RECLAMATION
Managing Water in the West

The Effects of Climate Change on the Operation of Boise River Reservoirs, Initial Assessment Report

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Boise Idaho

November 2008

U.S. DEPARTMENT OF THE INTERIOR

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1 Introduction

This report provides an initial assessment of the effects of future climate change on the management of reservoirs in the Boise River Basin in southwest Idaho. Boise River reservoirs are part of the Bureau of Reclamation's Boise Project and include Anderson Ranch, Arrowrock, Lucky Peak[1], and Lake Lowell Reservoirs. The reservoirs have a combined active capacity of about 1.18 MAF. This portion of the Boise Project serves 164,000 acres with primary water supply and 112,000 acres with supplemental water supply.

Two studies were completed:

1. The Planning Study, which evaluated the effects of climate change on water supply, reservoir refill, water deliveries, water rights distribution, and minimum streamflows, and
2. The Flood Risk Study which evaluated the adequacy of existing flood control regulations and practices in the context of climate change.

Inflows for the studies were developed from temperature and precipitation adjustments projected for the decade of the 2040s derived from global climate simulations published by the Intergovernmental Panel on Climate Change.

The most significant impact of climate change will be an increase in flooding on the Boise River during January through March. Existing flood control regulations, which were developed from observed inflows spanning 1895 to 1980, are not adequate to manage the spring runoff resulting from climate change, the majority of which will arrive up to two weeks earlier than anticipated.

The studies also indicate that the ability to refill Project reservoirs may not be significantly impacted by climate change. Refill, however, is linked to successful flood operations, and so the two studies together are used to provide this insight. Runoff which arrives too early for agricultural diversion may be stored, leading to a reduction in diverters' reliance on natural flow and an increase in reliance on stored water. But this result is built on the assumption that diverters will behave as they did historically and little research has been performed to quantify how agricultural diversions will be altered by climate change. Minimum streamflows currently requested by the Idaho Fish and Game Department are likely to continue to be met year round.

[1] Lucky Peak is owned and operated by the U.S. Army Corps of Engineers. Reclamation coordinates irrigation and flood control operations with the Corps' Walla Walla District office.

2 Study Approach

2.1 Global Climate Simulations

Projected changes in mean monthly temperature and precipitation for the 21st Century Pacific Northwest were developed using global climate simulations from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Working Group I (IPCC, 2007).

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme to assess scientific, technical and socio-economic information on climate change, to evaluate the potential impacts of climate change, and to provide options for adaptation and mitigation. The IPCC bases its assessments on peer reviewed and published scientific and technical literature (www.ipcc.ch).

The Fourth Assessment Report provides climate projections from a suite of global climate models and simulations. Each global climate model simulates assumed future greenhouse gas emissions and assumed natural influences on climate variability, resulting in a climate projection. Given the many available global climate models, emissions scenarios, and uncertainty in initial conditions, there are many available climate projections to consider. This study uses global climate projections for the decade of the 2040's from three IPCC global climate models, which were selected to represent a range of climate projections, and a single emissions scenario. The climate models are:

- ECHAM5, developed by the Max Planck Institute for Meteorology, Germany (Jungclaus et al., 2006). Echam simulations produce a moderate increase in temperature and precipitation when compared to other IPCC models applying the same emissions scenarios.
- GISS-ER, developed by NASA / Goddard Institute for Space Studies, USA (Russell et al., 2000). GISS simulations produce a small warming increase and a small *decrease* in precipitation when compared to other IPCC models applying the same emissions scenarios.
- IPSL-CM4, developed by the as the IPSL Institut Pierre Simon Laplace, France (IPSL, 2005). IPSL simulations produce a large increase in warming and precipitation when compared to other IPCC models applying the same emissions scenarios.

Future greenhouse gas emissions are the product of very complex and dynamic systems, driven by demographic development, socio-economic development, and technological change. The greenhouse gas emissions scenario family referred to as A2 was selected for this study. The A2 scenario family is a strong emissions scenario when compared to other emissions scenarios in the literature (Nakićenović, N., et al., 2000.). It describes high population growth, slow economic growth and slow technological change. Although uncertainties can not be assigned to any one emissions scenario, the A2 scenario family was selected for this study because it provides an estimated upper bound which is somewhat pessimistic, but not the worst case, for an impacts analysis.

Figure 1 shows the range of temperature and precipitation projections resulting from a representative selection of IPCC models for the decade of the 2040's and the relative placement of the three models selected for this study. The specific temperature and precipitation projections for the selected models are shown in Table 1 below.

Other variables are simulated by the climate models, but this study applies temperature and precipitation projections only. These variables have the greatest influence on the hydrologic response. The 21st century warming projections from the Fourth Assessment Report are described as "virtually certain" (Alley, et al. 2007), but there is considerably less certainty about precipitation projections. Therefore, this study evaluates the effects of temperature projections only, yet also extends the analysis to evaluate the effects of temperature and precipitation projections combined, resulting in six climate change scenarios. This approach provides a range of projections for global warming from dry to wet. All projections are for the decade of the 2040's. The six scenarios are:

- Scenario **Echam T**, which applies ECHAM5 A2 temperature projections *only,*
- Scenario **Echam TP**, which applies ECHAM5 A2 temperature and precipitation projections combined,
- Scenario **GISS T**, which applies GISS-ER A2 temperature projections *only*,
- Scenario **GISS TP**, which applies GISS-ER A2 temperature and precipitation projections combined,
- Scenario **IPSL T**, which applies IPSL-CM4 A2 temperature projections *only,* and
- Scenario **IPSL TP**, which applies IPSL-CM4 A2 temperature and precipitation projections combined.

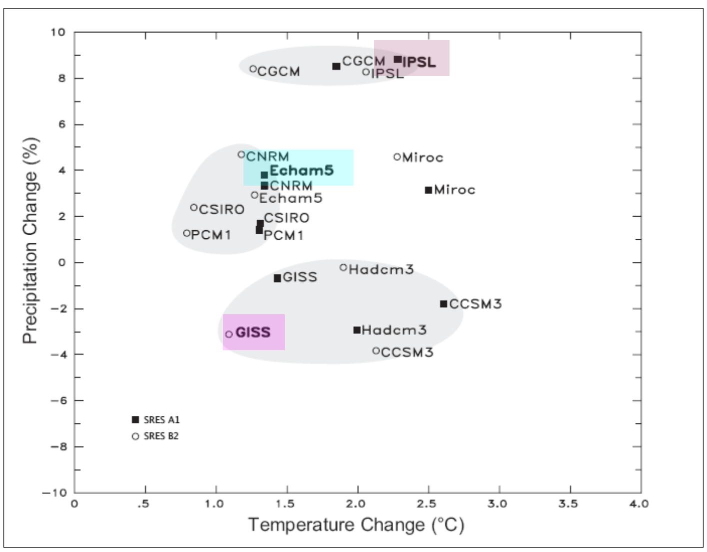

Figure 1. The range of temperature and precipitation projections for the decade of the 2040s from a selection of IPCC global climate models. The three models chosen for this study (Echam, IPSL and GISS) span the range of IPCC model results for the decade of the 2040s. From Salathé, et al. (2007).

