Appendices

Appendix A

RECLAMATION
Managing Water in the West

Statistical Analysis of Bighorn Lake Operational Criteria

Great Plains Regional Office
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Figures

Tables

Introduction

Severe drought conditions and record-low water supply during 2000-2007 significantly impacted the operation of Yellowtail Dam resulting in abnormally low levels in Bighorn Lake, Bighorn River flows near minimum levels for extended periods of time, and power generation output that was less than 50 percent of normal. During this time local, state, tribal, and federal entities expressed concern that the Bighorn River System was not being managed in a way that fully protects and utilizes the system's resources for the multiple demands, needs, and expectations of the public. To assist in addressing these concerns, an Issue Group was formed in 2007.

From 2007 to 2009, the Issue Group collaboratively worked together with Reclamation to create operating criteria that would best benefit water supply, power generation, flood control, river fishery, and lake recreation and fishery interests. The operating criteria was adopted in water year 2010. The criteria was later updated with revisions in 2012 and again in 2015 due to additional years of data and feedback from the Issues Group stakeholders.

As the operating criteria was developed, there were expectations that the new criteria would provide improved benefits as compared to historic criteria (historic operations) and therefore provide an increased water supply, an improved lake recreation and fishery, a more dependable river fishery flows, an increased power generation, and enhanced flood control benefits.

On behalf of the Montana Area Office, Reclamation's Great Plains Regional Office is independently reviewing the operating criteria. The goals of the review are to: 1) document differences between current and past operations of Bighorn Lake; 2) determine if significant differences exist between the realized and anticipated benefits of the operating criteria; 3) determine potential causes for any differences in operations and realized and anticipated benefits; and 4) propose potential operational improvements for future examination.

The first component of the criteria review consists of a statistical analysis of Bighorn Lake operational data. This memorandum describes the analyses performed on reservoir inflows and inflow forecasts, pool elevations, river releases, and hydropower generation.

Analysis

Reclamation's Hydromet system provided the data analyzed for the statistical analysis of the criteria. Except for hydropower generation, where only monthly data exist for the period of record, daily data were used for all analyses. Data were compared for three periods: Water year 1967-1992; 1993-2009; and 2010-2017. Due to increases in upstream reservoir storage in Reclamation's Buffalo Bill Reservoir completed in 1992, the pre-criteria period was divided into two distinct periods for analysis. Criteria were initially modified in 2010, setting the period for post-criteria analysis.

One impetus for this study was an analysis performed by the Montana Fish, Wildlife, and Parks (FWP). Mike Ruggles of the FWP presented an analysis comparing the number days by flow range in recent years, related to fisheries flow targets below Yellowtail Dam; pre- and post-criteria total percent of time in various flow ranges; and pre- and post-criteria summer pool elevations (Ruggles, 2017).

Within this presentation, Ruggles posed the question as to whether increased river releases were attributable to a current period of increased inflows or if other factors, such as the implementation of the operating criteria, were the cause. The subsequent analysis seeks to answer this question. Reservoir operations are complex and releases are not easily attributable to one factor. Reclamation makes decisions regarding releases based on factors including inflow volume and timing, inflow forecast uncertainty, and the operational criteria. To this end, data representing the results of operational decisions (pool elevation, river releases, and hydropower) were analyzed, as well as data impacting operational decisions (inflows, inflow forecasts, and operational criteria). The report describing the draft criteria (Reclamation, 2012) included anticipated changes to operations. The following sections below contain comparisons to these anticipated changes.

General Operations Background

To understand the statistical analysis, it is important to have a general understanding of the operational criteria. Reclamation operates Bighorn Lake in three general periods: January through July, when the reservoir is managed to draw down in preparation for and capture spring runoff; August through October, when releases are made to manage pool elevations for recreation, irrigation demands, and instream flows in the Bighorn River; and November through December when winter flows are set.

November through December flows are set targeting March 31 pool elevations. In January and February, forecasts are prepared based on the accumulating mountain snowpack and adjustments may be made in anticipation of runoff conditions. Beginning with the March 1 forecast, Reclamation targets the rule curves described within the operational criteria. The March 1 release rate targets the end of April rule curve, which is determined by the forecasted April through July runoff volume. Rule curves are shown below in Figure 1.

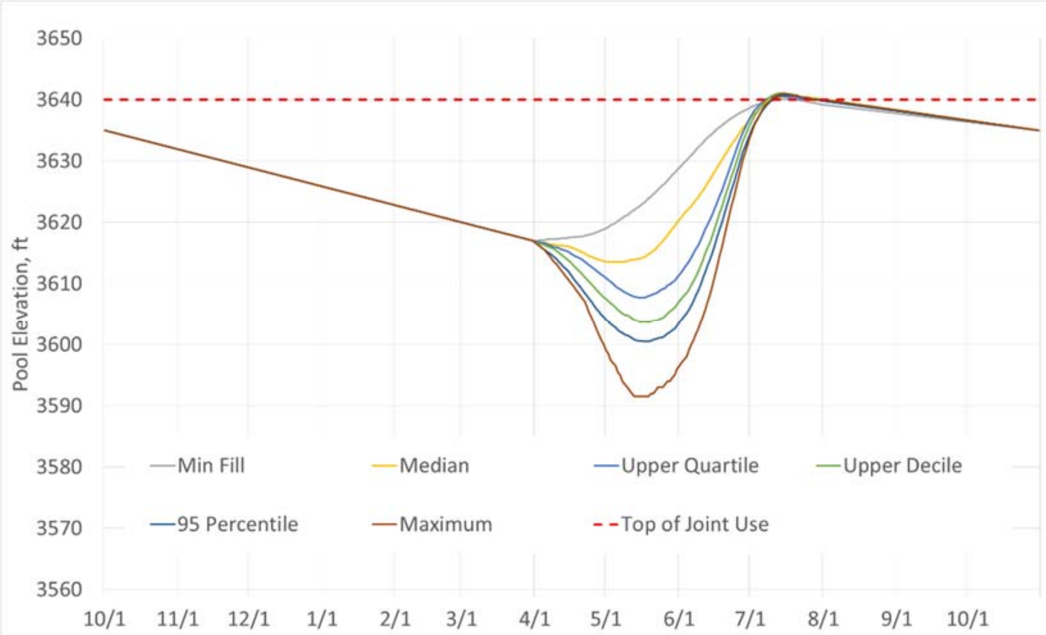


Figure 1: Rule curves and operational targets for Bighorn Lake. March 31 and October 31 targets are a range and not explicit, but a value was selected for plotting purposes.

The rule curves are used through the end of July, or until the peak inflow has passed. From August through October, flows are set either as the constant flow targeting the end of October pool elevation range or the end of March pool elevation range.

It should be noted that the March 31 target is not an explicit target; it is used for calculating winter flows. As we approach spring runoff operations, better information exists regarding snowpack and operations can be modified to store or evacuate water in anticipation of the predicted runoff.

Inflows

Inflows are a key metric to determine if comparisons between pre-criteria implementation and post-criteria implementation are valid. Releases are typically greater during periods of greater inflows. The reservoir serves to change the timing and magnitude of daily flows, but over long periods, the mean inflow, minus net evaporation, will equal mean outflow. Hydropower should increase with greater flows so long as turbine capacity is not exceeded, and pool elevations will also change. For example, reservoirs will be drawn down more in the spring of higher water years to evacuate space for flood control, resulting in lower pools. Also, late summer and early fall pool elevations may be lower due to reduced inflows in drier years.

Daily inflow data were obtained from Reclamation's Hydromet system (Reclamation, 2018) and were compared for water years (WY) 1967-1992, 1993-2009, and 2010-2017, as shown in Figure 2, below. The mean inflow was 3,503 cfs prior to 1993, 2,849 cfs from 1993 through 2009, and 3,843 cfs from 2010-

2017. This is a significant difference, with an inflow increase of nearly 720,000 acre-feet per year between the latter two periods.

As shown in Figure 2, significant differences exist in the mean peak flow timing and magnitude for the different periods. The mean peak flow rate is considerably higher during the post-criteria period than the pre-criteria period, and peaks arrived earlier as well. Similar differences exist for mean fall and winter period inflows. However, pre-criteria inflows for the period WY 1967-1992 were greater than post-criteria inflows. It should be noted that inflows to Bighorn Lake include regulated releases from Boysen and Buffalo Bill Reservoirs, and unregulated inflows from tributaries including streams on the east slope of the Bighorn Mountains such as Shell Creek and the Nowood River.

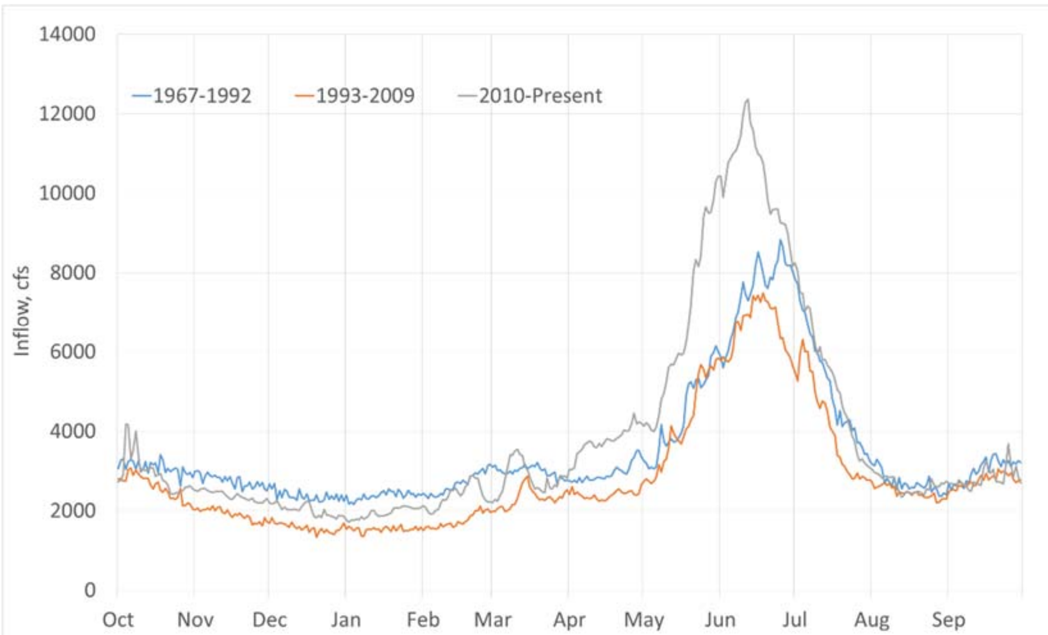


Figure 2: Pre- and post-criteria water year inflows to Bighorn Lake.

Forecasts

Forecasts are a key component of reservoir operations. Forecasts determine how Bighorn Lake is drawn down in anticipation of spring runoff, and winter flow forecasts are used to set winter flows in conjunction with March 31 targets. Two key statistical metrics are useful for examining forecasts in the context of operations. First, forecast bias occurs when forecasts systematically overestimate or underestimate runoff. Forecast bias is undesirable, as it introduces systematic error into operations.

Second, uncertainty exists with any forecast, as forecasts do not perfectly represent future conditions. Several metrics represent forecast skill, including coefficient of determination (r-squared); Nash-Sutcliffe efficiency; root mean squared error, and mean absolute error (MAE). MAE is calculated as the average of the absolute differences between forecasts and the observed runoff. These metrics are reported henceforth due to the operational consequence of the runoff volume error. Forecast error can result in releasing too much or too little water during the spring runoff season. Because uncertainty is inherent in all forecasts, Bighorn Lake operators attempt to mitigate forecast error by quantifying the range of potential future runoff through the most probable, minimum, and maximum plans.

NRCS Forecasts

Table 1 shows statistics from U.S. Department of Agriculture-Natural Resources Conservation Service (NRCS) season runoff forecasts. Forecasts were obtained for WY 1996-2017 from NRCS' Air-Water Database (NRCS, 2018). NRCS forecasts predict depleted runoff, meaning they forecast runoff after diversions and return flows are accounted for. These forecasts do not account for reservoir holdback, or the volume of runoff that upstream reservoirs (Bull Lake, Boysen Reservoir, and Buffalo Bill Reservoir) store during the forecast period. To compare the forecasted Bighorn Lake inflows to observed inflow, the Hydromet calculated inflow for the forecast period was added to the change in reservoir storage for the three major upstream reservoirs.

These statistics show that significant error exists in inflow forecasts for the reservoir. For example, the mean absolute error exceeds 400 thousand acre-feet (kaf) for the months January through April. For perspective, the joint use pool, which Reclamation utilizes for water supply and flood control, stores 240,342 acre-feet. The exclusive flood control pool is 258,331 acre-feet.

The number of forecasts available for analysis varied by month. For example, January forecasts were not available for the period WY 1966-1979, and June forecasts were not available for the period WY 1966-1990.

Table 1: Selected statistics from NRCS forecasts for the period WY 1967-2017 for Bighorn Lake inflows.

Forecast Date	Forecast Period	MAE, kaf	MAE, %	Bias, kaf	Bias, %	r-squared
January	April-July	468	30.7%	-41	-2.7%	31.7%
February	April-July	451	30.5%	-85	-5.7%	42.4%
March	April-July	429	28.2%	-80	-5.2%	42.9%
April	April-July	406	26.2%	-54	-3.5%	46.2%
May	May-July	337	23.1%	-38	-2.6%	63.4%
June	June-July	224	19.9%	-40	-3.6%	84.2%

NRCS forecasts also show a small negative bias, as shown in Figure 3 below. Years below the dashed one-to-one line indicate a forecast that over-predicted runoff, and years above the dashed line indicate a forecast that under-predicted runoff. The years 2010, 2011, and 2015 significantly under-forecasted runoff. These years resulted in high releases, as shown in subsequent sections. Higher than normal releases should be expected in years in which forecasts under-predict inflows, as reservoir operators might not draw down the reservoir as much as with a forecast exactly predicting the runoff volume. If reservoir drawdown is inadequate, releases must therefore be increased to avoid over-filling the reservoir.

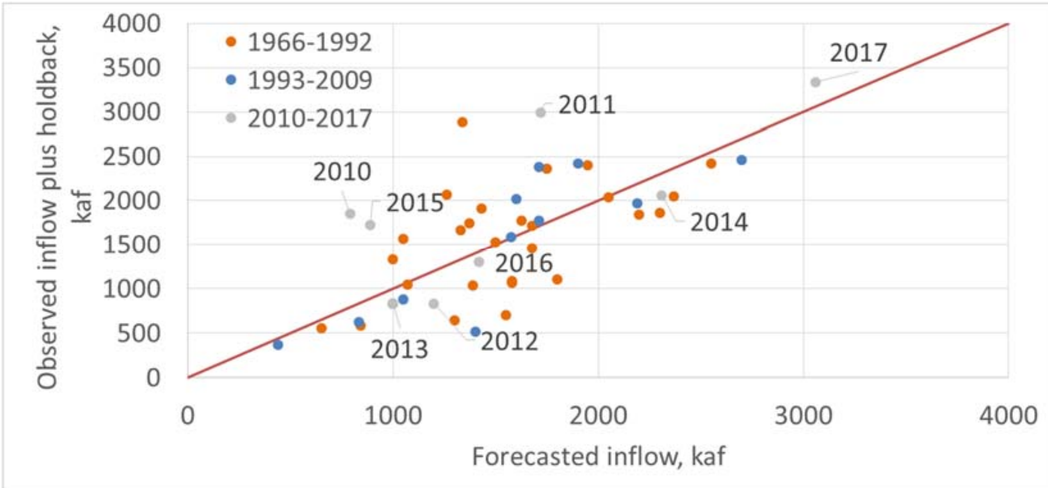


Figure 3: April 1 forecasted and observed inflows to Bighorn Lake for the period 1966-2017. Numbers indicate the forecasted year.

