9	7/6/2009	3642.9
7/7/2009	3639.9	7/7/2009	3642.9
7/8/2009	3639.9	7/8/2009	3642.9
7/9/2009	3639.9	7/9/2009	3642.9
7/10/2009	3639.9	7/10/2009	3642.9
7/11/2009	3639.9	7/11/2009	3642.9
7/12/2009	3639.9	7/12/2009	3642.8
7/13/2009	3639.8	7/13/2009	3642.8
7/14/2009	3639.8	7/14/2009	3642.8
7/15/2009	3639.8	7/15/2009	3642.7

7/16/2009	3639.7	7/16/2009	3642.7
7/17/2009	3639.7	7/17/2009	3642.7
7/18/2009	3639.6	7/18/2009	3642.6
7/19/2009	3639.6	7/19/2009	3642.6
7/20/2009	3639.5	7/20/2009	3642.5
7/21/2009	3639.5	7/21/2009	3642.5
7/22/2009	3639.4	7/22/2009	3642.4
7/23/2009	3639.4	7/23/2009	3642.4
7/24/2009	3639.3	7/24/2009	3642.3
7/25/2009	3639.2	7/25/2009	3642.3
7/26/2009	3639.2	7/26/2009	3642.2
7/27/2009	3639.1	7/27/2009	3642.1
7/28/2009	3639.0	7/28/2009	3642.0
7/29/2009	3638.9	7/29/2009	3642.0
7/30/2009	3638.8	7/30/2009	3641.9
7/31/2009	3638.8	7/31/2009	3641.8
10/15/2009	3635.0	10/31/2009	3641.0
11/30/2009	3630.0	12/31/2009	3633.5
12/31/2009	3624.0		

Table F.9. Yellowtail flood control rule curves used in the HEC-ResSim models. Tabular values were determined by reading values off of the figure in the USACE flood control manual (USACE, 1974).

		Reservoir Inflow (1000 cfs)									Max release (cfs)	Max spillway discharge (cfs)	Max spillway discharge + 50% powerplant discharge (cfs)
Elevation (ft msl)	Upper bound (cfs)	10	20	30	40	50	60	70	80	90			
3614.0	-	1200	6000	10000	14000	-	-	-	-	-	20000	15000	24000
3614.5	-	1235	6067	10100	14130	-	-	-	-	-	20000	15636	24600
3615.1	-	1270	6134	10200	14260	-	-	-	-	-	20000	16272	25200
3615.6	-	1305	6201	10300	14390	-	-	-	-	-	20000	16908	25800
3616.2	-	1340	6268	10400	14520	-	-	-	-	-	20000	17544	26400
3616.7	-	1375	6335	10500	14650	-	-	-	-	-	20000	18180	27000
3617.3	-	1410	6402	10600	14780	-	-	-	-	-	20000	18816	27600
3617.8	-	1445	6469	10700	14910	-	-	-	-	-	20000	19452	28200
3618.4	-	1480	6536	10800	15040	-	-	-	-	-	20000	20088	28800
3618.9	-	1515	6603	10900	15170	-	-	-	-	-	20000	20724	29400
3619.5	-	1550	6670	11000	15300	-	-	-	-	-	20000	21360	30000
3620.0	-	1585	6737	11100	15430	-	-	-	-	-	20000	22000	30714
3620.5	-	1620	6804	11200	15560	-	-	-	-	-	20000	22727	31428
3621.1	-	1655	6871	11300	15690	-	-	-	-	-	20000	23454	32142
3621.6	-	1690	6938	11400	15820	-	-	-	-	-	20000	24181	32856
3622.1	-	1725	7005	11500	16000	-	-	-	-	-	20000	24908	33570
3622.6	-	1760	7072	11600	16130	-	-	-	-	-	20000	25635	34284
3623.2	-	1795	7139	11700	16260	-	-	-	-	-	20000	26362	34998
3623.7	-	1830	7206	11800	16390	-	-	-	-	-	20000	27089	35712
3624.2	-	1865	7273	11900	16520	-	-	-	-	-	20000	27816	36426
3624.7	-	1900	7340	12000	16650	-	-	-	-	-	20000	28543	37140
3625.3	-	1935	7407	12118	16780	-	-	-	-	-	20000	29270	37854
3625.8	-	1970	7474	12236	16910	-	-	-	-	-	20000	30000	38568
3626.3	-	2000	7541	12354	17040	-	-	-	-	-	20000	30750	39282
3626.8	-	2077	7608	12472	17170	-	-	-	-	-	20000	31500	40000
3627.4	-	2154	7675	12590	17300	-	-	-	-	-	20000	32250	40889