2.2 Temperature and Precipitation Adjustments

This section describes the development of the temperature and precipitation adjustments which were applied to historic temperature and precipitation time series to produce climate affected temperature and precipitation time series.

The Joint Institute for the Study of Atmosphere and Oceans Climate Impacts Group (CIG) at the University of Washington used the IPCC global climate model output to prepare temperature and precipitation adjustments for the Pacific Northwest. CIG is a research organization committed to consolidating information and understanding the consequences of climate fluctuations and change for the Pacific Northwest (www.cses.washington.edu/cig/).

The spatial resolution of surface characteristics in the IPCC global climate models is too general to adequately simulate temperature and precipitation on a regional scale. So, even though each climate model produces output at about 12 to 20 grid points within the Pacific Northwest Region (Washington, Oregon, Idaho, and western Montana), the models are not accurate to within that resolution. CIG addressed this problem by using average output from across the Region to create adjustments to regional historic temperature and precipitation time series for each climate model. This approach removes some of the data noise and uncertainties in representing surface characteristics, yet still captures the major regional trends (Loa´iciga, 1999). The use of historic regional data is intended to retain the major regional characteristics. The same reasoning can be applied to further downscale the data to the Boise Basin. Other downscaling approaches have been advanced which rely on comparisons of statistics from the simulated and observed data sets (Salathé, 2007).

CIG processed the averaged Regional global climate model output into 30-year means for each calendar month to create values representative of specific decades. A 30-year mean provides a reasonable balance between smoothing out the natural inter-annual variabilities (such as El Nino effects) while still capturing the slower trends due to global climate change. The 30-year means by month from 1970 through 1999 were defined by CIG to represent the present climate. The climate for the decade of the 2040's was represented by the 30-year means of 2030 through 2059. Temperature and precipitation adjustments were then determined by the difference between the present climate and projected climate of the 2040's. This approach compares present climate *simulated* data to future climate *simulated* data and reduces the introduction of errors due to the limitations of global climate model calibration. The adjustments were then applied to *historic* temperature and precipitation time series (Refer to Section 2.3).

The mean monthly temperature and precipitation adjustments used in this study are shown in Table 1 below. The temperature adjustments reflect an increase in temperatures ranging from 0.54 to 3.05 degrees Celsius. The precipitation adjustments are factors applied to historic values. A factor less than 1.00 reflects drier conditions and a factor greater than 1.00 reflects wetter. The precipitation factors range from 0.64 to 1.33.

Table 1. Climate change temperature and precipitation adjustments.

	Temperature Adjustments (C)			Precipitation Adjustments (%)		
	Echam	GISS	IPSL	Echam	GISS	IPSL
Jan	2.42	0.54	2.53	1.27	0.97	1.31
Feb	1.43	0.85	2.54	0.82	1.16	1.19
Mar	0.67	1.39	1.80	1.14	0.97	1.13
Apr	0.84	0.63	2.14	1.08	0.99	0.96
May	0.48	1.34	1.59	1.00	0.87	1.04
June	2.24	1.78	2.59	0.79	0.82	0.81
July	1.21	2.60	2.45	1.02	0.70	0.91
Aug	0.99	2.68	3.05	1.34	0.80	0.64
Sept	0.81	1.93	2.85	1.16	0.88	0.93
Oct	1.44	1.47	1.63	1.04	1.14	0.95
Nov	1.52	0.63	1.77	0.97	1.02	1.33
Dec	1.77	1.00	2.12	1.05	1.04	1.11

The mean monthly adjustments to temperature and precipitation were assumed to also be adequate for daily adjustments.

2.3 Streamflow Adjustments

The temperature and precipitation adjustments developed from the IPCC climate models were applied to the baseline input of National Weather Service River Forecast System model (NWSRFS) to produce climate affected naturalized streamflow adjustments at six locations in the three major subbasins of the Boise system. The hydrologic core of NWSRFS consists of the Sacramento Soil Moisture Accounting Model (SAC-SMA; Burnash, 1995) and a component for snow called SNOW-17. The adjusted naturalized streamflows were then used to assess impacts to streamflows in the Boise Basin. ‘Naturalized streamflows’ are streamflows with the influences of upstream reservoirs and diversions removed.

NWSRFS uses precipitation, temperature and potential evaporation 6-hour time series inputs to simulate the physical processes which produce streamflow, including snowmelt, evapotranspiration, soil moisture, infiltration, and streamflow routing.

Baseline daily naturalized streamflows for water years 1949 through 1997 were developed using historic temperature, precipitation and potential evaporation time series. These baseline streamflows are calibrated to, but are not identical to, observed historic streamflows. An informal calibration check of the NWSRFS model of the Boise Basin is presented in Appendix A.

After the baseline streamflows were developed, the climate adjusted naturalized streamflows for the same period were developed for each of the six climate scenarios by applying the month-by-month temperature and precipitation adjustments in Table 1 to the baseline temperature and precipitation input 6-hour time series. The potential evaporation input time series was not adjusted for climate change, but other research indicates the error introduced is probably small (Miller, 2003), especially in comparison to the uncertainties in the climate models and the uncertainties of scaling the regional data.

The subset of the NWSRFS used for the Boise Basin produces inflows at three locations: naturalized streamflows above Anderson Ranch Dam, local naturalized gains above Arrowrock Dam, and local naturalized gains above Lucky Peak Dam. Gains are inflows to the main stem of the river that are not produced in the main stem. The NWSRFS inflows were produced at 6 hour intervals and were aggregated to create daily naturalized inflows and gains. The effects of climate change on natural system inflows were then quantified by comparing the naturalized inflows and local naturalized gains at each of the three locations for each climate scenario to the unadjusted unregulated streamflows:

$$\Delta Q = Q_{\text{NWSRFS climate change}} - Q_{\text{NWSRFS baseline}}$$

where, $Q_{\text{NWSRFS climate change}}$ are the daily naturalized inflows and gains for the climate change scenario, $Q_{\text{NWSRFS baseline}}$ are the daily naturalized inflows and gains from the NWSRFS baseline (calibration) model, and ΔQ are the daily differences in flow between the climate change and the baseline modeled naturalized inflows and gains.

The adjustments to be applied to historic streamflows are then ΔQ. Just as adjustments to temperature and precipitation historic time series were developed by comparing *simulated* present to *simulated* future temperature and precipitation time series (Section 2.2), these adjustments to historic streamflows were developed by comparing *simulated* baseline (calibrated) to *simulated* future streamflows. Again, this reduces the introduction of additional errors due to the limitations NWSRFS model calibration.

2.4 Unregulated Streamflows

2.4.1 Historic Unregulated Streamflows

Unregulated streamflows for 1967 through the present clearly indicate a shift toward earlier runoff (refer to Figure 2). ‘Unregulated streamflows’ are streamflows with the influences of storage and diversions removed. Unregulated streamflows differ from naturalized streamflows in that unregulated streamflows are developed using observed and estimated river discharge, storage and diversion data and naturalized streamflows are simulated from physical processes.