Figure 4 shows May 1 forecast error for May through July inflow volume. Negative forecast errors indicate over-prediction, and positive forecast errors indicate under-prediction. The negative slope of the trend line implies that absolute bias in April 1 NRCS forecasts has increased through time. However, this may be a result of the significant under-forecasting for 2010, 2011, and 2015.

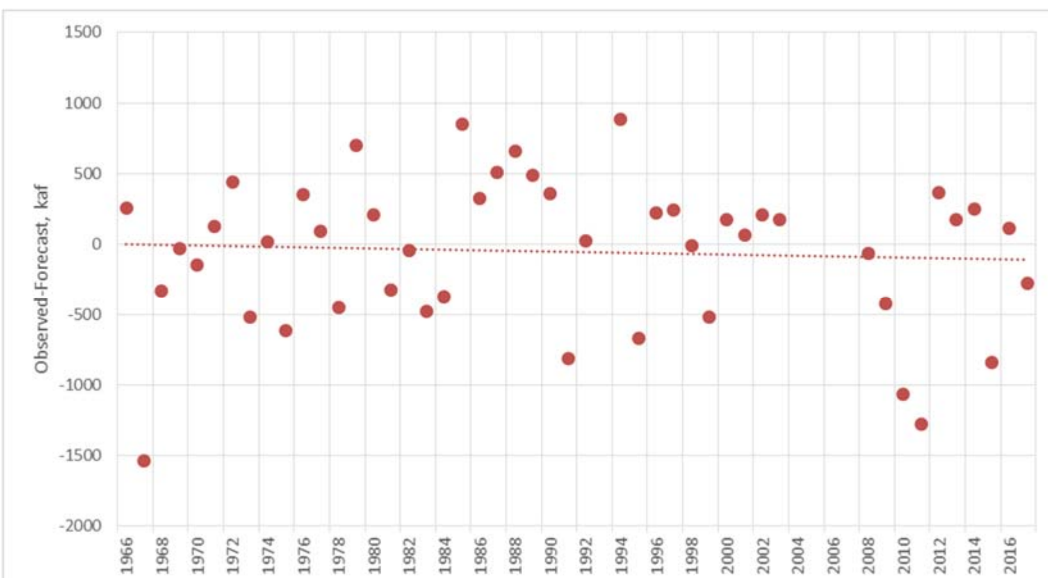


Figure 4: May 1 forecast residuals (observed runoff-forecast runoff).

Reclamation Forecasts

Reclamation forecasts were also examined for each month from calendar year 1990 through 2017. Reclamation issues monthly operations plans which contain monthly forecast volumes for one year into the future. Forecasts were summarized by the period most applicable to operations. For example, Reclamation operates Bighorn Lake from January through July for snowmelt runoff management and filling for water supply. Therefore, the April through July forecasts are summed for forecasts issued January through April. As inflows for the forecasting period come into Bighorn Lake, the forecast term decreases by a month: May forecasts are May through July runoff, June forecasts are June through July runoff, and July forecasts are for the month of July. After snowmelt runoff completes, forecasts are through the October 31 target and November and December forecasts are for the forecast date through March 31.

Table 2: Selected statistics for Reclamation forecasts from 1990-2017.

Forecast Date	Forecast Period	MAE, kaf	MAE, %	Bias, kaf	Bias, %	r-squared
January	April-July	431	35.8%	-235	-20.6%	39.2%
February	April-July	420	34.9%	-219	-19.2%	41.1%
March	April-July	404	33.6%	-180	-15.8%	44.9%
April	April-July	374	31.1%	-179	-15.7%	53.8%
May	May-July	234	22.5%	-105	-10.6%	73.1%
June	June-July	157	21.2%	-69	-10.0%	85.8%
July	July	56	20.3%	-9	-3.6%	94.5%
August	August-October	52	11.0%	-28	-6.0%	79.3%
September	September-October	41	12.8%	-11	-3.5%	54.6%
October	October	17	10.6%	-6	-3.6%	86.4%
November	November-March	93	16.2%	12	2.1%	42.4%
December	December-March	84	18.6%	3	0.8%	39.9%

As shown in Table 2, forecast skill increases in the spring as the April through July period nears. This is typical for snowpack-based runoff forecasts. Forecasts based on accumulated mountain snowpack contain more information as forecasters gain knowledge regarding the peak snowpack which typically occurs in April or May. The same skill improvement occurs for forecasts made in November and December.

Forecast MAE was lower for Reclamation forecasts than for comparable NRCS forecasts by an average of 50 kaf. The skill difference improved with May and June Reclamation forecasts showing significantly lower MAE. Conversely, Reclamation forecasts were significantly more biased than NRCS forecasts for the January through June forecast dates. All these forecasts were biased toward under-predicting runoff.

April 1 Reclamation forecasts and observed Bighorn Lake inflows are shown in Figure 5. Reclamation April 1 forecasts show a bias toward under-predicting inflows (forecasts above the one-to-one dashed line).

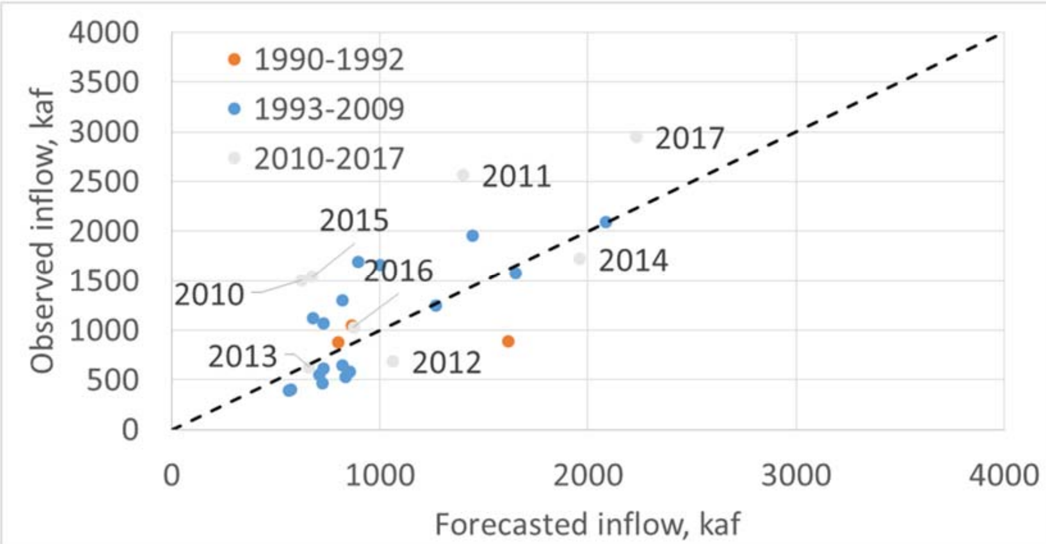


Figure 5: Reclamation April 1 forecasts and observed inflows for Bighorn Lake by year from 1990-2017.

Reclamation assesses uncertainty using a minimum, most probable, and maximum plan. These plan forecasts are close but do not exactly represent the 90% exceedance, median, and 10% exceedance forecasts. Figure 6 shows the plan forecasts plotted with observed Bighorn Lake inflows.

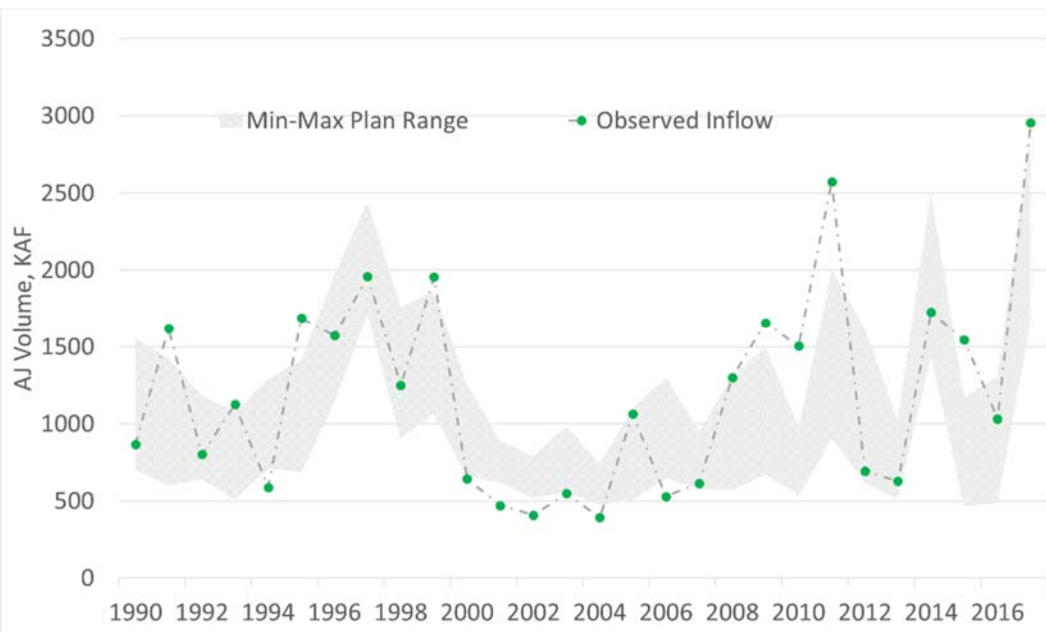


Figure 6: April 1st Minimum, Most Probable, and Maximum Plan and observed inflows to Bighorn Lake.

Assuming the minimum plan and maximum plan represent 90% and 10% exceedance, respectively, we can expect about 20% of the forecasts to be outside the bounds of the plans. Observed runoff for 16 of the 28 April 1 forecasts (57%) were outside of the bounds of the minimum and maximum plans. Observed runoff for 2010, 2011, 2015, and 2017 were all greater than the April 1 forecasted maximum plans. As described above, this indicates Reclamation forecasts misrepresent uncertainty and may account for greater than expected river releases and longer duration of high releases in these years.

The revised criteria (Reclamation, 2012) also implemented a new forecasting methodology for November through March gains. Gains are the volume of water in addition to Boysen and Buffalo Bill reservoirs releases flowing into Bighorn Lake. The November through March forecast is used to set winter releases, and therefore will impact winter pool elevations.

Figure 7 displays the forecast error for November 1st Reclamation forecasts. As shown in Table 2, November 1st forecasts are relatively unbiased (2.1%). However, forecasts from 2012 through 2016 all under-predicted inflows, with a MAE of 98.1 kaf. This forecast error could result in significant changes in pool elevation for Bighorn Lake. If an operator targeted elevation 3,617.0 ft using a constant flow rate from November through March and actual inflows were 98.1 kaf greater than forecasted, the lake would draft to elevation 3,629.4 ft if no adjustments were made. Winter flow adjustments can be undesirable due to potential fisheries impacts and to ice conditions on the lower Bighorn River and Yellowstone River.

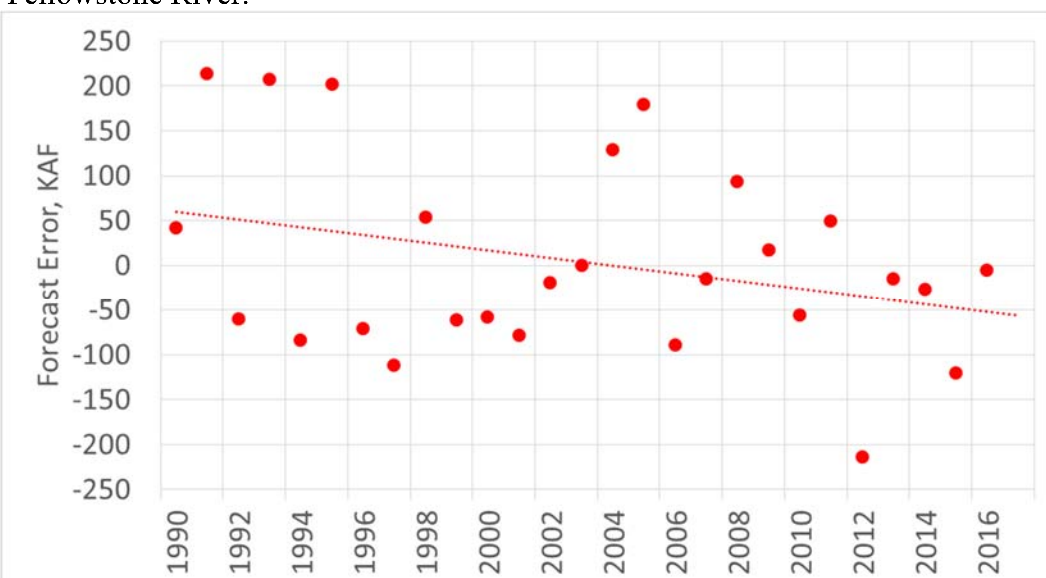


Figure 7: November 1 forecast error for the November through March inflow to Bighorn Lake. Negative values indicate under-estimation of inflows.

Releases and Fisheries Targets

To examine impacts to fisheries and other uses below Yellowtail Dam – Bighorn Lake, river releases were compared pre- and post-criteria implementation. Mean releases for the pre-criteria period were 3,157 cfs, and 3,753 cfs, a difference of

19%. It should be noted that inflows are greater than river releases due to irrigation diversions from the Yellowtail Afterbay to Bighorn Canal. Mean monthly Bighorn River releases appear below in Figure 8.

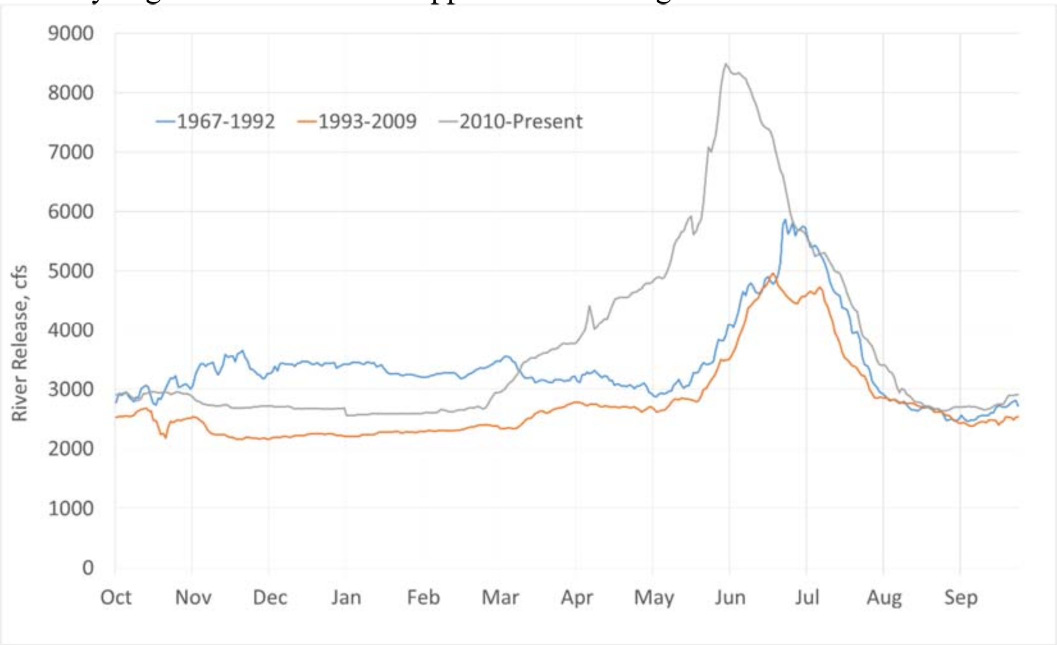


Figure 8: Mean daily Bighorn River releases from Yellowtail Dam pre- and post-criteria implementation.

