RECLAMATION

Managing Water in the West

DRAFT YELLOWTAIL UNIT OPERATING CRITERIA EVALUATION STUDY & REPORT

Draft

U. S. Department of the Interior
Bureau of Reclamation
Great Plains Region
GP-4600

Final Draft Report
April 9~~December 7~~, 2012~~1~~

EXECUTIVE SUMMARY

This report was prepared by the Bureau of Reclamation (Reclamation) to review the operating criteria for the Yellowtail Unit. As part of this review, studies were prepared to evaluate operations under a variety of different operating parameters with the goal of improving overall project benefits and to provide a better balance between competing interests. A 2010 draft report, proposing revision to operating criteria was prepared in September of 2010. The report was then provided for public review in November of 2010. Based on comments received on the 2010 report and experienced gained from a record runoff year in 2011 further revisions to the operating criteria have been made. The following 2011 draft report provides details on the review process and the revisions proposed to the earlier operating criteria. A summary description of the recommended 2012 operating criteria (2012 Draft Criteria) for the Yellowtail Unit is also included as Appendix A.

Severe drought conditions from 2000 through 2007 significantly impacted the Yellowtail Unit including the Bighorn River downstream from Yellowtail Dam and Bighorn Lake upstream from the dam. The prolonged drought resulted in historically low water levels in Bighorn Lake, near minimum flows in the Bighorn River for extended periods of time, and power generation output reduced to less than 50 percent of normal. During and after this time, local, state, tribal, and federal entities along with private individuals expressed concern that Yellowtail Unit is not being operated in a manner that manages water resources to meet all of the authorized purposes, demands, needs, and expectations of water users, management entities and the public. To help address these concerns, a Bighorn River Issue Group (Issue Group) was established by Reclamation in March 2007. The Issues Group meets regularly to discuss various dam, river and lake issues related to lake levels, river release rates, flood control, and power generation. Based on input received from The Issue Group, the existing Yellowtail Unit (Yellowtail Dam, Bighorn Lake, and Yellowtail Afterbay) operating criteria was reviewed and studies conducted. The objective of the review and studies was to determine if modifications could be made to the operating criteria to better satisfy the competing demands placed on operation of Yellowtail Unit.

Specific modifications reviewed and studied included:

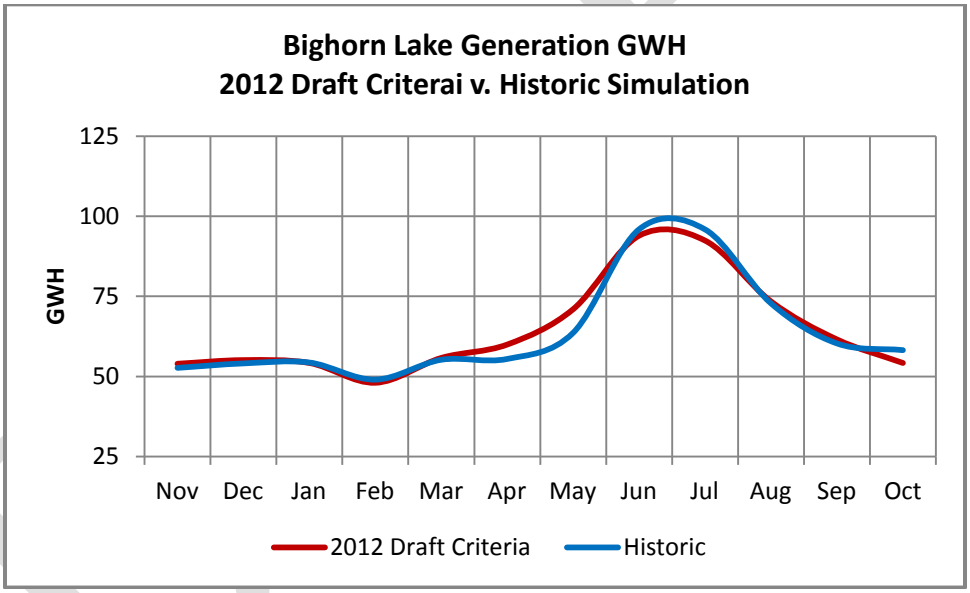
- Proposals to revise the lake operating level targets;
- A revised method for calculating lake gains;
- A new procedure for establishing a Fall/Winter (November through March) river release rate;
- Incorporation of lake elevation operational rule curves for the spring runoff season of April through July

The draft Yellowtail Unit operating criteria and operating tools were planned to provide increased water supply, improved lake recreation and fishery values, more dependable river fishery flows, increased power generation, and enhanced flood control benefits. The initial 2010 Draft Criteria was developed and used during water years 2010 and 2011. In November of 2010 a report on the draft criteria was presented to the issue group and comments were requested. In March of 2011 comments were received from about 80 different groups and individuals. Based on these comments and experience gained from a record runoff year in 2011 the criteria were

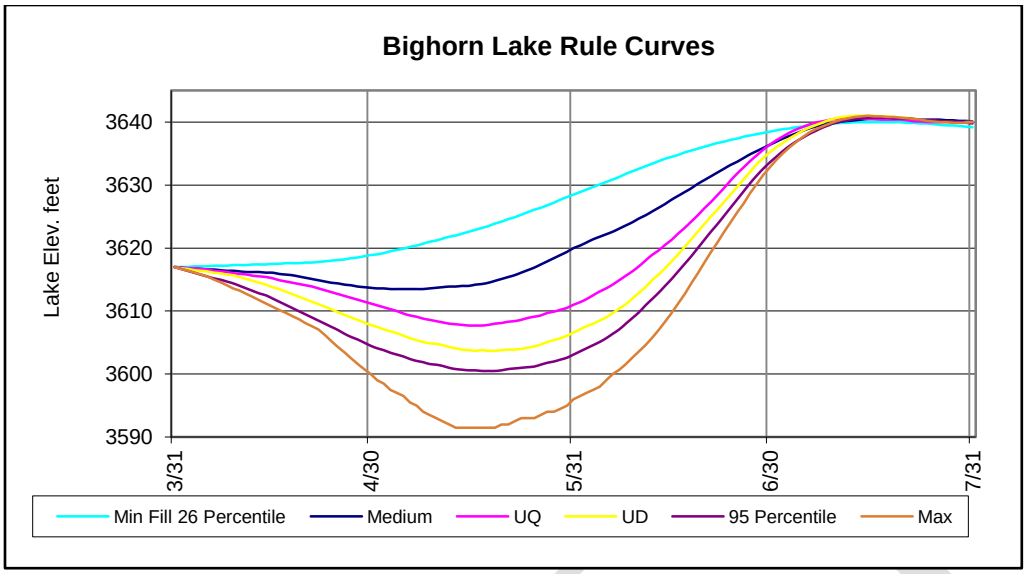
revised. A summary of the revised 2012 Draft Criteria is included as appendix A. The following is a brief summary of the benefits expected from the 2012 Draft Criteria.

Water Supply: A higher March 31 lake level target will be provided which will increase the probability that the lake will refill during the spring and remain higher during low runoff years. A higher end of October lake level target will also be provided which will also increase storage carryover for the following water year. With higher carryover storage, the draft criteria will improve the water supply reliability for future development and use by the Crow and Northern Cheyenne tribes both of which have significant rights and interest in water stored in Bighorn Lake.

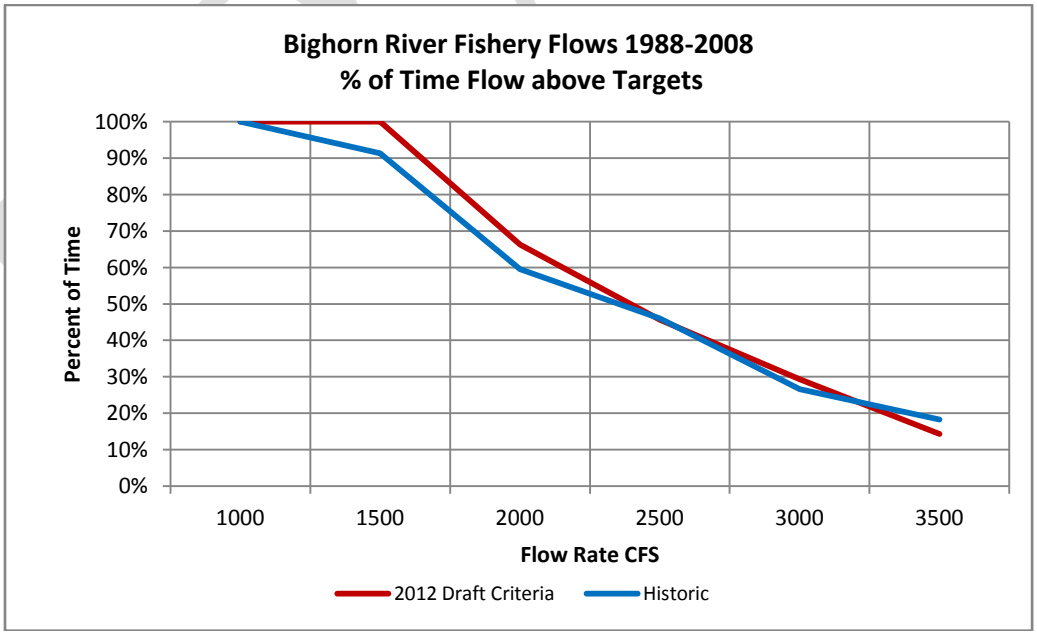
Power Generation: The higher lake level provides a somewhat higher "head" for power generation, slightly increasing the power generation efficiency and increasing average annual generation by about 1 percent. The addition of lake level rule curves to guide operations through the spring runoff season should reduce the quantity of water spilled past the power turbines during high runoff events.



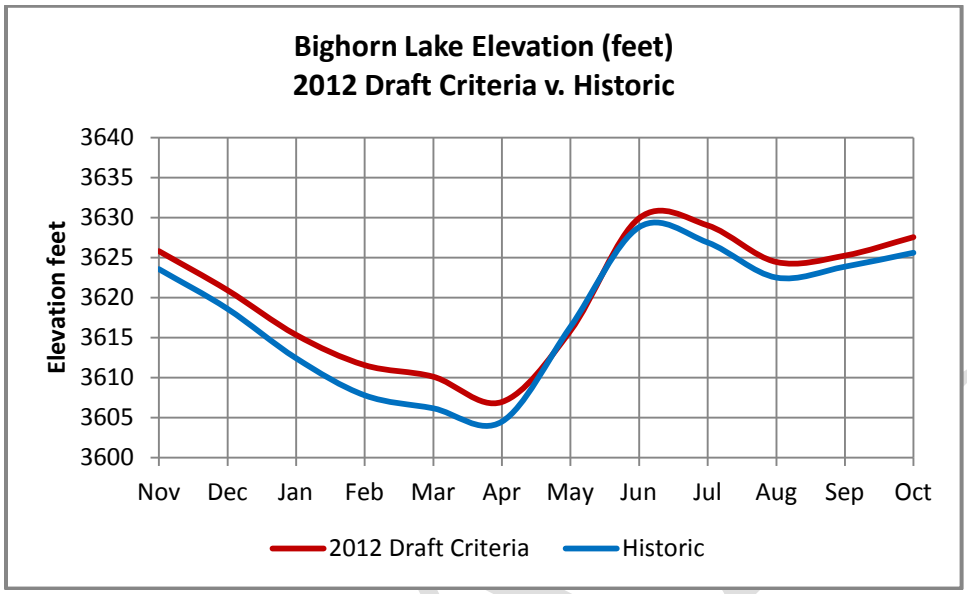
Flood Control: Improved flood control capability would be provided by utilizing new lake operational rule curves during the April-July runoff season. These curves are designed to better time the evacuation of storage to its low point such that it reaches this point just prior to high snowmelt runoff. In addition the rule curves will also carefully control the fill rate such that the lake is more likely to fill to its normal full level after the peak flood runoff has started to recede. In years with above average snowpack the rule curve will draft the lake to its lowest level in mid to late May, just prior to significant snowmelt runoff.



River Fishery: The trout fishery would benefit from: 1) an increase in the percent of time fishery flow targets are met; 2) an increase in river flow during the spring and early summer when the rainbow trout spawn, 3) a reduction in the percent of time river flows are reduced during the spring and: 3) improved reliability for water supply during drought periods with the risk of river flow less than 1,500 cfs significantly reduced. From 1988 through 2008, river flows were reduced to less than 1,500 cfs during 19 months, dropping as low as 1,300 cfs. Operation model runs, using the 2012 Draft Criteria, predict that a flow of 1,500 cfs or higher could be provided 100 percent of the time.



Lake Recreation and Fishery: The proposed modifications would result in the lake operating an average 2-3 feet higher than historic levels with an average of 3-4 feet higher during the late winter and early spring. This will enhance lake recreation and habitat conditions for the lake fishery.



Transparency: The modification and additional tools provided under the 2012 Draft Criteria would establish a more transparent process for making major operational decisions through each annual operating cycle. For example, the procedure for establishing the November through March release rate and developing April through July operational rule curves, based on forecasted lake inflows, would be available to the public to help explain why certain operating decisions are made.

The following table provides a summary of the expected benefits resulting from the 2012 Draft Criteria as compared to the historic operations. Graphs comparing the 1988-2008 (study period) end of month lake elevation and average monthly river release rates under the 2012 Draft Criteria with the actual historic operations follow the table.

Expected Benefits from the 2012 Draft Operating Criteria
As Compared to Historic Operation

Power Generation	Change in Generation GWHs	Percent Change
Annual	+ 6.1	1%
December-February	0	0%
*July-Aug	- 2.9	-2%

* Additional drawdown in the spring for flood control, as directed by the rule curves, reduces the average June through July release through the power turbines reducing generation. One side benefit of this is an increase in power reserve during June and July a time when power reserve is limited.

Flood Control

The following compares the 2012 Draft Criteria average peak end of month lake elevation and the average peak monthly river release values for the high runoff years of 1991, 1995, 1997, 1999 and 2008 with the actual historic record for these same years.