Even though the first two thirds of the 20th Century shows periods of backward as well as forward shifts, an apparent total shift during the last century results in runoff occurring about 5 days earlier. The median date at which 60% of the runoff occurred is about May 23. For 2000 through 2007, 60% of the runoff occurred about May 13. Figure 2 shows the date at which 60% of the total water year unregulated flows occurred for water years 1901 through 2006.

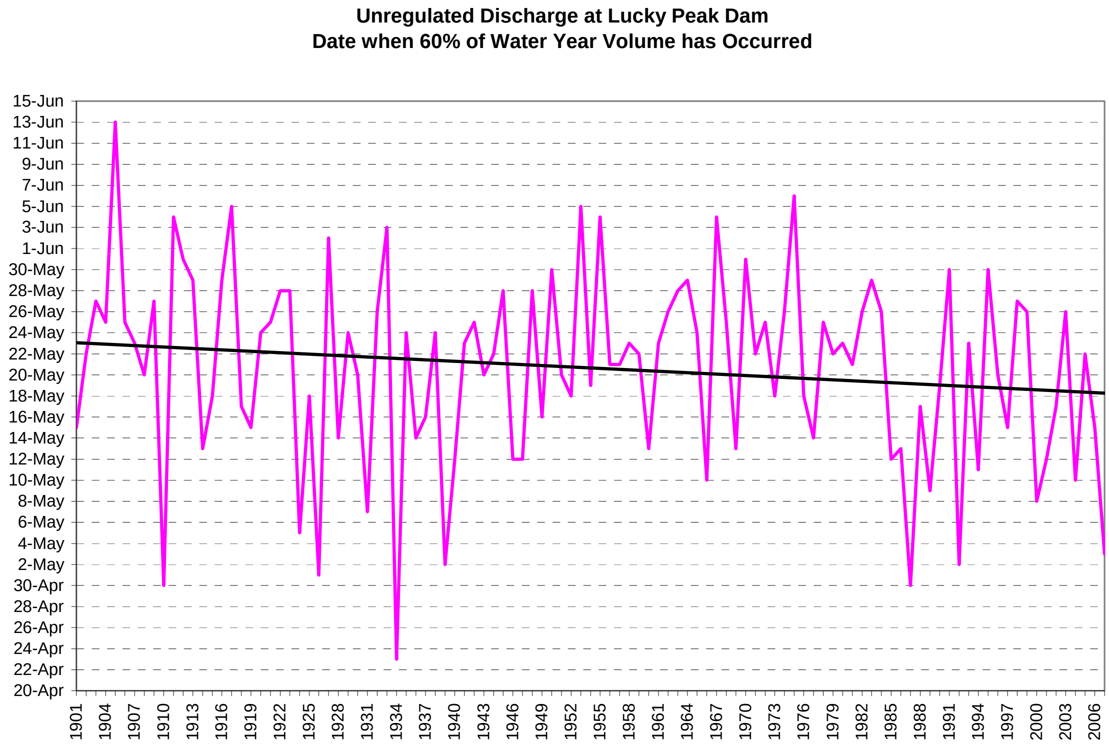

Figure 2. Historic unregulated discharge at Lucky Peak Dam for water years 1901 through 2006. The y axis shows that date at which 60% of the total water year unregulated flows occurred. The straight line is a least squares fit to the data, showing a possible backward shift of about 5 days during the last century.

2.4.2 Climate Adjusted Unregulated Streamflows

Six climate change scenarios and one reference scenario were developed for this study. The reference scenario is a 'No Adjustment' Scenario in which historic unregulated streamflows from water years 1949 through 1997 are used with current operating practices and water uses. The previous section discussed an observed trend toward earlier runoff during the last century. The historic unregulated streamflows could have been shifted to account for such a trend to condition the data for contemporary runoff timing, but the study period is short and exhibits both forward and backward shifts. So to avoid introducing additional uncertainty and complexity, the historic unregulated streamflows were not conditioned for earlier runoff in the No Adjustment Scenario.

The six climate change scenarios were constructed by applying flow adjustments to the historic unregulated streamflows (the No Adjustment Scenario) using the following formula:

$$Q_{\text{climate change}} = Q_{\text{No Adjustment}} + \Delta Q.$$

where $Q_{\text{climate change}}$ are the daily climate adjusted unregulated inflows and local gains for each climate change scenario, $Q_{\text{No Adjustment}}$ are daily historic unregulated inflows and local gains, and ΔQ are the daily flow adjustments developed from the NWSRFS model. Monthly values for the monthly Boise Project Planning model were developed similarly.

The unregulated inflows and local gains combine to produce unregulated streamflows at Lucky Peak Dam. Figure 3 shows the average daily unregulated streamflows at Lucky Peak Dam for the study period (water years 1941-1996) for historic inflows (the No Adjustment Scenario) and the 6 simulated climate change scenarios. For the purposes of this study, the scenarios which apply temperature adjustments only are identified with ‘T’ (Echam T, GISS T, and IPSL T). The scenarios which apply both temperature and precipitation adjustments are identified with ‘TP’ (Echam TP, GISS TP, and IPSL TP).

In general, the climate change scenarios reflect an earlier rise in streamflows during the spring and an earlier runoff peak. In the Section 2.4.1, it was shown that 60% of the total water year unregulated streamflows at Lucky Peak Dam historically occurred before May 23 (No Adjustment Scenario). The climate change scenarios shift this date earlier by up to 3 weeks. For the Echam T and Echam TP scenarios, 60% occurs before about May 10 (a 13 day back shift); for the GISS T and GISS TP scenarios, 60% occurs before about May 15 (an 9 day back shift); and for the IPSL T and IPSL TP scenarios, 60% occurs before about May 2 (a 21 day back shift).

For the climate scenarios which adjust temperature only (Figure 4), the GISS T Scenario is most similar to the No Adjustment (historic inflows) values: it starts to rise about 10 days earlier and peaks 5 days earlier to about the same level. The Echam T and IPSL T scenarios rise and peak about a month earlier and, although the peak is several thousand cfs lower, the peak duration is longer. The climate scenarios which adjust both temperature and precipitation (Figure 5) produce larger quantities of water during the rising limb than their temperature only counterparts, with the IPSL TP Scenario producing an even greater peak than the No Adjustment Scenario (historic inflows).

Average monthly unregulated discharge at Lucky Peak Dam for the No Adjustment and climate change scenarios is shown in Figures 6 and 7.

A comparison of the date of peaking for all scenarios shows: the Echam T, Echam TP and GISS T scenarios peak 5 days earlier than the No Adjustment Scenario (historic inflows); the GISS TP Scenario peaks 12 days earlier, and the IPSL T and IPSL TP scenarios peak 28 days earlier.

The climate change scenarios produce significantly more variability in unregulated streamflows. For example, for the first 2 weeks in March, the spread between the maximum and minimum discharge is 560 cfs greater in the Echam T Scenario than the No Adjustment Scenario (historic inflows). For the IPSL TP Scenario, the spread is 2,060 cfs greater than the No Adjustment Scenario (historic inflows). Figure 8 shows the spread between maximum and minimum discharge values for the first 2 weeks in March.