Significant differences appear between pre- and post-criteria releases. Most notably, releases in the months of April, May, and June are much greater post-criteria. Winter releases (November through February) on average were greater for the period 1967-1992, and lower for the period 1993-2009 compared to post-criteria releases. This may be a result of a lower pre-criteria March 31 pool elevation target used to set winter releases or differences in fall and winter inflows, as described above. Pre-criteria winter flows were set with a March 31 target between 3,605 ft and 3,614 ft March 31 targets were set in 2010 to between 3,616.7 ft and 3,620.6 ft, and were revised to the range between 3,615 ft and 3,619 ft in 2012 (Reclamation, 2012) and set to 3,617 ft in 2015

The draft criteria anticipated changes to the frequency of flows within various fishery flow targets, as shown below in Table 3.

Table 3: Pre-criteria and post-criteria percent of time greater than fisheries flow targets.

	Percent of time greater than or equal to flow target				Change from pre-criteria	
Fishery Flow Targets	**1967-1992**	**1993-2009**	**1967-2009**	**2010-2017**	**Anticipated**	**Observed**
>=1,500 cfs	95.2%	80.6%	89.4%	100.0%	9%	10.6%
>=2,000 cfs	80.7%	57.8%	71.7%	81.1%	7%	9.4%
>=2,500 cfs	68.1%	40.6%	57.3%	56.6%	0%	-0.7%
>=3,000 cfs	54.2%	26.2%	43.2%	36.9%	3%	-6.3%
>=3,500 cfs	37.6%	20.0%	30.7%	27.1%	-4%	-3.6%
>=4,000 cfs	25.6%	15.3%	21.6%	23.4%	no est.	1.8%
>=4,500 cfs	15.2%	12.1%	14.0%	19.9%	no est.	5.9%
>=6,000 cfs	5.8%	7.1%	6.3%	15.8%	no est.	9.5%
>=15,000 cfs	0.3%	0.0%	0.2%	0.4%	no est.	0.3%

The draft criteria anticipated eliminating any flows below 1,500 cfs, and no flows below this target were observed after 2010. Similarly, the criteria anticipated increasing flows greater than 2,000 cfs and no changes to flows greater than 2,500 cfs, and these anticipated changes were both realized. The percentage of time above 3,000 cfs was anticipated to increase by about three percent of the time and flows greater than 3,500 cfs were anticipated to decrease. Actually, the time above both flow targets decreased after 2010.

The draft criteria report (Reclamation, 2012) did not describe anticipated changes to flow targets greater than 4,000 cfs. However, all flow levels greater than 4,500 cfs showed significant increases in the percent of time after criteria implementation. As described previously, differences in inflows for the examined periods make it difficult to draw conclusions as to the cause of these release differences.

Flood Control

Flood control expectations from the operational criteria (Reclamation, 2012) were defined by the amount of drawdown, the maximum release, and the duration of releases greater than 8,000 cfs. These expectations appear below in Table 4.

Table 4: Flood control expectations from the revised operational criteria. From Reclamation (2012).

Percentile Rank	Percent of Average	April – July Inflow Forecast (acre-feet)	Rule Curve Minimum Elevation	Date	*Max. Release (cfs)	Duration Releases > 8,000 cfs
10	48%	548,900	3,617.0	4/1	1,500	
25	58%	655,000	3,617.0	4/1	2,000	
35	84%	950,000	3,616.0	4/1	3,400	
50	99%	1,121,800	3,613.5	5/3	4,500	
60	116%	1,310,000	3,611.5	5/13	5,700	
75	140%	1,584,000	3,607.7	5/15	7,500	
90	163%	1,850,000	3,603.7	5/18	9,500	30 days
95	173%	1,957,300	3,600.5	5/17	10,000	41 days
98	204%	2,310,000	3,594.5	5/14	12,000	58 days
Max (99+)	221%	2,500,000	3,591.5	5/14	13,000	66 days

*The estimated maximum release assumes somewhat ideal runoff conditions. The actual peak releases may be higher (as much as 10 to 20 percent) due to natural variability in the spring runoff. Spring temperatures, snowpack conditions, significant rain events, and the potential for more runoff than forecast are all factors that could result in the actual peak release exceeding the estimated release.

Each runoff year from 2010 through 2017 was analyzed for comparison to the metrics in Table 4. These metrics appear in Table 5 below.

Table 5: Flood control statistics for each year post-criteria implementation.

Year	April-July Inflow Volume	April 1 Forecast	Peak Outflow	Min. Pool Elevation	Min. Pool Elevation Date	Duration of Releases > 8,000 cfs
	ac-ft	ac-ft	cfs	ft		days
2010	1,504,726	625,000	9,993	3,623	2/26/2010	44
2011	2,572,305	1,400,000	15,461	3,607	5/19/2011	73
2012	693,154	1,064,100	6,446	3,615	5/10/2012	0
2013	627,886	660,700	1,982	3,625	5/15/2013	0
2014	1,724,880	1,960,800	8,525	3,602	5/23/2014	21
2015	1,542,768	675,500	14,024	3,621	5/6/2015	28
2016	1,031,796	873,000	7,030	3,616	5/6/2016	0
2017	2,953,121	2,231,800	14,070	3,603	5/9/2017	127

In general, the observed peak outflow was greater than the expected peak outflow described in the revised operating criteria report (Reclamation, 2012). The duration of releases greater than 8,000 cfs was also longer than anticipated under the new criteria. The criteria predicted no days with releases greater than 8,000 cfs for years in which April through July inflows were less than 1,584 kaf. However, 2010 and 2015 both showed long periods of flows greater than 8,000 cfs.

The minimum pool elevation for all years was significantly higher than the rule curves provided by the revised criteria would prescribe. For example, the rule curves contained within the revised operating criteria anticipate a low pool elevation of 3,598.5 ft on May 18 for a runoff volume of 1,500 kaf. In 2010 and 2015, with similar inflow volumes, Reclamation only drew down the reservoir to 3,623.4 ft and 3,621.2 ft respectively.

Reclamation's April 1 forecast volumes (Table 5) put these inconsistencies into perspective. Forecasts under-predicted runoff for the four years with much greater than expected releases (2010, 2011, 2015, and 2017) by an average of 910,155 acre-feet. Rule curves would therefore direct operators to draw the reservoir down much less than had the inflow volume been perfectly forecasted.

Lake Levels

Lake levels directly impact recreation on Bighorn Lake. Low lake levels can render certain boat ramps on the upstream end of Bighorn Lake inaccessible, as well as limit waterfowl hunting opportunities in the fall (Reclamation, 2012). Lake levels also indicate the volume of storage for water supply and levels of drawdown for runoff capture. Mean daily pool elevation from Hydromet (Reclamation, 2018) was compared for the periods 1967-1992, 1993-2009, and 2010-present, as shown below in Figure 9. Typically, the reservoir pool elevation is drawn down slowly from October through December, providing for constant winter releases. Beginning with the January 1 runoff forecast, operators draw down Bighorn Lake in anticipation of April through July snowmelt runoff. As forecast skill increases throughout the spring, the reservoir is drawn to its lowest point in May. As runoff peaks, operators capture inflows to mitigate peak flows downstream and store for summer and fall water supply.

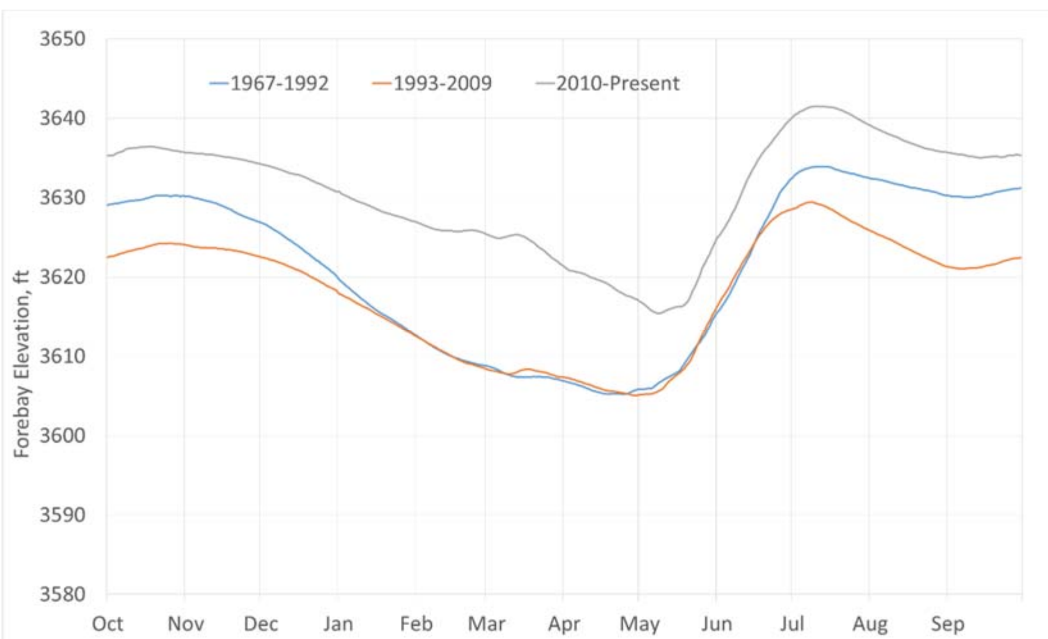


Figure 9: Mean daily pool elevation for pre- and post-criteria periods.

Significant differences in pool elevation exist between the three periods. The post-criteria period shows mean pool elevations, on average, of 9.6 ft higher than the period WY 1967-1992 and 12.8 ft higher than the period 1993-2009.

The revised criteria anticipated smaller changes than have been realized, as shown in Table 6. The criteria expected winter pool increases of about 3.5 ft but mean increases in winter pool were as large as 16.6 ft on average for the current period as compared to the period WY 1967-1992. Similarly, spring and early summer increases were expected to be negligible but increases in pool elevation ranging from 7.5 ft to 12.7 ft were observed, depending on month and period analyzed.

Table 6: Mean pool elevation by month and anticipated changes.

	Mean Pool Elevation, ft			Change in elevation from period, ft		Revised criteria expected change
Month	**1966-1992**	**1993-2009**	**2010-2017**	**1966-1992**	**1993-2009**	**ft**
Oct	3,629.8	3,623.6	3,636.0	6.2	12.4	2
Nov	3,628.8	3,623.4	3,635.1	6.4	11.7	2
Dec	3,623.7	3,620.7	3,632.7	8.9	12.0	2
Jan	3,616.0	3,615.4	3,628.7	12.7	13.3	3.5
Feb	3,610.4	3,610.3	3,625.9	15.6	15.7	3.5
Mar	3,607.6	3,608.0	3,624.2	16.6	16.2	3.5
Apr	3,605.8	3,606.1	3,619.3	13.5	13.2	3.5
May	3,609.0	3,608.6	3,617.8	8.8	9.2	0
Jun	3,623.9	3,623.5	3,633.0	9.0	9.5	1
Jul	3,633.3	3,628.1	3,640.8	7.5	12.7	2
Aug	3,631.4	3,623.6	3,637.1	5.7	13.6	2
Sep	3,630.5	3,621.5	3,635.3	4.8	13.7	2

As with releases and fisheries targets, the complicated relationship between inflow volume and timing makes conclusions difficult as to the cause of the much greater than expected pool elevations in the post-criteria period. Similarly, inflow forecasts (and forecast error) significantly impacts pool elevations. The mean April 1 forecast under-predicted April through July inflows by about 395,000 acre-feet. Forecast underestimation would typically result in much smaller drawdowns in the spring and could account for some of the large differences from January through April.

Power Generation

Mean daily hydropower generation was also compared for three periods. As daily generation data from Hydromet (Reclamation, 2018) are only available for the period October 1, 1986 through present, the initial period is different than that of the previous analyses. Impacting hydropower generation is the fact that only 3 of 4 units has been available due to generator rewinding since June 9, 2014, limiting hydropower generation for the post-criteria period.

The Western Area Power Administration markets the power generated at Yellowtail Dam. WAPA uses the hydropower facilities for energy grid reliability, in addition to marketing the generated energy. Yellowtail Dam hydropower facilities provide both regulation of the grid and reserve. Recent increases in wind and solar generation in the balancing area have increased reserve requirements which may decrease the amount of power generated compared to pre-criteria periods (Personal Communication, Grubbs, 2018).

In general, hydropower decreased post-criteria in the winter months and shifted earlier in the runoff season, from a peak in July to a peak in May and early June. This is shown in Figure 10.

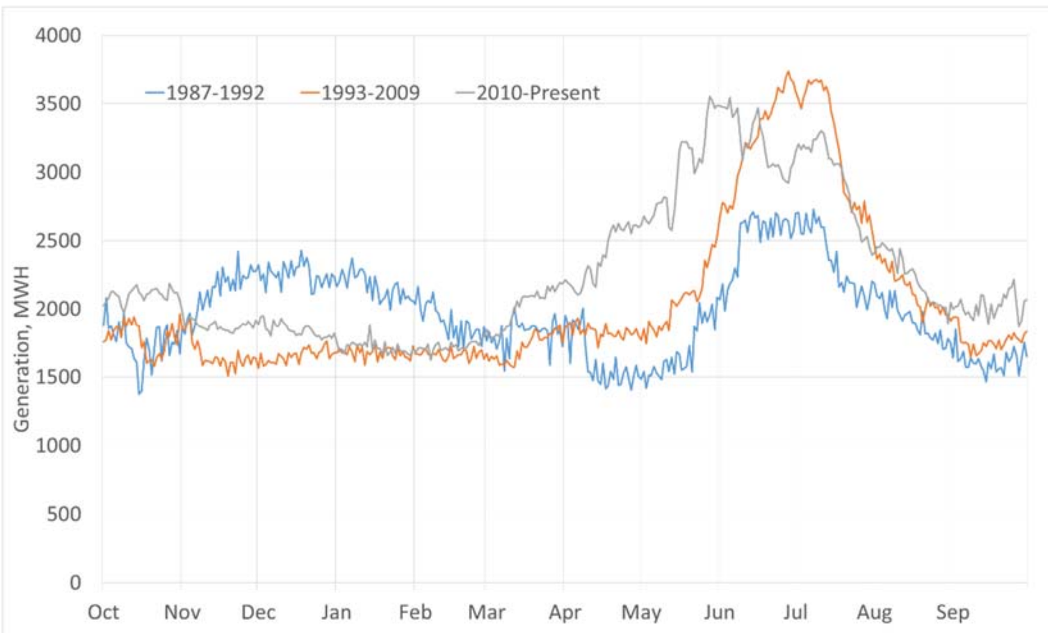


Figure 10: Mean daily pre- and post-criteria hydropower generation at Yellowtail Dam.

Monthly hydropower generation data exist for the period WY 1967-present (Reclamation, 2018). These data were examined to determined post-criteria differences in hydropower generation. The criteria anticipated annual increases in hydropower, no decreases in winter hydropower, and decreases in July through August. As shown in Table 7, annual hydropower generation increased by 7% over the period 1993-2009 and decreased by 14% from the period 1966-1992.

Table 7: Observed and expected hydropower generation, pre- and post-criteria implementation.

