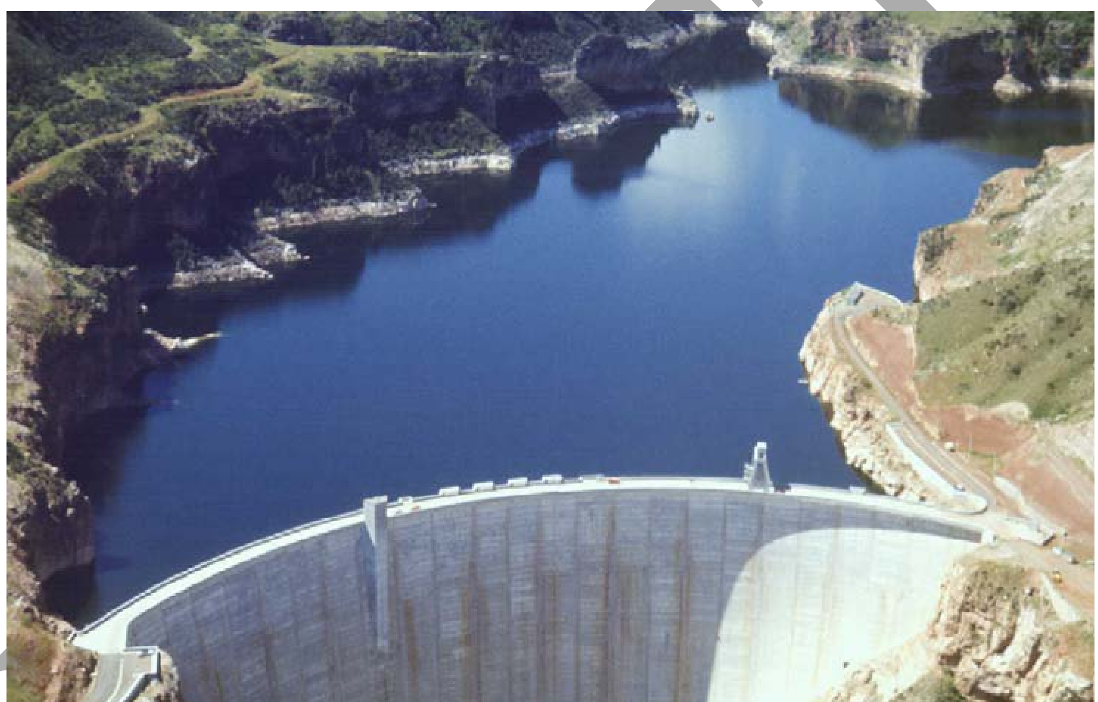
RECLAMATION

Managing Water in the West

DRAFT BIGHORN LAKE OPERATING CRITERIA EVALUATION STUDY & REPORT



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

Draft Report
September 14, 2010

EXECUTIVE SUMMARY

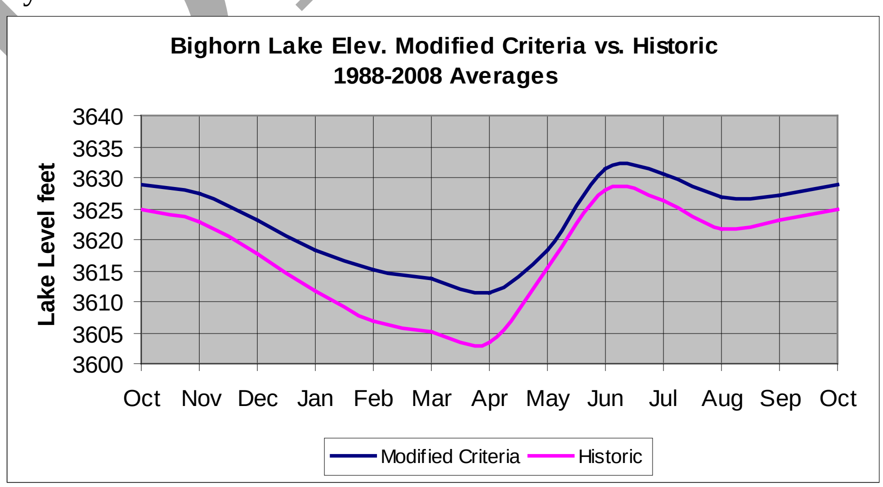
Severe drought conditions and record-low water supply during 2000-2007 significantly impacted the operation of Yellowtail Dam resulting in abnormally low levels in Bighorn Lake, Bighorn River flows near minimum levels for extended periods of time, and power generation output that was less than 50 percent 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 March 2007. Issues discussed in these meetings dealt with the various management aspects related to reservoir levels, river release rates, flood control, and power generation. Based on input provided from all of the various interests attending the issue group meetings, 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 modifications studied included:

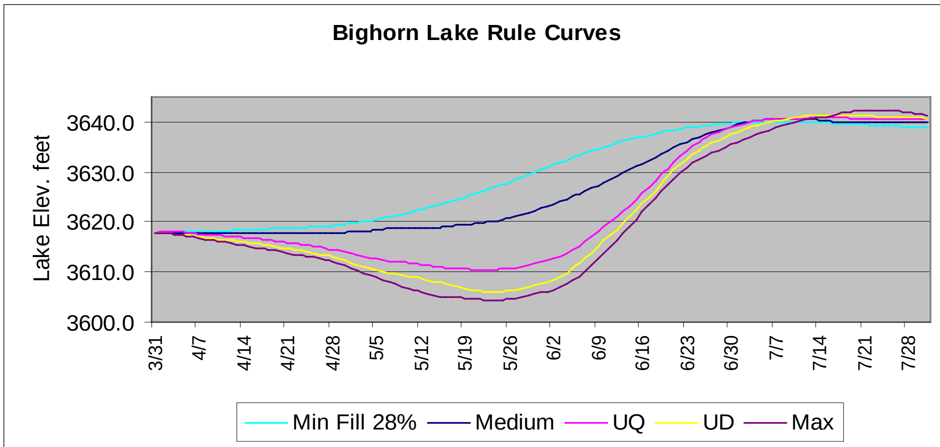
- Revised reservoir level targets,
- A revised method for calculating the gains,
- A new procedure for establishing a Fall/Winter (November through March) river release rate,
- Incorporation of operational rule curves for the April through July

Modification of these Bighorn Lake operating criteria and operating tools was found to provide significant benefits for the lake recreation and fishery, while still providing river fishery flows equal to or better than provided in the past.

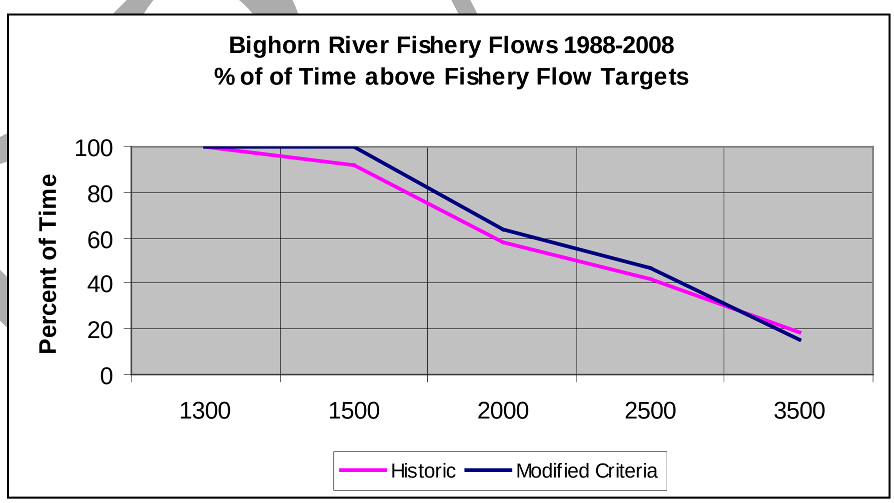
The proposed modification allows the reservoir to operate 3 to 8 feet higher on average than historic operations mostly during late winter and early spring. The higher reservoir provides a somewhat higher "head" for power generation, slightly increasing the power generation efficiency and increasing average annual generation by about 2 percent. A higher March 31 reservoir level target also increases the probability that the reservoir will refill in the spring and in lower runoff years.



Improved levels of flood control will be provided by utilizing reservoir operational rule curves during the April-July runoff season to draft the reservoir sufficiently to handle higher runoff during years with above-normal mountain snowpack.



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 risk of river flow below 1,500 cfs significantly reduced. During the period of 1988-2008, river flow was reduced to less than 1,500 cfs in a total of 19 months, dropping to a low-flow of 1,300 cfs. Model runs, using the revised operating criteria show that for this same period a flow of 1,500 cfs or higher could be provided 100 percent of the time.



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

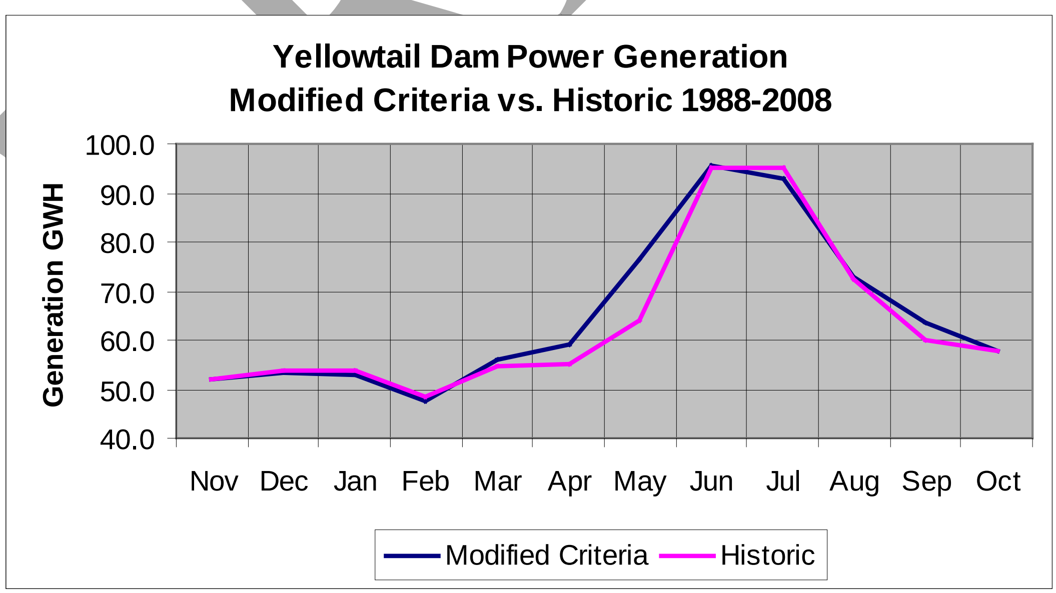
Expected Benefits of Revised Operating Criteria
Values Compared to Historic Operation

Lake Levels	
January-April	7-8 feet higher
May-June	3 feet higher
July-December	4-5 feet higher

River Flows	Improvement in Percent of Time Provided
1500 cfs	+8% (met 100% of time for study period)
2000 cfs	+5%
2500 cfs	+5%
3500 cfs	-3%

Power Generation	Increased Generation GWHs	Percent Increase
Annual	+17.9	2%
December-February	- 2.2	-1%
July-Aug	- 1.8	-1%

Flood Control	
June	Slight decrease in peak release rate Decrease in peak reservoir level for most high runoff years



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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 into 2010. Issues discussed in these meetings have dealt with the various management aspects related to reservoir 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, 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 reservoir operating level targets.
- Improving the method for forecasting November through March gains to the reservoir.
- 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 reservoir storage during the spring runoff season.