	Historic	Draft Criteria	Change
Peak avg. End of Month Lake Elev.	3644.8	3643.3	- 1.5 feet
Peak average Monthly Release	9,064 cfs	8,368 cfs	-697 cfs

River Flows

Fishery Flow Targets	Change in Percent of Time Target Provided
1500 cfs	+9% (met 100% of time for study period)
2000 cfs	+7%
2500 cfs	+0%
3000 cfs	+3%
3500 cfs	-4%

Lake Levels	Change in Lake Elevation
January-April	3-4 feet higher than historic
May	0 feet higher than historic
June	1 foot higher than historic
July-December	2 feet higher than historic

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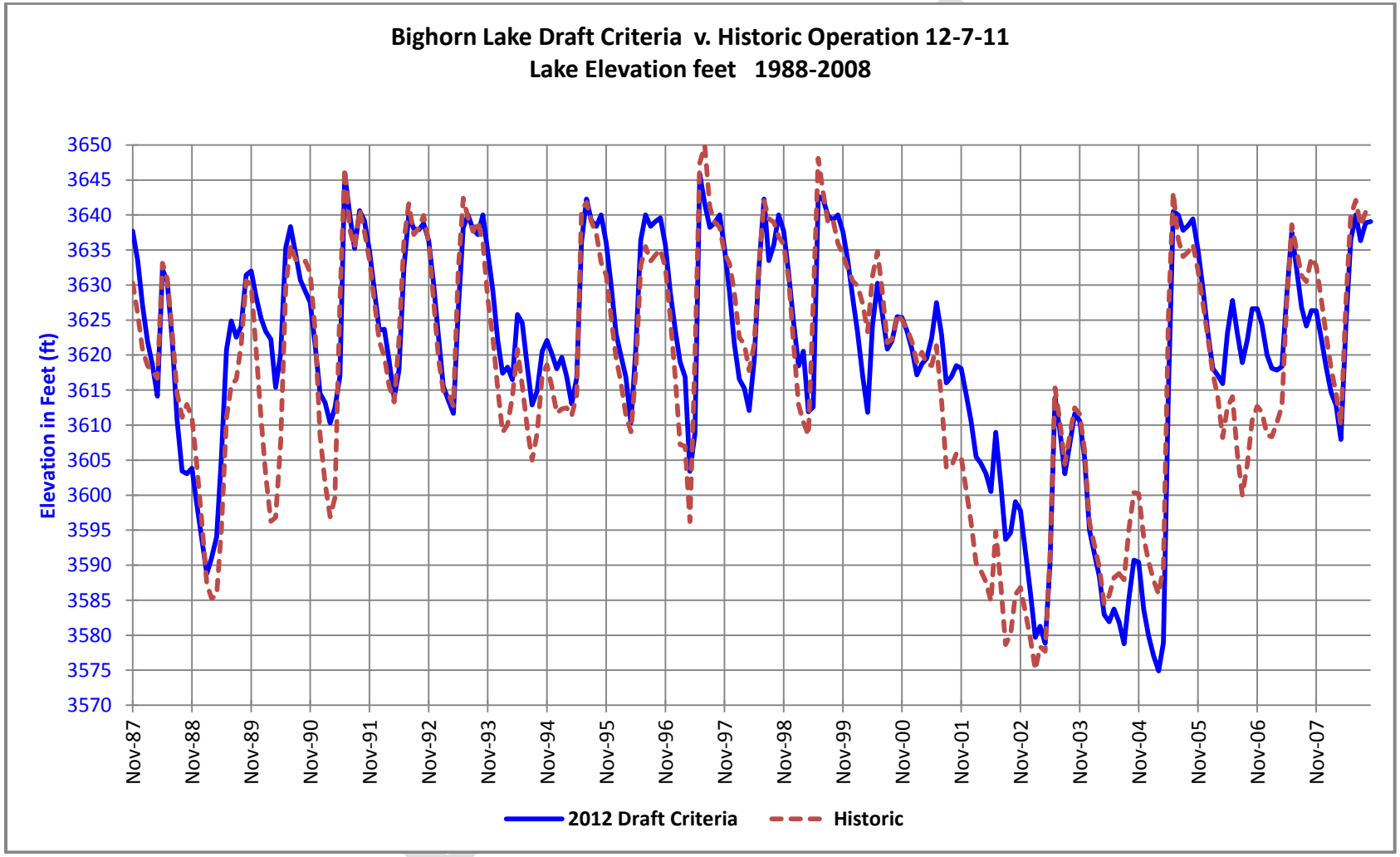
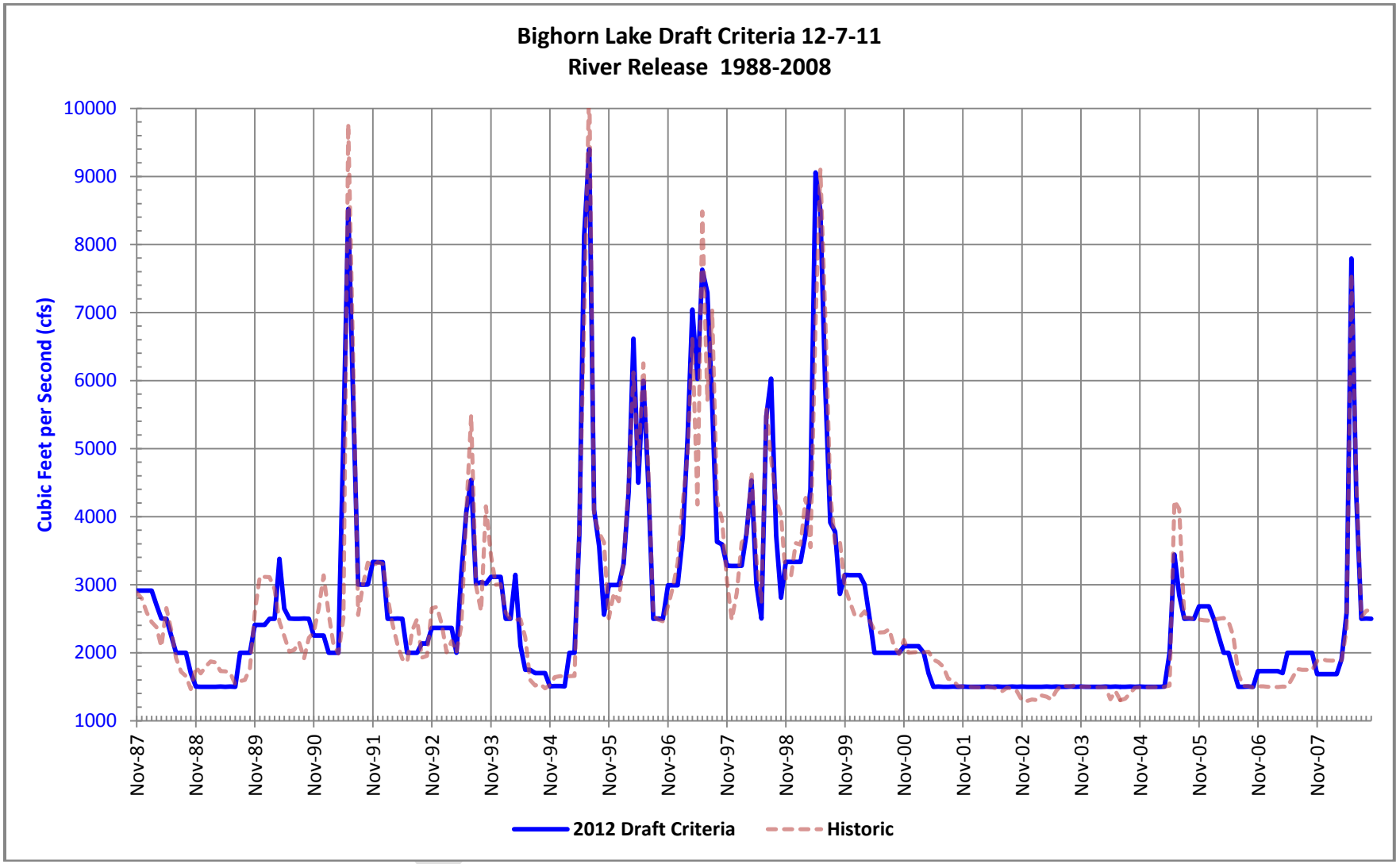


Bighorn Lake Elevation Draft Criteria vs. Historic Operations



Bighorn River Flow Below Afterbay Dam Draft Criteria vs Historic Operations

TABLE OF CONTENTS

PURPOSE: 1
INTRODUCTION: 1
BACKGROUND 2
2000 YELLOWTAIL UNIT OPERATING CRITERIA 3
Bighorn Lake Storage Allocations 3
Legal and Contractual Operating Requirements 4
Operating Requirements and Objectives 5
Lake Level Targets 6
CONCERNS EXPRESSED BY ISSUE GROUP MEMBERS AND GENERAL PUBLIC 7
Lake Recreation and Fishery Concerns 7
River Fishery Concerns 8
River Erosion 9
Flood Control 9
Power Generation 9
Water Supply 9
Bighorn River System Coordination 9
2007 BIGHORN LAKE SEDIMENT RESURVEY 10
REVISIONS TO THE BIGHORN LAKE OPERATING CRITERIA 11
October 15/November 30 Target 11
March 31 Target 12
July 31 Target 12
Revised Procedure for Establishing the November - March Release Rate 15
November-March Gain Forecast 15
Determining the November through March Release Rate 20
APRIL-JULY INFLOW FORECASTS: 22
Spring Operational Rule Curves: 24
Years with Forecasted April- July Inflow Less than a 26 Percentile Volume 27
EVALUATION OF THE 2012 DRAFT OPERATING CRITERIA 27
SYSTEM OPERATIONS 34
CONCLUSIONS: 34

FIGURES

Figure 1: Bighorn Lake 1986 Storage Allocations 4
Figure 2: Bighorn lake 2011 Storage Allocations 11
Figure 3: Bighorn Lake Nov-Mar Gains 16
Figure 4: Buffalo Bill Nov-Mar Inflow 16
Figure 5: Bighorn Lake Gains 1991-2009 Correlation Plot 17
Figure 6: Bighorn Lake Gains 1968-2011 Correlation Plot 18
Figure 7: Bighorn Lake Nov-Mar Gains Forecasted vs. Actual 19968-2011 19
Figure 8: 2011 v. 2010 Gain Forecast Comparison 20
Figure 9: Bighorn River nr. St. Xavier (MT): Apr-Jul Forecast Volume 22
Figure 10: Bighorn Lake Inflow Hydrographs 25
Figure 11: Bighorn Lake Rule Curve 25
Figure 12: Bighorn Lake Elev. Modified Criteria vs. Historic 28

DRAFT

Figure 13: Bighorn River below Afterbay Dam, Modified Criteria vs. Historic 29
Figure 14: Bighorn River Fishery Flows % of Time above Fishery Targets 30
Figure 15: Yellowtail Dam Average Power Generation, Gigawatt Hours 1988-2007 31
Figure 16: Bighorn Lake Elevation, 2012 Draft Criteria vs. Historic.....32
Figure 17: Bighorn River Discharge, 2012 Draft Criteria vs. Historic.....33

APPENDIX

Appendix A: 2012 Draft Criteria Summary
Appendix B: Summary of Comments on the 2010 Draft Criteria and Responses

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Purpose

This report was prepared by the Bureau of Reclamation (Reclamation) to review the operating criteria for the Yellowtail Unit. As part of this review, studies were prepared to evaluate operations under different operating parameters with the goal of improving overall project benefits. The 2010 Draft Bighorn Lake Operating Criteria Evaluation Study and Report (2010 Draft Criteria Report), proposing revision to operating criteria was prepared in September of 2010. The report was then provided for public review in November of 2010. Based on comments received on the 2010 report and experienced gained from a record runoff year in 2011 further revisions to the operating criteria have been made. This 2011 draft report provides details on the review process and the revisions proposed to the earlier operating criteria. A summary description of the recommended 2012 operating criteria for the Yellowtail Unit (2012 Draft Criteria) is included as Appendix A. To limit redundancy and possible confusion, references to the earlier 2010 Draft Criteria are limited to those areas where changes were made. For further information on 2010 Draft Criteria refer to the 2010 report.

Introduction

Severe drought conditions over an 8-year period, (2000-2007), significantly impacted the operation of Bighorn Lake, Yellowtail Dam, and Yellowtail Powerplant. This record-low water supply resulted in abnormally low lake levels, river flows near minimum levels for extended periods of time, and power generation output that was less than 50 percent of normal. All of the functions and benefits, served by the project, were significantly impacted by the drought. During this time a conflict developed between managing Bighorn Lake for flat water recreation and managing the Bighorn River below Yellowtail Dam as a river fishery. This conflict stemmed considerable public interest and concern with the overall operation and management of the project. 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. Beginning in March of 2007, quarterly meetings were held and these meetings have continued through 2011. Issues discussed in these meetings have dealt with the various management aspects related to lake levels, river release rates, flood control, and power generation at Bighorn Lake and Yellowtail Dam.

Based on input provided from all of the various interests attending the issue group meetings along with comments received on the 2010 report the Bighorn Lake operating criteria was reviewed and studies were prepared to determine if modifications could be made to these criteria which would improve the overall operations and enhance the benefits derived from the Yellowtail Unit. Specific issues studied were the possibility of:

- Raising the lake fall and end of winter operating level targets.
- Improving the method for forecasting November through March gains to the lake.
- A new and more transparent method for establishing the November through March river release rate.
- The use of rule curves as a tool for improved management of lake storage during the spring runoff season.

Each of these issues is discussed in this report.

Background

The Yellowtail Unit of Pick-Sloan Missouri Basin Program is located in south-central Montana on the Bighorn River near Hardin, Montana. This unit was planned and constructed as a multi-purpose development for irrigation, flood control, power generation, sediment retention, fishery and waterfowl resource improvement, recreation enhancement, and municipal-industrial water supply. The Yellowtail Unit consists of a dam and lake, a powerplant, an afterbay dam and lake, a switchyard, and related or appurtenant structures and facilities. Yellowtail Dam, at the mouth of the Bighorn Canyon, impounds flows of the Bighorn River in Bighorn Lake.

Bighorn Lake is about 72 miles long at its maximum water surface elevation (elevation 3657) and 66 miles long at its normal full level (top of its joint use pool, elevation 3640). At its normal full level it extends into the Bighorn Basin of Wyoming. The lake is confined in the canyon for most of its length. The widely-varying releases from the powerplant required to meet peak power demands are regulated by the Yellowtail Afterbay Dam, constructed 2.2 miles downstream from Yellowtail Dam. The Yellowtail Unit was authorized by the Flood Control Act of December 22, 1944.

Bighorn Lake in the heart of the Bighorn Canyon

2000 Yellowtail Unit Operating Criteria

The operating criteria used prior to this review for the Yellowtail Unit are included in Chapter IV of the Standing Operating Procedures (SOP) for Yellowtail Dam dated 2000. These criteria generally consist of the following:

- Lake Storage Allocations.
- Legal and contractual operating requirements.
- Operating objectives for water supply, flood control, power generation, lake recreation, fishery, and the river fishery.
- Lake level targets for specific dates through the year.

A brief summary of the criteria is included below.

Bighorn Lake Storage Allocations: The lake storage allocations were defined in the 1962 Yellowtail Unit Definite Plan Report (DPR) developed prior to construction of the project. These allocations determine how certain storage zones, within the lake, are used to meet the various project purposes. The lake storage allocations for Bighorn Lake based on the 1986 area-capacity table are defined as follows:

*Bighorn Lake Storage Allocations (based on 1986 Area-Capacity Table)

Storage Zone	Elevation (Feet)	Total Storage (Acre-feet)	Allocation (Acre-feet)
Top of Inactive and Dead Pool	3547.0	493,584	493,584
Top of Active Conservation Pool	3614.0	829,687	336,103
Top of Joint Use Pool	3640.0	1,070,029	240,342
Top of Exclusive Flood Pool	3657.0	1,328,360	258,331
Top of Surcharge Pool	3660.0	1,381,189	52,829

*A new area-capacity table based on a 2007 resurvey of the lake was implemented in January 2011. The 2000 Bighorn Lake Operating Criteria and operations from 1986 through December of 2010 were based on the area-capacity table that went into effect in January of 1986.