	Monthly Generation, GWH			Change in generation from period				Revised criteria expected change	
Month	**1967-1992**	**1993-2009**	**2010-Present**	**1967-1992, MWH**	**1967-1992, %**	**1993-2009, MWH**	**1993-2009, %**	**GWH**	**%**
Oct	72.6	53.8	58.6	-14.0	-19%	4.8	7%	--	--
Nov	79.4	50.2	50.8	-28.6	-36%	0.7	1%		
Dec	80.7	52.0	53.1	-27.6	-34%	1.2	1%	0.0	0.0
Jan	75.8	51.9	53.0	-22.7	-30%	1.1	1%		
Feb	67.2	47.0	48.7	-18.5	-28%	1.7	3%		
Mar	74.1	53.2	62.3	-11.8	-16%	9.1	12%	--	--
Apr	67.5	55.0	71.6	4.1	6%	16.5	25%		
May	72.2	63.8	92.7	20.5	28%	29.0	40%		
Jun	104.6	97.2	96.8	-7.8	-7%	-0.4	0%		
Jul	108.6	99.5	91.8	-16.7	-15%	-7.7	-7%	-2.9	-2.0
Aug	75.7	66.4	69.2	-6.5	-9%	2.7	4%		
Sep	64.1	53.0	60.6	-3.5	-5%	7.6	12%	--	--
Annual	**942.5**	**742.9**	**809.3**	**-133.2**	-14%	**66.4**	7%	**6.1**	**1.0**

Conclusions

Significant differences exist between pre-criteria and post-criteria operations in all operational metrics examined. Releases tended to be greater in the post-criteria period, particularly for the spring and summer runoff months. Releases were also greater than anticipated by the criteria based on April through July inflow volume. Pool elevations were also significantly greater for the post-criteria period, and elevations were higher than anticipated by the criteria based on inflow volume. Hydropower was also higher during the post-criteria period than the period from 1993-2009 and lower than the period 1966-1992, with one of the four turbines inoperable for nearly half the post-criteria timeframe.

Of interest to the recreational fishing industry downstream of Yellowtail Afterbay is the distribution of river releases. Flows below 1,500 cfs are undesirable, and recreational use of the Bighorn River declines when flows are greater than 6,000 to 8,000 cfs (Reclamation, 2012). Flows of 6,000 to 10,000 cfs are considered useful for preventing vegetation encroachment and periodic flows greater than 10,000 cfs are desirable to prevent side channel aggradation (Reclamation, 2014).

Flows below 1,500 cfs were eliminated in the post-criteria period, but flows greater than 6,000 cfs increased dramatically, to 15% of the time.

Isolating the cause of these differences, however, is difficult. Inflows for the post-criteria period averaged nearly 1,000 cfs higher than the period from 1993-2009. Because releases necessarily will be the same as inflows over a long period of time, this means outflows from Bighorn Lake were also 1,000 cfs greater on average. Similarly, peak inflow timing and magnitude were substantially different in the post-criteria period. As inflow magnitude increases, outflow magnitude will also likely increase. Reservoir storage can mitigate this to some extent, but the pool available for spring runoff storage is limited and a fraction of the total runoff volume in years such as 2011 and 2017. By necessity, high water years such as these will have flows greater than 8,000 cfs.

Also impacting the frequency of high flows is operations, including rule curves and inflow forecasts. Rule curves prescribe a drawdown based on forecasted inflow, but if forecasts under-predict inflow as in 2011 and 2015, operators will not draw down the reservoir as much in preparation to capture snowmelt runoff. Four primary factors impact pool elevations and releases: inflow timing, inflow volume, operational criteria, and inflow forecasting. Changes in Buffalo Bill Reservoir storage upstream of Bighorn Lake also impacts inflow timing and volume. However, the statistical analysis cannot control for these variables when comparing pre- and post-criteria operations. Accordingly, differences in releases are not attributable to any one factor. Some releases were greater than anticipated by the operational criteria by inflow volume. This indicates that inflow timing, operational criteria, or inflow forecasting are the likely reason for the greater number of days with flow greater than 8,000 cfs than anticipated.

As with Bighorn Lake releases, pool elevations also varied considerably from both pre-criteria operations and expectations following implementation of the criteria. Pool elevations were significantly higher than anticipated, and higher than prior operations. As noted above, inflows were significantly higher in the post-criteria period, which should result in higher summer, fall, and winter pool elevations. Reservoirs providing flood control typically have lower pool elevations in the spring to capture peak runoff during high inflow years. Bighorn Lake pool elevations were significantly higher during the post-criteria period, when inflows were significantly higher. As with reservoir releases, due to the four mitigating factors, the statistical analysis cannot directly determine causation for these differences in pool elevation. Spring reservoir drawdown was significantly lower than prescribed by the operational criteria. This indicates these differences in pool elevation may be attributable to inflow forecasting error or variation from the operational criteria. Also coming into play is the fact that rule curves are fixed in drawdown and filling timing, where inflows vary widely. This may result in differences in the drawdown volume, with inflows coming earlier or later than expected.

Power generation also changed significantly after criteria implementation. Generation increased when compared to the drier period from 1993-2009 and decreased when compared to the period 1967-1992. As with releases, timing of hydropower generation also significantly changed. Like pool elevation and releases, hydropower is dependent on several mitigating factors. The post-criteria period had a significant time in which one of the four hydropower units was inoperable due to a generator rewind, further complicating comparisons. As such, we cannot attribute differences in hydropower to any one factor.

Forecast error appears to be a significant component determining reservoir operations. Reclamation forecasts appear biased toward under-predicting inflows for April through July forecasts. Both NRCS and Reclamation forecasts significantly under-predicted inflows in four above-average runoff years, likely resulting in inadequate drawdown of Bighorn Lake prior to snowmelt runoff. Reclamation forecasts showed somewhat greater skill than NRCS forecasts.

Ultimately, the statistical analyses do not describe the relative impact of inflow hydrology, operational criteria, and forecasting on differences between pre and post-criteria operations and between post-criteria operations and anticipated benefits. Therefore, several recommendations appear below for further investigation.

Recommendations

Because several factors impact differences in reservoir operations between pre- and post-criteria, conclusions of this analysis are limited. We therefore recommend several additional analyses to differentiate the impacts of operational criteria from that of hydrology and upstream regulation.

To control for changes in inflow volume and timing and forecast error, a modeling approach is recommended. The daily model would represent pre- and post-criteria operations and use the period of record inflows (1967-2017). “Perfect” forecasts, or forecasts without error, would determine reservoir operations. This allows for direct comparisons of operational criteria for the same inflow hydrology.

The second analysis would use the same modeling approach but determine reservoir operations using historical Reclamation forecasts. This allows for a more realistic comparison of operations with historical, observed operations. This analysis should provide some insight as to whether Reclamation followed the criteria as described, or if operational differences are attributable to the differences in anticipated results. For example, it is not clear whether the higher pool elevations during spring runoff are attributable to forecast bias or missed operational targets. Also, it is not clear if development of operational criteria and rule curves considered mitigation of forecast error.

It should be noted that only monthly forecasts are available and that Reclamation makes operational decisions on a daily, or even sub-daily basis during the peak of snowmelt runoff. Therefore, this effort will not provide a perfect representation of Reclamation operations under forecast uncertainty.

Reclamation should also further investigate its methods for forecast generation. Both spring and fall historical forecasts appear biased and the minimum and maximum plan forecasts may not realistically represent the true uncertainty contained within the forecasts. The magnitude of the historical forecast errors is significant and could result in large deviations from criteria anticipated pool elevations and releases.

References

Grubbs, R., 2018. Personal Communication with Rachelle Grubbs, Western Area Power Administration.

Ruggles, M., 2017. 2017 Bighorn Fisheries Update.

U.S. Department of Interior, Bureau of Reclamation, 2018. Hydromet Data available on the World Wide Web.

U.S. Department of the Interior, Bureau of Reclamation, 2012. Bighorn River Side Channel Investigation: Hydraulic and Sediment Transport Analysis (Technical Report No. SRH-2012-26). Denver, CO.

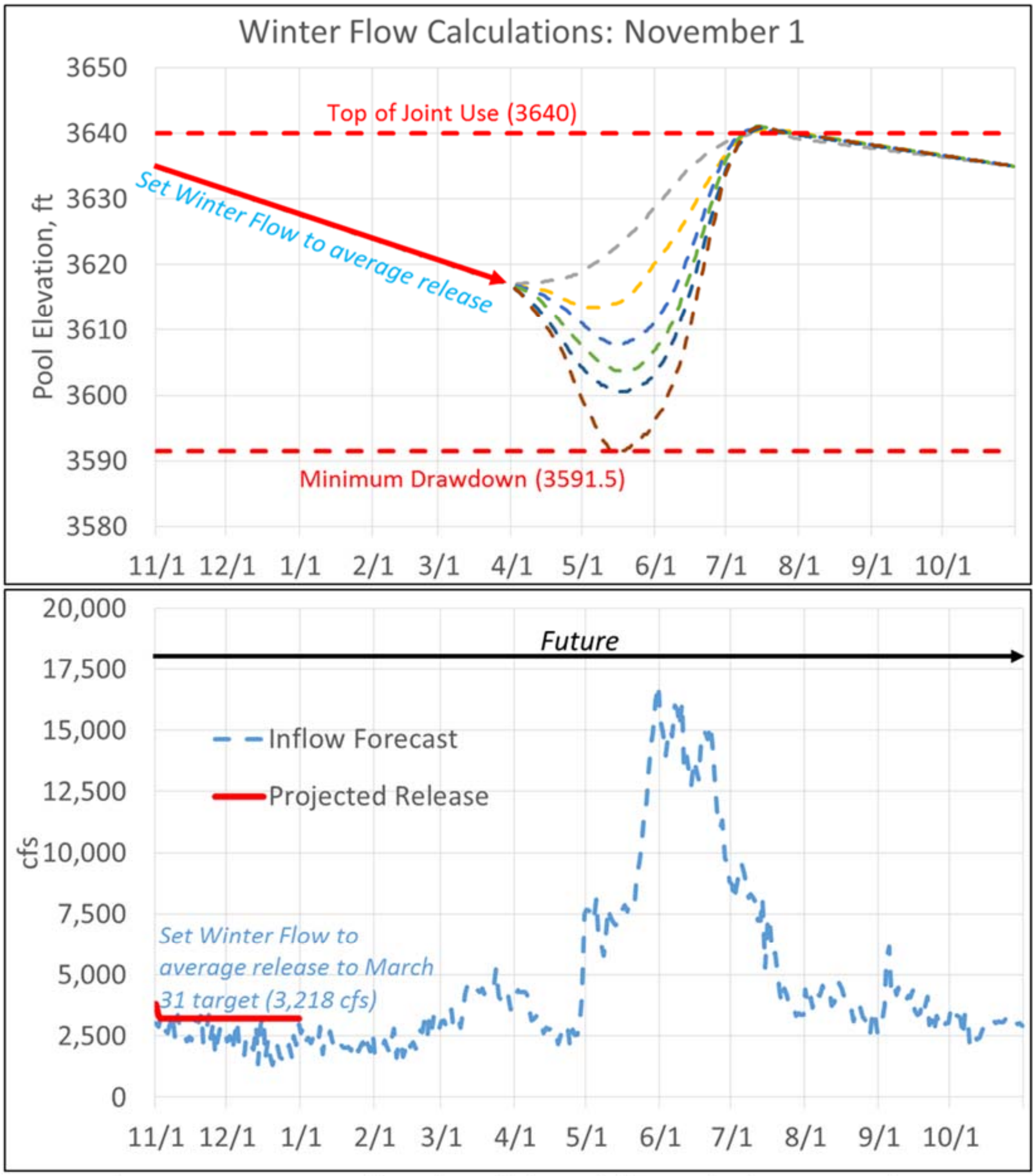
U.S. Department of Interior, Bureau of Reclamation, 2012. Draft Yellowtail Unit Operating Criteria Evaluation Study & Report. Billings, MT.

U.S. Department of Interior, Bureau of Reclamation, 2011. Draft Bighorn Lake Operating Criteria: Changes for the 2012 Water Year. Billings, MT.

U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), 2018. Air-Water Database Data available on the World Wide Web.

Appendix B

Appendix B



Winter releases are set on November 1 through the end of December by targeting the average release to draft Bighorn Lake to pool elevation 3617.0 by March 31.

Figure B-1: Release decisions on November 1.