The average annual quantity of water produced by the basin during the study period is about 2 million acre feet. The climate change scenarios which adjust temperature only

(Echam T, GISS T and IPSL T) and the GISS TP Scenario do not produce significantly more or less water. However, two of the climate change scenarios which adjust both temperature and precipitation produce more water: Echam TP increases precipitation by 5% and produces 10% more water. IPSL TP increases precipitation by 12% and produces 25% more water. A percentage increase in discharge which exceeds the percentage increase in precipitation can be expected in relatively dry basins like the Boise due to the effects of evaporation. When precipitation is increased, proportionately less water is lost to evaporation. This relationship between change in precipitation and change in runoff is supported by the observed data presented in Appendix B.

3 Hydrologic Modeling Studies

3.1 Flood Risk and Planning Studies

Two studies were completed, each consisting of six climate change scenarios and one reference (No Adjustments) scenario. The studies applied the daily naturalized streamflow adjustments (ΔQ) described in Section 2.3 to the unregulated streamflows of two existing Reclamation models of the Boise Basin. The studies are:

1. The Flood Risk Study of Boise Basin Reservoirs (daily time step)
2. The Planning Study of Boise Basin Reservoirs and Delivery Obligations (monthly time step)

The daily time step Boise Operations model was used for the Flood Risk Study. The monthly Upper Snake Planning Model[2] was used for the Planning Study. Both models were constructed in MODSIM[3]. Both studies were limited to water years 1949 through 1997 due to the limitations of the input data set for the NWSRFS model which provided the streamflow adjustments.

The daily time step operations model was used to evaluate the consequences of applying current flood control operating rules to manage inflows resulting from climate change conditions. The monthly planning model was used to evaluate the impacts of climate change on project reservoir refill, project and non-project agricultural and municipal deliveries, and the delivery of minimum streamflows.

[2] The Upper Snake Planning Model was used in the November 2004 Biological Assessment (Reclamation, 2004) and was revised in 2007 to reflect 2.0 million acre feet of annual groundwater depletion. This version of the model requests augmentation flows for salmon starting about June.
[3] MODSIM is a generalized river basin decision support system and network flow model developed at Colorado State University (http://modsim.engr.colostate.edu/).

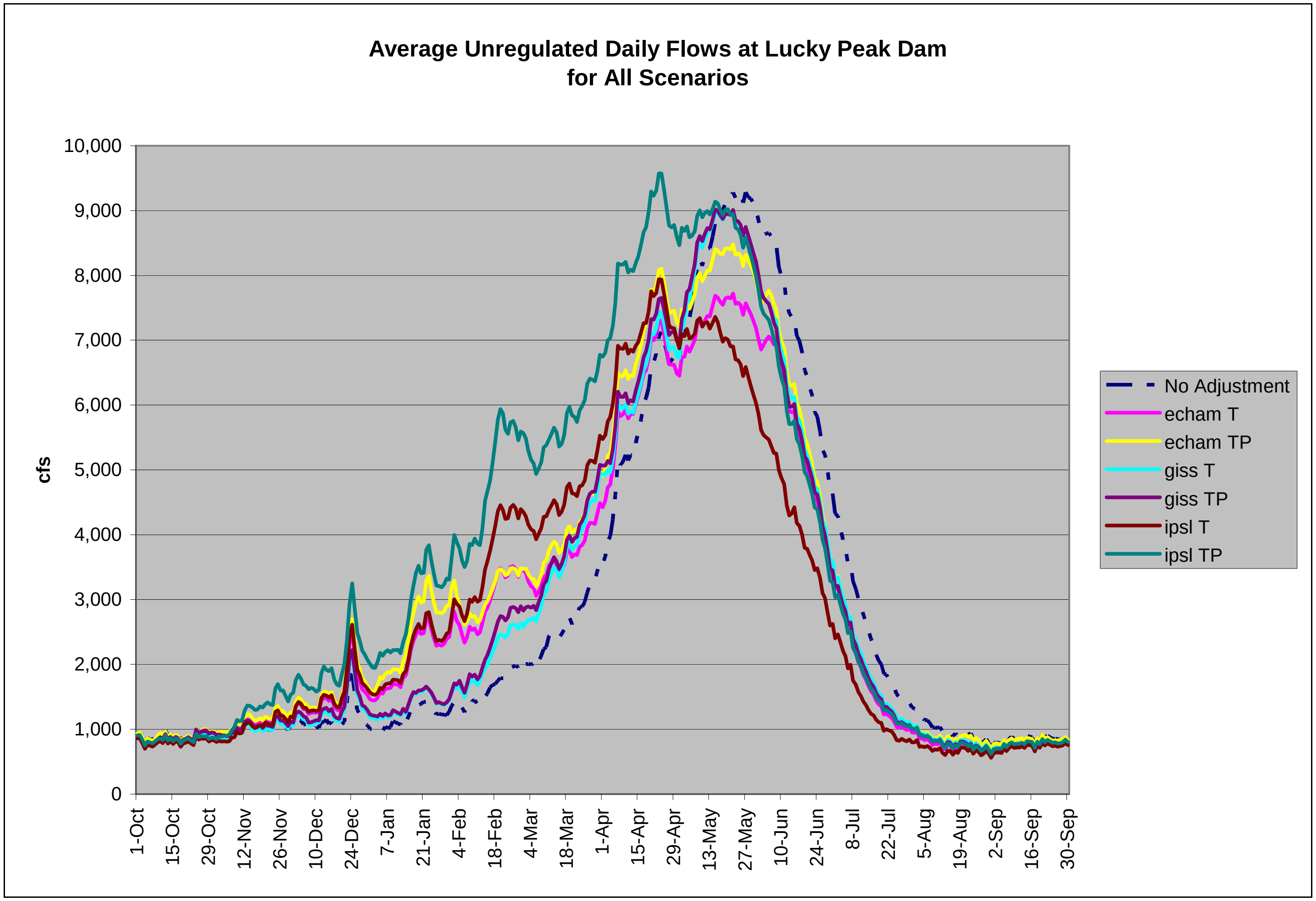

Figure 3. Unregulated daily flows at Lucky Peak Dam for all scenarios: average of simulated daily flows for water years 1941-1996. For the purposes of this study, the scenarios which apply temperature adjustments only are identified with 'T' (Echam T, GISS T, and IPSL T). The scenarios which apply both temperature and precipitation adjustments are identified with 'TP' (Echam TP, GISS TP, and IPSL TP).