The following image, Figure 1, graphically displays the lake storage allocations:

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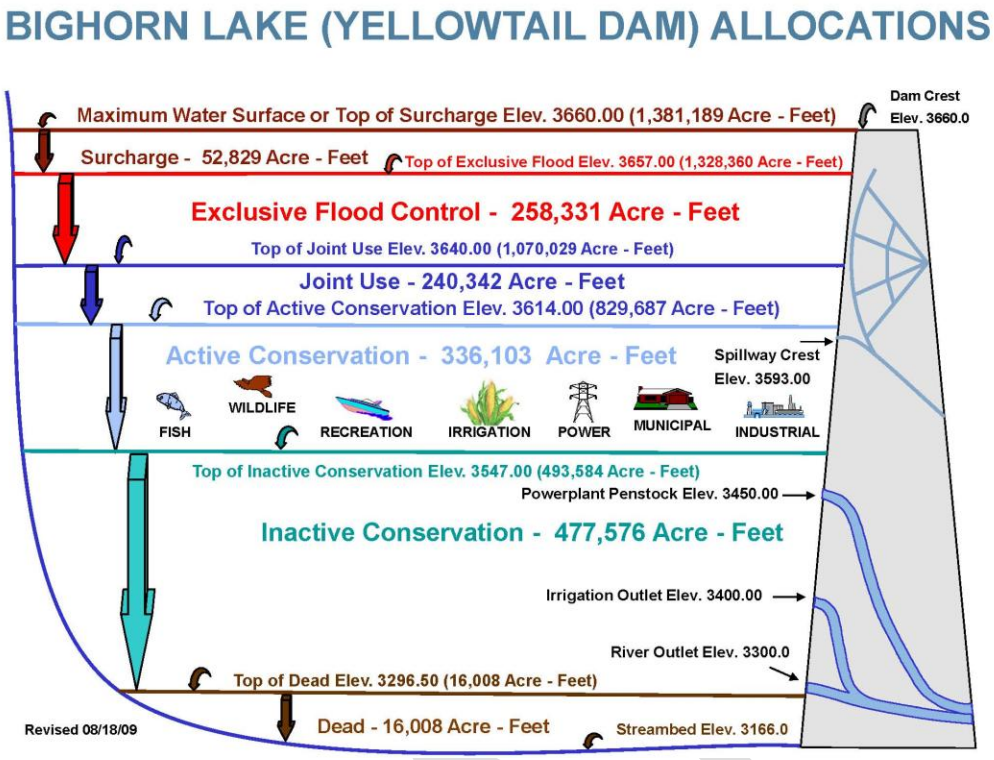

1986 Storage Allocations
Figure 1

The inactive conservation and dead pools, below elevation 3547, are necessary to maintain a minimum lake level to allow for the operation of the hydroelectric power turbines. Below elevation 3547 the power turbines must be shut off. The Yellowtail Unit is not intended to operate below a lake elevation of 3547.

The active conservation pool, between elevation 3547 and 3614, is the storage space available for use in meeting all of the water supply needs served by the Yellowtail Unit.

The joint use pool, between elevation 3614 and 3640, is used jointly in meeting water supply needs and to provide sufficient storage space for regulating high spring snowmelt runoff for flood control purposes. The exclusive flood pool, between elevation 3640 and 3657, is reserved exclusively for flood control purposes. When the lake is in the exclusive flood control pool lake operations are under the jurisdiction of the U.S. Army Corps of Engineers (COE).

Changing or adjusting these storage allocations was not considered as part of this study. A separate study is being performed to evaluate the possibility of raising the top of the joint use pool. Since this involves a change in the storage space allocated for flood control, this study is being conducted by the COE.

<u>Legal and Contractual Operating Requirements</u>: The mandatory and legal requirements consist of satisfying senior downstream water rights, meeting the existing and future reserved water right obligation for the Crow and Northern Cheyenne Indian tribes, meeting Reclamation's contract

commitments for water stored in Bighorn Lake and operating and managing Bighorn Lake and Yellowtail Dam in a manner that is consistent with dam safety requirements.

Operating Requirements and Objectives: The operating goals and objectives include conserving stored water for water supply needs, maintaining sufficient storage space to provide for flood control in the spring, maximizing the power generation benefit, maintaining desired lake levels for recreation and lake fishery and waterfowl, and maintaining desired releases to the Bighorn River below the Afterbay Dam for the river fishery.

The desired lake levels for recreation are based on recommendations by the National Park Service (NPS). In the past, these recommendations were based on the need to maintain the lake elevation above minimum levels required for launching boats during the summer recreational season from the various boat ramps provided at Bighorn Lake. Desired fall lake levels recommendations for waterfowl were provided by the Wyoming Game and Fish (WYGF). The desired river releases for the river fishery were based on studies prepared initially by the U. S. Fish and Wildlife Service in the 1970s and then additional studies prepared by the Montana Fish, Wildlife and Parks (MTFWP) in the 1980s.

The recommended lake level for recreation and the recommended flow for the Bighorn River fishery included in the 2000 SOP are as follows:

> Minimum Lake Levels for Boat Launching: To prevent the marinas from being impacted, the lake level should be maintained at or above elevation 3614. This was based on the need for the lake to be at or above elevation 3614 to launch boats from the Horseshoe Bend boat ramp. The other two main boat ramps located at Barry's Landing and OK-A-BEY are useable down to elevation 3590.
>
> Desired River Fishery Flows: The minimum flow identified in the 1962 DPR was 1000 cfs. Based on studies by the Montana Fish, Wildlife and Parks (MTFWP) and their formal request for fishery flows made in 1986 the following desired fishery flows were adopted and included in Chapter IV of the 2000 SOP:
>
> | | |
> |---|---|
> | Optimum Fishery Flow | 2,500 cfs |
> | Standard Fishery Flow | 2,000 cfs |
> | Minimum Fishery Flow | 1,500 cfs |
> | Minimum DPR Flow | 1,000 cfs |
>
> These flows and their descriptive titles are also included in the Streamflow and Lake Level Management Plan, Bighorn River and Bighorn Lake signed by Marc Rasicot, governor of Montana, Clara Nomee, Chairman for the Crow Tribe and William Benjamin representing the Secretary of the Interior on Jun 21, 2000. This plan is now a part of the Crow Tribe Water Right Compact.

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Bighorn River below Afterbay Dam

Lake Level Targets: Lake elevation targets were established for each key decision point in the annual operational cycle. Generally these key decision points are: (1) the early fall, at the end of the irrigation season, when operations change from a irrigation season operation to a winter operation; (2) the end of the winter when operations transition from a winter operation to a spring snowmelt runoff operation; and (3) the end of spring snowmelt runoff season when the lake normally reaches its peak level and operations transition from a spring runoff fill operation to a summer water supply operation. The lake elevation targets for Bighorn Lake were established to provide an early fall target for the benefit of waterfowl hunting, a late fall target used to set a maximum lake level prior to winter freeze up to provide sufficient storage for winter operations, a desired level of lake drawdown in early spring to provide adequate storage space for expected spring snowmelt runoff, and a full lake level target at the end of spring runoff. The lake targets listed in the 2000 SOP are as follows:

Date	Lake Operating Level Targets
October 15	Elev. 3635 (desired minimum for waterfowl hunting)
November 30	Elev. 3630 (desired maximum to prevent ice-jams)
March 31	Elev. 3605-3614 (depending on mountain snowpack)
July 31	Elev. 3640 (top of joint use, normal full level)

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Concerns Expressed by Issue Group Members and General Public

Over the years between 2007 and 2011 a number of Issue Group meetings have been held to allow various interest groups opportunities to provide input on the desired operation of the Yellowtail Unit. In addition, following the issuance of the 2010 Draft Criteria Report, Reclamation requested comments on the draft criteria and in February and March of 2011 approximately 80 separate comment letters were received. Based on a careful review of each of these comments along with the experienced gained from a record runoff year in 2011, the 2010 Draft Criteria was revised. The revised criteria are referred to throughout this report as the 2012 Draft Criteria.

Below is a brief summary of the input and concerns received during the review process for each of the main interest categories.

Lake Recreation and Fishery Concerns: The main concern expressed by lake recreation and fishery interests is the need for higher lake levels, especially during the summer recreation season. Over the years as sediment has accumulated in the upper end of the lake, it has restricted the use of the Horseshoe Bend boat ramp to progressively higher lake levels. The Horseshoe Bend Recreation Area is located in the upper end of the lake near Lovell, Wyoming. Originally, the Horseshoe Bend boat ramp was useable down to elevation 3590. Sediment accumulating in the Horseshoe Bend area over time has changed this and under current conditions the boat ramp is no longer useable when the lake elevation is below elevation 3617.

The upper end of the lake is the only portion that is more typical of a lake. The lake from just below Horseshoe Bend to the dam is in a narrow steep canyon. It is not until the lake level is near elevation 3630 that the upper end spreads out forming a good flat water recreation lake for boating and water skiing. The NPS has recently expressed the desire to maintain the lake above 3630 during the summer recreation season and above 3620 during the rest of the year. The Wyoming Game and Fish (WYGF) made similar recommendations requesting that the lake needs to be at or above 3620 and preferably above 3630. To adequately produce the food supply needed to support the sport fishery, the WYGF recommends that the lake be at or above elevation 3630 during the summer growing season. WYGF believes that below elevation 3620 the lake fails to provide fishing opportunities in Wyoming and greatly reduces the preferred habitat of many fish. These desired levels were not considered when the lake level targets were first established as the above recommendations were not available.

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Horseshoe Bend Recreation Area

River Fishery Concerns: The MTFWP believes that the river flow below the Afterbay Dam needs to be at or above 2500 cfs to provide good spawning, rearing and cover conditions in all major side channels along the river. Although MTFWP recognizes that the water supply in the basin is not sufficient to provide this level of flow in low runoff years they have recommended that this be the minimum flow target for the river fishery. If water supply conditions allow, the MTFWP would prefer flows near 3500 cfs. When water supply conditions are not adequate to provide a minimum flow of 2500 cfs then the next lower recommended flow is 2000 cfs. A river flow of 2000 cfs provides some level of spawning and rearing conditions in the side channels but cover for adult fish is limited. The MTFWP's also recommended an absolute minimum flow of 1500 cfs. A flow of 1500 cfs dewaters all of the important side channels providing very limited spawning and rearing habitat. Fish populations are expected to noticeably decline at this flow rate since spawning is significantly restricted but adult fish will continue to survive in the main channel of the river.

With spring spawning rainbow trout and fall spawning brown trout in the Bighorn River, spawning or egg incubation of one or the other species occurs during all months except August, September and October. These three months are, however, important to the rearing of the young trout. Rainbow trout spawn primarily in April and May, with eggs incubating during June and July. Brown trout spawn primarily in November and December with egg incubation lasting into April due to colder water temperatures. The best possible situation is to maintain stable flows. Since that isn't always possible the next best thing is to ensure that flows during egg incubation periods do not fall below spawning levels. Consequently, if water shortages are anticipated, the

MTFWP recommends that flows be reduced prior to the onset of spawning. This increases the likelihood that adequate flows can be maintained during the egg incubation period.

River flows also impact the fishability of the river. Based on a number of comments from various fishing interests included the Bighorn River Alliance and the Friends of Bighorn River the consensus appears to be that when the river flow raises above somewhere between 6,000 - 8000 cfs the use of the river by fisherman noticeable declines.

There were also quite a few comments related to the need to provide a more equable balance between the river interests and the lake interest. Many believed that the 2010 Draft Criteria went too far in providing benefits to lake recreation and fishery with no noticeable benefit to the river fishery.

River Erosion: Concern has been expressed by partiers living along the river that higher river flows and the rate at which the river release is reduced contributes to bank erosion. These interests requested that flow be held at or below 8,000 cfs when possible and as flows are reduced they be reduced gradually over a longer period of time than in the past.

Flood Control: Concern was expressed with the need to have the lake evacuated a sufficient amount in the spring to effectively manage high spring snowmelt and rain induced flood flows. Input from interests along the river indicated that a flow above 10,000 cfs results in some overbank flow and minor flooding. This is much lower than the channel capacity of 20,000 cfs identified by the Corps of Engineers at the time the Yellowtail Unit was constructed.

Power Generation: Western Area Power Administration (WAPA) interests are in the gross power generated by the Yellowtail Unit, the timing of this generation such that it best fits with periods of high power demand, and the ability of the powerplant to regulate power over the course of each day to meet the diurnal fluctuating power demands. WAPA is also concerned with the reserve capacity of the powerplant that can be called on instantaneously (spinning reserves) or on short notice in response to electrical system emergencies. Generally, peak power demands occur during the hot months of July and August and the cold months of January and February. On a daily cycle, power demands generally drop off at night and then return during the day light hours.

Water Supply: Three entities hold entitlements to stored water in Bighorn Lake; the Crow Tribe has a right to 300,000 ac-ft, the Northern Cheyenne Tribe has a right to 30,000 acre-feet and Pennsylvania Power and Light of Montana currently have a contract for 6,000 acre-feet. Future development of water by the Crow and Northern Cheyenne Tribe will place new demands on the stored water in the lake. A higher lake operating level would increase the amount of stored water available for meeting these new demands.

Bighorn River System Coordination: Several of the interested parties in Montana raised concern over what they perceive as lack of system coordination between Boysen and Buffalo Bill reservoirs located in the Bighorn basin in Wyoming and Bighorn Lake. These parties requested improvements in the process and tools used to coordinate and communicate operations between Reclamation's Montana Area Office and its Wyoming Area Office.

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A more detailed summary of the comments received on the 2010 Draft Criteria Report along with Reclamation responses are included in Appendix B.

2007 Bighorn Lake Sediment Resurvey

In 2007 Bighorn Lake was resurveyed to address the quantity of sediment that has entered the lake since the last survey which was conducted in 1982. Technical Report No. SRH-2010-12 addressing the findings of this survey was completed in September of 2010. The 2007 survey measured a net lake storage capacity loss of 49,464 acre-feet since the earlier survey in 1982. This represents about 3.5 percent of the lake's total capacity. Based on this resurvey the area-capacity table for Bighorn Lake was revised and a new storage allocation table and diagram were prepared. The new area-capacity table and storage allocation where implemented in January of 2011. The following table compares the 1986 storage allocations (based on the 1982 survey) with the current 2011 storage allocations. The table also shows the loss in storage space from each storage allocation zones.

Bighorn Lake Storage Allocations 2011 compared to 1986

Storage Zone	Elevation (Feet)	2011 (Acre-feet)	1986 (Acre-feet)	Loss (Ac-ft)
Top of Inactive and Dead Pool	3547.0	469,910	493,584	23,674
Top of Active Conservation Pool	3614.0	318,298	336,103	17,805
Top of Joint Use Pool	3640.0	232,365	240,342	7,977
Top of Exclusive Flood Pool	3657.0	258,323	258,331	8
Top of Surcharge Pool	3660.0	52,829	52,829	0

The revised storage allocation diagram for 2011 is shown below.