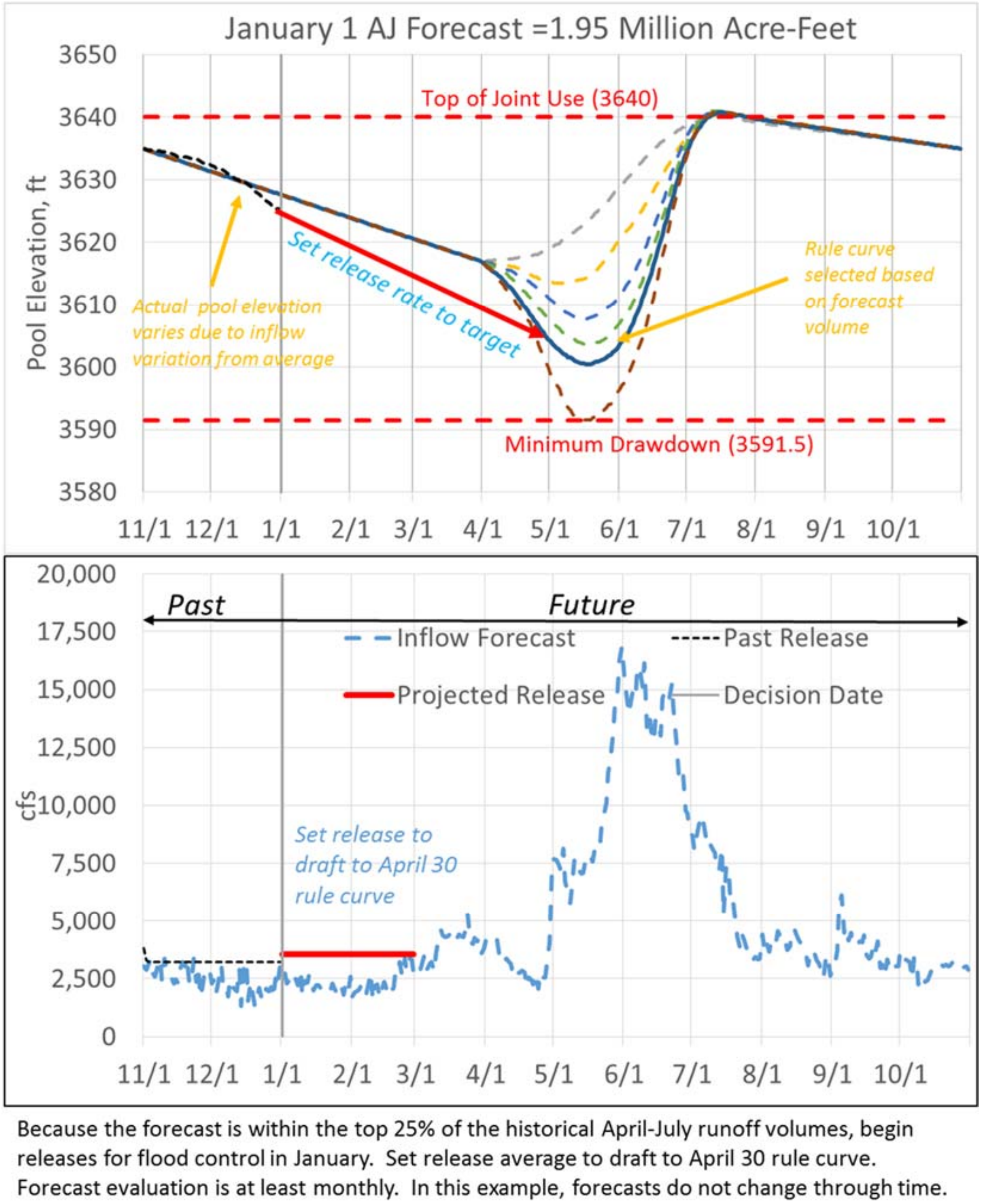
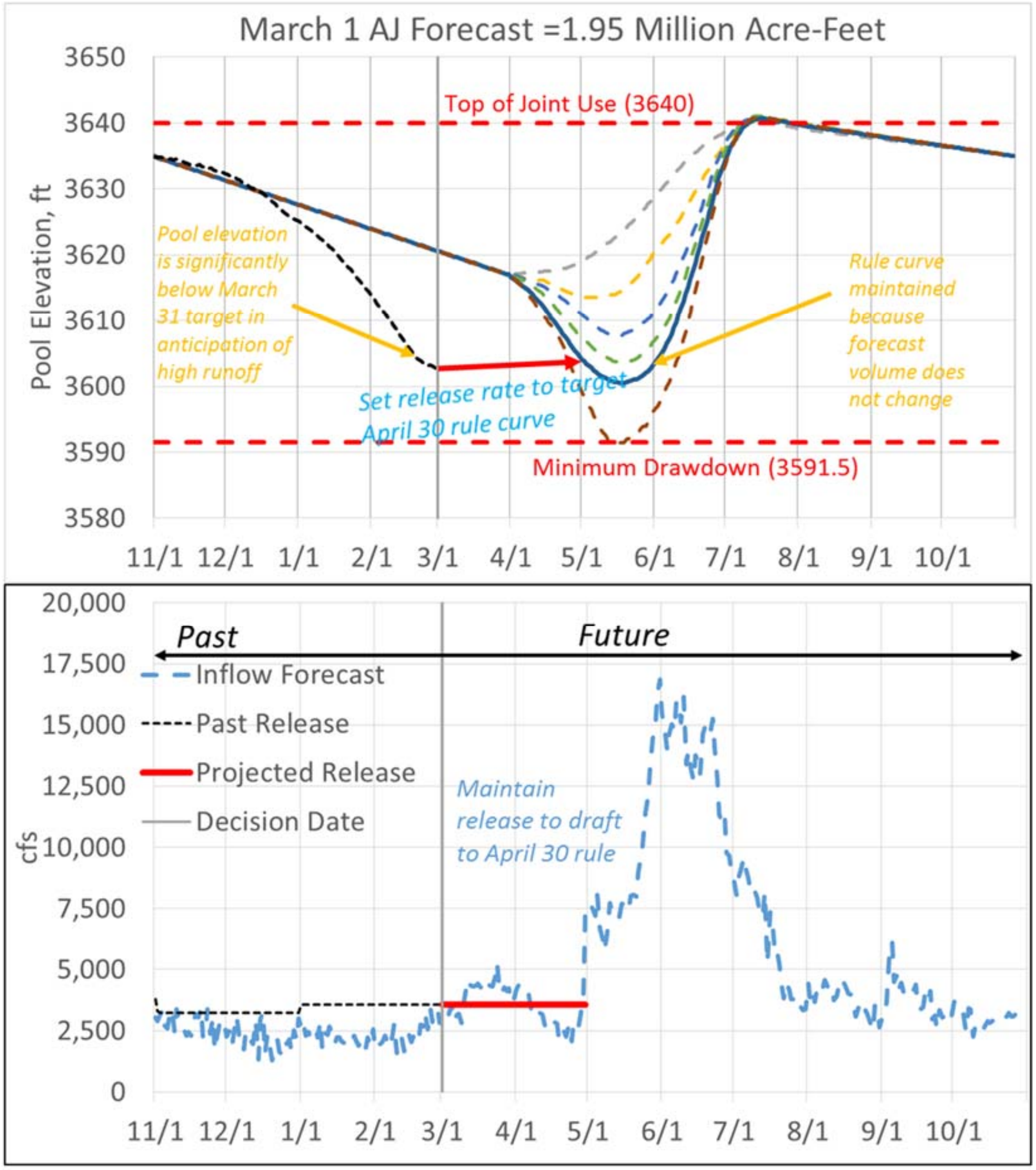
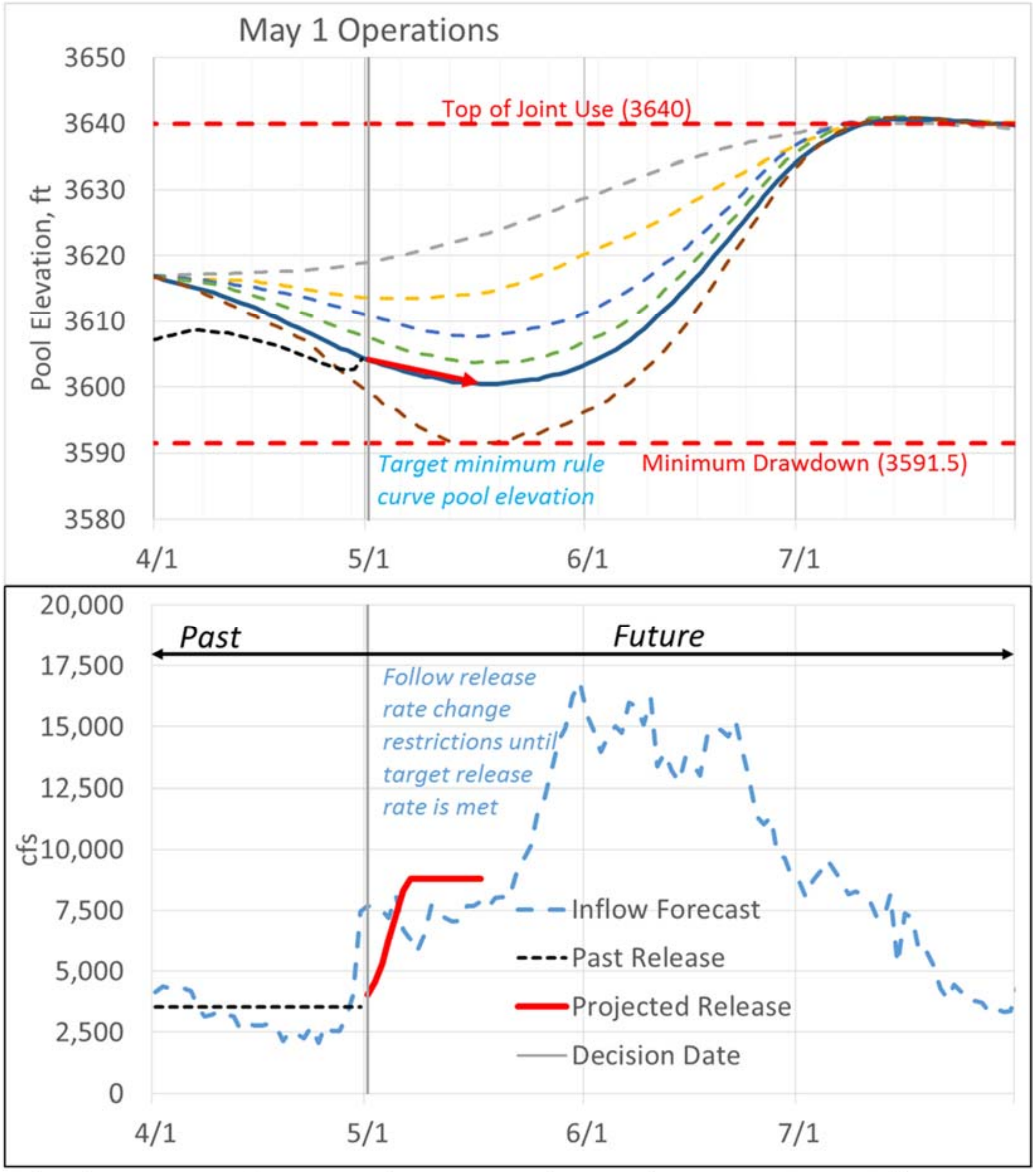


Figure B-2: Release decisions on January 1.



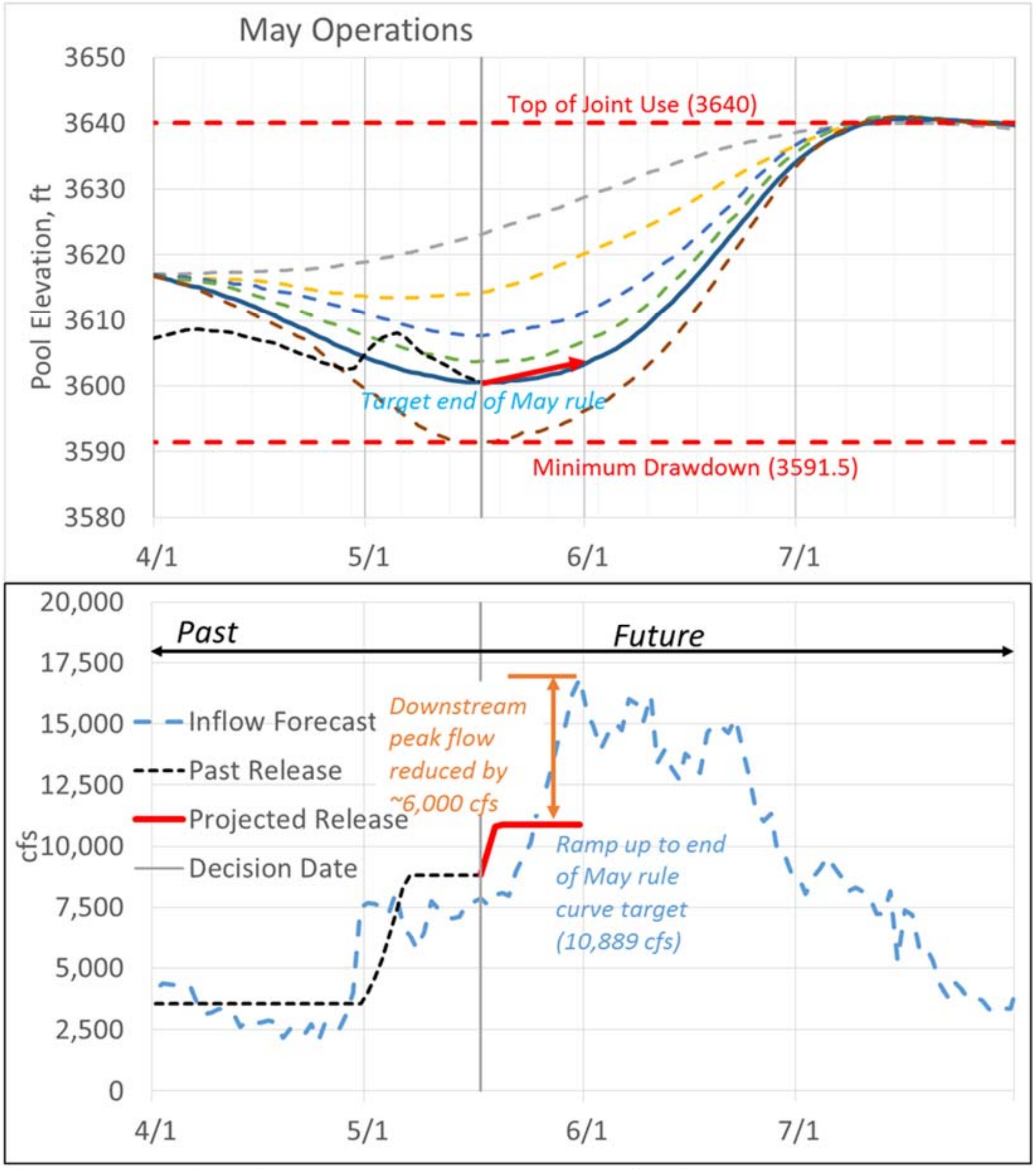
On March 1, always target April 30 rule curve when forecast volume is greater than the minimum fill volume (727,000 ac-ft). Release is set to average to draft to April 30 rule curve.

Figure B-3: Release decisions on March 1.



The release rate is set by targeting the minimum rule curve elevation on May 17. Release rate changes restrict the flow rate and it takes a week to reach the desired release.

Figure B-4: Release decisions on May 1.



The release rate is set by targeting rule curve elevation on May 31. Release rate changes again restrict the flow rate as it ramps up to the desired flow.

Figure B-5: Release decisions on May 15.