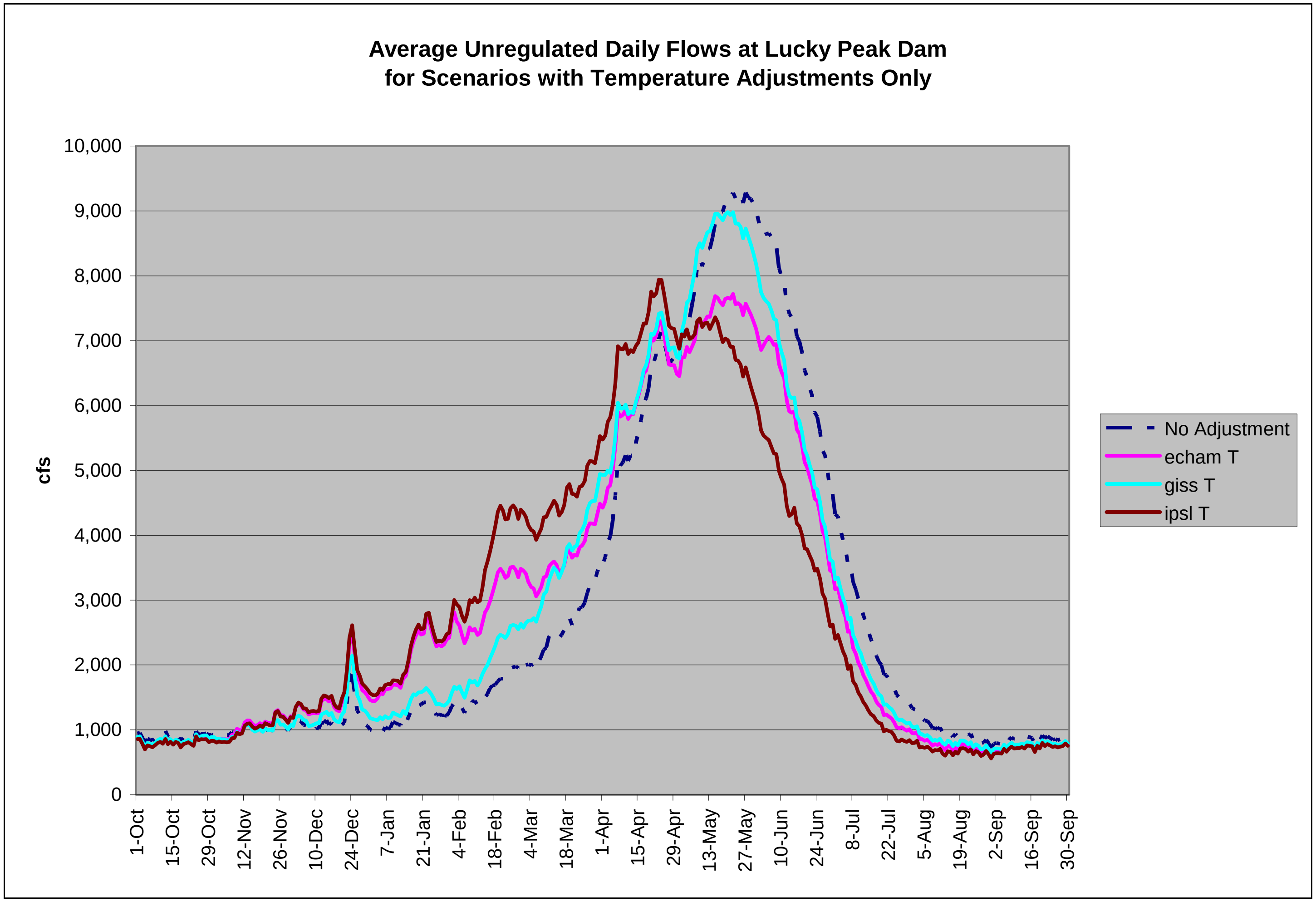

Figure 4. Unregulated daily flows at Lucky Peak Dam for the No Adjustment Scenario (historic inflows) and the climate change scenarios which apply temperature adjustments only: average of simulated daily flows for water years 1941-1996.

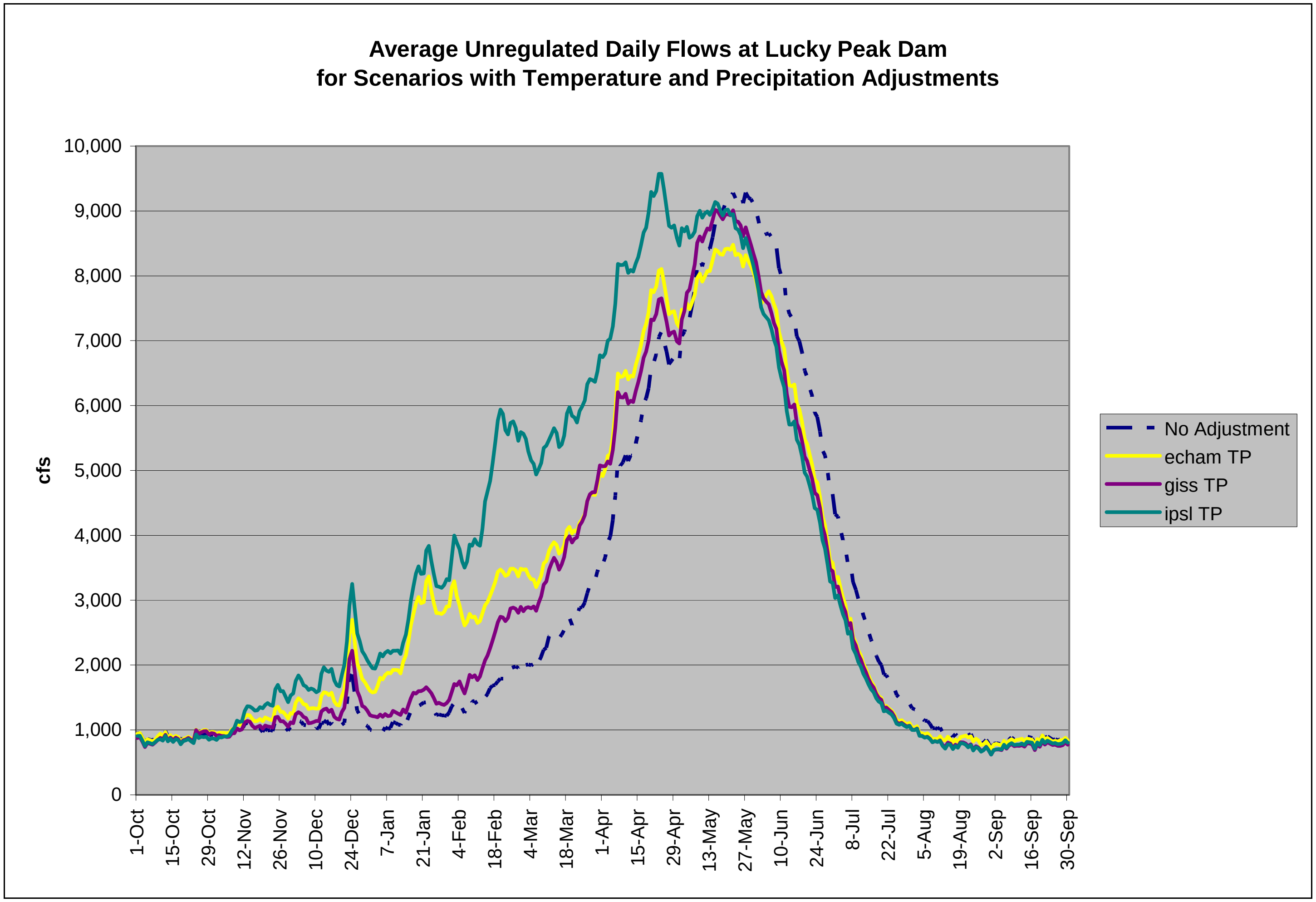

Figure 5. Unregulated daily flows at Lucky Peak Dam for the No Adjustment Scenario (historic inflows) and the climate change scenarios which apply both temperature and precipitation adjustments: average of simulated daily flows for water years 1941-1996.