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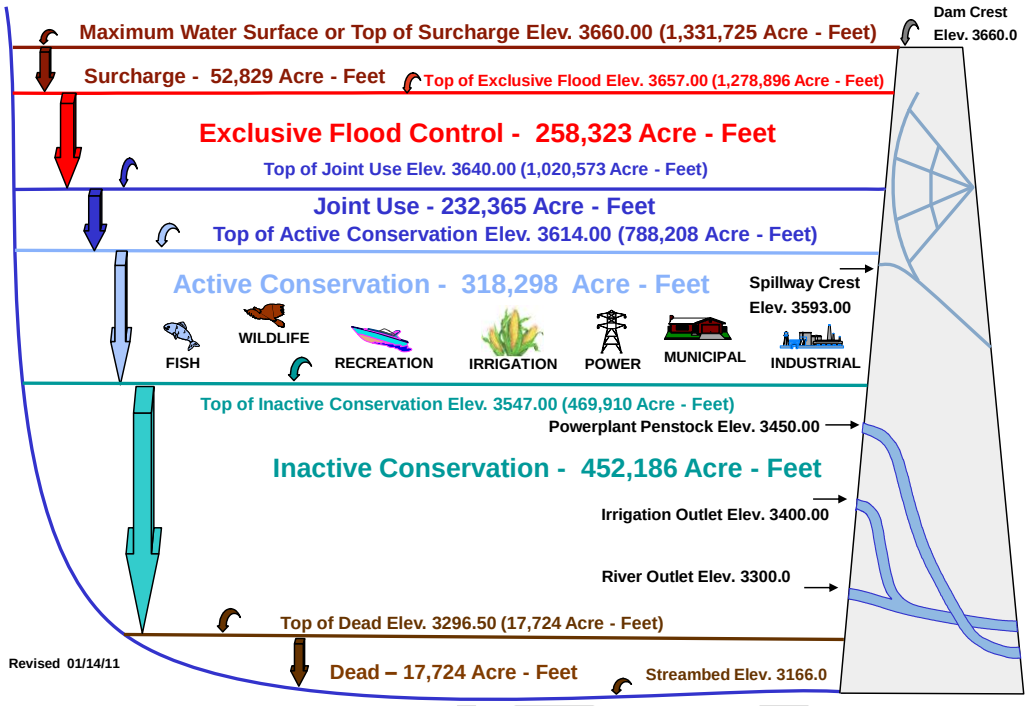
BIGHORN LAKE (YELLOWTAIL DAM) ALLOCATIONS



2011 Storage Allocations
Figure 2

Revisions to the Bighorn Lake Operating Criteria

Before addressing the need for revisions to the 2000 operating criteria and later 2010 Draft Criteria a careful review of the 2000 criteria was needed.

A review of the reasons for establishing the existing lake level targets was made prior to determining if any changes could be made to the target levels. Each of the target levels are discussed below.

> <u>October 15 Target of Elevation 3635 and November 30 Target of Elevation 3630</u>: The original purpose of the fall lake targets was to lower the lake a sufficient amount to prevent ice-jams from forming in the lower end of the Shoshone River while maintaining the lake at a high enough elevation to facilitate waterfowl hunting. When these targets were first established it was believed that a high lake level would potentially result in considerable ice forming in the lower section of the river directly upstream of the lake leading to ice-jams and flooding. There were a few years in the early 1970s, prior to establishing the fall lake level targets, when this appeared to be a problem especially in relation to flooding of the railroad tracks near Bryon and Lovell. Since that time the railroad tracks have been raised, reducing their risk for flooding. Based on input received

DRAFT

from Issues Group attendees this no longer appears to be a significant problem. After considerable discussion, it was agreed that the November 30 target level could be raised or even eliminated at least on a trial basis with little additional risk of increased ice-jam flooding.

March 31 Targets Elevations of 3605-3614: The March 31 lake level targets were established to provide a balance between the need to provide sufficient lake storage space for regulating spring runoff and the need to have the lake high enough to ensure that the lake refill in all but very low runoff or drought years. These targets also allow for the use of stored water during the fall and winter to enhance power generation and river fishery flows. Storage space for controlling high spring or flood runoff is required just prior to high spring runoff which normally begins in mid to late May.

Drafting of the lake in the spring after the end of March was considered detrimental to the Walleye fishery further supporting the lake reaching its low point near the end of March versus the low point around mid to late May. Walleye have not done as well as expected in Bighorn Lake and over time other fishery species, such as Sauger, have replaced most of the walleye fishery in Bighorn Lake. Both the MTFWP and the WYGF now agree that a spring draft, after the end of March, is not a real concern for the existing lake fishery.

July 31 Target Elevation of 3640: The July 31 target elevation of 3640 is the top of the joint use pool or the normal full level for the lake. Filling the lake to its normal full level by the end of the spring runoff provides the maximum storage supply for all project purposes. Under current storage allocations this provides the maximum conservation pool for meeting water supply needs through the coming year and an optimum lake level for recreation and the lake fishery. No concerns were raised with this target other than the possibility of raising the top of the joint use pool by 5 feet. To accomplish this, the lake storage allocations would need to be changed to convert a portion of the exclusive flood pool space to joint use space. This option is being considered under a separate study and is not part of this evaluation. No change to the lake storage allocations was considered under this study and is not addressed in this report.

Studies were prepared using the Bighorn Lake monthly operation model (ROMS Access Model) to determine if there would be benefits to the project purposes by raising both the fall and spring target levels. The period of study for these model runs was 1988-2008. From the model study it was found that the lake could be operated several feet higher, on the average, if the March 31 target was raised to between 3615 and 3619 and the October 15 and November 30 targets were replaced with an October 31 target level range set between elevation 3635 and 3640.

The studies show that this modification to the lake level targets would allow the lake to fill somewhat higher in lower runoff years and improve water supply availability. In years with above average snow conditions and runoff forecasts the lake would continue to be drafted by as much 25 feet after March 31 as need to provide adequate space for controlling expected high spring runoff. Since the target levels would increase lake storage levels by equal amounts in both the fall and the spring, this change would allow the November through March river release rate to continue at the same levels as in the past.

DRAFT

An October 31 lake level of 3640 is the highest practical operating level for the lake prior to the winter season under the current storage allocations. A lake level target range of 3635-3640 would meet the desired lake levels in October and November for water fowl hunting.

Based on the results of these model studies modified lake level targets were established for the 2010 Draft Criteria. After reviewing the comments provided on these criteria and implemented a new area-capacity table (based on a 2007 resurvey of the lake) further refinements were made to the targets for the 2012 Draft Criteria. A comparison of the 2000, 2010 and 2012 lake level targets is show below.

DRAFT

Bighorn Lake Operational Level Targets

2012 Targets		2010 Targets		2000 Targets	
Date	Target Elev.	Date	Target Elev.	Date	Target Elev.
October 31	3635-3640	October 31	3638-3640	October 15	3635
November 30	Eliminated	November 30	Eliminated	November 30	3630
March 31	3615-3617	March 31	3616.7-3620.6	March 31	3605-3614
April-July	Rule Curve	April-July	Rule Curve	April-July	None
	3591.5 minimum		3602.7 minimum		
July 31	3640	July 31	3640	July 31	3640

DRAFT

Revised Procedure for Establishing the November - March Release Rate

After reviewing past operations it was determined that it would be beneficial to develop a more formal procedure for setting the winter release rate. The first step in developing a method for establishing a November through March release rate that will meet the March lake target elevation was to find a reliable procedure for forecasting the November through March inflow to Bighorn Lake. The inflow to Bighorn Lake is composed of the releases from Buffalo Bill and Boysen reservoirs plus the "gain" occurring in the river reaches between the two upstream lakes and Bighorn Lake. The gain is the accretions less the depletions that occur in the river reaches between the two upstream dams (Boysen and Buffalo Bill dams) and Yellowtail Dam. This gain is calculated as the difference between the inflow to Bighorn Lake and the water released from Boysen and Buffalo Bill dams. Generally, late fall and winter natural flows are dependent on soil moisture and groundwater providing a base flow until snowmelt runoff begins in the spring. Runoff events from precipitation or snowmelt are rare during this time of year. Groundwater levels vary from year to year depending on groundwater recharge or depletion that occurred during the past year.

November through March Gain Forecast: Before evaluating methods for forecasting the gain, a correction was needed to the formula for calculating the gain. In the past, the gain was calculated as the Bighorn Lake inflow less the total release from Boysen Dam and the release to the river from Buffalo Bill Dam. This method of determining the gain did not include the water released directly from Buffalo Bill Dam to the Heart Mountain Canal. This method of calculating the gain was initiated shortly after Yellowtail Dam was constructed and it is unclear why only the river release was used rather than the total release. Although the Heart Mountain Canal diverts directly from Buffalo Bill Dam rather than from the river below the dam, its impact on the downstream river flow is essentially the same as other canals that divert from the river. Water diverted for irrigation is only partially consumed as nearly 50 percent of these diversions return to the river as return flow. The method used to calculate the gain should be consistent and include all of the water released from the upstream lake to the river basin below the dams.

Once the gains were recalculated for the full period of record, an evaluation was made to determine if a satisfactory method could be developed for forecasting the November through March gain.

The first evaluation made was to determine if there has been any change over time to the November through March gain. The November through March gain was plotted for each water year from 1967 through 2007. Since water year 1967 was a record high year and 2001-2007 were extreme drought years these years were then excluded from the plot so that these extreme events would not overly influence the trend line. The following graph (Figure 3) shows the gains from 1968 through 2000 along with the calculated trend line. The trend line was statistically determined by an Excel spreadsheet routine. As shown on the graph, there is a strong downward trend to this data even with the late 1990s being high runoff years. It is not totally clear why the gains have significantly declined but some of the factors that likely contributed to this are: (1) changes in irrigation practices from gravity systems to sprinkler: (2) a major rehabilitation betterment program on the Shoshone Irrigation Project during the 1980s including the replacement of many of the open lateral irrigation delivery canals with closed pipelines (which

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reduced system losses but also reduced groundwater recharge); (3) and some increased groundwater use in the basin.

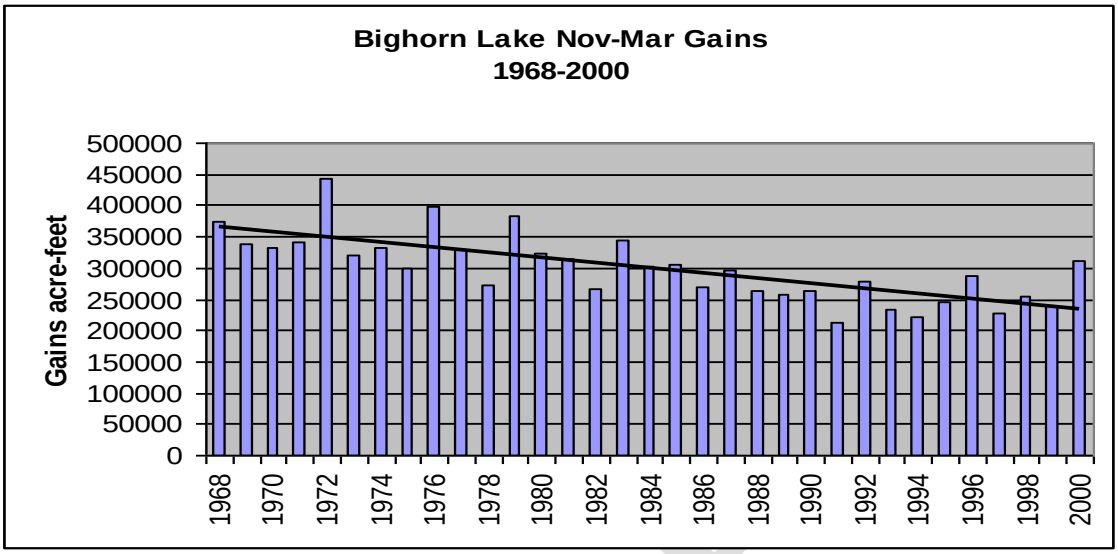

Figure 3

To verify that the downward trend was not due to some climate anomaly, the November through March inflow to Buffalo Bill Lake was also reviewed. There has been very little development above Buffalo Bill Lake so these inflows are fairly close to virgin conditions with only very minor impacts from irrigation practices or groundwater use. The Buffalo Bill November through March inflows were plotted for the same period of record to compare with the Bighorn Lake Gain. As shown on the Figure 4 there is no noticeable trend either downward or upward in the Buffalo Bill inflow over this same period of record.

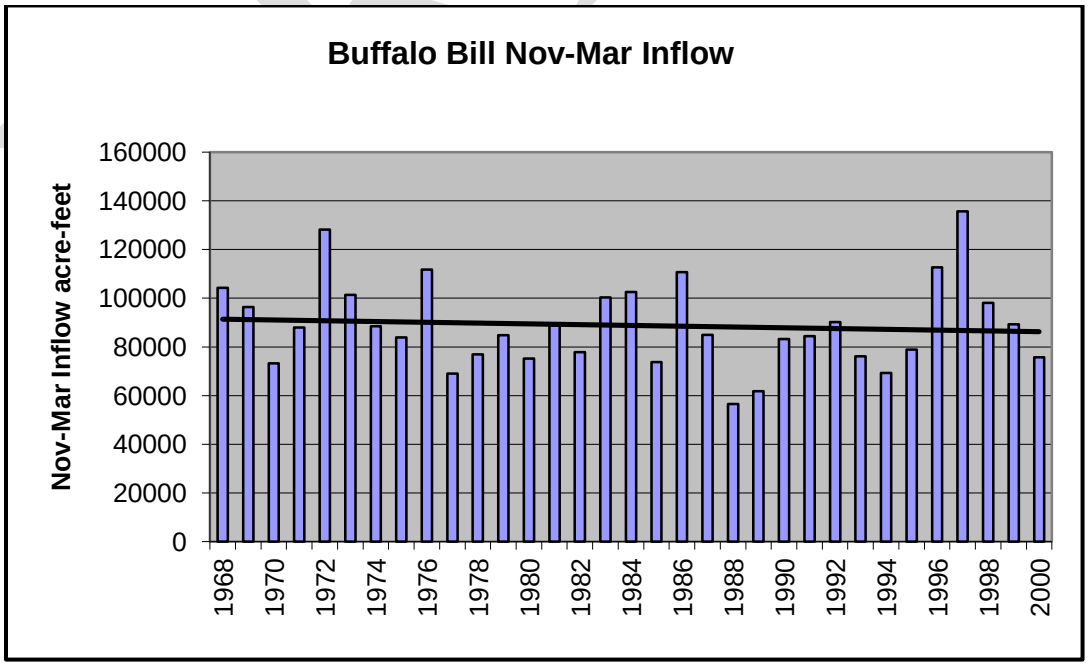

Figure 4

In reviewing the November through March Bighorn Lake gains in more detail it was found that since about 1990 the gains have stabilized as there does not appear to be a trend either downward or upward since that time. Based on this review, it was determined that the gain data prior to 1991 should not be used in developing a forecast relationship unless adjusted to account for current level of depletion and other changes that occurred during the 1980s.

Comparing the April through October gain with the November through March gain for the period of 1991 through March of 2010, it was found that there was a fairly good correlation between the gains for these two separate time periods. The graph below (Figure 5) is a plot of the April through October gain in acre-feet vs. the following November through March gain in acre-feet for the period of 1991 through 2010. The forecast discussed in the 2010 report was based on this relationship although a polynomial equation was used rather than a linear equation as shown on the graph.