Each of these issues are discussed in this report.

Report Purpose

The purpose of this report is to document new methods and procedures studied for improving the overall project benefits of the Yellowtail Unit and more specifically, providing a better balance between the desire to operate Bighorn Lake for flat water recreation and operating the project to maintain desired releases to the Bighorn River for the river fishery.

Background

The Yellowtail Unit 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 reservoir, a powerplant, an afterbay dam and reservoir, 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 reservoir 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 Bighorn Lake Operating Criteria

Operating Criteria: The operating criteria for Bighorn Lake and Yellowtail Dam generally consist of the following:

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

A brief summary of the criteria is included below.

Reservoir Storage Allocations: The reservoir storage allocations were defined prior to construction of the project. These allocations determine how certain storage zones, within the reservoir, are used to meet the various project purposes. The reservoir storage allocations for Bighorn Lake are defined as follows:

Reservoir Storage Allocations

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

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

BIGHORN LAKE (YELLOWTAIL DAM) ALLOCATIONS

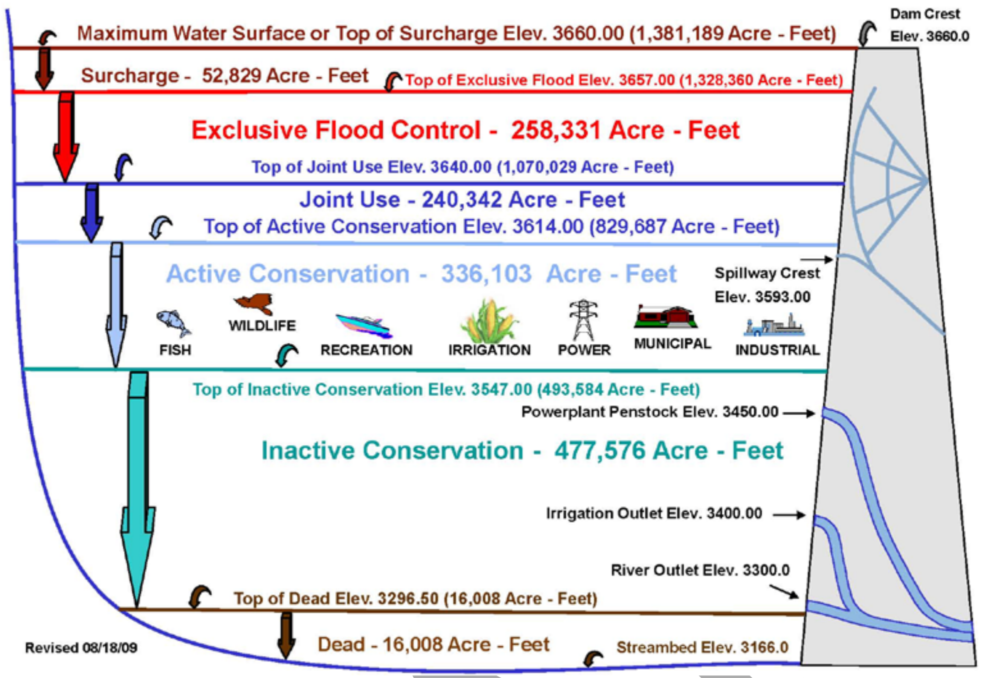

Figure 1

The inactive conservation and dead pools, below elevation 3547, are necessary to maintain a minimum reservoir level to allow for the operation of the hydroelectric power turbines. Below elevation 3547 the power turbines must be shut off.

The active conservation pool, between elevation 3547 and 3614, is 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 reservoir is in the exclusive flood control pool reservoir 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 maintaining sufficient storage space to provide for flood control, maximizing the power generation benefit, maintaining desired lake levels for recreation and reservoir 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 reservoir 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 3580.

Desired River Fishery Flows: The following are the desired fishery flows as included in Chapter 4 of the 2000 SOP:

Optimum Fishery Flow	2,500 cfs
Standard Fishery Flow	2,000 cfs
Minimum Fishery Flow	1,500 cfs
Absolute Minimum Fishery Flow	1,000 cfs

Bighorn River below Afterbay Dam

Reservoir Level Targets: Reservoir elevation targets are 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 reservoir normally reaches its peak level and operations transition from a spring operation to a summer water supply operation. The reservoir 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 reservoir level prior to winter freeze up to provide sufficient storage for winter operations, a desired level of reservoir drawdown in early spring to provide adequate storage space for expected spring snowmelt runoff, and a full reservoir level target at the end of spring runoff. The reservoir targets listed in the 2000 SOP are as follows:

Date	Reservoir Operating Level Targets
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)
October 15	Elev. 3635 (desired minimum for waterfowl hunting)

Proposed Revisions to Reservoir Level Targets

The main concern expressed by reservoir recreation and lake fishery interests is the need for higher reservoir levels, especially during the summer recreation season. Over the years as sediment has accumulated in the upper end of the reservoir, 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 reservoir 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 reservoir is the only portion of the reservoir that is more typical of a lake. The reservoir from just below Horseshoe Bend to the dam is in a narrow steep canyon. It is not until the reservoir is near elevation 3630 that the upper end of the reservoir 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 WYGF has made similar recommendations requesting that the reservoir 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 reservoir be at or above elevation 3630 during the growing season. WYGF believes that below elevation 3620 the reservoir fails to provide fishing opportunities in Wyoming and greatly reduces the preferred habitat of many fish. These desired levels were not considered when the reservoir level targets were first established as the above recommendations had not been available.

Horseshoe Bend Recreation Area

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

October 15 Target of Elevation 3635 and November 30 Target of Elevation 3630: The purpose of the fall reservoir targets was to lower the reservoir 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 reservoir level would potentially result in considerable ice forming in the lower section of the river directly upstream of the reservoir leading to ice-jams and flooding. There were a few years in the early 1970s, prior to establishing the fall reservoir level targets, when this appeared to be a problem especially in relation to flooding of the railroad tracks. Since that time the railroad tracks have been raised, reducing their risk for flooding. Based upon input received 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 of Elevations 3605-3614: The March 31 reservoir level targets were established to provide a balance between the need to provide sufficient reservoir storage space for regulating spring runoff and the need to have the reservoir high enough to ensure that the reservoir 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.

The March 31 target was established to provide a reservoir level that would allow the reservoir to refill in all but very low snowpack years and also allow sufficient storage space for controlling high May through June runoff in years with high mountain snowpack. Drafting of the reservoir in the spring after the end of March was considered detrimental to the Walleye fishery further supporting a low end of March reservoir target. 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 reservoir fishery.

July 31 Target of Elevation 3640: The July 31 target elevation of 3640 is the top of the joint use pool or the normal full level for the reservoir. Filling the reservoir to its normal full level by the end of the spring runoff season provides the maximum storage supply for all project purposes.

Under the current storage allocations this provides the maximum conservation pool for meeting water supply needs through the coming year and an optimum reservoir level for recreation and the reservoir 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 reservoir storage allocations would need to be adjusted to convert a portion of the exclusive flood pool space to joint use space. This option is being considered under a separate study.

A preliminary study was prepared using the Bighorn Lake monthly operation model (ROMS Access Model) to determine if there would be a benefit to raising both the fall and spring target levels. The period of study for this model run was 1967-2007. From the model study it was found that the lake could be operated about 5 feet higher, on the average, if the March 31 target was raised to near 3618 and the October 15 and November 30 targets were replaced with an October 31 target level set between elevation 3638 and 3640.

The study results show that this modification to the reservoir level targets would allow the reservoir to fill more often in lower runoff years, but would require that the reservoir be drafted by up to 13 feet after March 31 in years with well above normal snowpack to provide adequate space for controlling high spring runoff. Since the target levels would increase reservoir storage levels by equal amounts in both the fall and the spring, this change would allow the level of the November through March river release to continue near the same levels as in the past.

In addition, the results show that during years with high mountain snowpack, the reservoir may need to be drafted several feet below elevation 3618 during April and May to provide adequate storage space to regulate high spring runoff.

An October 31 target of 3638 to 3640 is the highest practical operating level for the reservoir prior to the winter season under the current storage allocations. This target level continues to provide the desired lake levels in October and November for water fowl hunting. Based on the results of these model studies the following modified reservoir level targets are recommended.

Reservoir Operational Target Levels

Old Targets		New Targets	
Date	Target Elev.	Date	Target Elev.
October15	3635	October 31	3638 to 3640
November 30	3630	Eliminate Nov. 30 target	
March 31	3605-3614	March 31	3618
July 31	3640	July 31	3640

The benefit of the proposed modification would be that the reservoir would operate about 5 feet higher on the average then in the past while still maintaining the same level of fall and winter release for the benefit of both power generation and the river fishery. The higher reservoir would also provide somewhat higher "head" for power generation, slightly increasing the power generation efficiency.

A higher March 31 reservoir level target also increases the probability that the reservoir will refill in the spring during low runoff years. The same level of flood control, as provided by the old elevation targets, can still be provided by drafting the reservoir after March 31 through mid to late May to desired levels in years with high mountain snowpack.