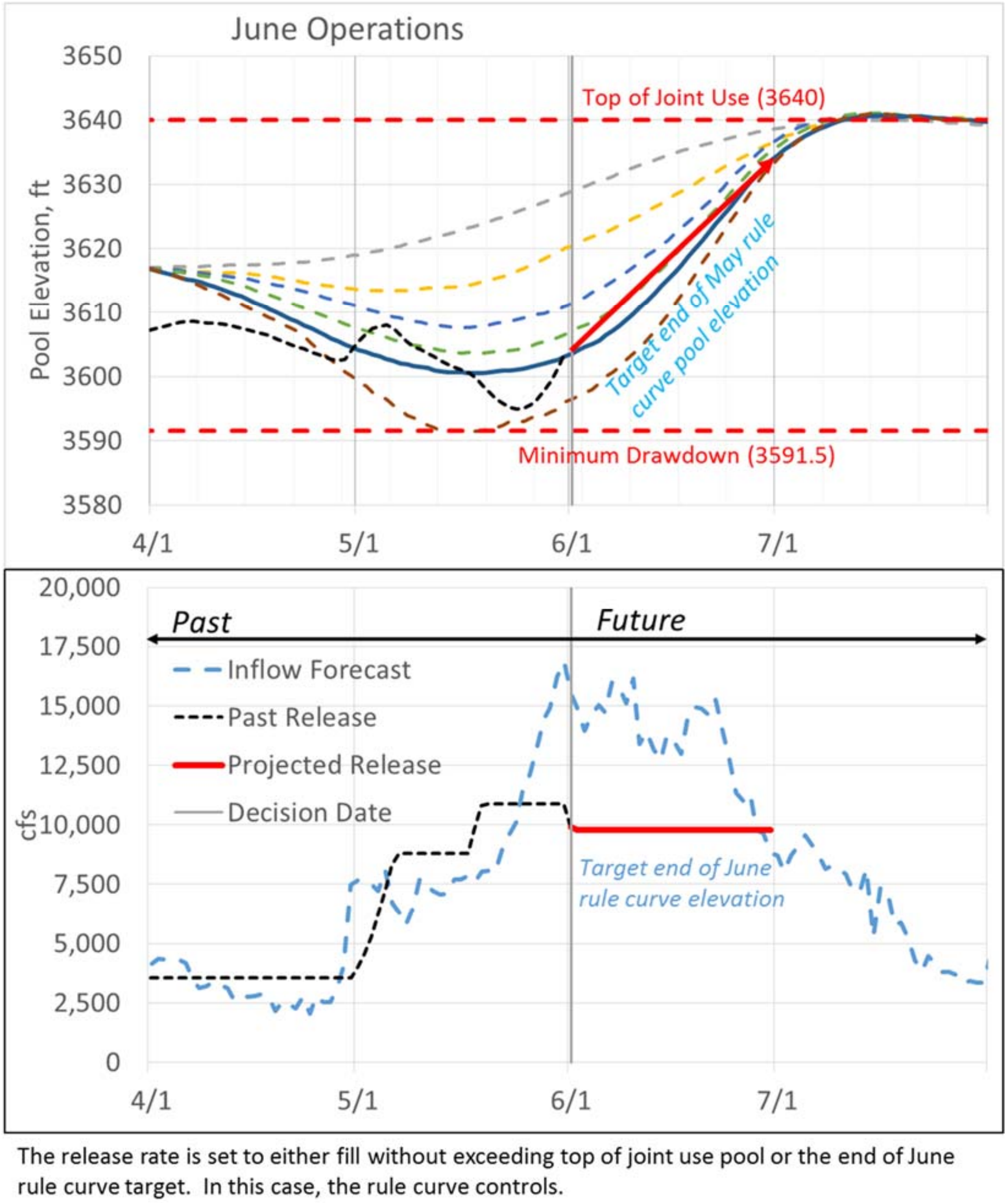
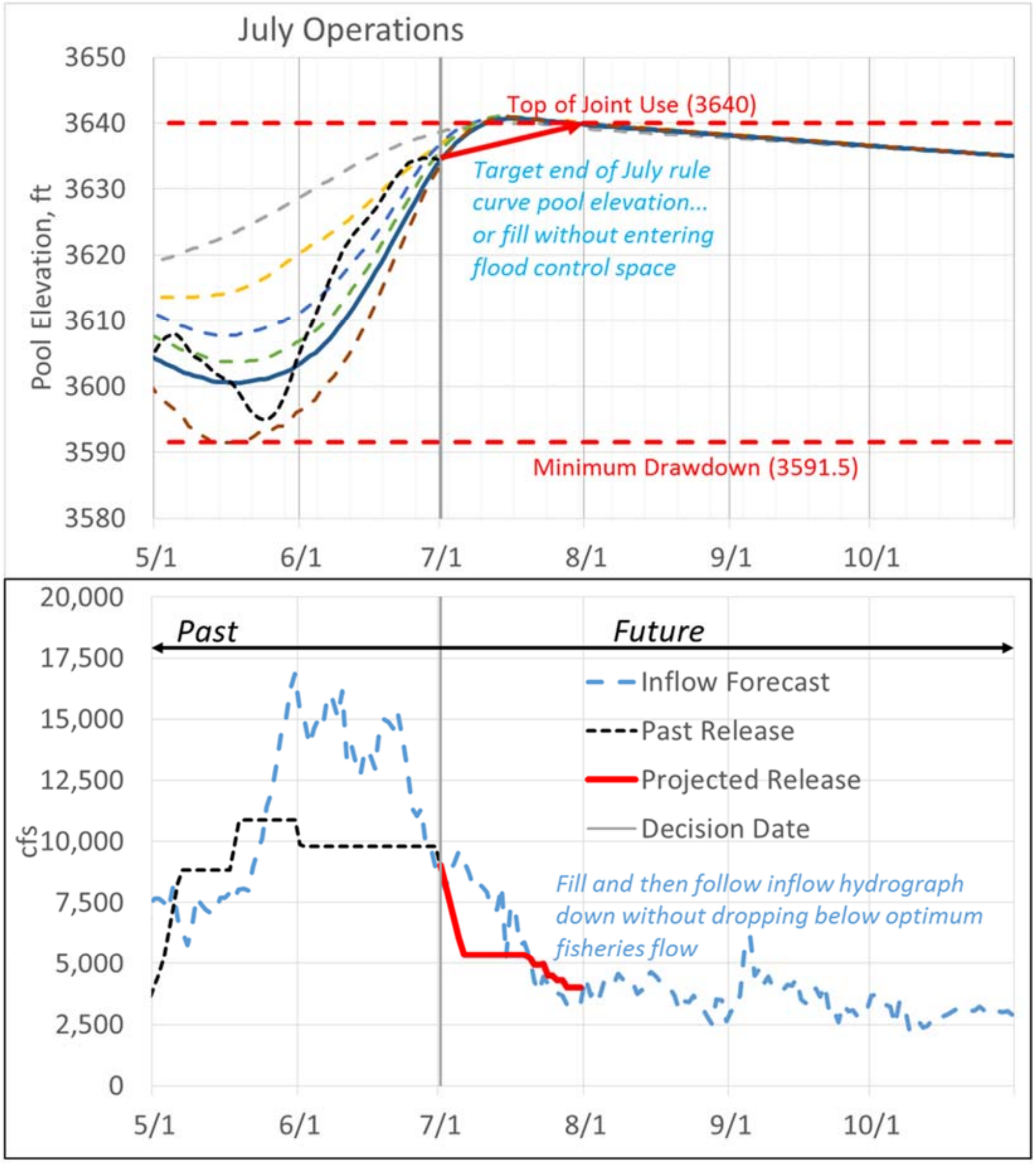


Figure B-6: Release decisions on June 1.



The release rate is set to either fill without exceeding top of joint use pool or the end of July rule curve target. In this case, the reservoir fills on the declining limb of the inflow hydrograph and releases are reduced, maintaining a full pool.

Figure B-7: Release decisions on July 1.

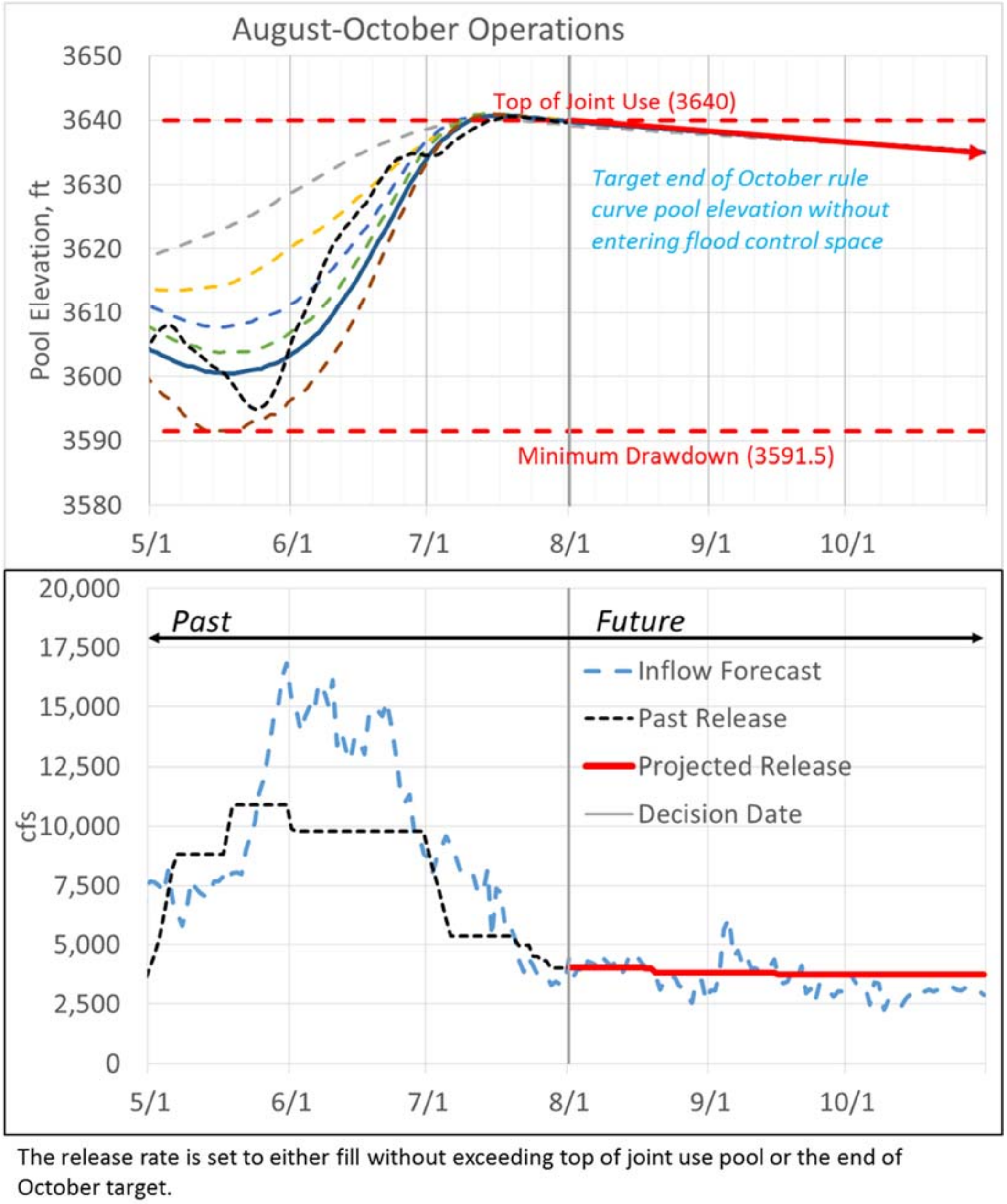


Figure B-8: Release decisions on August 1.

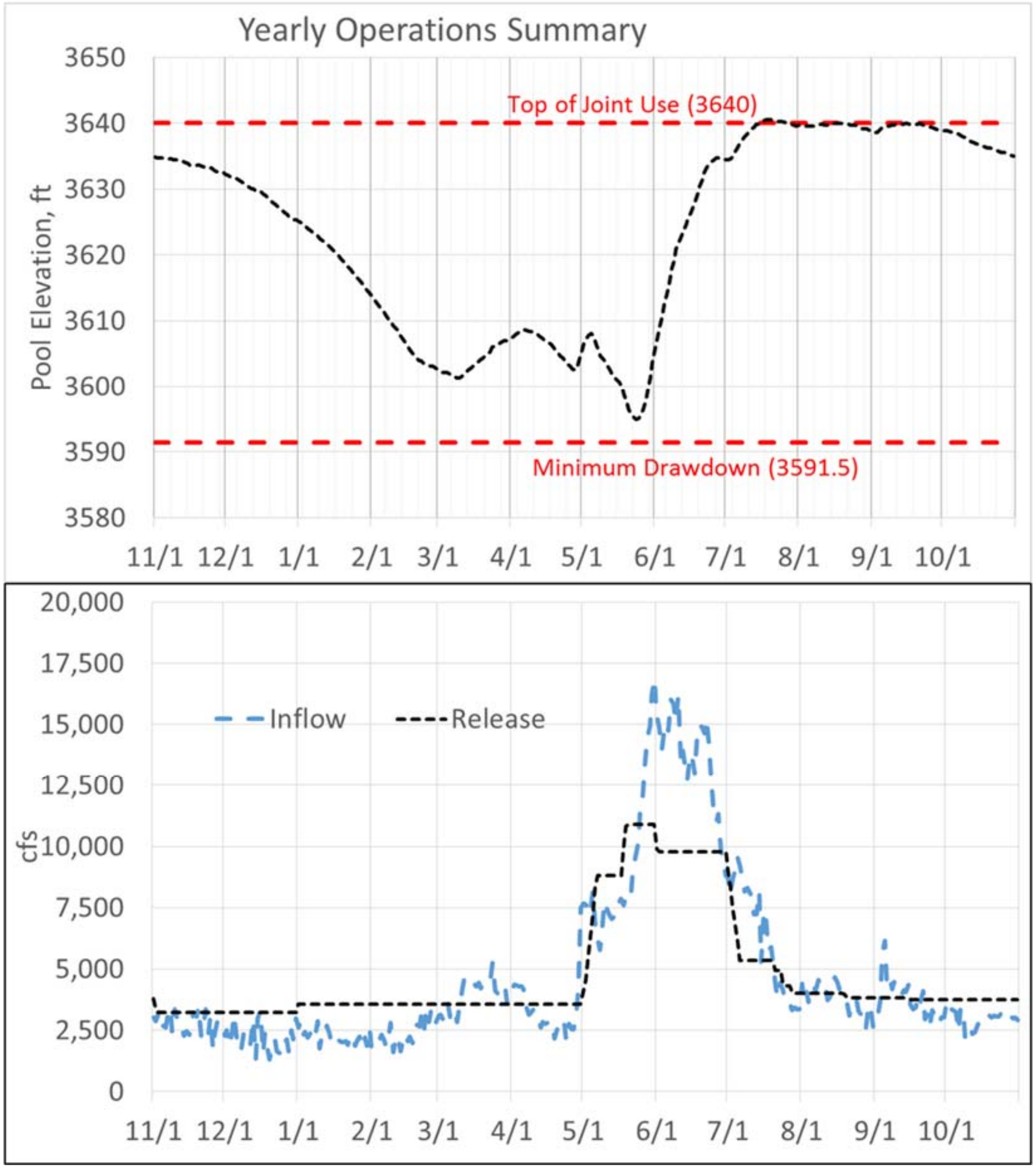


Figure B-9: Summary of example water year pool elevations and releases.