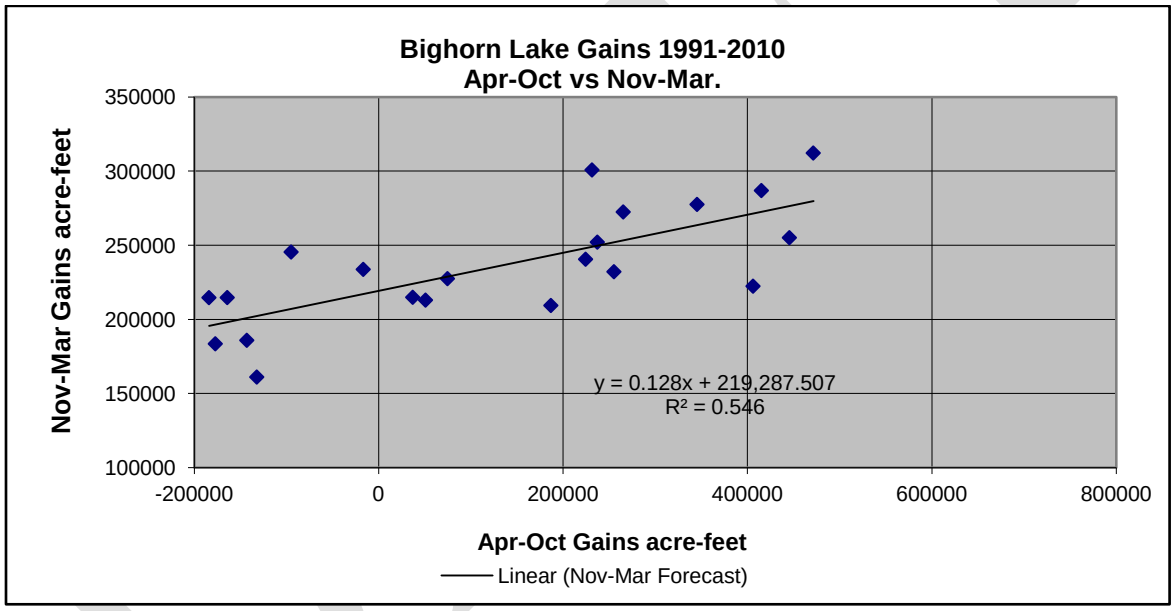

Figure 5

Following the record spring runoff in 2011 it was noted that the dated used for the 2010 forecast procedure did not contain any years with April through July gains in excess of about 480,000 acre-feet. The April through July gains in 2011 were over 800,000 acre-feet well beyond the maximum values used in the correlation. Because of this large gap between the highest gains uses for the forecast procedure and those in 2011 there was a need to expand the data base to include higher runoff years. To do this some reasonable adjustment for the gains recorded prior to 1991 was needed such that the earlier year gains would be compatible with the gains after 1990. Since there is no record of exactly when and to what degree the gains declined during the 1980s a trial and error approach was attempted to find a reasonable adjustment. From this approach it was found that by reducing each of the November-March gains for 1968 through 1990 by 45,000 acre-feet a good correlation occurred for the full period of record. One

additional adjustment was made. In 1972 a large plains snowmelt runoff event occurred in March significantly increasing the March gains. Because this resulting in 1972 being a noticeable outlier from the rest of the data, it was removed from the correlation analysis. From this evaluation the following relationship was determined.

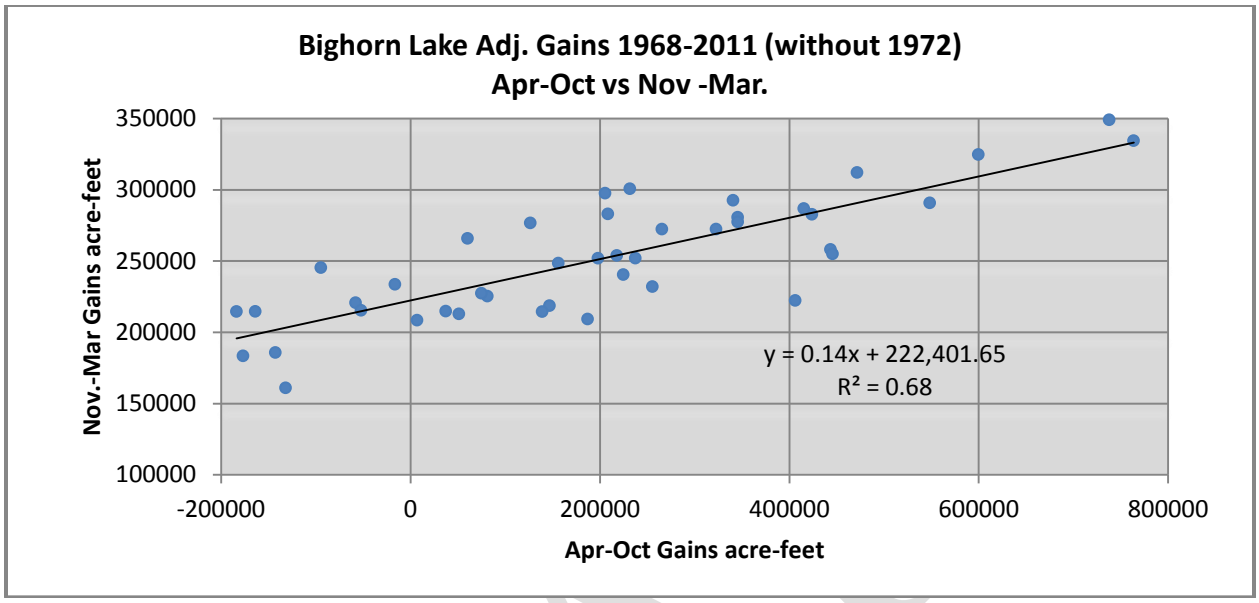

Figure 6

The plot (Figure 6) shows a fairly tight pattern of data points. These data and the resulting linear correlation equation provides an acceptable method for forecasting the November through March gain for Bighorn Lake. The resulting R^2 value of 0.68 shown on the plot indicates a good correlation between April through October gains and the November through March gains (a R^2 value of 1 would indicate an exact correlation). The equation adopted for forecasting the November through March gain (NMG) based on the April through October gain (AOG) is the linear relationship shown below:

$$NMG = 0.14(AOG) + 222{,}401.65$$

To compare how well the above equation forecasts the November through March gain the forecasted gains were plotted against the actual gain for each year from 1967 through 2010 (using adjusted depleted gains for the 1968 through 1990 period).

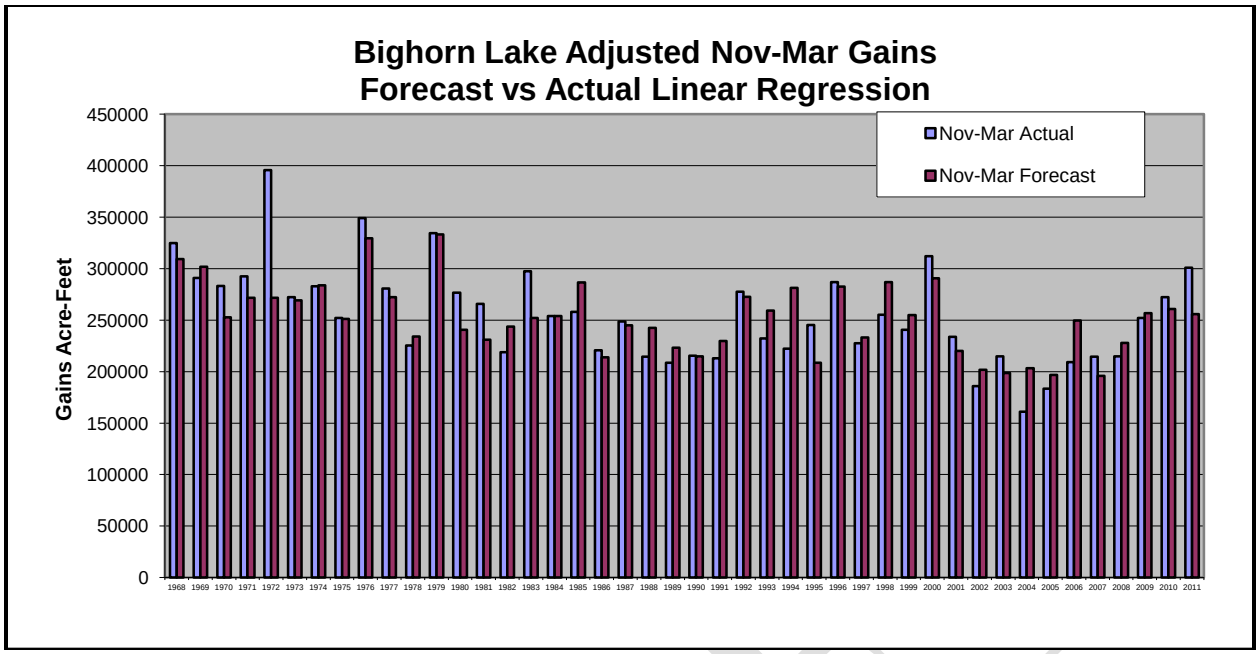

Figure 7

This graph (Figure 7) shows an acceptable forecast method for estimating the November through March gain over the last 44 years of record.

To provide a comparison between the earlier forecast equation and the 2012 equation the two linear relationships were plotted together. As can be seen in Figure 8 the two relationships provide near identical results for years with lower gains but diverge for years with higher gains. This was expected and helped to provide some validity for the adjustment to the pre 1991 gain data.

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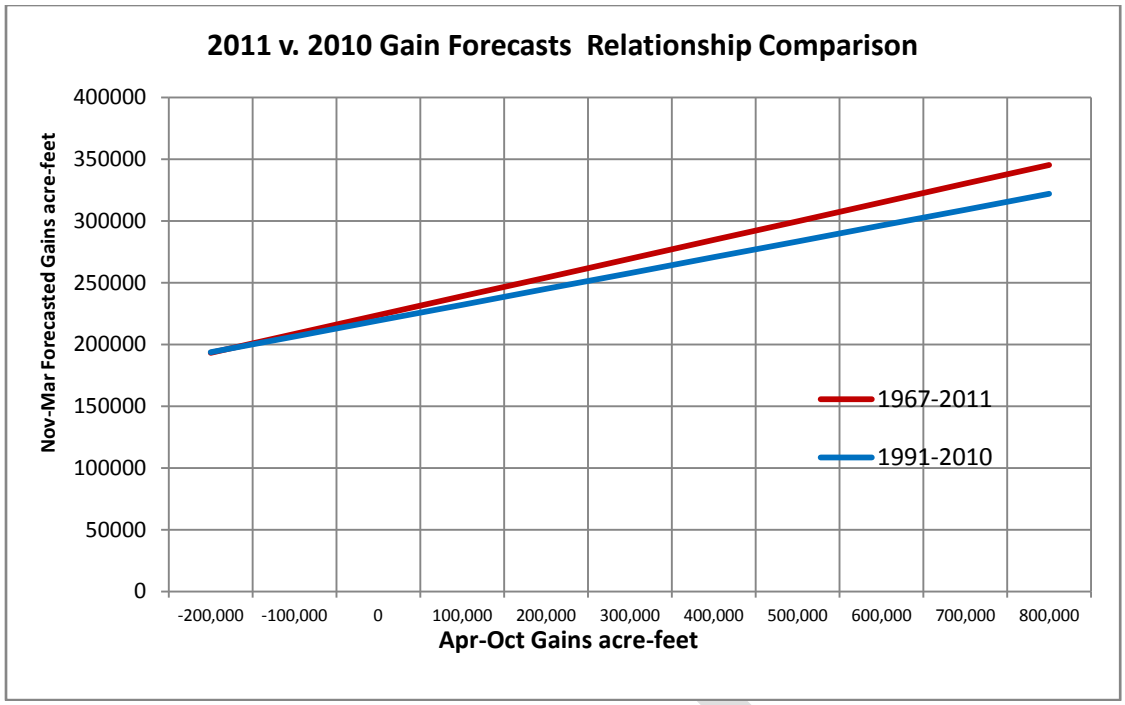

Figure 8

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Determining the November through March Release Rate: The method for establishing the November through March release rate is based on the November through March planned releases from Buffalo Bill and Boysen reservoirs (November 1 operating plans), the forecasted November through March Bighorn Lake gain and the goal of drafting the lake to an initial March 31 target level of 3617 (807,921 acre-feet). The release rate in cubic feer per second (cfs) is based on the water balance equation shown below with each of the values entered in acre-feet. The 70 cfs at the end of the equation accounts for the spring flow that enters the river between Yellowtail Dam and the Afterbay Dam:

Nov-Mar Rel. = (Oct 31 Bighorn Storage + Buffalo Bill Lake Nov-Mar Release
+Boysen Nov-Mar Release + NMG -807,921)/(151*1.98347)+70

As with any forecasting technique there is always a certain amount of risk that the actual gains will be higher or lower than the forecast. To deal with this risk and to help provide a better balance between the needs in the river versus the need in the lake the following additional steps have been included into the procedure for setting the November through March river release rate. In addition to the basic water balance equation shown above, there's a desire to find a way to reduce risks to the river flow whenever it appear necessary to reduce releases below 2,000 cfs and to reduce risks to the lake level before releases are increased above 2,500 cfs. During times of drought when lake inflows are low there is more of a need to draw from storage to help maintain minimum stream flows. During years when runoff is above average it is beneficial to bank some of this higher flow in the lake for later use should flows drop back to average or below. Having a little extra in storage provides benefit to the lake and also provides some buffer so the probability of having to reduce river releases during the spring is reduced. To provide this

balance between the needs in the river and the needs in the lake adjustments were made to the above equation under specific situations.

The adjustments work as follows. The above equation is initially used to calculate the river release rate. If the initial calculated release is less than 2,000 cfs then the river release is recalculated using an end of March target elevation of 3615 (794,613 acre-feet) rather than 3617. If the initial calculation is more than 2,500 cfs then the river release is recalculated using an end of March target elevation of 3619 (821,949 acre-feet) rather than 3617. A couple of other limits are also included in this procedure. These are: (1) If the river release is calculated to be less than 1,500 cfs then the river release is set at 1,500 cfs; (2) if the initial calculated release is less than 2,000 cfs and after using an adjusted end of March target elevation of 3615 the recalculated release is more than 2,000 cfs, then the release is set at 2,000 cfs; (3) if the initial calculated release is more than 2,500 cfs and after using an adjusted end of March target elevation of 3619 the recalculated release is less than 2,500 cfs, then the river release is set at 2,500 cfs. A summary of these adjustments is shown below.

Summary of Adjustments to the November through March Release for Calculated Release Below 2,000 cfs or Above 2,500 cfs

1. To reduce risks to the river when the calculated release is less than 2,000 cfs
   - Adjust the end of March target down to elevation 3615 and recalculate the November through March release
   - If the calculated release is less than 1,500 cfs, set the release to 1,500 cfs
   - If the calculated release is more than 2,000 cfs, set the release to 2,000 cfs
   - If the calculated release is between 1,500 and 2,000 cfs, set the release to the calculated release
2. To reduce risks to the lake when the calculated release is more than 2,500 cfs
   - Adjust the end of March target up to elevation 3619 and recalculate the November through March release
   - If the calculated release is less than 2,500 cfs, set the release to 2,500 cfs
   - If the calculated release is greater than 2,500 cfs, set the release to the calculated release

A summary of the effect on the March 31 lake level target based on different November through March release rates is shown in the following table.