Revised Procedure for Establishing the November - March Release Rate

The first step in developing a method for establishing a November through March release rate that will meet the March reservoir target elevation is 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 reservoirs 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. The 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 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 directly 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 consistently treat all of the canals the same. Either all of the canals diversion should be subtracted from the reservoir releases or none of them should be subtracted. The least complicated and consistent method to account for the gain is to calculate it as the inflow to Bighorn Lake less the total releases from Boysen and Buffalo Bill Dams.

Once the gains were recalculated for the full period of record of 1967-2009, 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 1968 through 2007. Since water year 1967 was a record high year and 2001-2007 were extreme drought years these years were excluded from the plot so that these extreme events would not overly influence the trend line. The following graph (Figure 2) 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 higher runoff years. It is not totally clear why the gains have significantly declined but some of the factors that have likely contributed to this are as follows: (1) changes in irrigation practices from gravity systems to sprinkler: (2) a major rehabilitation betterment program on the Shoshone Irrigation Project during the 1980s that replaced many of the open lateral irrigation delivery canals with closed pipelines reducing groundwater recharge; (2) and increased groundwater use in the basin.

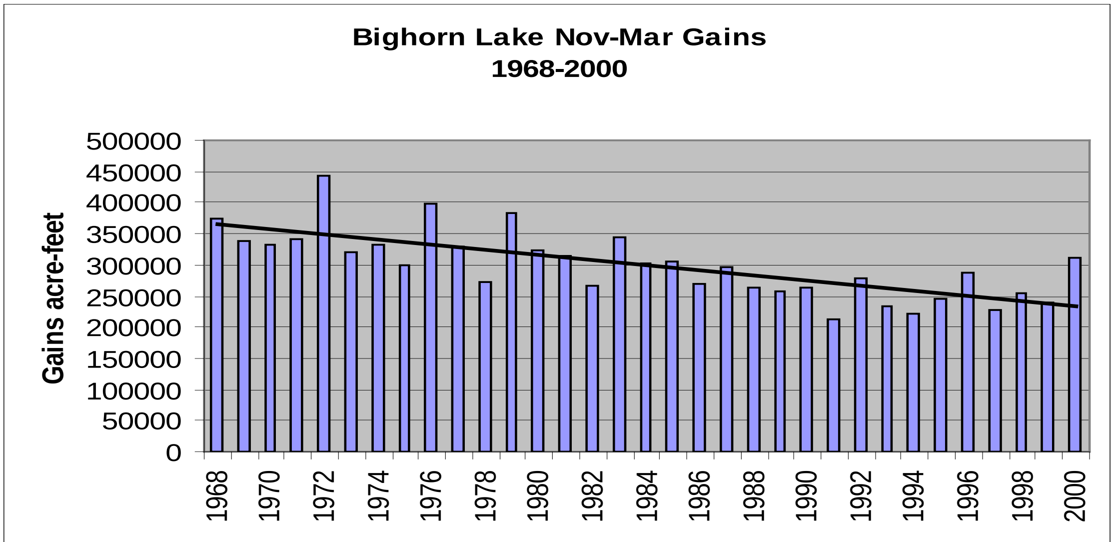

Figure 2

To verify that the downward trend was not due to some climate anomaly, the November through March inflow to Buffalo Bill Reservoir was also reviewed. There has been very little development above Buffalo Bill Reservoir so these inflows are fairly close to virgin conditions with 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 3 there is no noticeable trend either downward or upward in the Buffalo Bill inflow over this same period of record.

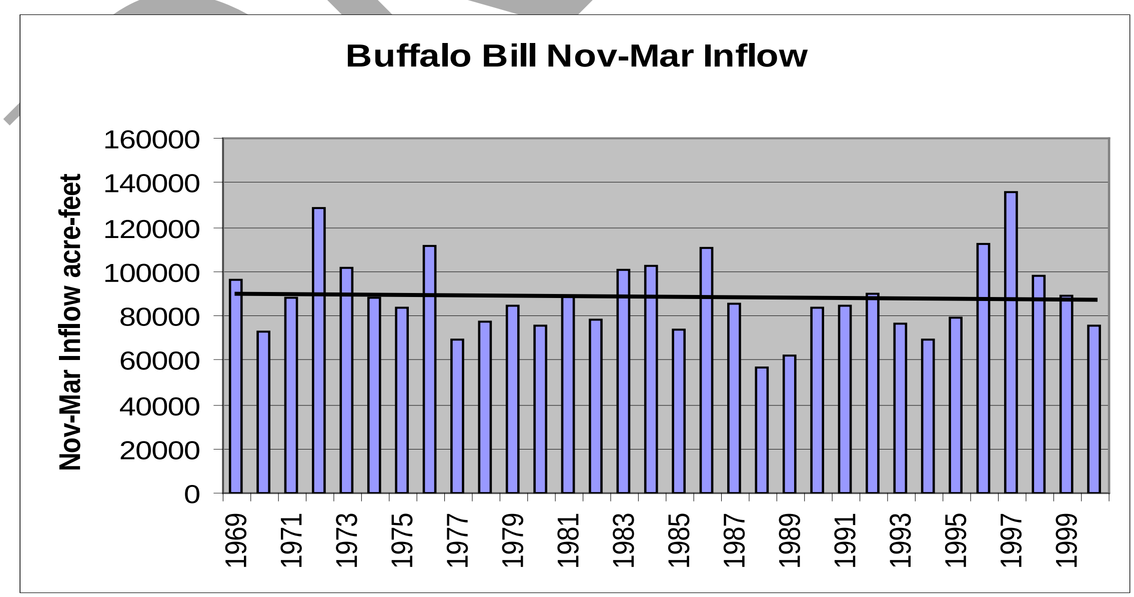

Figure 3

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 correlation between the April-October gains and the November-March gains.

Comparing the April through October gain with the November through March gain for the period of 1991 through March of 2009, it was found that there was a fairly good correlation between the gains for these two separate time periods. These data were updated in 2010. The graph below (Figure 4) 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.

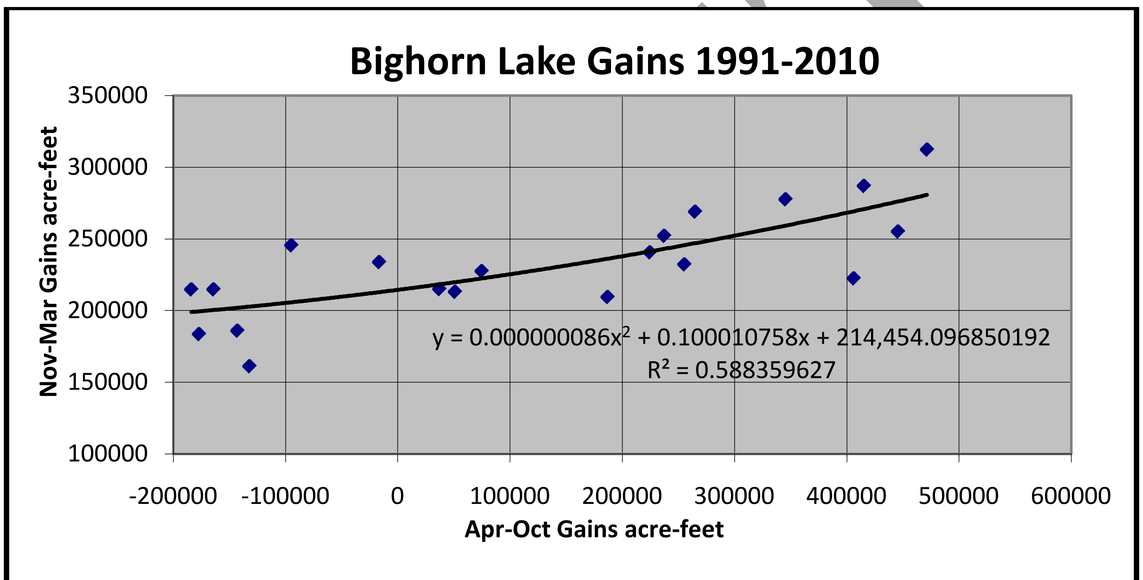

Figure 4

The plot shows a fairly tight pattern of data points. These data and the resulting correlation curve provide a fairly good method for forecasting the November through March gain for Bighorn Lake. The resulting R^2 value of 0.59 shown on the plot indicates a fair correlation between the gains for the two different time periods (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 shown below:

$$NMG = 0.000000086(AOG)^2 + 0.100010758(AOG) + 214{,}454.096850194$$

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 1991 through 2009 Figure 5).

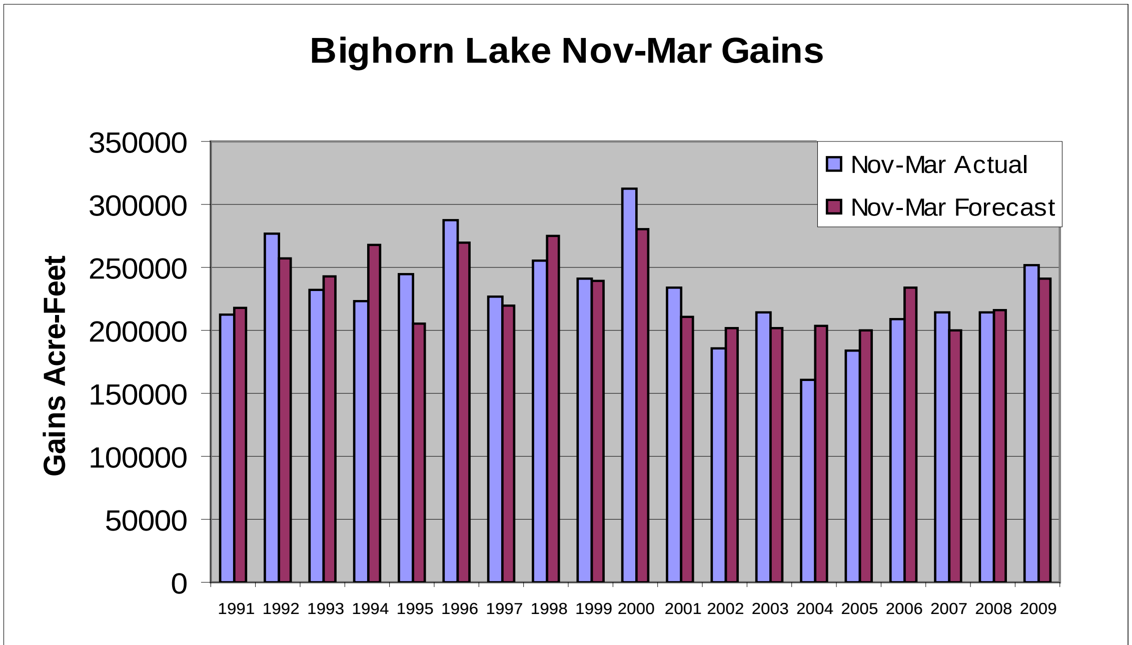

Figure 5

This graph shows that the forecast method did an acceptable job in estimating the November through March gain over the last 19 years of record.