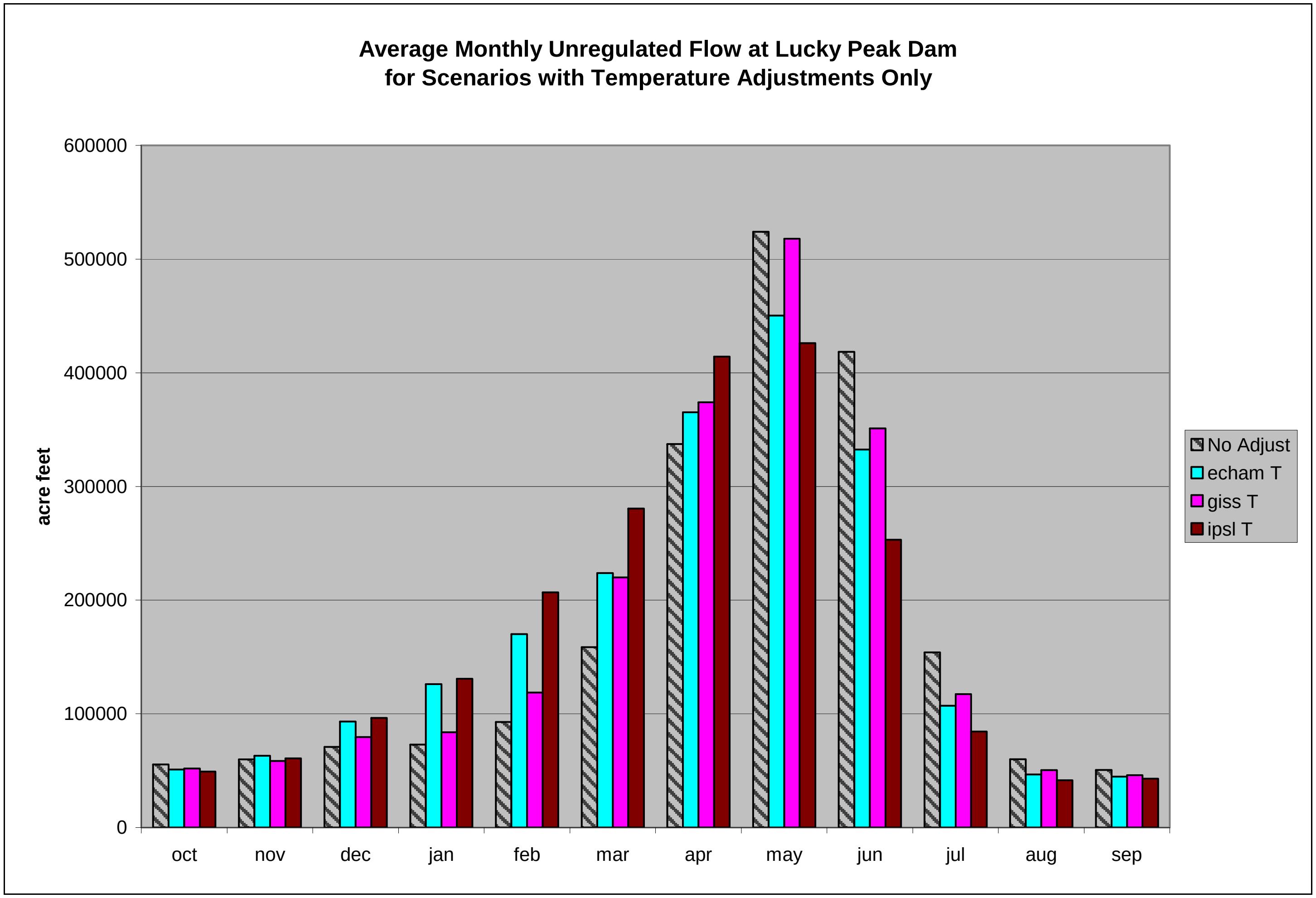

Figure 6. Unregulated average monthly flows at Lucky Peak Dam for the No Adjustment Scenario (historic inflows) and the climate change scenarios which apply temperature adjustments only: average of simulated daily flows by month for water years 1941-1996.