March 31 Lake Level Targets

River Release Rate	March 31 Lake Target Elevation
Greater than 2500 cfs	3619
2000-2500 cfs	3617
Less than 2000 cfs	3615

DRAFT

April-July Inflow Forecasts:

Beginning on January 1 and continuing through June 1 spring runoff forecasts are prepared to estimate the April through July inflow to Bighorn Lake. These forecasts are based on mountain snowpack, soil moisture conditions, upstream reservoir forecasted operations and other runoff-contributing factors. Forecasts are prepared by Reclamation, the U.S. Natural Resources and Conservation Service (NRCS) and the U.S. Army Corps of Engineers (COE). Due to a wide range of variability in spring precipitation and temperature the forecasts are not for one specific runoff amount but rather a range of flows varying from a minimum probable forecast (90 percent chance of exceedance) to a maximum probable forecast (10 percent chance of exceedance). These forecasts are formally updated near the first of each month as additional data becomes available. Informal mid-month forecasts are also prepared. The following graph shows an example of NRCS 2009 natural flow forecasts for Bighorn River near St. Xavier, MT. The forecasts graphed are not the official NRCS forecasts but demonstrate the range between various forecast levels and the changes in forecasts from month to month. The graph also shows how the various forecasts come closer together as the end of the forecast period approaches. The final forecasts are made in early June. The flat graphed lines, after June 1, continue to plot the final early June forecast values.

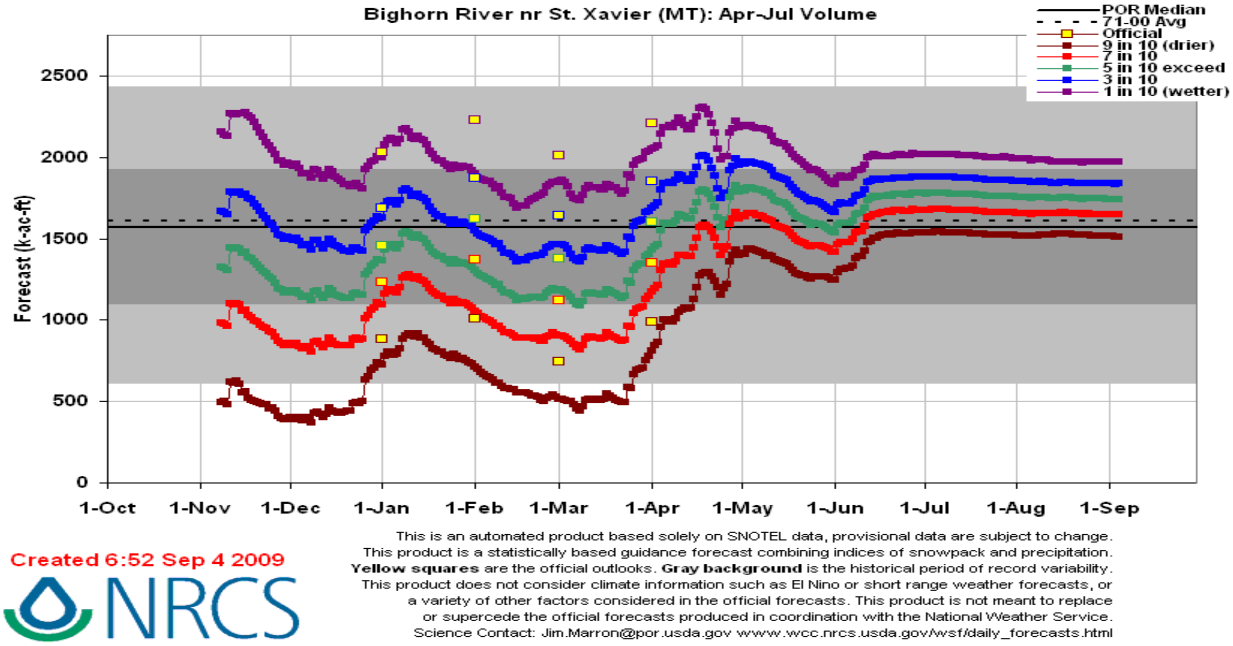

Figure 9

There are a number of factors that limit the accuracy of the spring runoff forecasts. These includes limited snow course measuring sites, unpredictable spring precipitation, considerable variations in upstream irrigation use and depletions, and considerable variation in spring temperatures that impact snowmelt.

Existing snow measurement sites (SNOTEL stations) are limited to mountain elevations at or below 10,000 ft. This leaves 3,000 ft or more of the upper mountain range with no snow measurements. As temperatures warm the snow melts from the lower elevations up with little of the higher elevation snow melting until temperatures on the plains climb into the upper 80s and 90s. Often, during the spring and early summer, daytime high temperatures will remain in the upper 70s and lower 80s until nearly all of the snow at the SNOTEL stations has melted. Graphs plotting the snow amounts at the SNOTEL stations will then indicate that the snowmelt is essentially over. This can be misleading as a large amount of heavy snow may still exist above the highest SNOTEL stations. When temperatures finally push into the 90s, runoff may suddenly increase to high flood flows. These high flows can continue for days or even weeks as the higher and heaviest snow melts. For this reason, temperatures along with the snow stations are monitored closely during the snowmelt season.

Even with the best information possible on mountain snowpack and snow water content, the amount and timing of spring rains remains a big factor in the actual spring runoff. In an average precipitation year, spring rain accounts for about 25-30% of spring runoff. In wetter years this percentage is much higher and in dry years, much lower. The spring rain also plays a significant role in the percentage of snowmelt that reaches the river. Flexibility must be built into lake operations to account for a wide variation in rainfall-produced runoff. Until our ability to predict the weather improves significantly, there will remain a large amount of uncertainty in the spring runoff forecasts.

The medium forecast, as represented by the green line on the graph, is often referred to as the most probable forecast. This is a misnomer as this specific forecast amount is no more likely than the other graphed forecast amounts. The medium forecast is simply at the midpoint, having a 50 percent chance that the actual flows will be higher and a 50 percent chance that the flows will be lower than this medium forecast amount. Lake operating plans prepared at the beginning of each month are prepared for three runoff scenarios; (1) minimum probable, (2) medium probable and (3) maximum probable. This allows the lake manager to review operations for a wide range of possible runoff conditions. Actual operations are based initially on the medium probable plan with provisions for adjustment either upward, towards the maximum probable plan, or downward, towards the minimum probable plan, depending on actual runoff conditions. This approach provides necessary operating flexibility to adequately handle most runoff situations.

Once the February 1 spring runoff forecasts become available, the March 31 lake level target may be allowed to vary somewhat dependant on the forecast amount. In years with a forecast for very low spring runoff, it may be beneficial to reduce the February and March river release rate to prevent the need for larger release reductions later in the spring. In years with a well above normal spring runoff forecast, it may be beneficial to increase the February and March release rate to draft the lake sufficiently to meet desired lake levels for flood control Based on the use of the Rule Curve which begins on April 1.

DRAFT

Spring Operational Rule Curves:

Due to the amount of variation in weather conditions and especially precipitation, the spring season is the most difficult period to forecast lake inflow and meet desired lake operational goals. Even slight changes in precipitation amounts can significantly affect the quantity of rainfall and snowmelt entering the streams. In addition, dry conditions result in significant river depletion due to upstream irrigation practices, while wet conditions can completely eliminate these irrigation depletions. As a means of improving the spring operations and to provide a more transparent operation, some members of the issues group requested that we look at the work Reclamation's Pacific Northwest Region did in establishing a varying set of rule curves for operating Hungry Horse Lake located in Northwestern Montana. Lake operational rule curves provide a set of lake level graphs that define the amount of storage space needed through the spring and early summer season to regulate anticipated spring runoff. These curves, which are based on historic runoff events, carefully guild the drawdown and refill of the lake through the snowmelt runoff season. The studies prepared for Hungry Horse Lake were reviewed and an evaluation made to determine if rule curves would be applicable for Bighorn Lake. Based on this review it was determined that while the situation at Hungry Horse Lake is quite different from Bighorn Lake, a set of rule curves could still be developed as a useful tool in assisting managers with Bighorn Lake operational decisions during the spring runoff season. Basically, for Bighorn Lake the curves would indicate that in years with high runoff forecast the lake should be drawn to its lowest level by mid to late May and in years with low snowpack the lake should begin to fill as early as April. Also in years with high runoff forecast the curves would show that the lake should be filled sometime during the second week in July while in years with low runoff forecasts the curves would indicate that the lake should be filled by mid to late June if sufficient runoff is available to refill the lake. These curves are established and adjusted based on runoff forecasts which are revised at least monthly throughout the spring and early summer runoff season.

Rule curves were first developed for Bighorn Lake in early 2009 for use during the 2010 water year. These earlier curves were presented in the 2010 Draft Criteria report issued in September of 2010. During 2011 the curves were updated to take advantage of the runoff data for the record runoff year of 2011 and also to add in the runoff events during 2009 and 2010. The following is a discussion covering the development of the 2012 Rule Curves.

Starting with 1967, each spring runoff event and its accompanying runoff forecasts were reviewed. From this evaluation, the years were sorted into groups of low, medium, and high runoff years. Using the historic records, typical runoff hydrographs were developed for each set of years and routed through Bighorn Lake in a manner that provided near-optimum operations. From these routings, rule curves were developed. For each of the years from 1967-2011 the April through July actual inflows to Bighorn Lake were then routed through the lake using the preliminary rule curves and an Excel spreadsheet daily operational model. From the results of these routings, adjustments were made to finalize the rules curves. A final set of operational rule curves were then developed for runoff events ranging from a 26 percentile year (minimum fill year) up to a 99 percentile year. Rule curves for years with inflow less than a 26 percentile year were not developed, as it was found that these are years when the lake should be managed to provide a careful balance between the need for minimum river fishery flows (2,000 cfs or less)

DRAFT

and sufficient storage to provide minimum service levels for lake recreation and fishery. In most of these years the lake will fill to a level less than the normal full level at elevation 3640. Figure 10 shows a set of inflow hydrographs developed for the different levels of inflow and Figure 11 shows a set of rule curves that were developed to fit different runoff situations ranging from the 26 percentile runoff (labeled Min Fill) event up to a 99 percentile year (labeled "Max" on the graphs).

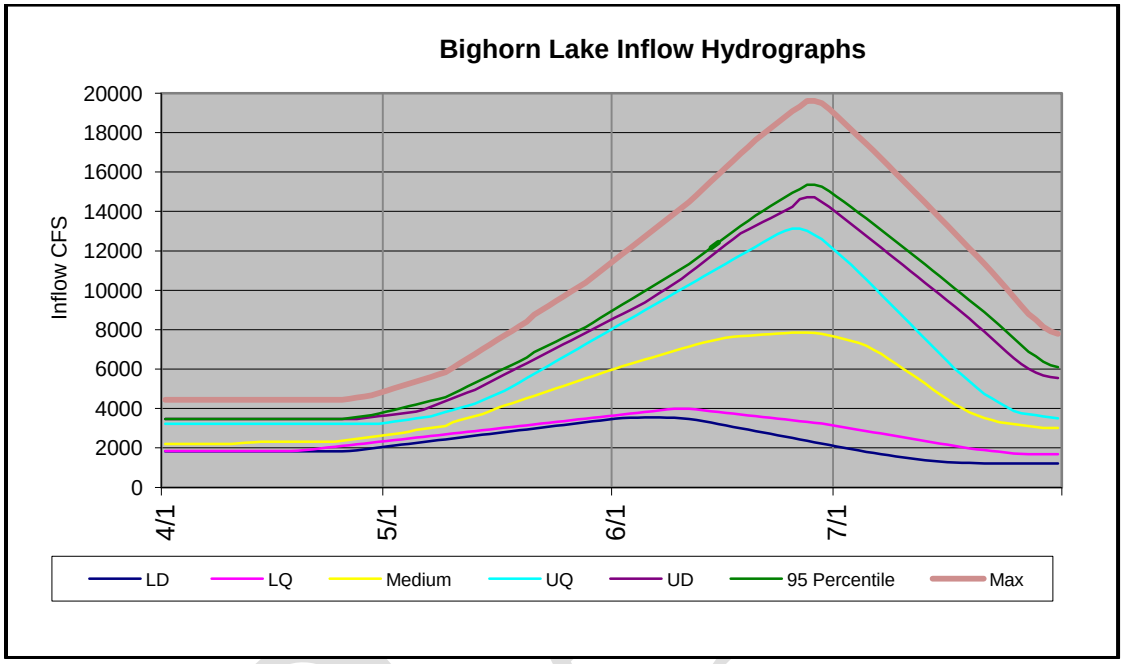

Figure 10

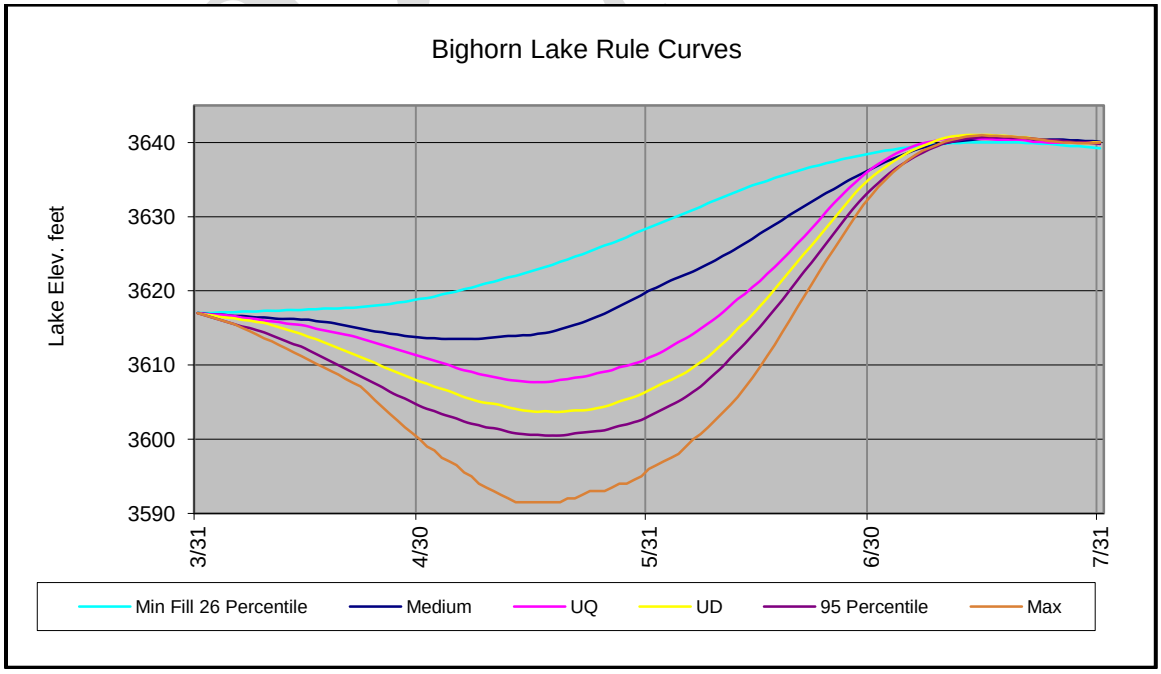

Figure 11

On Figures 10 and 11 the hydrograph and rule curve labeled Max is estimated to be a 99 percentile runoff year or a year that has only a 1 percent chance of being exceeded. LD stand for a lower decile event (90 percent change of exceedance), LQ for a lower quartile event (75 percent change of exceedance), UQ for an upper quartile event (25 percent change of exceedance) and UD for an upper decile event (10 percent change of exceedance). The rule curves developed for a specific forecast amount is based on interpolating between the two rule curves that are closest to that forecast amount.