Determining the November through March Release Rate: The method for establishing the November through March release 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 reservoir to an initial March 31 target level of 3618 (858,442 acre-feet). The release rate in cubic feer per second (cfs) is then 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 Reservoir Nov-Mar Release +Boysen Nov-Mar Release + NMG -858,442)/(151*1.98347)+70

Ballancing Risk: In addition to the basic water balance equation shown above, there was a desire to find a way to reduce risks to the river flow whenever it is necessary to reduce releases below 2,000 cfs and to reduce risks to the lake level before increasing releases above 2,500 cfs. To provide a better balance between the needs in the river and the needs in the lake some 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 after adding an additional 10,000 acre-feet to the forecasted gain. If the initial calculation is more than 2,500 cfs then the river release is recalculated after subtracting 20,000 acre-feet from the forecasted gain. 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 adding an 10,000 acre-feet adjustment to the gain 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 subtracting off the 20,000 acre-foot adjustment to the gain and the calculated 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
   - Add 10,000 acre-feet to the forecasted gain and recalculate the November through March release
   - If the release is less than 1,500 cfs, set the release to 1,500 cfs
   - If the release is more than 2,000 cfs, set the release to 2,000 cfs
   - If the 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
   - Subtract 20,000 acre-feet from the forecasted gain and recalculate the November through March release
   - If the release is less than 2,500 cfs, set the release to 2,500 cfs
   - If the release is greater than 2,500 cfs, set the release to the calculated release

Another way of looking at these adjustments is to consider their impact on the March 31 lake level target. If the 20,000 acre-foot adjustment level is applied when releases are set above 2,500 cfs, it increases the March 31 lake level target to 3620.6. If the 10,000 acre-foot adjustment is applied when flows are set below 2,000 cfs, this decreases the March 31 lake level target to 3616.7. A summary of the effect on the March 31 reservoir level target based on different November through March release rates is shown in the following table.

March 31 Reservoir Level Targets

River Release Rate	March 31 Reservoir Target Elevation
Greater than 2500 cfs	3620.6
2000-2500 cfs	3618.0
Less than 2000 cfs	3616.7

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 storage 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 for 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.

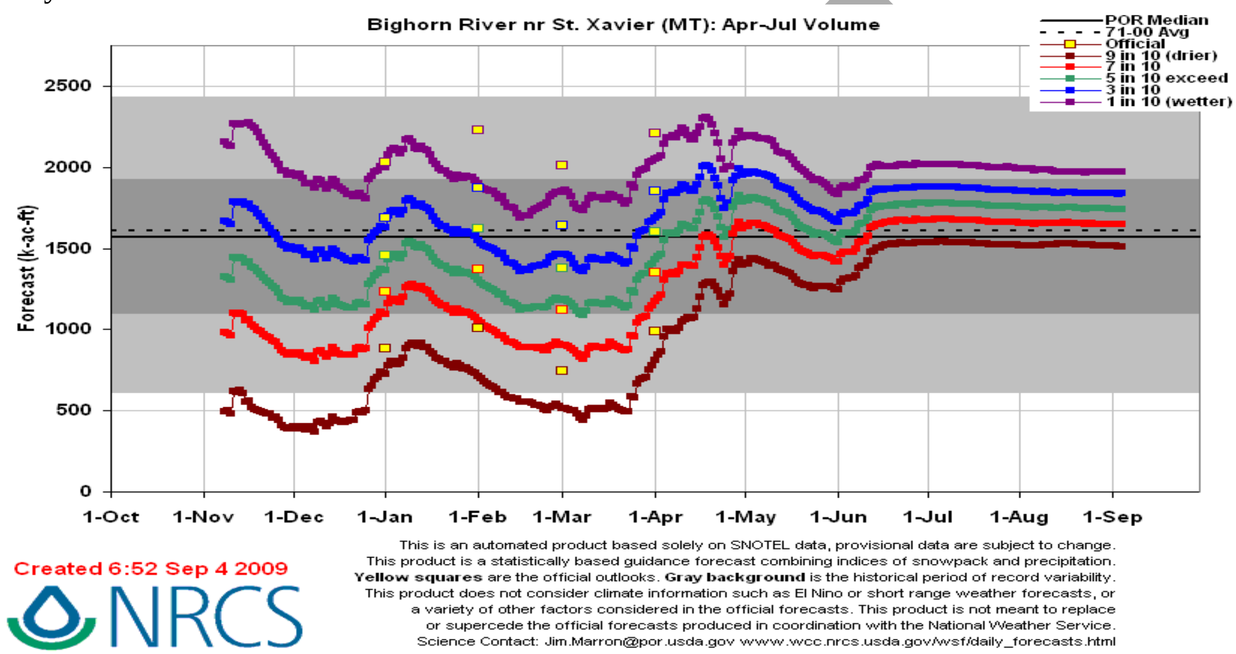

Figure 6

There are a number of factors that limit the accuracy of the spring runoff forecasts. Existing snow measurement sites (SNOTEL stations) are generally 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 often 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 all of the snow at the SNOTEL stations has melted. Graphs plotting the snow levels 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 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 reservoir 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. Reservoir 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 reservoir 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 reservoir 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 March (and in some cases the February) 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 March release rate to draft the reservoir sufficiently to meet desired reservoir levels for flood control.

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 reservoir inflow and meet desired reservoir 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 that Reclamation's Pacific Northwest Region did in establishing a varying set of rule curves for operating Hungry Horse Reservoir located in Northwestern Montana. Reservoir operational rule curves provide a set of graphs that define the amount of storage space needed during the spring and early summer season to regulate anticipated spring runoff. These curves, which are based on historic runoff events, also show the timing for evacuating storage and refilling the reservoir as snowmelt runoff occurs. Basically, for Bighorn Lake the curves would indicate that in years with high mountain snowpack the reservoir should be drawn to a lower than normal level by mid to late May and in years with low snowpack the reservoir should begin to fill as early as April. These curves are established and adjusted based on runoff forecasts which are revised at least monthly throughout the spring and early summer runoff season. The studies prepared for Hungry Horse Reservoir 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 Reservoir 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.

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 1967-2008 the April through July actual inflows to Bighorn Lake were then routed through the reservoir 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 28 percentile year (minimum fill year) up to a 98 percentile year. Rule curves for years with inflow less than a 28 percentile year were not developed, as it was found that these are years when the reservoir should be managed to provide a careful balance between the need for minimum river fishery flows (2,000 cfs or less) and sufficient storage to provide minimum service levels for lake recreation and fishery. In most of these years the reservoir will fill to a level less than the normal full level of at elevation 3640. Figure 7 shows a set of inflow hydrographs developed for the different levels of inflow and Figure 8 shows a set of rule curves that were developed to fit different runoff situations ranging from the 28 percentile runoff (labeled Min Fill) event up to a 98 percentile year (labeled "Max" on the graphs).