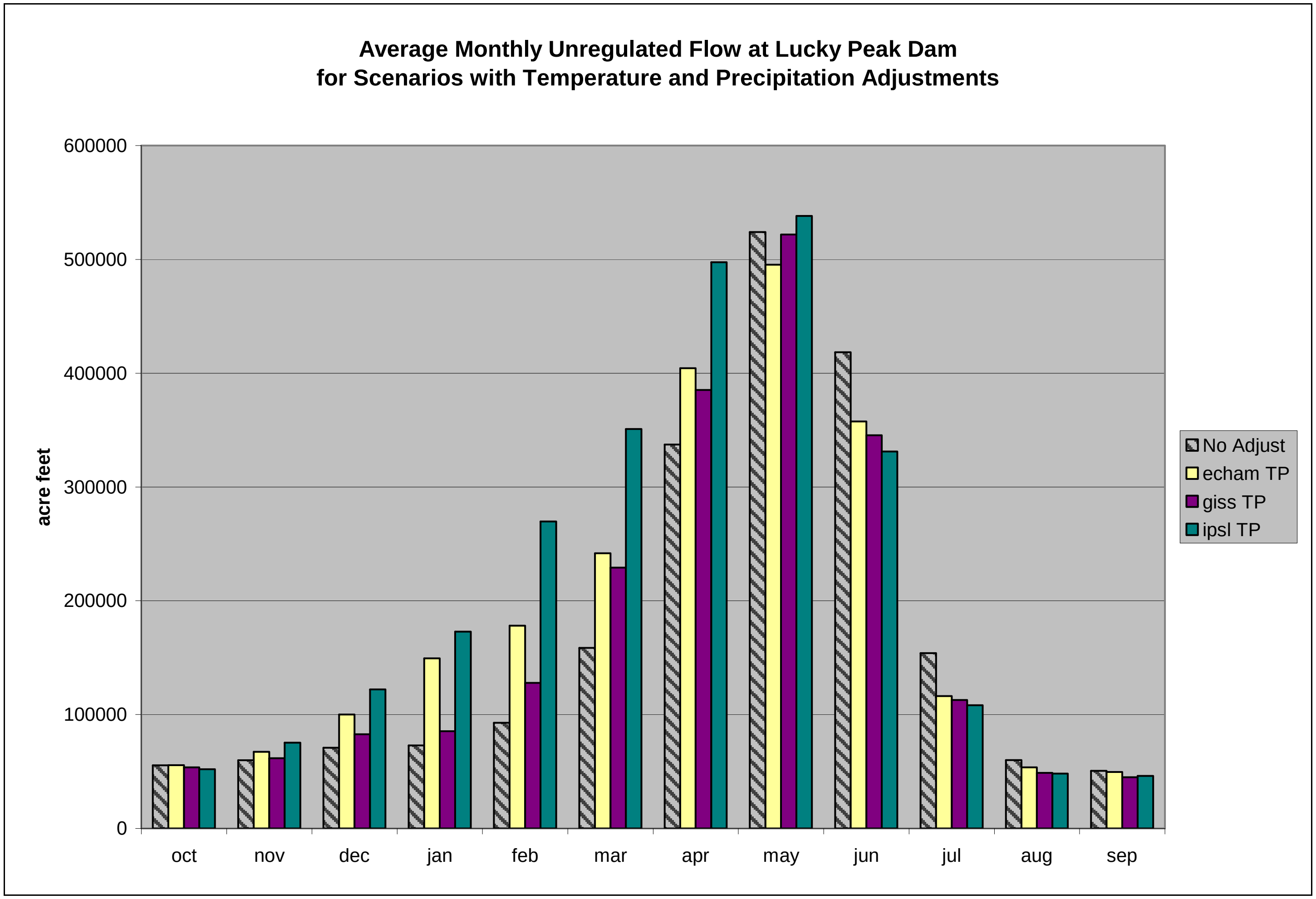

Figure 7. Unregulated monthly flows at Lucky Peak Dam for the No Adjustment Scenario (historic inflows) and the climate change scenarios which apply both temperature and precipitation adjustments: average of simulated daily flows by month for water years 1941-1996.

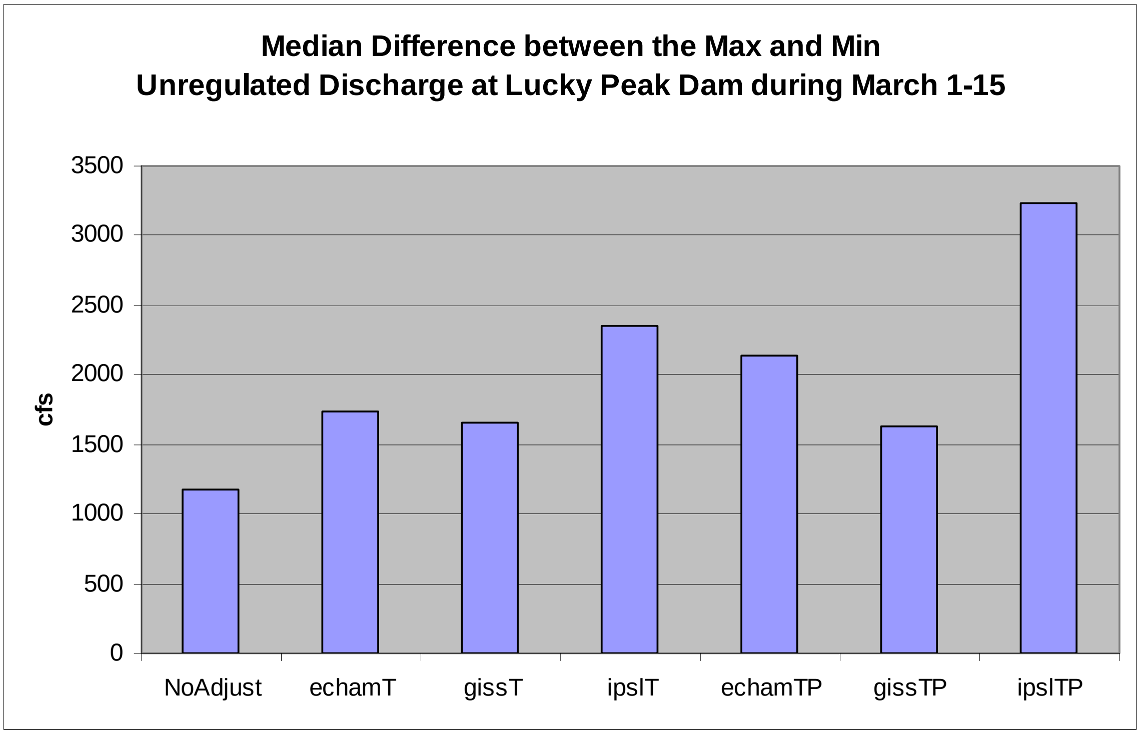

Figure 8. An example of increased variability in simulated unregulated discharge with climate change. For March 1 – 15 of each year modeled, the minimum unregulated discharge at Lucky Peak Dam during that period was subtracted from the maximum for the same period. This produces the spread or variability of the discharge over this specific 15 day period. The median of those values is shown in this chart. When compared to the No Adjustment Scenario (historic inflows), the Climate Change scenarios produce greater variability in unregulated discharge.

3.2 Planning Study

3.2.1 Diversions

With climate change, diverters will experience wetter spring months and drier summer months. Historically, when faced with wet springs, diverters have responded by reducing diversions, because the water is not needed, and when faced with dry summers, they have reduced diversions to conserve storage. The Planning Study simulates a reduction in annual diversions by up to12% in about 15 percent of the years.

Modeled requests for diversion are based on the historic monthly diversions which occurred during similar runoff forecast periods. Each runoff forecast is compared to a range of forecasts for that month from wet to dry and the diversion request is set according to where the forecast falls within that range. For example, if the current month is May and the runoff forecast to the end of July is dry relative to other years in the scenario, the diverter might reduce their request for water in response to dry conditions. The response differs for each diversion and in every month of every year. Since the diversion request is based on observed response, it is a product of the diverters' cropping patterns, water sources and perception of risk. For this reason, simulated requests for diversion in the climate change scenarios differ from the No Adjustment Scenario (historic inflows).

More information is required to understand how diverters would actually respond to climate change. Preliminary discussions of irrigator response to climate change suggest increased dry land farming and changes in cropping patterns and timing of diversions (Windes, 2007). Reduction in crop yield and crop quality may also affect water requirements.

Nearly all water requested for diversion is satisfied in all climate change scenarios. This indicates that if irrigators respond to climate change as they have to hydrologic states in the past, they will be as satisfied as they were historically given similar conditions. April and May deliveries are reduced under climate change at both the low and high ends. July and August deliveries are reduced at just the low end. The quantity of annual diversion requested in the climate change scenarios is up to12% less than the No Adjustment Scenario in about 15 percent of the years modeled (compare diversions between the 70 and 85 percentile levels in Figures 9 and 10).