Once these curves were completed, a spreadsheet was developed to calculate individual rule curves to fit the April 1, April 15, May 1, May 15 and June 1 forecasted inflow for future years of operation. This spreadsheet allows the user to import the actual lake operational data (from the Hydromet Database) for the current year and compare the actual operations with the rule curve. From this comparison, adjustments to the river releases are made to keep actual lake operations near or on track with the rule curve guide. Some flexibility and judgment should be exercised in determining how close the actual operations follow the rule curves as making operations strictly follow the rule curve could result in a number of significant and frequent release adjustments. Normally, adjustments to the lake releases should be based on looking several days or a week ahead to allow time for the lake level to come back on track with the rule curve.

The rule curves show that for low snowpack years the lake should be allowed to begin filling in early April, and for high snowpack years the lake should continue to be drafted through April and May to its low point around mid to late May. The 2012 Draft Criteria expanded the rule curves to cover April through July inflow forecasts up to 2,500,000 acre-feet as compared to an upper limit of 2,000,000 acre-feet under the 2010 Draft Criteria. The following table provides a comparison of the 2012 Draft Criteria rule curve target elevations with the 2010 Draft Criteria rule curve target elevations.

Comparison of Rule Curve Lake Target Elevations

Runoff Acre-feet	Percentile Rank	Percent of Average	2012 Minimum Target Elevation	2010 Minimum Target Elevation
548,900	10	48%	3617.0	3618.0
655,000	25	58%	3617.0	3618.0
1,121,800	50	99%	3613.5	3614.7
1,584,000	75	140%	3607.7	3607.3
1,850,000	90	163%	3603.7	3604.7
1,957,300	95	173%	3600.5	3603.3
2,310,000	98	204%	3594.5	3602.7
2,500,000	Max (99)	221%	3591.5	3602.7

The next table provides more detail on the lake elevation level targets established by the 2012 Draft Criteria rule curves for various April through July forecasted inflow volumes.

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Bighorn Lake 2012 Rule Curve Results

A-J Inflow Forecast AF	Percentile Rank	Percent of Average	Rule Curve Apr 30 Elev	Rule Curve May 31 Elev	Rule Curve Min Elev	Date Min
548,900	10	48%	3620.4	3629.4	3617.0	4/1
655,000	25	58%	3617.1	3624.6	3617.0	4/1
950,000	35	84%	3616.0	3623.9	3616.0	4/1
1,121,800	50	99%	3613.7	3620.0	3613.5	5/3
1,310,000	60	116%	3612.7	3616.5	3611.5	5/13
1,584,000	75	140%	3611.2	3611.0	3607.7	5/15
1,850,000	90	163%	3607.8	3606.6	3603.7	5/18
1,957,300	95	173%	3604.5	3603.1	3600.5	5/17
2,310,000	98	204%	3601.6	3598.5	3594.5	5/14
2,500,000	Max (99)	221%	3600.0	3596.0	3591.5	5/14

Years with Forecasted April- July Inflow Less than a 26 Percentile Volume:

For years with forecasted April-July Inflow falling below a 26 percentile year (April-July inflow less than 727,000 acre-feet) rule curves were not developed, as it was found that these are years when the lake will need to be managed to provide a careful balance between the need for a minimum river release for the river fishery flows (2,000 cfs or less) and sufficient storage to provide adequate longer term water supply for all users. In these years the lake is not expected to fill to its normal full level at elevation 3640. The goal, in these low runoff years should initially be that of holding a river release near 2,000 cfs through the end of the following March if this will allow the lake to end up near its desired March 31 target elevation of 3617. The ROMS Access model should be used along with the November through March operating criteria and forecasted inflows to determine if this is probable. If this is not probable then a decision will be needed to determine when and to what degree river flows are reduced below 2,000 cfs. Reducing the river release below 1,500 cfs should only be considered when needed to prevent full depletion of the active conservation pool. Decisions to reduce releases below 2,000 cfs and especially 1,500 cfs are not decisions that can or should be spelled out in this report. Flexibility should be left to Reclamation to address the needs of each of the interests in Bighorn Lake in determining a properly balanced operation between the lake and the river under these situations.

Evaluation of the 2012 Draft Operating Criteria:

To test the effectiveness of the proposed modifications to the Bighorn Lake operating criteria, the ROMS Access model was used to simulate Bighorn Lake operations using the modified criteria. A study period of 1988-2008 was selected to avoid the earlier years when the river gain was declining while still including the majority of drought years that have occurred since construction of the dam as well as several high runoff years. This period also includes some very

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high runoff years during the 1990s. Because the drought years are the most difficult to manage for the competing interests, it was desirable to include these years in the study period. This period is also recent enough to incorporate the monthly spring runoff forecasts used in the actual past operations.

The model simulation used the revised operating target included on page 14 the new revised gains explained on page 15-19, the November through March release rates calculated with the procedure described on pages 20-21, and the rule curves described on pages 22-27. The results of the model simulation were then compared to the actual historic operations to determine how lake levels and river flows would vary from past operations. Figure 12 is a graph comparing the average monthly lake elevations using the 2012 Draft Criteria compared to the historic operations.

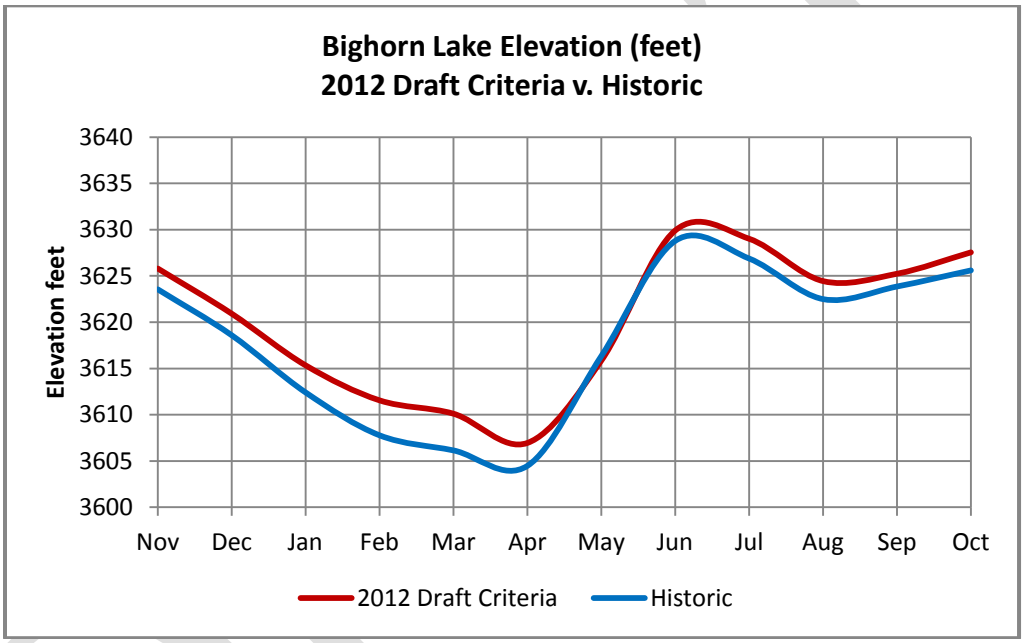

Figure 12

Figure 12 shows that the lake would operate noticeably higher on the average under the 2012 Draft Criteria. The period of the year when the difference in the operating level is most pronounced is during the January through April period when the lake level averages 3-4 feet higher under the 2012 Draft Criteria as compared to historic conditions. During May the average lake elevation is shown to equal that of the historic operations. It's important to note, however, that the 2012 Draft Criteria will hold the lake a somewhat higher at the end of May in low runoff years but somewhat lower during high runoff years as additional storage space will be evacuated by the rule curves for enhanced flood control. In some low runoff years (such as 1990 and 2001) the 2012 Draft Criteria will hold the lake as much as 20 feet higher than under the historic operations.

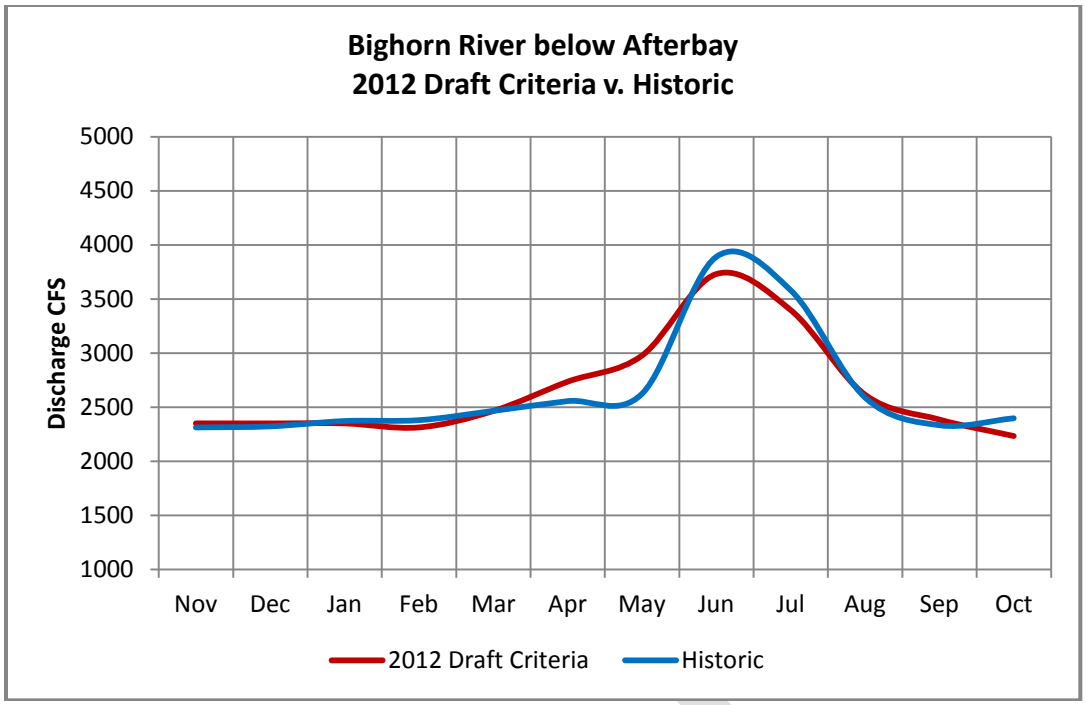

Figure 13

Figure 13 compares average monthly flows in the Bighorn River below Afterbay Dam for the 2012 Draft Criteria versus the average historic river flows. This graph shows that under the 2012 Draft Criteria the November through March river flow will average essentially the same as under historic operations. In the early spring river flow will be noticeably higher but flows in June and July will be somewhat lower improving flood control.

To gain a better understanding of how the 2012 Draft Criteria affects river fishery flows, the river flows were examined from the context of meeting the desired fishery flow targets established by the MTFWP. Each of the months of operations were examined to determine the percent of time the river flow met or exceeded the fishery flow targets of 1500 cfs, 2000 cfs, and 2500 cfs. In addition higher flow values of 3000 cfs and 3500 cfs were also examined. Figure 14 is a graph comparing the percent of time the various fishery flow targets are exceeded for the modified criteria versus historic operations.

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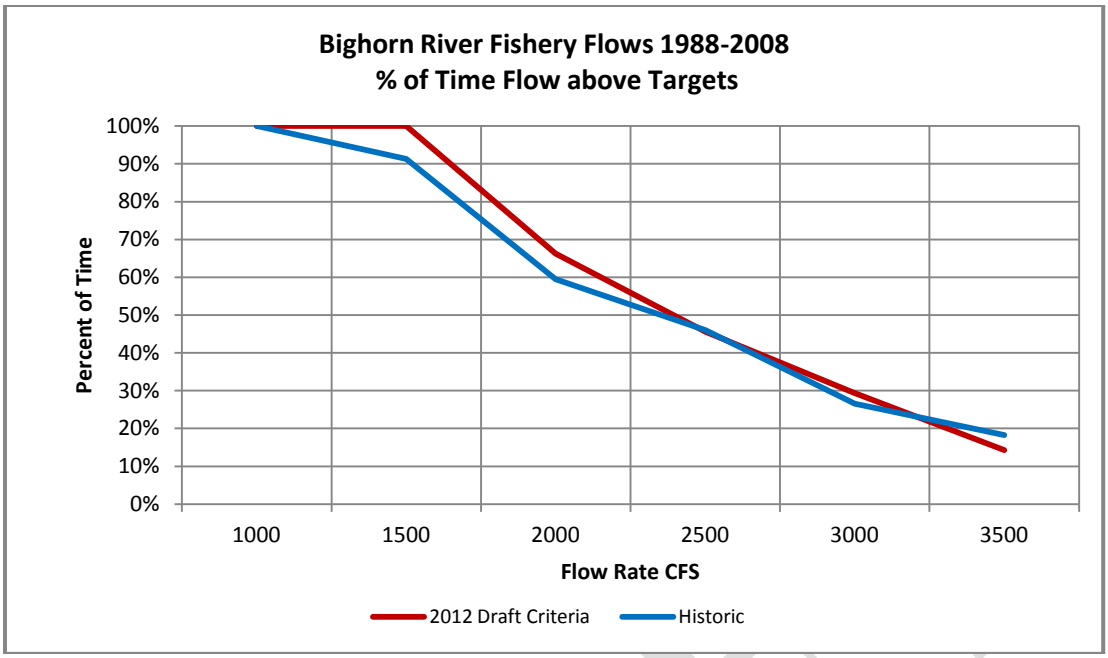

Figure 14

This graph show that the 2012 Draft Criteria provide an improvement in the percent of time the desired fishery flow targets are met for the targets of 1500 cfs, and 2000 cfs. A flow level of 3000 cfs was also met more often. For a flow of 2500 cfs the 2012 Draft Criteria matched the percent of time this flow was provided under the historic operation. The percent of time flows are at or above 3500 cfs is reduced slightly by the 2012 Draft Criteria.

Power generation was also compared between the 2012 Draft Criteria and actual historic operations. Since actual generation can vary from the model estimates due to maintenance, peaking operation and other factors, the historic dam releases were entered into the ROMS model and the model was run to duplicate historic lake operations. This then provided a better comparison of the change due to the 2012 Draft Criteria. The resulting power generation quantities were then compared between the 2012 Draft Criteria and the simulated historic conditions. The following table and graph provides a summary of the results. The graph labeled Figure 15 compares the average monthly generation values between the 2012 Draft Criteria and the simulated historic operations.