3627.9	-	2231	7742	12708	17430	-	-	-	-	-	20000	33000	41778
3628.4	-	2308	7809	12826	17560	-	-	-	-	-	20000	33750	42667
3628.9	-	2385	7876	12944	17690	-	-	-	-	-	20000	34500	43556
3629.5	-	2462	7943	13062	17820	-	-	-	-	-	20000	35250	44445
3630.0	-	2539	8000	13180	18000	-	-	-	-	-	20000	36000	45334
3630.5	-	2616	8100	13298	18222	-	-	-	-	-	20000	37000	46223
3631.1	-	2693	8200	13416	18444	-	-	-	-	-	20000	38000	47112
3631.6	-	2770	8300	13534	18666	-	-	-	-	-	20000	39000	48000
3632.1	-	2847	8400	13652	18888	-	-	-	-	-	20000	40000	48857
3632.6	-	2924	8500	13770	19110	-	-	-	-	-	20000	40909	49714
3633.2	-	3001	8600	13888	19332	-	-	-	-	-	20000	41818	50571
3633.7	-	3078	8700	14000	19554	-	-	-	-	-	20000	42727	51428
3634.2	-	3155	8800	14167	19776	-	-	-	-	-	20000	43636	52285
3634.7	-	3232	8900	14334	20000	-	-	-	-	-	20000	44545	53142
3635.3	-	3309	9000	14501	20000	-	-	-	-	-	20000	45454	54000
3635.8	-	3386	9100	14668	20000	-	-	-	-	-	20000	46363	54913
3636.3	-	3463	9200	14835	20000	-	-	-	-	-	20000	47272	55826
3636.8	-	3540	9300	15002	20000	-	-	-	-	-	20000	48181	56739
3637.4	-	3617	9400	15169	20000	-	-	-	-	-	20000	49090	57652
3637.9	-	3694	9500	15336	20000	-	-	-	-	-	20000	49999	58565
3638.4	-	3771	9600	15503	20000	-	-	-	-	-	20000	50908	59478
3638.9	-	3848	9700	15670	20000	-	-	-	-	-	20000	51817	60391
3639.5	-	3925	9800	15837	20000	-	-	-	-	-	20000	52726	61304
3640.0	-	4000	9900	16000	20000	-	-	-	-	-	20000	53635	62220
3640.5	-	4125	10000	16143	20000	-	-	-	-	-	20000	54544	63330
3641.1	-	4250	10154	16286	20000	-	-	-	-	-	20000	55453	64440
3641.6	-	4375	10308	16429	20000	-	-	-	-	-	20000	56362	65550
3642.1	-	4500	10462	16572	20000	-	-	-	-	-	20000	57271	66660
3642.6	-	4625	10616	16715	20000	-	-	-	-	-	20000	58180	67770
3643.2	-	4750	10770	16858	20000	-	-	-	-	-	20000	59089	68880
3643.7	-	4875	10924	17001	20000	-	-	-	-	-	20000	60000	69990
3644.2	-	5000	11078	17144	20000	-	-	-	-	-	20000	61110	71100
3644.7	-	5125	11232	17287	20000	-	-	-	-	-	20000	62220	72210
3645.3	-	5250	11386	17430	20000	-	-	-	-	-	20000	63330	73320

3645.8	-	5375	11540	17573	20000	-	-	-	-	-	20000	64440	74210
3646.3	-	5500	11694	17716	20000	-	-	-	-	-	20000	65550	75100
3646.8	-	5625	11848	17859	20000	-	-	-	-	-	20000	66660	75990
3647.4	-	5750	12000	18000	20000	-	-	-	-	-	20000	67770	76880
3647.9	-	5875	12222	18286	20000	-	-	-	-	-	20000	68880	77770
3648.4	-	6000	12444	18572	20000	-	-	-	-	-	20000	69990	78660
3648.9	-	6182	12666	18858	20000	-	-	-	-	-	20000	71100	79550
3649.5	-	6364	12888	19144	22000	-	-	-	-	-	22000	72210	80440
3650.0	-	6546	13110	19430	24000	-	-	-	-	-	24000	73320	81330
3650.5	-	6728	13332	19716	26000	-	-	-	-	-	26000	74260	82220
3651.1	-	6910	13554	20000	28000	-	-	-	-	-	28000	75200	83330
3651.6	-	7092	13776	20400	28500	-	-	-	-	-	30000	76140	84440
3652.2	-	7274	14000	20800	28750	-	-	-	-	-	32000	77080	85550
3652.7	-	7456	14333	21200	29000	-	-	-	-	-	34000	78020	86660
3653.2	-	7638	14666	21600	29500	-	-	-	-	-	36000	78960	87770
3653.8	-	7820	14999	22000	30000	37000	-	-	-	-	38000	79900	88880
3654.3	-	8200	15332	22667	30700	38000	-	-	-	-	40000	80840	89990
3654.8	-	8500	15665	23334	31100	39000	-	-	-	-	42000	81780	91100
3655.4	-	9000	16000	24000	32000	40000	48500	-	-	-	50000	82720	92210
3655.9	-	9500	17000	25000	32750	41000	49000	60000	-	-	60000	83660	93320
3656.5	-	10000	18000	26000	34000	42000	50000	60740	69102	-	72210	84600	94430
3657.0	0	12000	20000	28000	35500	43800	51000	61480	69990	78870	84440	85550	95540
3657.0	12000	12000	20000	28000	35500	43800	51000	61480	69990	78870	95540	85550	95540
3657.5	30000	30000	30000	30000	37000	45000	52500	62500	71100	80000	96600	86660	96600
3658.0	42000	42000	42000	42000	40000	47000	54000	63885	72210	81110	97300	87770	97200
3658.5	54000	54000	54000	54000	54000	54000	57000	65550	73500	82400	98000	89435	98100
3659.0	66660	66660	66660	66660	66660	66660	66660	67770	75000	84440	98650	92210	98650
3659.5	78870	78870	78870	78870	78870	78870	78870	78870	77700	86660	99300	95400	99300
3660.0	91100	91100	91100	91100	91100	91100	91100	91100	91100	88880	100000	98870	100000