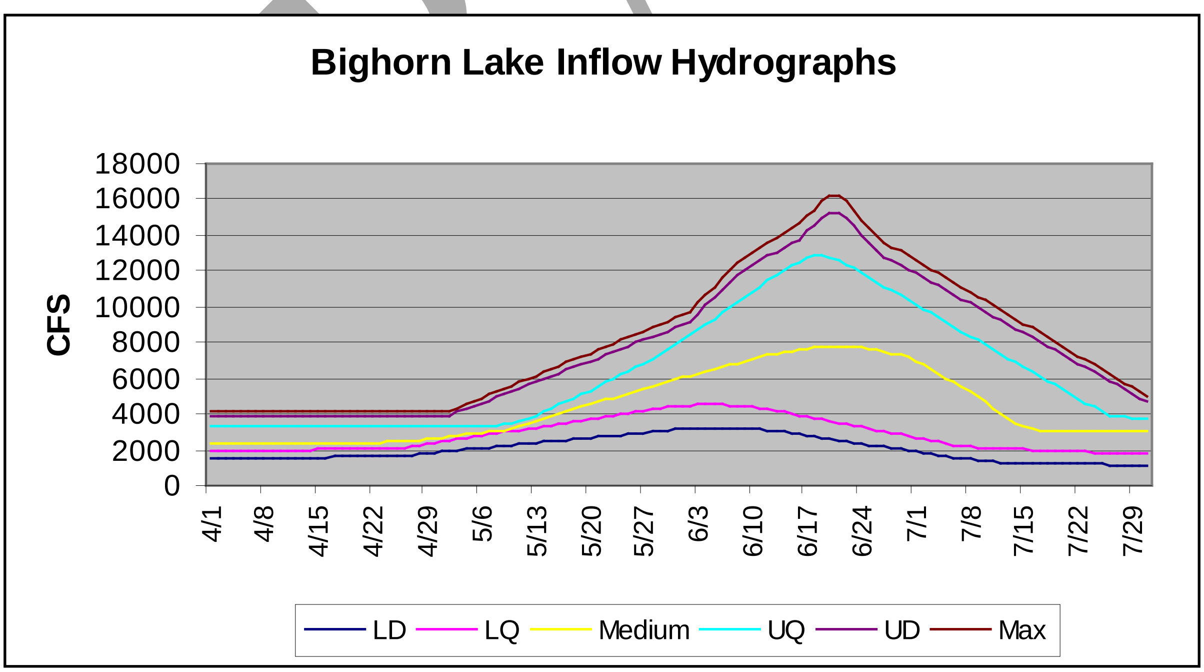

Figure 7

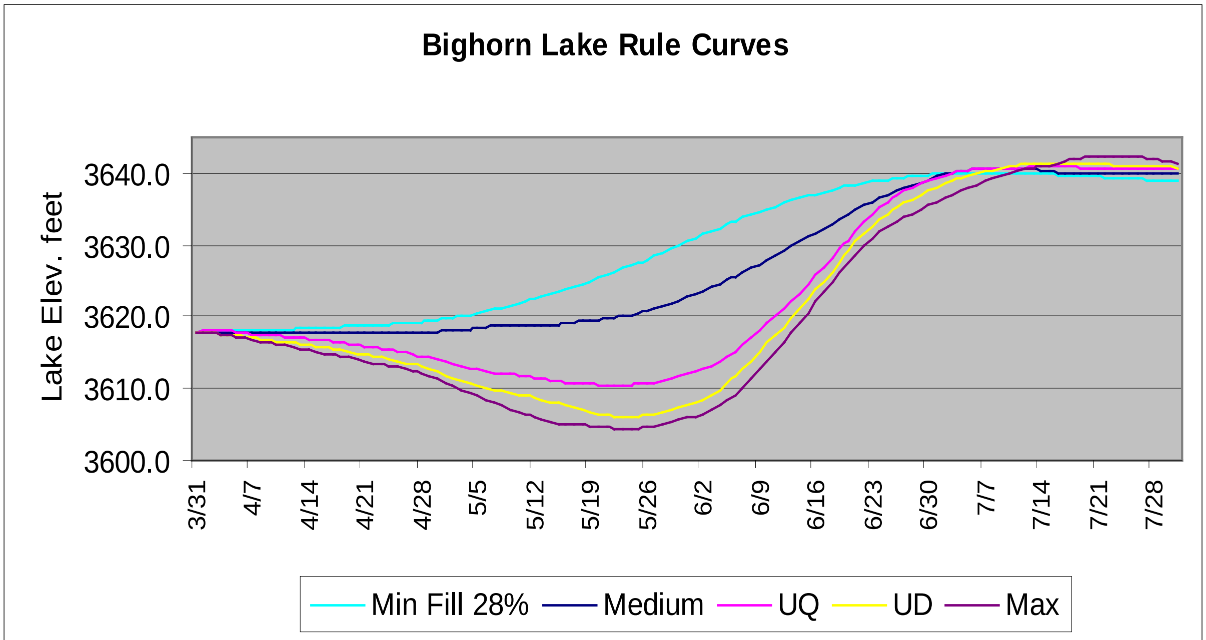

Figure 8

On Figure 7 the hydrograph labeled Max is a 98 percentile runoff year or a year that has only a 2 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).

Once these curves were completed, a spreadsheet was developed to calculate individual rule curves to fit the April 1, May 1, and June 1 medium forecasted inflow for future years of operation. This spreadsheet then allows the user to import the actual reservoir 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 reservoir operations near or on track with the rule curve guideline. 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 will result in a number of significant and frequent release adjustments. Normally, adjustments to the reservoir releases should be based on looking at least a week ahead to allow time for the reservoir level to come back on track with the rule curve.

The rule curves show that for low snowpack years the reservoir should be allowed to begin filling in early April, and for high snowpack years the reservoir should be drafted to an elevation as low as 3605 by near the end of May.

Years with Forecasted April- July Inflow Less than a 28 Percentile Volume:

For years with forecasted April-July Inflow falling below a 28 percentile year (April-July inflow less than 719,000 acre-feet) rule curves were not developed, as it was found that these are years when the reservoir should be managed to provide a careful balance between the need for a minimum level for the river fishery flows (2,000 cfs or less) and sufficient storage to provide minimum service levels for lake recreation and fishery. In these years the reservoir 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 of no less than 2,000 cfs through the end of the following March if this will allow the reservoir to end up near elevation 3618 by the end of March. 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 would 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.

Evaluation of Proposed Modified 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 period of study 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. 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 11 the new revised gains explained on page 9, the November through March release rates calculated with the procedure described on pages 13-14, and the rule curves described on pages 16-19. The results of the model simulation were then compared to the actual historic operations to determine how reservoir levels and river flows would vary from past operations. Figure 9 is a graph comparing the average monthly reservoir elevations using the new modified operating criteria compared to the historic operations. Figure 10 compares average monthly flows in the Bighorn River below Afterbay Dam for the modified operating criteria with the average historic river flows.

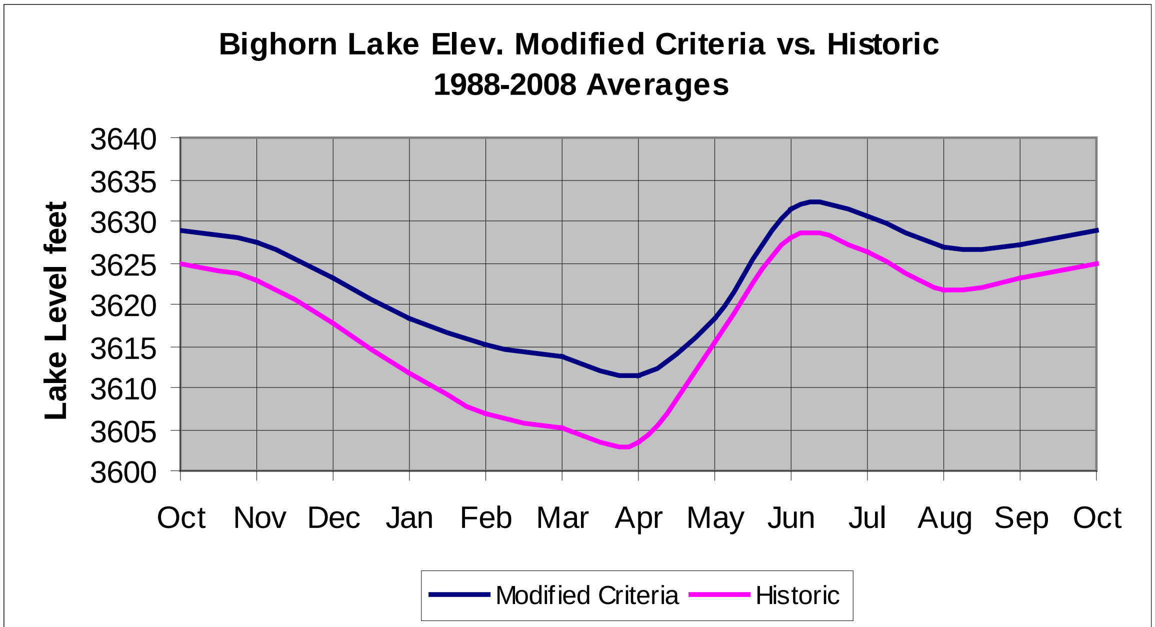

Figure 9

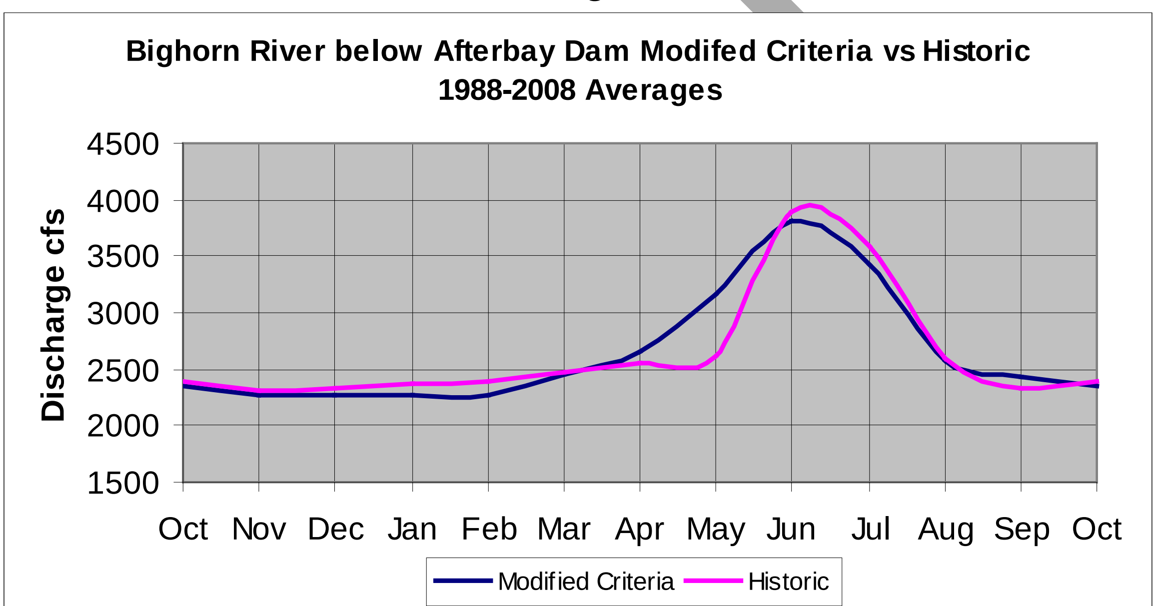

Figure 10

Figure 8 show that the reservoir would operate noticeably higher on the average under the new operating 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 7-8 feet higher under the modified operating criteria than under historic conditions. Figure 9 shows that under the modified operating criteria the November through March river flow will average very close to the historic operations. In the spring river flow will be noticeably higher but peak flows in June and July will be somewhat lower.

To gain a better understanding of how the revised criteria affected river fishery flows, the river flows were examined from the context of meeting the desired fishery flow targets established by the Montana FWP. 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, 2500 cfs and 3500 cfs. The 3500 cfs is a recent addition to Montana FWP requested flow targets as a flow that fully meets all of the fishery needs. Figure 10 is a graph comparing the percent of time the various fishery flow targets are exceeded for the modified criteria versus historic operations.