Appendix C

	From	Section Title	Page	Problem or missing information	Solution (How to address the problem)	
Number	Name	Report section	Page	Review Comment	Suggested response	Response
1	Mark Elison		67	Removing future precipitation as a potential predictor variable has never been discussed and does not appear in any of the recommendations. It is not clear to me how this would change predictions or increase their reliability.	Jordan to add detail to linear regression model used in past and enhance report.	The report text was edited to add clarity regarding the nature of linear regression for forecasting. Previously, forecasters would use historical *future* precipitation to build a model. For example, a January 1 forecast would include April-July precipitation. Forecasters would then guess what future precipitation would be when forecasting. This has been shown to reduce forecast skill.
2	Mark Elison		56-59	Graphics for the alternate scenarios are extremely difficult to read. The lines overlap in some cases and the entire graphs are too compressed to be useful.	Jordan to expand and make readable	These graphs were doubled in height and each alternate scenario was graphed individually.
3	Mark Elison		13	There appear to be some artifacts from the modeling that show up as spikes in the 2010 OC Perfect Forecast results. I believe that it was suggested that these result from the requirement to not enter the exclusive flood pool.	Spikes are due to the fixed timing of the rule curve. Model is attempting to hit a fixed target.	Added description of why spike occurs in 2015 (pg. 14)
4	Mike Ruggles		7	Do rule curves apply to years above and below the upper and lower quartiles? if so are they informative and how does that differ between upper and lower exceedances?	Rule Curves do not apply to driest 26%. Upper quartile - used an arbitrary decision. Nothing in the Operating Criteria is stated in the rule curves.	added text for clarity; pg. 7
5	Mike Ruggles		74	What deviation from the rule curves when the upper quartile years occur would meet the need to make changes to the SOP, what is significant and not?	Add a recommendation to the report for the Operating Criteria to include more specifically when, where, why, how to follow rule curve.	Added text and changed title of this recommendation to rule curve targeting recommendation
6	Loren Smith		1	Transparency (A)- The Draft Report indicates that the review of the 2010 Operating Criteria was undertaken at the behest of relevant stakeholders. This creates the impression that all stakeholders sought review of these criteria, which is not the case. This should be clarified by specifically identifying which stakeholders sought review of the 2010 Operating Criteria.	Will change the report to include this	Deleted reference to stakeholders requesting review; parsing all the different reasons why the review has been undertaken is not essential to improving operations. ES-1 and pg 1.
7	Loren Smith			Transparency (B)- The process resulting in the Draft Report has involved multiple units within the BOR playing different roles. To avoid potential confusion and concern, the Draft Report should include a detailed explanation of the full process to date, which BOR units are playing what roles, how those units are related to one another, what each unit's purposes and responsibilities are, who the relevant decision-makers are within each unit, any anticipated future process, and the roles anticipated for each BOR unit in any future process. It has been said that the Montana Area Office (MTAO) requested an independent review by the Great Plains Regional Office of the Bureau yet there has been significant participation in the independent review process by individuals from the MTAO.	Remove "Independent Review", replace with BOR Review.	Removed the word "independent".
8	Loren Smith			Transparency (C)- Some language contained within the Draft Report creates the impression that no changes to the 2010 Operating Criteria are advisable, yet the report presents recommendations which would or could result in such changes. The presentation of this information in this way is contradictory and potentially misleading and should be clarified.	Jordan to clarify descriptions.	Edited the text to clarify that numerous suggestions would change operations, but pool elevation targets are not suggested to be changed.
9	Loren Smith	Scope		The first goal identified in the Draft Report is to "document differences between current and past operations of Bighorn Lake." This goal, and the analysis in service of this goal, is beyond the relevant scope of the review of the 2010 Operating Criteria, which should be limited to comparing actual, expected, and ideal operations and results post-2010. The use of pre-2010 data for purposes outside of assessing forecast accuracy over time and comparing post-2010 water conditions to their historical context should be eliminated from the Draft Report.		This goal was an original goal of the Statistical Analysis study. At past user group meetings, Montana FWP had presented statistics showing differences between past operations and present operations. The underlying assertion was that changes to operations may have had negative impacts to fisheries. The statistical analysis was unable to isolate the causes of the differences between pre-2010 operations and post-2010 operations. Accordingly, the pre-2010 operations were represented in the modeling study.
10	Loren Smith	Model Assumptions		(A) - The comparisons between operations before and after 2010 assume that pre-2010 operations adhered to the 2000 Standard Operating Procedures ("2000 SOPs"). There is evidence that the 2000 SOPs was not the primary operational determinant during this period. Therefore, the pre-2010 operational data and modeling contained in the Draft Report, and the comparisons drawn therefrom, are of questionable accuracy. This is an additional reason that pre-2010 operational data should be eliminated from the Draft Report.	Can be viewed as an alternate scenario. Removing from the report will allow the perception of better operations to persist	Some stakeholders viewed pre-2010 operations as better, based on certain metrics, than post-2010 operations. Accordingly, the pre 2010 operations can be considered as an alternative operating scenario, similar to other stakeholder-suggested operations.
11	Loren Smith	Model Assumptions		(B) The model used in the Draft Report operates on principles of "first in time, first in right." On Bighorn Lake, however, dam operations are influenced primarily by flood control and power generation considerations rather than the priority of water rights. This mismatch between the primary operational determinant of the model and that of actual operations could undermine the accuracy of the expected results under the 2010 Operating Criteria. This, in turn, could undermine the accuracy of the comparison between actual, expected, and ideal results under these criteria.	This model does not apply the water rights solver.	Text was added to the model assumptions describing water rights.
12	Loren Smith	Recommendat ions		(A) - The recommendations contained within the Draft Report are not in the form of a proposal to either change or maintain the 2010 Operating Criteria. Rather, they are in the form of general goals that the BOR should target to improve operations on Bighorn Lake. It is the question of how BOR intends to meet these goals that will determine whether all stakeholder interests are being balanced effectively and appropriately. As such, the Draft Report provides little basis for the BOR to make any specific determination as to whether and how the 2010 Operating Criteria might be changed, and no basis for stakeholders to comment on the advisability of any BOR decision in this regard. For stakeholders to have meaningful input into the assessment of the 2010 Operating Criteria, additional process will be required wherein the BOR advances a clearly defined, specific proposal to either change or maintain these criteria and solicits comments from stakeholders on that proposal.	Will be getting to this point, but not there yet. Area Manager to ultimately make final decision, but with input from public and working group.	Montana Area Office has responsibility for selecting and implementing recommendations. It will prepare an implementation plan separate from this report.
13	Loren Smith	Recommendat ions (2.2)		(B) - Recommendation 2.2 is to "update rule curves to anticipate higher inflow volumes." To the extent that this amounts to a change in the 2010 Operating Criteria, it would be unwise to make any such change given the grossly anomalous water conditions since 2010 when compared to the historical record. The Draft Report identifies forecasting error rather than deficient rule curves as the primary factor limiting ideal operations. To change the rule curves "to anticipate higher inflow volumes" on the scale of what has occurred since 2010 would be to set operations based on the exception rather than the rule.	Anticipate for future high water years.	Added text for clarity
14	Anne Marie Emery	Recommendat ions (2.2)		Updating rule curves to anticipate higher inflow volumes is important as it provides new extremes that min and max scenarios can adjust too, or provide better operating instruction to operators when these events occur. Currently, rule curves cannot be followed due to unpreceded high water- which reduces transparency and increases reliance of operator judgement. If changes were made to operations for drought years exceptions than the same should be done for high water exceptions.	Anticipate for future high water years.	Added text as suggested.
15	Anne Marie Emery	Conclusions	4	Last bullet point - in addition to 2010 operating criteria note defining operations during dry years, we should also not that it does not define operations in high water years.	Anticipate for future high water years.	Edited text to state "•Rule curves were built using an assumed inflow hydrology and maximum inflow volume. " indicating they did not anticipate the record inflows. It's not clear how much impact this had, as forecasts did not reach the maximum volume in those record years.
16	Anne Marie Emery	Conclusions	5	It would be beneficial to state all interests	Jordan to look at this	Added text as suggested
17	Anne Marie Emery	Pool Elevation	11	Looking at average winter monthly flow releases from 68 to present, winter releases were on average higher than what we see today. That, in addition to the higher pool elevations makes me wonder why the model cannot determine the cause?	The report did not analyze different winter releases. Previously they were higher and now lower. 3500 cfs is ideal, but understood it can't always be met (Mike). Jordan to perform additional analysis	Raising the end of March target to 3,617.0 ft., on average, will reduce winter releases. Added a new scenario using a fixed 3,500 cfs winter release rate.
18	Anne Marie Emery	Pool Elevation	11	Since implementation of the 2010 SOP, how many times have we drawn down to the 3591 elevation? It would be interesting to model holding at this elevation during high flow years, using perfect forecast to understand how sustaining the 3591 elevation for a period of time would help high flows downstream and if or if not sustaining minimum elevation would conflict with NPS recommendation target.	Has not been drawn down since using the 2010 Operating Criteria. This has been modeled in report on pages 15, 16, and 17.	This was contained within original report text; no changes necessary.
19	Anne Marie Emery	River Release	12	Figure 4. This graph does not reflect daily fluctuations performed by operator. I would like to see all graphs show daily operator fluctuations as opposed to set river releases (especially during the winter), as maintaining a constant release may prevent operator from staying on track when trying to achieve important targets. This seems like an important preventative measure that keeps operations on track.	There are no fluctuations because this is a long term average plotted daily.	The intent of this plot is to show general differences between the two operating policies. It uses perfect forecasts to eliminate the impacts of operators on operations.
20	Anne Marie Emery	River Release	12	I would like to see average winter monthly releases (Nov - Feb) from 1968 to present in a line graph to help identify changes between operations. See attached graph	Per previous comment, additional analysis	This analysis is shown in Figure 4.

	From	Section Title	Page	Problem or missing information	Solution (How to address the problem)	
Number	Name	Report section	Page	Review Comment	Suggested response	Response
21	Anne Marie Emery	Idealized operations to minimize river releases during record inflows	15	Was the Bighorn Lake drawn down to 3591 for just one day, or was it sustained? Please clarify. Also, why are inflows and releases constant- can't we use perfect forecast?		The goal of this analysis is to show the absolute best possible conditions-basically the physical restrictions of the system. The reservoir is drawn down on the first day of the period and allowed to fill over the April through July period.
22	Anne Marie Emery		16	Report should not assume that 12% reduction in flows is not significant for downstream users.	remove "only"	changed as suggested.
23	Anne Marie Emery		17	Last paragraph - I think incorporating hydropower into the model is important to understand how the timing and duration of draw downs impact generation. Is a low head in the spring, better than increased spillage in the summer?	Jordan to perform additional analysis to include hydropower. Per Rachelle, low head in the spring is better in this instance.	This paragraph indicates that the outages we observed over the last decade are not analyzed; it's a best-case analysis. Hydropower is represented in the model.
24	Anne Marie Emery	Water year operations review	18	Why are operators today not able to update forecasts on a frequent basis?	They currently do this. Daily conversations are had looking at National Weather Forecast data. Jordan does not have these forecasts, only monthly.	text was added to clarify intramonth forecasting.
25	Anne Marie Emery		43	Need legend for figure.	Jordan to add	Figure added
26	Anne Marie Emery	Results	54	Looks like nearly all mean pool elevations allow for access for lake recreationists by June 1st? Perhaps that should be discussed and considered.	Larger graph may help	enhanced figures for better scrutiny.
27	Anne Marie Emery		63	There is no transparency during high or low water years when rule curves cannot be applied. If we are seeing a momentary trend of high water today, then shouldn't we look at dry years as a momentary trend as well? Operations were changed in 2010 to adjust to mother natures drought, now we need improve operations for mother natures high water.	Need to anticipate any condition and not ignore high or low years.	A number of recommendations address operations in both high and low inflow years.
28	Anne Marie Emery	General Question		If the reservoir was kept ten feet lower over the past 10 years, is there one instance where end of March and May targets would have been met?	In most years the targets would be met, but in 2016 the targets were not met. Mark to draft a suggested Operating Criteria change	Analyzed suggested operating scenario ("MELS Scenario.")
29	Anne Marie Emery	General Comment		I agree with many of the recommendations provided and do not see a single recommendation that disrupts balance or challenges interests. While the CADSWES report input and the RiverWare report suggest further areas to study, I would like to see the group identify what recommendations can be implemented ASAP, in addition to noting what recommendations need further evaluation.	BOR is working behind the scenes on forecast improvements and upstream modeling.	Developed a preliminary implementation plan.
30	Anne Marie Emery	CADSWES	8	"Logic not intended to follow the rule curves" - does this mean that daily adjustments are not made to keep on track with rule curves? I would think that constant releases are part of our problem with not being able to stay on track with rule curves and thus missing important targets. Could you clarify this?	Not followed daily, and Jordan set how frequently to target the rule curve.	The model does not track the rule curves on a daily basis. This would result in daily changes to release rates, which would be undesirable for hydropower, fisheries, and recreation downstream. I attempted to balance the need to track the rule curves and minimize operational changes.
31	Anne Marie Emery	CADSWES	8	I understand why Boysen should be disabled for this model run, but reiterate my interest in having both Boysen and Buffalo Bill included.	Noted	The report likewise recommends implementing a basin-wide operations model. Significant effort will be required to develop and calibrate this model prior to implementation.
32	Anne Marie Emery	CADSWES	9	Agree with suggestion to model Afterbay	Afterbay operated on a subdaily basis. Model shows it on a daily basis. Only impacts WAPA and outside parameters of study	Yellowtail Afterbay was constructed to smooth the releases from Yellowtail Dam, allowing for peaking power releases. This also allows us to model the system on a daily timestep, as river releases do not vary throughout the day due to the Afterbay.
33	Anne Marie Emery	CADSWES	11	3.4 Running the Model, Third bullet point: please clarify "we could see how the model was altered to produce other similar results, but we did not do further testing on this,"	CADSWES ran a scenario but not all of the years, 2010-2018	This statement indicates that CADSWES ran a single scenario to verify the results within the report, but did not run every year examined within the report.
34	Anne Marie Emery	CADSWES	12	I think transparency on USACE manages on the reservoir when in the EFP would be beneficial.	This is a USACE decision and outside of study. USACE Water Control Manual (not public).	USACE operations are based on its Water Control Manual, and both local and Missouri Basin-wide conditions. Reclamation cannot provide transparency on USACE operations as a part of this study because it lacks authority over the exclusive flood control pool.
35	Anne Marie Emery	CADSWES	13	CADSWES recognizes bias that under predicts water which will lead inevitably into entering the exclusive FCP on wet years. I interpret this a bias of operator judgement and forecasting error. Forecasting improvement is needed, but operator bias and judgement also needs to be improved.	Statement agrees with those in the report.	Several recommendations were developed to address these concerns.
36	Anne Marie Emery	CADSWES	14	The model cannot represent history, but conclusions can be made looking at historic water delivery patterns which include frequent, minor fluctuations to water releases and higher winter flows.	Addressed in previous comments	Addressed in previous comments
37	Keith Grant		1	*Stakeholder groups called for review of the 2010 Operating Criteria -* This statement is very misleading, it insinuates that all stake holders called for this review. This is a false mis-leading statement and is mentioned in several places in this document. It was initially called for by the Bighorn river Alliance, and a few folks that have encroached in the Bighorn River Flood plain, in January of 2018. This was followed by a letter by the Montana Fish and Wildlife Commission to Steve Davies on March 12, 2018 asking for a change in management. This does not represent the Stake Holders Group! This must be clarified it is a group of Montana folks with a single purpose in mind! We can read what that purpose is by reviewing their past writings	Look at Loren's ?	Deleted reference to stakeholders requesting review; parsing all the different reasons why the review has been undertaken is not essential to improving operations. ES-1 and pg 1
38	Keith Grant	Executive Summary	1	*Reclamation implemented changes to its Bighorn Lake/Yellowtail Dam operating criteria in water year 2010 .* - This is another mis-leading statement; The Chapter IV 2000 SOP management was not followed, it was managed from about 2000 through 2006 to accommodate the informal agreement BOR had with Montana Fish Wildlife and Parks, with no consideration for Lake Recreation! At a Lovell Chamber meeting in 2006 Darrel Cook, Bighorn Canyon Park Superintendent told a group of Lovell residents, that due to the fact that the Bureau was not interested in water recreation in Wyoming, that he could get no cooperation from the Bureau, he was going to decommission Horseshoe Bend! We disagreed with him, Horseshoe Bend in still thriving, in 2007 BOR changed management to the Chapter IV SOP which continued until 2010, when Reclamation implemented the 2010 changes! This mis-leading information must be changed, and accurate data installed, anywhere it is used in this document. Which probably will change some assumptions and require some rewriting of this document. Why are we going back and using the 2000 Chapter IV SOP, especially since it wasn't followed? Why are we going backward to review BuRec;s past faulty bias mis-management? I thought the direction was to determine how the 2010 criteria worked and how it could have worked better?	2000 SOP was represented because of claims that it was better in the past. Provides a comparison to review with the 2010 Operating Criteria. 2000 was modeled based on Jordan's interpretation of the 2000 SOP. Doesn't believe it to be a strong representation	A. Reclamation did implement changes to operating criteria in water year 2010. B. I found no evidence that Chapter IV SOP's were not followed. The 2000 Operating Criteria were somewhat vague, leading to great operator flexibility in operations. Also, the period 2000 through 2006 was extremely dry. Modeled operations using the 2000 Operating Criteria and perfect forecasts show that nearly the entire period should have had lake levels below elevation 3617 (Figure 3). C. As described above, the 2000 Operating Criteria can be considered an alternative operating scenario, and provides important context for the changes in operations from the 2000's to 2010 Operating Criteria.
39	Keith Grant	Executive Summary	1	*On behalf of the Montana Area Office, Reclamation's Great Plains Regional Office is independently reviewing the operating criteria. The goals of the review are to: 1) document differences between current and past operations of Bighorn Lake; 2) determine if significant differences exist between the realized and anticipated benefits of the operating criteria; 3) determine potential causes for any differences in operations and realized and anticipated benefits; and 4) propose potential operational improvements for future examination.* We believe this has gone far outside the original intent of these technical meetings. It seems all we have discovered so far, is that we need perfect forecasting? This study surely does not have any similarity to the River Ware program outlined by The University of Colorado Boulder, what criteria was being followed in this study?	Answered already	Several recommendations were developed to address these concerns, in addition to forecasting improvements. Additional detail was added to the description of operating criteria.
40	Keith Grant			**This states the purpose of this study;** *Preliminary exploration of modifications to the operating criteria show operations with the 2010 Operating Criteria and perfect forecasts are relatively balanced between competing uses. Reclamation and stakeholders endured a long process resulting in the 2010 Operating Criteria. Potential improvements should not attempt to mitigate the high flows observed over the last nine years at the expense of operations for water supply during dry years and should maintain the agreed upon balance between interests. It is important to incorporate only those improvements that benefit all parties, rather than improvements coming at the expense of a competing interest.*		