Yellowtail Dam Average Power Generation
Gigawatt Hours (GWH) 1988-2008

Period	2012 Draft Criteria	Simulated Historic	Percent Change
Annual	773.7	767.6	+1%
Dec-Feb	157.4	157.5	0%
July-Aug	165.8	168.7	-2%

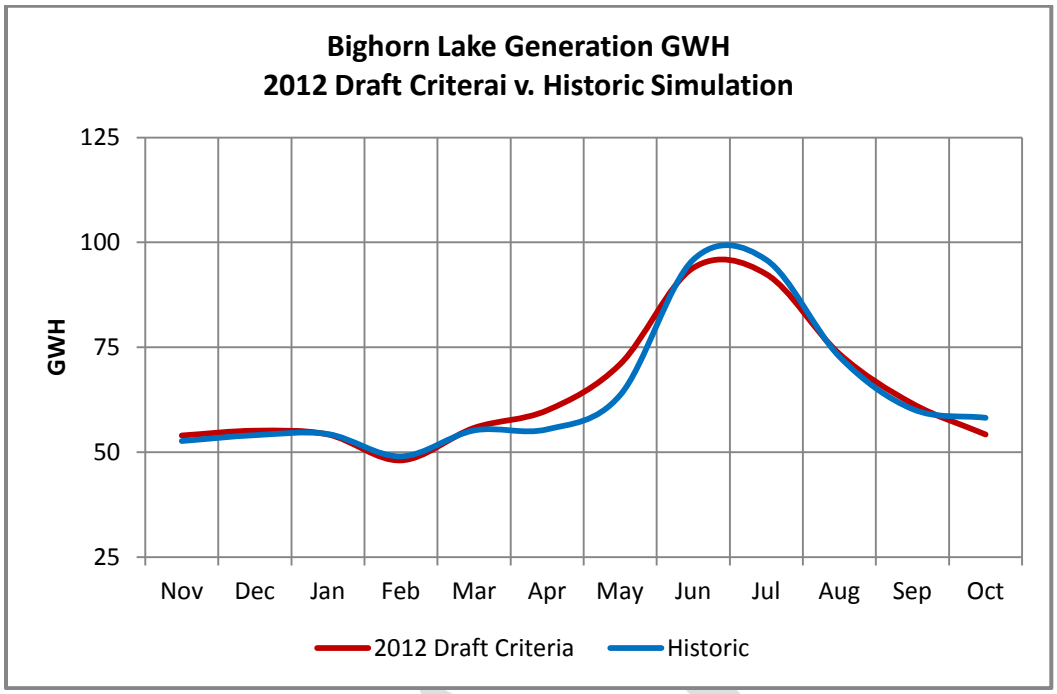

Figure 15

The table and graph show that overall generation will be increased by about 1 percent on the average with noticeable increases in the spring. The critical periods for power generation are generally in the hot mid-summer months and the cold winter months. During the winter generation will remain the same as under historic operations while generation during the mid-summer will be reduced slightly. The reduction in mid-summer generation is due to the higher releases in April and May used to provide more space in the lake for flood control. This then limits the water released during June through August. While the mid- summer generation is shown to be less there will be a benefit to power generation by allowing for some additional reserve capacity in the spring when system generating reserve is limited. The main reasons for the overall increase in power generation under the 2012 Draft Criteria is due to the higher lake operating levels and a minor reduction in the June release reducing the amount of water bypassing the power turbines in that month. Holding the lake higher increases "head" on the power turbines which in turn increases power generation efficiency.

Graphs showing monthly lake levels and river release for the full 1988-2008 study period are included as Figures 16 and 17 respectively.

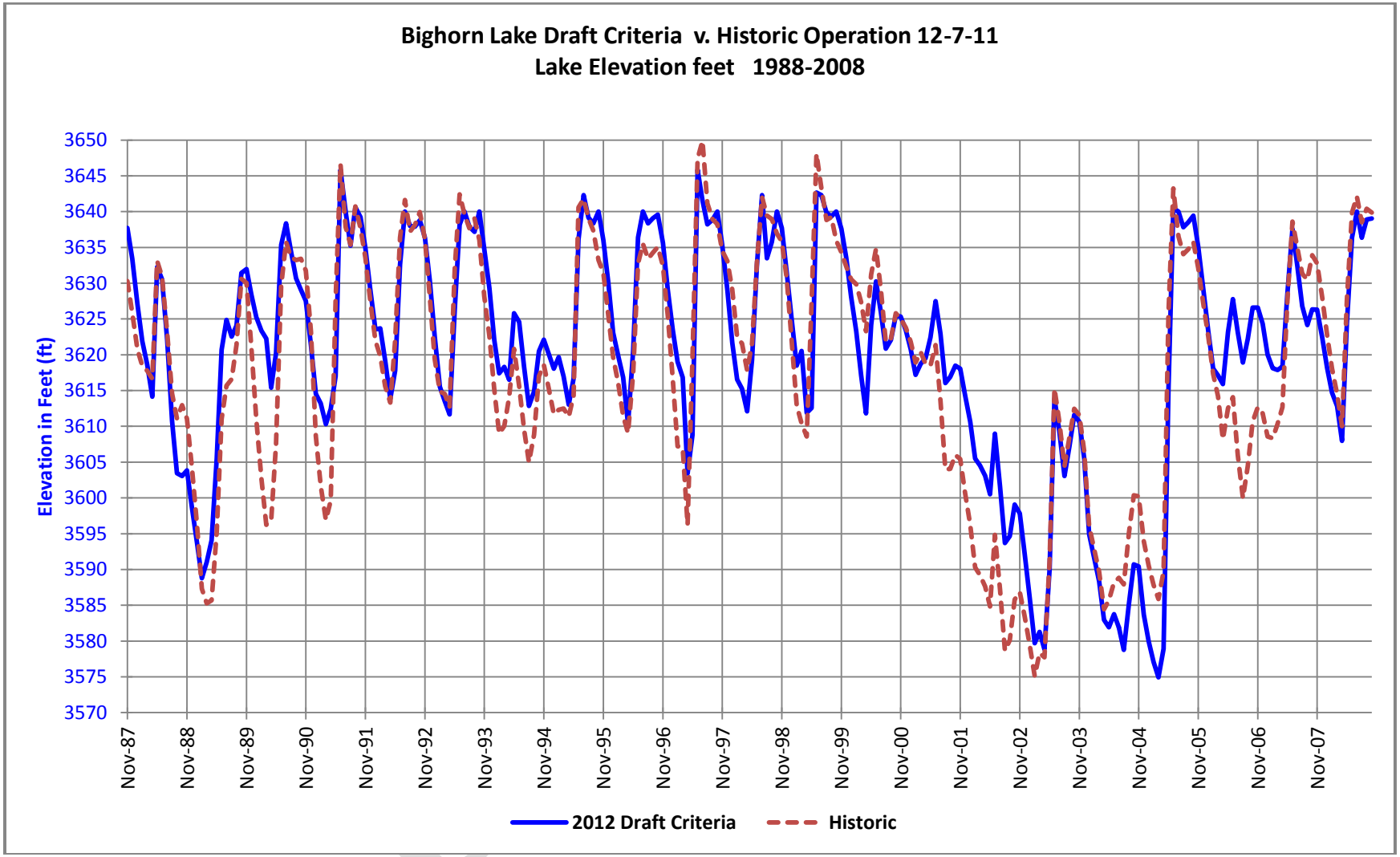
Bighorn Lake Draft Criteria v. Historic Operation 12-7-11
Lake Elevation feet 1988-2008
Elevation in Feet (ft)
3650
3645
3640
3635
3630
3625
3620
3615
3610
3605
3600
3595
3590
3585
3580
3575
3570
Nov-87
Nov-88
Nov-89
Nov-90
Nov-91
Nov-92
Nov-93
Nov-94
Nov-95
Nov-96
Nov-97
Nov-98
Nov-99
Nov-00
Nov-01
Nov-02
Nov-03
Nov-04
Nov-05
Nov-06
Nov-07
2012 Draft Criteria
Historic

Figure 16

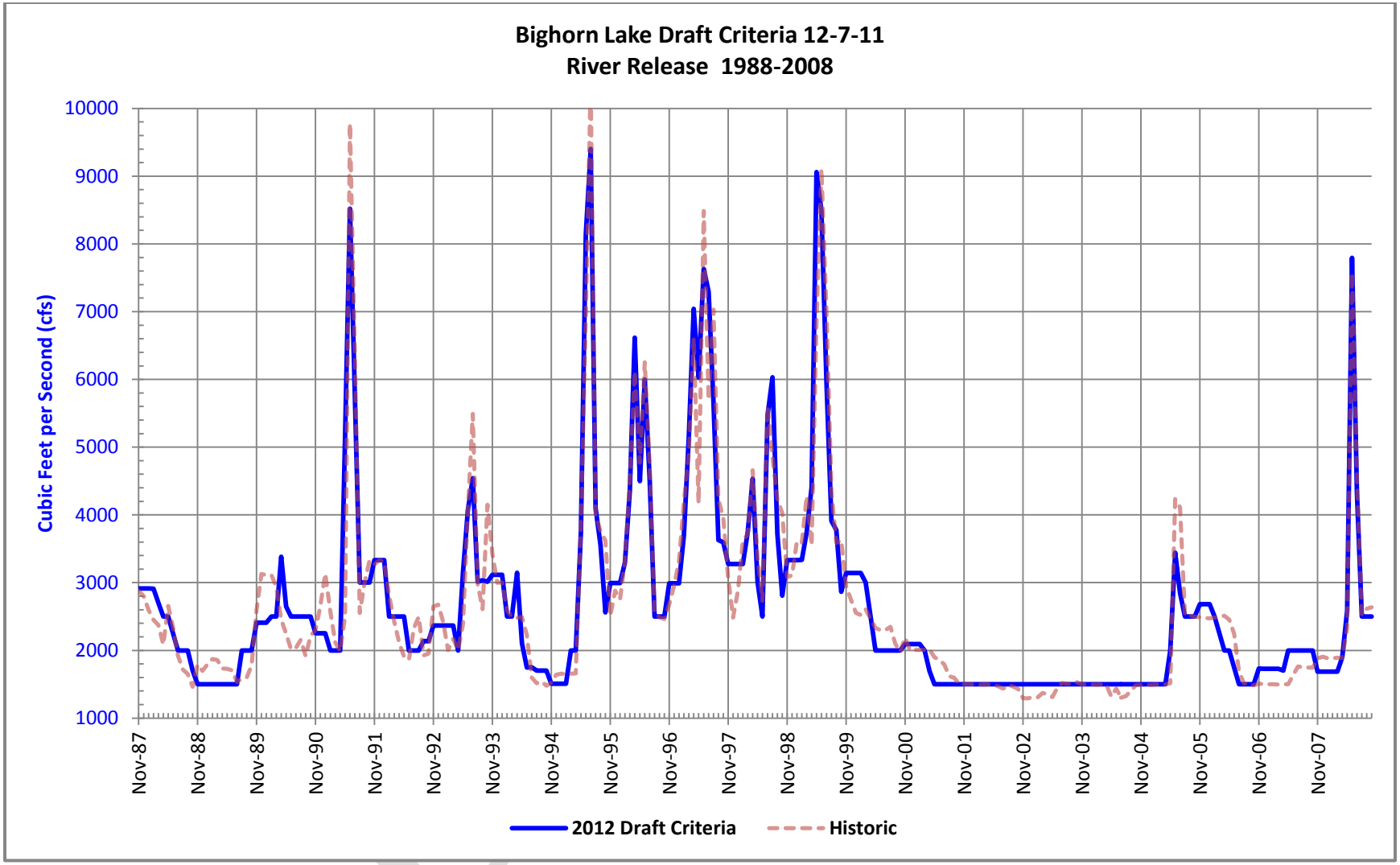
Bighorn Lake Draft Criteria 12-7-11
River Release 1988-2008
Cubic Feet per Second (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
Nov-87
Nov-88
Nov-89
Nov-90
Nov-91
Nov-92
Nov-93
Nov-94
Nov-95
Nov-96
Nov-97
Nov-98
Nov-99
Nov-00
Nov-01
Nov-02
Nov-03
Nov-04
Nov-05
Nov-06
Nov-07
2012 Draft Criteria
Historic

Figure 17

SYSTEM OPERATIONS:

While the operating criteria is only intended to address the operations of the Yellowtail Unit efforts have also been made to develop tools which can enhance the overall coordination and operations among each of the larger Reclamation's dams and reservoirs in the Bighorn River Basin. A daily operational spreadsheet model was developed in 2011 to integrate the planned operation of Boysen and Buffalo Bill reservoir with Bighorn Lake. This tool allows operating managers in both the Montana Area Office and the Wyoming Area Office to quickly evaluate planned changes in operations and also run operating simulations for different operating options. This tool provides information in both tabular and graphic form to assist in evaluating results. Procedures for sharing data and scheduling meetings and conference calls between the two offices have also been improved to ensure that communications are improved.

CONCLUSIONS:

Modification of the Bighorn Lake operating criteria to include revised lake level targets, a revised method for calculating the gains, a new procedure for establishing a November through March river release rate and the incorporation of operational rule curves for the April through July period will provide benefits for the lake recreation and fishery and provide some improvements in the river fishery flows during most periods of the year. The major benefit the proposed modification provides for the lake is it allows the lake to operate 2-3 feet higher on average than historic operations. The most significant change in lake elevations will be during late winter and early spring when the lake will operate 3-4 feet higher on the average. The higher lake would also provide a somewhat higher "head" for power generation, slightly increasing the power generation efficiency and increasing average annual generation by about 1 percent. A higher March 31 lake level target also increases the probability that the lake will refill in the spring in lower runoff years improving overall water supply. Flood control improvements will be provided by utilizing lake operational rule curves during the April-July runoff season to carefully guide operations through the critical spring runoff season such that storage is evacuated to its lowest level just prior to flood runoff. Also the rule curves will help delay the fill date in years with well above average forecasted spring runoff. This will help limit the use of the flood pool as well as somewhat reduce peak river release during this higher runoff years.

The trout fishery will benefit by an increased percent of time the fishery flow targets are met, an increase in river flow during the spring and early summer when the Rainbow trout spawn, and a more reliable overall water supply through periods of drought. With the higher lake levels provided by the proposed modified criteria, the risk of reducing the river flow in the spring and especially below 1,500 cfs would be reduced. During the period of 1988-2008, the actual river flow was reduced to less than 1,500 cfs in a total of 19 months. Actual river releases during the drought dropped to a low-flow of 1,300 cfs. Model runs, using the 2012 Draft Criteria, show that for this same period a flow of 1,500 cfs or higher could be provided 100 percent of the time.

Additionally, the recommended modification to the operating criteria would provide a more transparent method for establishing major operational decisions through each annual operating cycle. The procedure for establishing the November through March release rate and developing

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April through July operational rule curves, based on forecasted lake inflows, will be available to share with the public.

The following table provides a summary of the expected benefits provided by the proposed revised operating criteria.

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Expected Benefits from the 2012 Draft Operating Criteria
As Compared to Historic Operation

Power Generation	Change in Generation GWHs	Percent Change
Annual	+ 6.1	1%
December-February	0	0%
*July-Aug	- 2.9	-2%

* Additional drawdown in the spring for flood control, as directed by the rule curves, reduces the average June through July release through the power turbines reducing generation. One side benefit of this is an increase in power reserve during June and July a time when power reserve is generally very limited.

Flood Control

The following compares the 2012 Draft Criteria average peak end of month lake elevation and average peak monthly river release values for the high runoff years of 1991, 1995, 1997, 1999 and 2008 with the actual historic record for these same years.

	Historic	Draft Criteria	Change
Peak avg. End of Month Lake Elev.	3644.8	3643.3	- 1.5 feet
Peak average Monthly Release	9,064 cfs	8,368 cfs	-697 cfs

River Flows

Fishery Flow Targets	Change in Percent of Time Target Provided
1500 cfs	+9% (met 100% of time for study period)
2000 cfs	+7%
2500 cfs	+0%
3000 cfs	+3%
3500 cfs	-4%

Lake Levels	Change in Lake Elevation
January-April	3-4 feet higher than historic
May	0 feet higher than historic
June	1 foot higher than historic
July-December	2 feet higher than historic

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