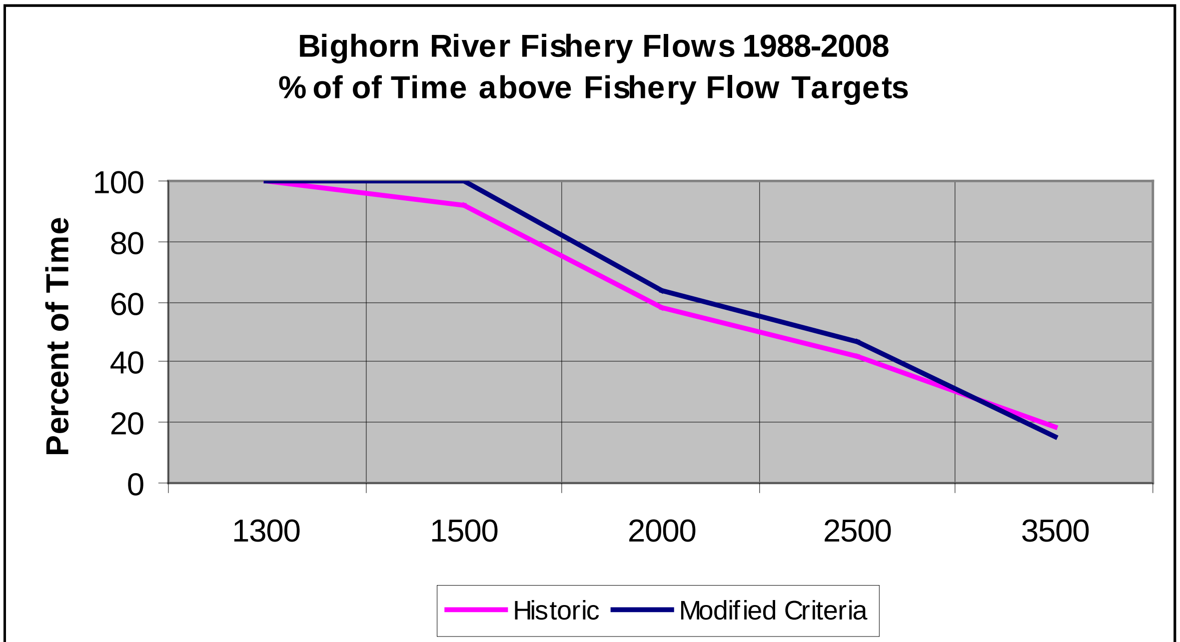

Figure 11

This graph show that while the average river flow during the November through March period is slightly lower under the modified criteria, the modified criteria provides an improvement in the percent of time the desired fishery flow targets are met for each of the primary targets of 1500 cfs, 2000 cfs and 2500 cfs. The percent of time flows are at or above 3500 cfs is, however, reduced slightly by the new criteria.

Power generation was also compared between the proposed modified criteria and actual historic operations. Since actual generation can vary somewhat from the model estimates, the historic power turbine releases were entered into the model and the model was run to simulate historic conditions. The power generation quantities were then compared between the proposed modified criteria and historic conditions. The following table and graph (Figure 14) provides a summary of the results.

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

Period	Historic Conditions	Modified Criteria	Percent Change
Annual	762.2	780.1	+2%
Dec-Feb	156.0	152.8	-1%
July-Aug	167.4	165.7	-1%

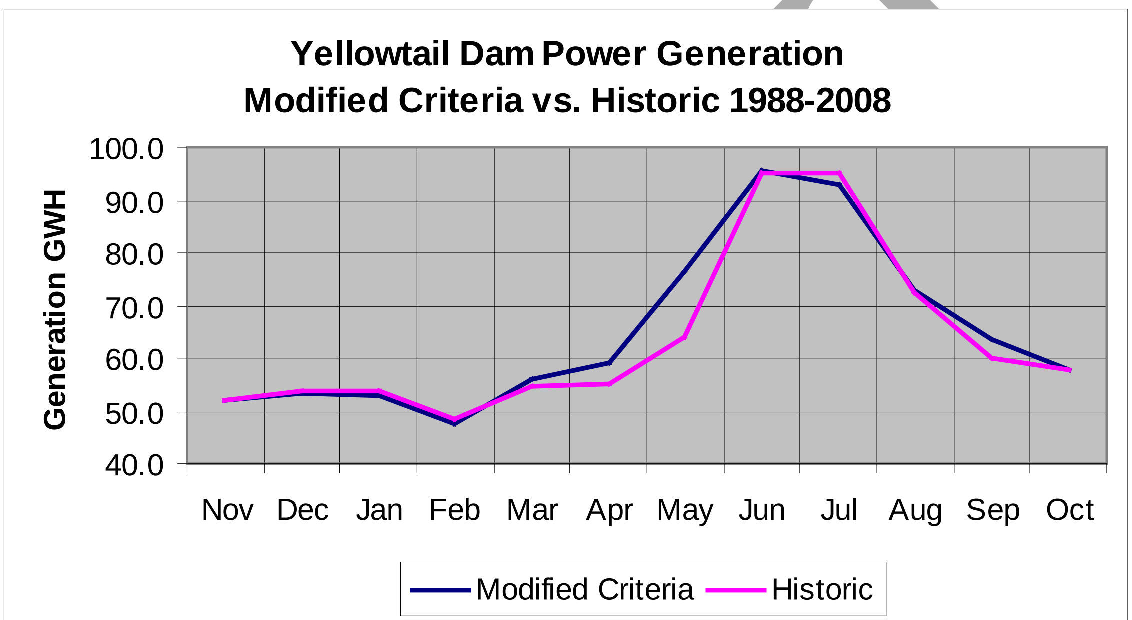

Figure 14

The table and graph show that overall generation will be increased by about 2 percent on the average with noticeable increases in the spring and late summer months. The critical periods for power generation are generally in the hot mid-summer months and the cold winter months. During these two periods generation will be reduced slightly by about 1 percent. The main reasons for the overall increase in power generation is due to the higher lake operating levels under the proposed modified criteria and a minor reduction in the June release reducing the amount of water bypassing the power turbines. Holding the lake higher increases "head" on the power turbines which in turn increases power generation efficiency.

Since the 1988-2008 period of study includes a number of drought years (especially the extreme drought years of 2001-2007) the average reservoir inflow for this period is significantly lower than the long term average. The average inflow for the 1967-2008 period of record is 2,343,002 acre-feet while the average inflow for 1988-2008 is only 1,992,619 acre-feet or 85 percent of the long term average. Because of this, the average lake elevations and river flows shown in the above graph (Figure 11) are lower than one would expect under long term average conditions. To provide a better example of long term average operating conditions, the river flows and reservoir elevations for 2001-2007 were removed from the sample years and the averages were recalculated. The average inflow for 1988-2008, excluding 2001-2007, is 2,327,807 acre-feet, essentially the same as the long term average. Figures 12 and 13 show the average reservoir elevations and river flows with the 7-year extreme drought period removed.

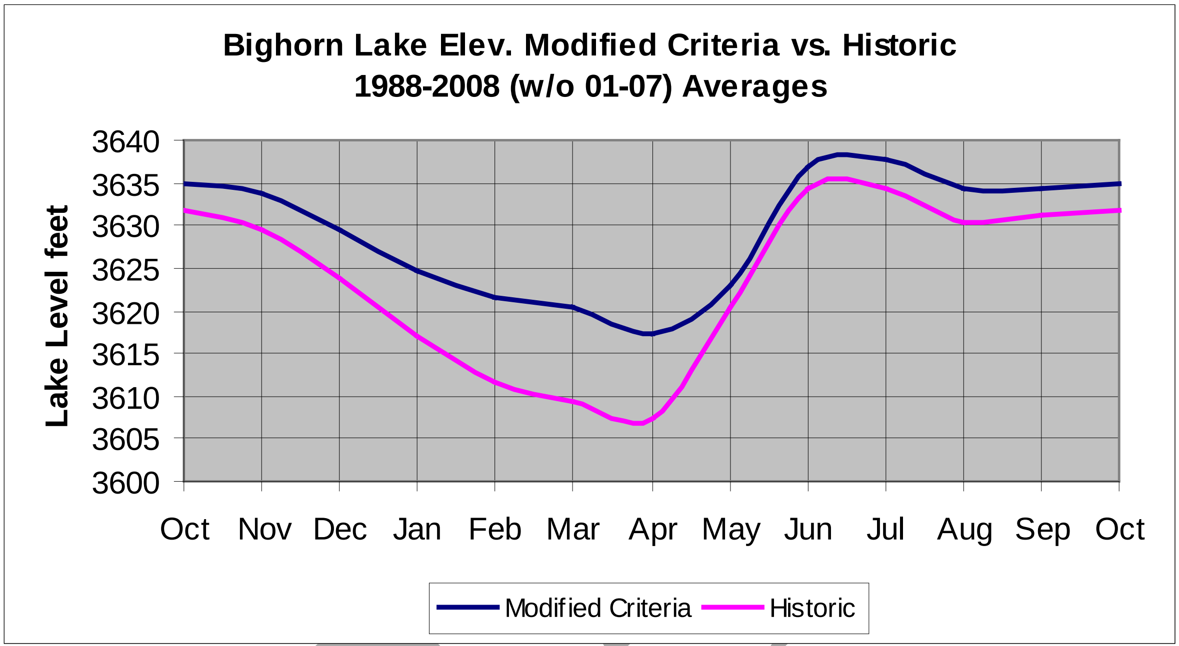

Figure 12

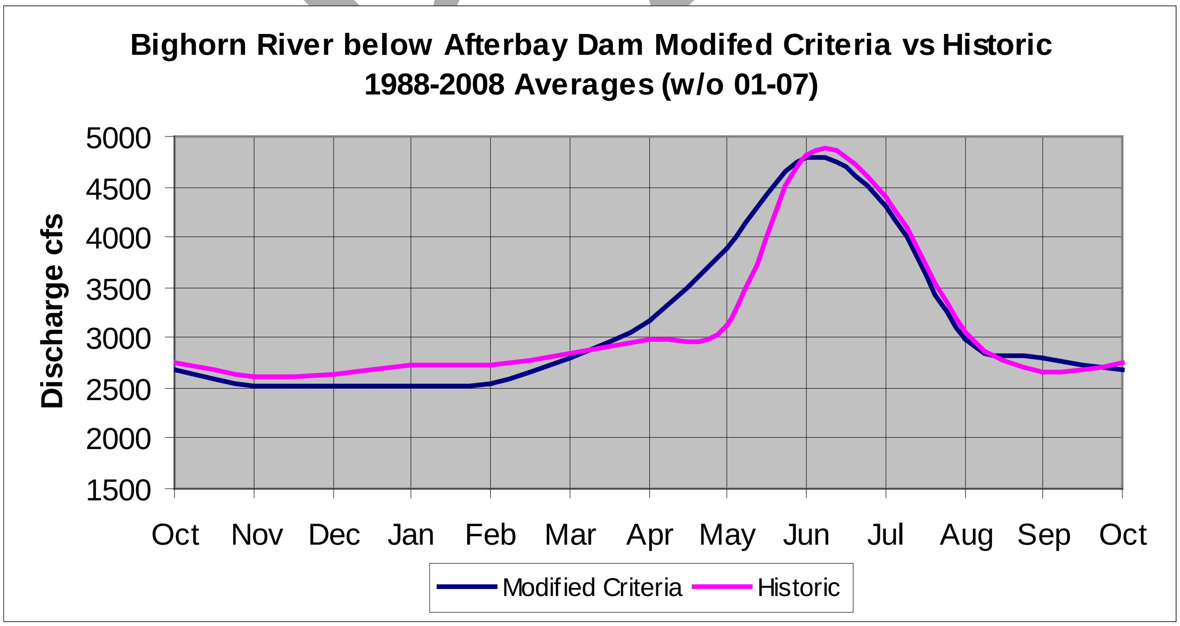

Figure 13

Figure 12 demonstrates that on the average the reservoir, under the modified operating criteria, will operate between a low of elevation 3618 and a high of elevation 3638. During April the reservoir level would be about 10 feet higher on the average than it has historically been operated. Figure 13 shows that under the modified operating criteria, flows in the Bighorn River, below the Afterbay Dam, will vary between an average low of 2,500 cfs during November through March up to an average high of about 4,800 cfs in the June-July period. River flows during November through March will be slightly lower than in the past while flows during April and May will be noticeably higher. Peak flow in June and July will be slightly lower under the modified operating criteria as compared with historic operations.