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41	Keith Grant			**It also states;** *weather forecasting is only skillful over short periods.* As such, there is a limit to how much Reclamation's forecasts can be improved.		It is important to understand the differences between weather (short-term) and climate (mid- and long-term). Weather forecasting refers to the skill of a 5- to 10-day forecast. Further improvements can be made through incorporating climate indices. However, because we cannot accurately forecast weather past about 10 days, it is unlikely that we can significantly reduce forecast uncertainty. As such, we must strive to use the forecasts in a better manner.
42	Keith Grant			This study tells us; Any Recommendations are likely to show small impact to operations.		Some recommendations will have small impacts; others will have larger impacts. However, Reclamation should strive to improve its operations regardless of the level of impact. Reclamation should also prioritize the most impactful changes.
43	Keith Grant	Model Development	2	*A river system model was developed using the RiverWare™ software. RiverWare was developed by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) of Boulder, Colorado.* Why weren't these priorities that this software requires included in this in this study? It seems that this study cherry picks what it wants out of this software program, and ignores what doesn't fit someone's agenda?		Additional information regarding policy in the model was added to the report.
44	Keith Grant		9	No information regarding low flow releases existed 2000 SOP operations. Read the Chapter IV 2000 SOP, It definitely has low flows criteria! As witnessed in 2007 SOP management.	Not enough information for Jordan to put into a rule.	The SOPs state: "Whenever an adequate water supply is available, releases from Bighorn Lake will be maintained at rates to sustain flows in the Bighorn River at 2,500 cfs or higher. This is normally required to protect the quality and quantity of the river fishery and protect lake and river recreation activities. When there is not an adequate water supply available, it may be necessary to reduce releases to the Bighorn River to 2,000 cfs or the absolute minimum flow of 1,500 cfs required to protect the river fishery." This does not relate forecasting, inflows, or pool elevations to releases in any quantifiable way. Accordingly there was inadequate information to define rules under the 2000 SOPs for low flow operations.
45	Keith Grant		13	*A few short periods under the 2000 SOP operations resulted in releases below 1,500 cfs, when releases were reduced to avoid drafting below the top of inactive conservation.* In April 2003 and 2004 there were only 5 days when the out flows were above 1500 cfs, just one month in two years, someone wasn't very thorough in their data review! It is a fact that from 2000 through 2006 the river was managed to accommodate the infamous, informal agreement with MFWPS. This whole study is faulty, nothing more than a biased effort to appease the Montana Fishery Folks! This whole exercise is nothing more than an effort to try to regulate the Reservoir to accommodate the Montana River Fishery at the expense of Lake recreation!	Referred to modeled operations. Jordan to revise.	This section refers only to modeled operations and not historical operations. Added a statement to clarify.
46	Keith Grant	Forecasting	65	*it is important to use accurate statistics* - We totally agree with this statement, and it has not been followed!	Modeled Operations were used for 2000 SOP and not what actually happened.	The report recommends improving statistical forecasting techniques.
47	Keith Grant		67	Forecasting using La Nina and El Nino is a little bit far-out, as referenced earlier "**weather forecasting is only skillful over short periods**"	weather is short term conditions. Climate is general patterns for long term. Would need to verify if this adds skill.	weather is short term conditions. Climate is general patterns for long term. Would need to verify if this adds skill.
48	Keith Grant			At the last meeting all stake Holders were in favor of using the flood control space to better control lake levels and river flows. As we all witnessed this year this space was available to help reduce out flows, something we had been told was not possible! Why was this information not included in this study? I believe lack of available information is as damaging to a study as Mis-information! River Ware suggests doing just that, why wasn't it considered in this study? Consider increasing yield by reallocating some flood pool space	Jordan suggested setting up RiverWise so it can be modeled. Worried it comes across as endorsement. Jordan to run the top of joint pool elevation scenario (raise by 5 ft). Jordan to model what Mark and Loren provide.	Analyzed an alternative scenario which raised the top of joint use pool by 5 feet.
49	Keith Grant			Could we get an explanation on why this study totally ignored siltation and the obvious reason higher lake levels are advantageous? Ignoring the siltation studies by the CORP and the Bureau seems strange?	Jordan can make an estimation by analyzing the local timing of the tributaries with comparison to lake elevation and flows	Sedimentation is one component of a complex system with multiple competing uses. Likely, sediment load is largest when inflows are highest, and when the reservoir needs to be operated considering flood control. Performing the suggested study analyzing the timing of sediment inflows might provide additional information but is outside the scope of the current effort.
50	Keith Grant			This study talks about the years and years the Stakeholders have spent working on this issue, yet the studies and information we have gleaned over those years are totally ignored, could we get an explanation on why no consideration was given to this information? Side Channel Study, opening up side channels to provide more capacity.	Can review and see what information can be added. This report looks at a model, which is an overview of the river, and not specific portions of the river. Safe channel capacity from USACE, 15,000 cfs max rate from BOR.	A recommendation from the report is to examine the relationship between various release levels during flood control.
51	Keith Grant			Riverware requires prioritized Rules. What is the Rule Based prioritized rules? How are priorities determined? What determines the criteria to be used? Will the Bias be left out? Will the criteria include the legal priority when determining the Rule Based prioritized rules? What determines the priorities and criteria that will determine for the Rule Based Operating Criteria? Acts Congress or the Directives, Standards, Rules, and regulations of the Bureau?	Rules are based on 2010 Operating Criteria. Hierarchy of Congress, D&S, Regulations came from discussion with Mike Tranel and Steve Davies. They discussed the Solicitor's Opinion and shared portions of it with Technical Working Group. CADSWES was hired to review the model and verify. Will review description in report and re-review it/make changes if needed.	Additional information regarding policy in the model was added.
52	Keith Grant			What determines the data supplied to reach the conclusions requested? Can we assume the data specified and used is complete and accurate?	Inflow data comes from Hydromet and is a calculated value. MTAO performs quality control/data corrections. Jordan to review 2017 data. Will review end of year data corrections.	Inflow data comes from Hydromet and is a mass balance calculation using daily change in storage and release. MTAO performs quality control/data corrections. Reviewing MTAO's quality control procedures is outside of the scope of this project.
53	Keith Grant			What determines the priorities and criteria that will determine the Riverware Rule Based Operating Criteria? Congressional Acts or the Bureau Directives and Standards?	Rules are based on 2010 Operating Criteria. Hierarchy of Congress, D&S, Regulations came from discussion with Mike Tranel and Steve Davies. They discussed the Solicitor's Opinion and shared portions of it with Technical Working Group. CADSWES was hired to review the model and verify. Will review description in report and re-review it/make changes if needed.	Additional detail was added to the "Policy Assumptions" describing priorities and criteria.
54	Keith Grant			Who and What determines the data supplied to reach the conclusions requested?	Inflow data comes from Hydromet and is a calculated value. MTAO performs quality control/data corrections. Jordan to review 2017 data. Will review end of year data corrections. Jordan reaches these conclusions. If different opinion, please share and comment	Inflow data comes from Hydromet and is a mass balance calculation using daily change in storage and release. MTAO performs quality control/data corrections. Reviewing MTAO's quality control procedures is outside of the scope of this project.
55	Keith Grant	3.2 - General Comments on Use of a Model		The model is only as good as the formation of equations, the input values, and the resolution at which the equations are solved. The model should represent only those processes that are required to answer the modeling objectives.	CADSWES was hired to review the model and provide input/suggestions	Reclamation hired CADSWES to perform an independent review of the model. CADSWES generated a report describing its procedures and conclusions regarding the applicability of the model for reviewing Yellowtail Dam operating criteria.
56	Keith Grant	3.3 - Use of RiverWare Functionality		This section describes how well the model uses RiverWare to meet the modeling objectives. Belief that it has a strong biased towards the river.	The model doesn't have a bias. It takes the data input and runs with that information based off the rules of the mode. It models reservoirs based of elevation. Keith to review 2010-2012 Operating Criteria for any biases.	The model represents operating criteria, which was verified through independent review.
57	Keith Grant	3.3.2 - Rules and Operating Policy		"The operating objectives for the projects include: water supply needs downstream of Bighorn, maintaining storage space for flood control in the spring, maximizing hydropower benefit, maintaining lake levels for recreation and lake fisheries, and maintaining desired fishery releases to the Bighorn River below the Yellowtail Afterbay Dam." 1. Irrigation 2. Flood 3. Hydro power 4. Lake Levels and Lake fishery 5. Desired river flows for river fishery "We assume the data specified for a particular scenario was complete"?		CADSWES was stating that they did not have adequate budget to verify the particular data within the model.
58	Keith Grant	4.1 - Include Quantification of Hydropower		We recommend modeling the hydropower	Jordan to incorporate this.	Hydropower is represented in the model.

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59	Keith Grant	4.2 - Represent water supply more explicitly		One approach would be to explicitly model all diversions and water rights "first in time first in right"	Review Loren's questions	The "Policy Assumptions" section now describes the approach to water rights.
60	Keith Grant	4.3 - Represent Rules and the use of the exclusive flood pool		Once expanded, perhaps flood control in this region could be included. ("RIVERWARE (CADSWES) states) (" Consider increasing yield by reallocating some flood pool space"!)	Will look at that and discuss in RiverWISE	Represented increasing the top of joint use pool.
61	Keith Grant	5 - Conclusions		Model the use of the USACE exclusive flood pool in the analysis if possible. Improve forecasts as much as possible. Although perfect forecasts are never possible.	To discuss with RiverWISE modeling. Can include in report.	Represented increasing the top of joint use pool.
62	Keith Grant			As we review the Relevant Yellowtail Unit and Bighorn Canyon National Recreation Area Authorities document handed out at the last Tec meeting, it is my opinion that it cherry picks the documents presented in order to push the Bias of the author. As I review the "Bighorn Lake RiverWare Model and Report Review" document it seems to solidify my previous comments. (Higher lake levels causing sedimentation to drop out further upstream) 1. Problems with the data 2. Purpose of this study not adhered to 3. Forecasting It is not Possible to have perfect forecasting 4. Any changes to current management will have minimal effect 5. It is important to use accurate data 6. Use of flood control space is possible 7. Siltation is totally ignored --- higher lake levels keeps siltation further up the reservoir 8. Studies done over the years by the Bighorn River Issues group ignored	Recap of previous comments	Addressed previously.
63	Keith Grant	Reclamation Manual Directives and Standards CMP 01-01		It seems that Reclamation has a directive to manage the Flood Plain, "Introduction. Reclamation will proactively seek and implement appropriate floodplain management activities to sustain, restore, or enhance the functions of the floodplain. Watershed and floodplain management issues will be approached on an integrated systems approach accounting for watershed hydrology, river hydraulics, land form and channel geomorphology, river mechanics and sedimentation, land use, water quality and quantity, ecosystems, and functions of the floodplain." It would seem this D&S is applicable to all Reclamation activities in floodplains or affecting floodplain management? Our past studies have told us that over growth and loss of side channels increase's flooding problems. Is Reclamation in charge of managing for these flood plain problems? Should reclamation be controlling flood plain encroachment? Rather than trying to find a way to lower river flow releases, at the expense of providing for the needs of a National Park? If the River Fishery is a project purpose then also is the Flood Plain management, and preventing encroachment in the Flood Plain? These are all Bureau Standards and Directives, they relate to the river management problem, Flood plain management could help with all these problems.	Reclamation to review and discuss D&S internally and provide a response.	MTAO to review.
64	CADSWES		15	Include hydropower quantification as it one of the stated operating objectives. Even if the quantification is not perfect, it gives the readers a sense of the impacts on hydropower based on the scenario.	Jordan will model hydropower	Represented hydropower and added some figures representing generation.
65	CADSWES		15	Model the use of the USACE exclusive flood pool in the analysis if possible.	At this time it is not possible to model how USACE makes decisions based on the exclusive flood pool	This would require representation of the entire Missouri Basin, which is well outside the scope of this study.
66	Tech. Working Group			Run scenarios where the flood pool is utilized	Provide group with RiverWise to run situations	This scenario was run and added to the report.
67	Keith Grant		5-6	Pages 5-6 Policy Assumptions; seem incomplete and misleading in some areas. I think that misleading assumptions put a whole document at risk. Which Congressional acts does the Bureau plan on managing under, we were told of one that the Bureau doesn't plan on managing for?		The policy section defines relevant congressional authorities. I cannot respond without specifics on misleading assumptions or what "the Bureau doesn't plan on managing for."
68	Keith Grant			It would seem that the Bureau cherry picks information from these documents to achieve the outcome they have chosen. Definate Plan Report 1950 – 1962 – 1965, why was 1965 update not included? Was it to help justify a desired outcome?		The definite plan report referenced in the report is the version transmitted in 1965. The report is dated 1962. For this reason, I dated the reference 1962. It's now changed to 1965 for clarity. There was no predetermined outcome for this study.
69	Keith Grant			Consider 2010 Crow Water Rights Settlement ? Why is the Sec. 412 Yellowtail Dam, Montana, requirement of "Federal activity of Lake level stream flow left out"?		This is considered and described in the policy assumption section.
70	Keith Grant			Why is the Sec. 412 Yellowtail Dam, Montana, requirement of "Federal activity of Lake level stream flow left out"?		Sec. 412(a)(2) BIGHORN LAKE MANAGEMENT.—Bighorn Lake water management, including the Streamflow and Lake Level Management Plan, is a Federal activity, and the review and enforcement of any water management decisions relating to Bighorn Lake shall be as provided by Federal law. This section means that Reclamation cannot ignore its congressional authorization and that the Streamflow and Lake Level Management Plan does not take priority over federal law.
71	Keith Grant			Why does the Bureau ignore the congressional act that made Bighorn Canyon National Recreation Area a project purpose of the dam? Congress set apart the Reservoir for public outdoor recreation in the states of Wyoming and Montana.		Reclamation does not ignore the Bighorn National Recreation Area act. It states: SEC. 3. (a) The Secretary shall coordinate administration of the recreation area with the other purposes of the Yellowtail Reservoir. Nothing in the act prioritizes one use over another.
72	Keith Grant			There is a Water Compact between NPS and the State of Montana, MCA 85-20-401 with it accompanying Water Court document Case NO. WC – 94-1, this document would seem to have significant bearing on the subject at hand.		This act settled the National Park Service's water rights. NPS has rights to 251.5 acre-feet in consumptive use and instream flow rights for some tributaries. The priority date is October 15, 1966 and is specifically junior to Crow Tribal Water Rights. NPS has no rights to instream flows in the Bighorn River or storage in Bighorn Lake.
73	Keith Grant			The Bureau has stated that this study may change Chapter IV, (a legal document) so we need to be sure it is accurate to the degree possible, I am sure all these documents I have found and more are available to the Bureau, please consider correcting incomplete and misleading criteria.		The previous comments did not provide evidence of any incomplete or misleading criteria. As such, the report has not been edited with the exception of changing the date for the definite plan report.
74	Keith Grant			In my comments I asked, "Definate Plan Report 1950 – 1962 – **1965**, why was 1965 update not included? Was it to help justify a desired outcome?" I thought maybe the author didn't realize the Definate Plan Report had a 1965 update, but I find on page 71, that the author references the 1965 update. This answers my question, I now am aware that leaving out the 1965 update was to justify a 1962 desired outcome! I think that the Policy Assumptions section that list the legal authorizations should be deleted, it even states, **" It is not within the scope of this study to examine the relevant legal authorities."** We do not want to get bogged down in legal disagreements.		The report date is described above. The policy assumptions section provides relevant context to how Reclamation's authority is derived. As such, I am leaving it in the report.