WATER YEAR 2010:

The revised operating criteria were used on a trial basis during water year 2010 to test its validity and effectiveness. The following is a summary of the 2010 reservoir operations and how the criteria were used in making operating decisions.

<u>October – March Operations</u>

Reservoir releases were carefully managed during October with the goal of meeting an October 31 reservoir target elevation between 3638 and 3640. The actual October 31 reservoir elevation reached was 3639.5. Using the October 31 reservoir level and the previous April-October gains to the reservoir, the November-March release rate procedure was used to establish the winter release rate. Following this procedure the river release rate was set at 2750 cfs on November 5 with an end of March reservoir target level of elevation 3620.6.

The fall and winter of 2010 were extremely dry and by February 1 mountain snowpack in the drainage basin above Bighorn Lake was only 60 percent of average. Based on this low mountain snowpack and below normal fall soil moisture conditions, the medium April through July Bighorn Lake inflow forecast prepared near the first of February was only 634,000 acre-feet or 57 percent of average. This forecast volume was considerably less than the 719,000 acre-feet (28 percentile year) volume required for establishing an April-July rule curve. This indicated that the spring operation should not be based on filling the reservoir following a rule curve but rather on managing the limited water supply to conserve stored water in a manner that would allow maintaining a release near 2,000 cfs through the coming year. Using the February 1 forecast together with a number of reservoir and river basin model runs, an evaluation was made to determine the reduction in the river release rate needed to adequately conserve water. These model runs indicated that to best assure a river release of at least 2,000 cfs through the coming spring, summer and fall, the February release needed to be reduced to at least 2,500 cfs and preferably to 2,000 cfs. After discussing the situation with both upstream and downstream interests, a decision was made to reduce the river release to 2,500 cfs on February 12 and to further reduce releases to 2,000 cfs on February 25. Dry conditions continued through February and in early March the medium April-July inflow forecast dropped to 591,000 acre-feet or 53 percent of average. Based on this revised forecast, the decision was made to continue the 2,000 cfs release rate through March.

April-July Operations

Mountain snowpack conditions improved slightly during March and by early April the medium April-July inflow forecast had increased to 625,000 acre-feet or 57 percent of average. With only a minor improvement, the April 1 forecast continued support for the 2,000 cfs release rate. Weather conditions changed abruptly in April as several significant storms moved through the basin providing greatly needed mountain and valley precipitation. By April 15 the mid-month medium inflow forecast had improved to an April-July inflow volume of 730,000 acre-feet or 65 percent of average. This forecast amount was finally sufficient to establish an operational rule curve for the April 15-July period. At this time preparations were put in place to increase the river release and on April 28 the river release was increased to 2,250 cfs. The May 1 medium inflow forecast again showed a marked improvement with the May-July volume increasing to 900,400 acre-feet or 79 percent of average. Based on the May 1 forecast, the rule curve was adjusted down and the river release was stepped up to 3,250 cfs on May 8 and to 5,500 cfs on May 15. Wet weather continued in May and the mid-May medium inflow forecast showed another sharp improvement increasing the April-July volume to 1,121,400 acre-feet or 98 percent of average. With this sharp improvement, the rule curve was further adjusted down by about 3 feet and the river release was gradually stepped up to a discharge of 9,500 cfs on May 28. Water supply conditions continued to improve during the second half of May and in early June the medium forecast increased again to an April-July volume of 1,263,300 acre-feet or 111 percent of average. Based on the June 1 forecast, the rule curve was adjusted down by another foot. Although the reservoir was still about 10 feet higher than the rule curve, model runs indicated that the 9,500 cfs river release would be sufficient to control the reservoir fill rate and possibly allow the reservoir level to intersect the rule curve in late June. Based on this evaluation and a desire to limit the river release to a flow near 9,500 cfs, the decision was made to hold the 9,500 cfs release rate.

Actual runoff in June was significantly more than the forecast. The reservoir reached the top of its joint use pool (elevation 3640) on June 18 and continued to fill. In response to the higher inflow the river release was increased to 10,000 cfs on June 17. The reservoir continued to fill during the second half of June and into early July, reaching a peak elevation of 3645.6 on July 4. This level was 5.6 feet into the reservoir's exclusive flood pool and about 5 feet above the rule curve. Snowmelt runoff began to recede after June 20 and on July 7 release reductions were initiated. River releases were gradually stepped down during the first half of July to a flow rate of 3,500 cfs on July 19.

The following table summarizes the spring runoff forecasts prepared between February 1 and June 1 and also compares these forecasts with the actual April-July reservoir inflow. For comparison purposes, each of the forecasts is shown for the April-July runoff period. The actual April-July inflow was 1,504,354 acre-feet or 135 percent of average.

April-July Inflow Forecasts

Date	Inflow Forecast	Percent of Average
February 1	634,000 acre-feet	57%
March 1	591,000 acre-feet	53%
April 1	625,000 acre-feet	56%
April 15	730,000 acre-feet	65%
May 1	900,400 acre-feet	81%
May 15	1,121,400 acre-feet	101%
June 1	1,263,300 acre-feet	113%
Actual	1,504,354 acre-feet	135%

Figure 15 below shows the 2010 snow water equivalent in inches for the mountain snow monitoring stations (SNOTEL) located in the drainage basin above Bighorn Lake, compared to the long term average snow water equivalent for those same stations.

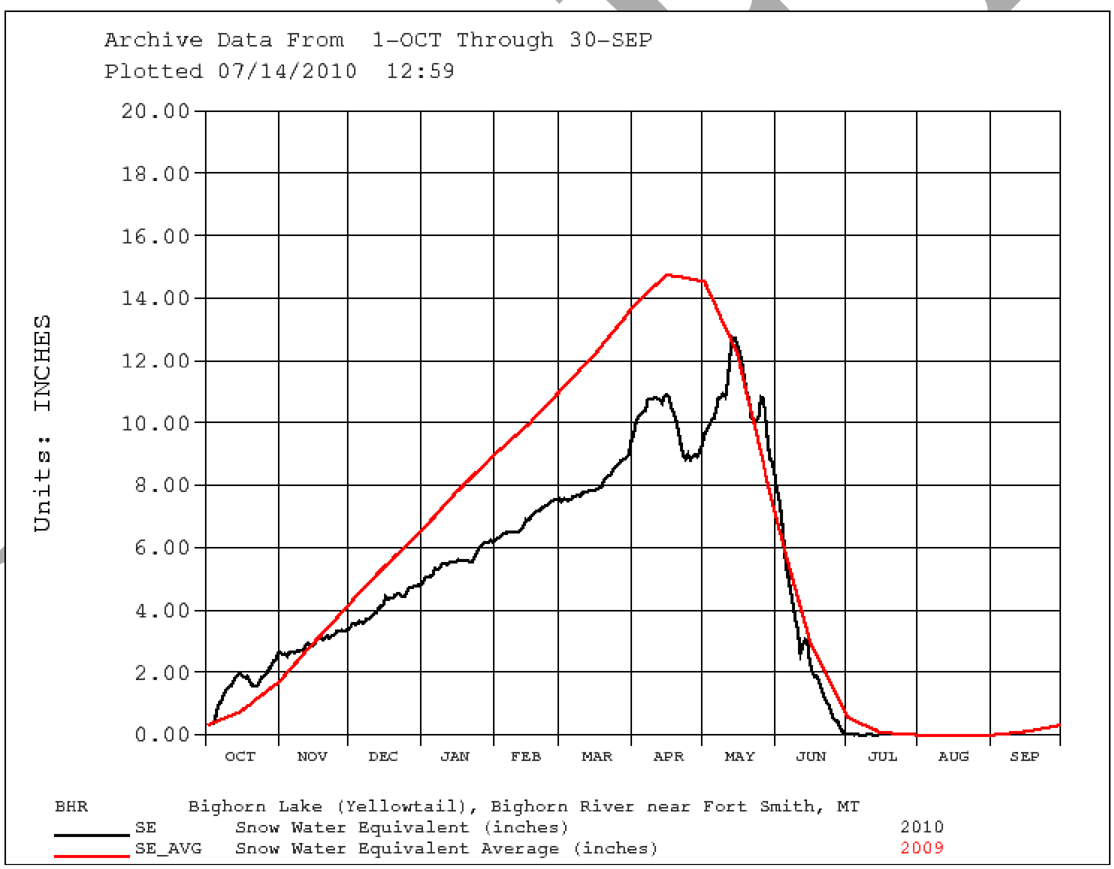

Figure 15

The next graph (Figure 16) shows the reservoir operations during the April-July period compared to the rule curve.

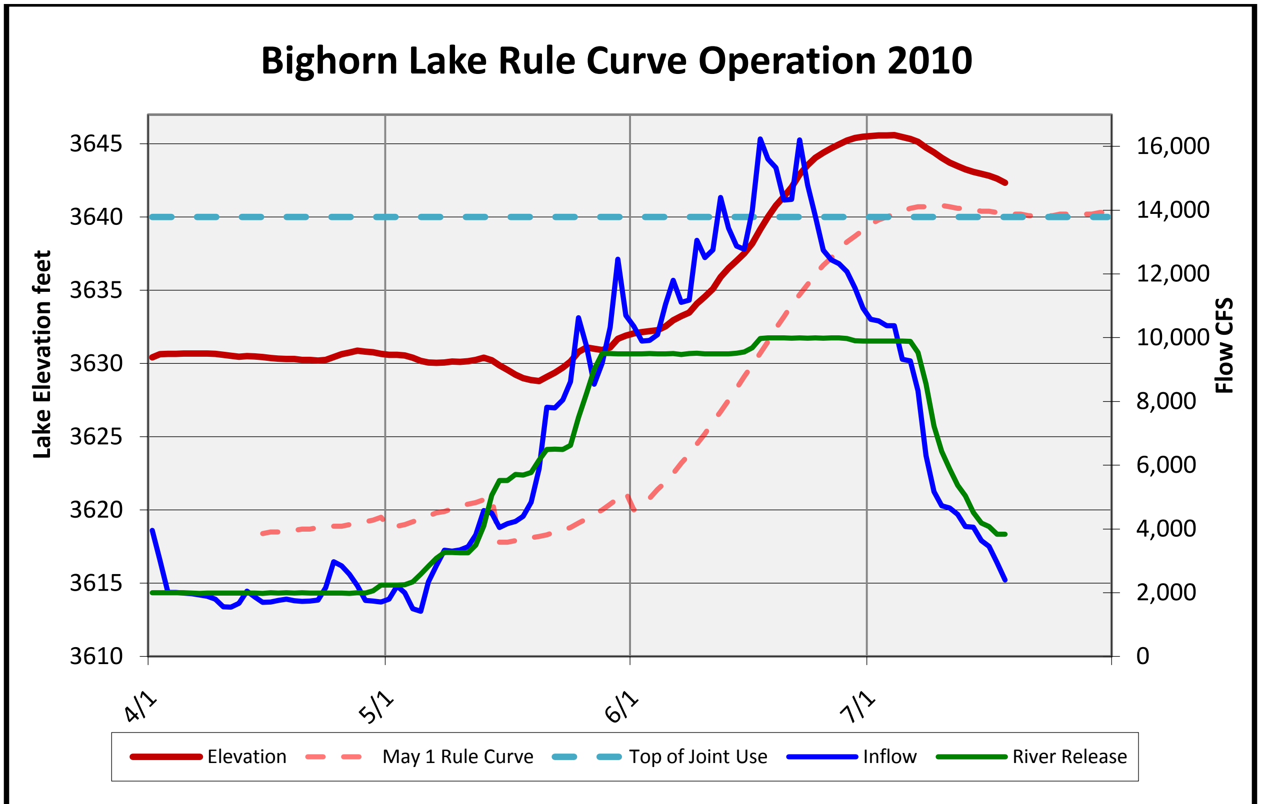

Figure 16

Due to the dramatic and continual change in the inflow forecasts over the February to June period, it was impractical to operate the reservoir to strictly adhere to the rule curve. As shown in the above graph, the reservoir entered the spring about 10 feet above the end of March reservoir target elevation (elevation 3620.6) due to the reservoir releases being purposely reduced in February to conserve storage based on the critically low inflow forecasts prepared in February and March. Even with significant increases in the release rate, the lake level continued near elevation 3630 through April and most of May. Once the inflow forecast improved and a rule curve was established in the middle of April, the goal was to slowly draft the lake in a manner that would allow the rule curve to catch up with the lake level. This proved to be unsuccessful due to the continual increase in the forecast amount and its corresponding effect on the rule curve. Each time the forecast was updated, showing an improved water supply, it was necessary to lower the rule curve. While the reservoir did not match up with the rule curve, it was managed to follow the rule curve fill rate. This resulted in the reservoir level paralleling closely with the rule curve from late May until the reservoir reached its peak elevation in early July. During most of this time the release to the river remained fairly constant between 9,500 and 10,000 cfs. This indicates that the rate of fill, defined by the rule curve, is consistent with this year's runoff hydrograph and worked well in controlling runoff by significantly reducing peak flood flows and allowing the reservoir release to remain fairly constant. Even with the unprecedented change in expected inflow, from a low near 50 percent of normal in March to an actual April-July inflow of 135 percent, most of the operating goals were satisfied.

To gain a better understanding of how well the rule curve performed, the reservoir operations were simulated to determine how the reservoir would have operated had the early forecasts indicated that reservoir inflow would be sufficient to maintain the 2,750 cfs release through March. This operating scenario was evaluated with the daily operational model using a release of 2,750 cfs through March followed by a 2,500 cfs release in April allowing the reservoir to match up with the rule curve in early May. Once the rule curve was defined on April 15, the reservoir was operated to closely follow the rule curve. Since the actual operations resulted in the reservoir level paralleling closely with the rule curve, it was found that after the first week in May the actual 2010 release schedule allowed the reservoir level to match up very closely with the rule curve. As a result, the actual river release during May 8 through June 30 was not changed under this scenario except for late June when a release of 9,800 cfs was used in place of the actual river release of 10,000 cfs release. The major difference in this operation compared with the actual operation was a higher release rate in the late winter and early spring followed by a lower release rate in July. Also, the reservoir only filled a little over a foot into the exclusive flood pool rather than the actual 5.6 feet.

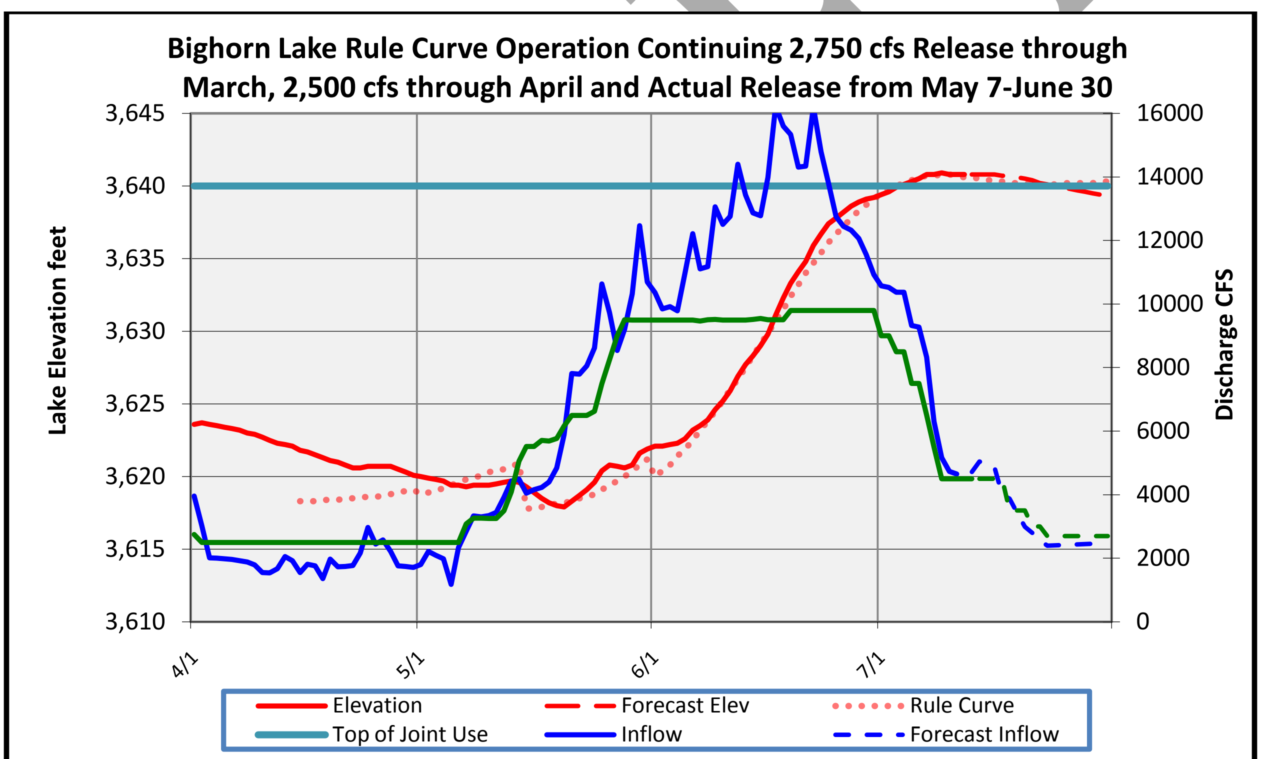

Figure 17

Even with the unusual and extremely variable winter and spring weather conditions, the operating criteria provided sufficient flexibility for controlling unexpected high runoff while meeting most of the operating goals.

CONCLUSIONS:

Modification of the Bighorn Lake operating criteria and operating tools to include revised reservoir 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 significant benefits for the lake recreation and fishery, while still providing river fishery flows equal to or better than provided in the past. The major benefit the proposed modification provides for the reservoir is it allows the reservoir to operate 3 to 8 feet higher on average than historic operations. The most significant change in lake elevations will be during late winter and early spring. The higher reservoir would also provide a somewhat higher “head” for power generation, slightly increasing the power generation efficiency and increasing average annual generation by about 2 percent. A higher March 31 reservoir level target also increases the probability that the reservoir will refill in the spring in lower runoff years. Under actual operations the reservoir filled to its normal full level, at elevation 3640, in 9 of the 21 year study period (1988-2008). With the modified operating criteria the reservoir is expected to fill an additional 3 years for a total of 12 out of the 21 year study period. Improved levels of flood control will be provided by utilizing reservoir operational rule curves during the April-July runoff season to draft the reservoir sufficiently to handle higher runoff during years with above-normal mountain snowpack.

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 below 1,500 cfs would be significantly 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 revised operating 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 April through July operational rule curves, based on forecasted reservoir 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.

Expected Benefits of Revised Operating Criteria
Values Compared to Historic Operation

Lake Levels

January-April	7-8 feet higher
May-June	3 feet higher
July-December	4-5 feet higher

River Flows	Improvement in Percent of Time Provided
1500 cfs	+8% (met 100% of time for study period)
2000 cfs	+5%
2500 cfs	+5%
3500 cfs	-3%

Power Generation	Increased Generation GWHs	Percent Increase
Annual	+17.9	2%
December-February	- 2.2	-1%
July-Aug	- 1.8	-1%

Flood Control

June	Slight decrease in peak release rate Decrease in peak reservoir level for most high runoff years