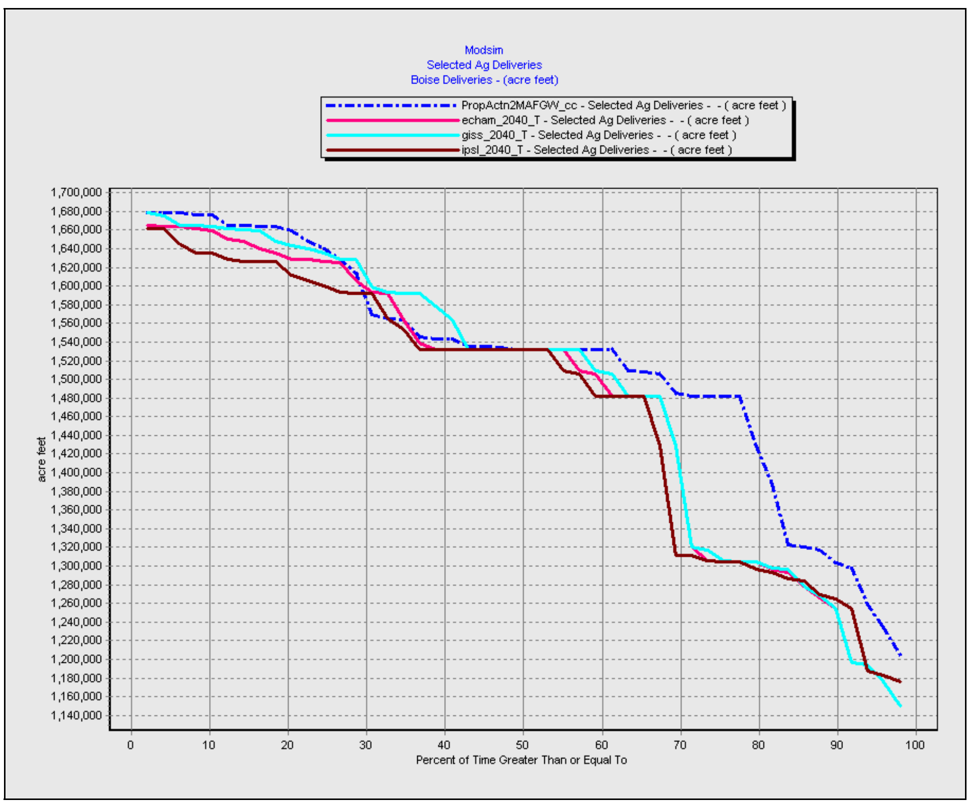

Figure 9. Planning Study: Selected modeled annual diversions from the Boise system for the No Adjustment Scenario (dotted blue line) and the three climate scenarios which apply temperature adjustments only.

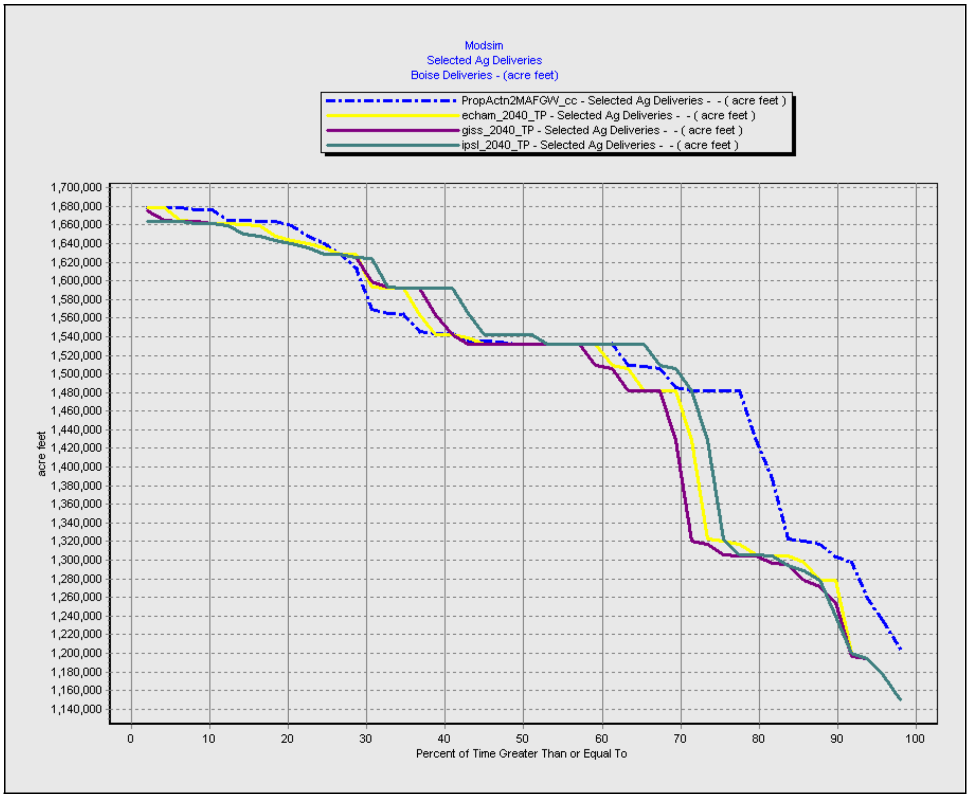

Figure 10. Planning Study: Selected modeled annual diversions from the Boise system for the No Adjustment Scenario (dotted blue line) and the three climate scenarios which apply both temperature and precipitation adjustments.

3.2.2 Natural Flow and Project Contract Deliveries

In the climate change scenarios less natural flow is available for distribution when irrigation starts up in April or May because the peak runoff has been shifted several weeks earlier. Junior water rights are then less likely to be satisfied. But during the period of earlier runoff when irrigation requests are still small, the reservoirs are able to capture the 'additional' water that occurs with climate change. This results in about a 7-9% decrease in natural flow diversion with climate change and a corresponding increase in reliance on stored Project water.

3.2.3 Probability of Refill

The Planning Study demonstrates moderately successful probability of refill for the three system reservoirs given the present level operating requirements as described in the Biological Assessment (Reclamation, 2004). Climate change scenarios which adjust temperature (and not precipitation) reduce the ability at the mean to refill the reservoirs by up to 59,800 acre feet out of a possible total system storage of 949,800 acre feet. But the probability of refill is *increased* in dry years by about 270,000 acre feet (see Figure 11). Climate change scenarios which adjust temperature *and* precipitation reduce the probability of refill at the mean by up to 41,500 acre feet, and *increase* the probability of refill in very dry years by about 358,000 acre feet (see Figure 12). The opportunity to fill the reservoirs during dry periods is more significant to water users than filling during wet periods, so it's important to understand why the reservoirs appear to fill more successfully in dry years under climate change conditions. The result is explained by a combination of events. First, runoff arrives too early for some diverters to take advantage of their junior natural flow rights, so the reservoirs, in turn, store this water. Secondly, the modeled diversion requests are based on historic diversions which occurred during similar forecast periods. Historically, diverters request less water if April and May are relatively wetter. But they also request less water if the months of June through August are relatively dry because they conserve water in response to drought. These shifts in demand occur at the same time the shifts in runoff occur with climate change, resulting in relatively less water diverted in some years and relatively more water stored.

Probabilities of refill results were also produced by the Flood Risk Study. The Flood Risk Study demonstrates very successful probability of refill when starting at average November reservoir contents. Combined, the studies indicate an opportunity for successful refill. Differences in refill probabilities between the Planning Study and Flood Risk Study results are discussed in Section 3.3.2.4.1 on page 28.

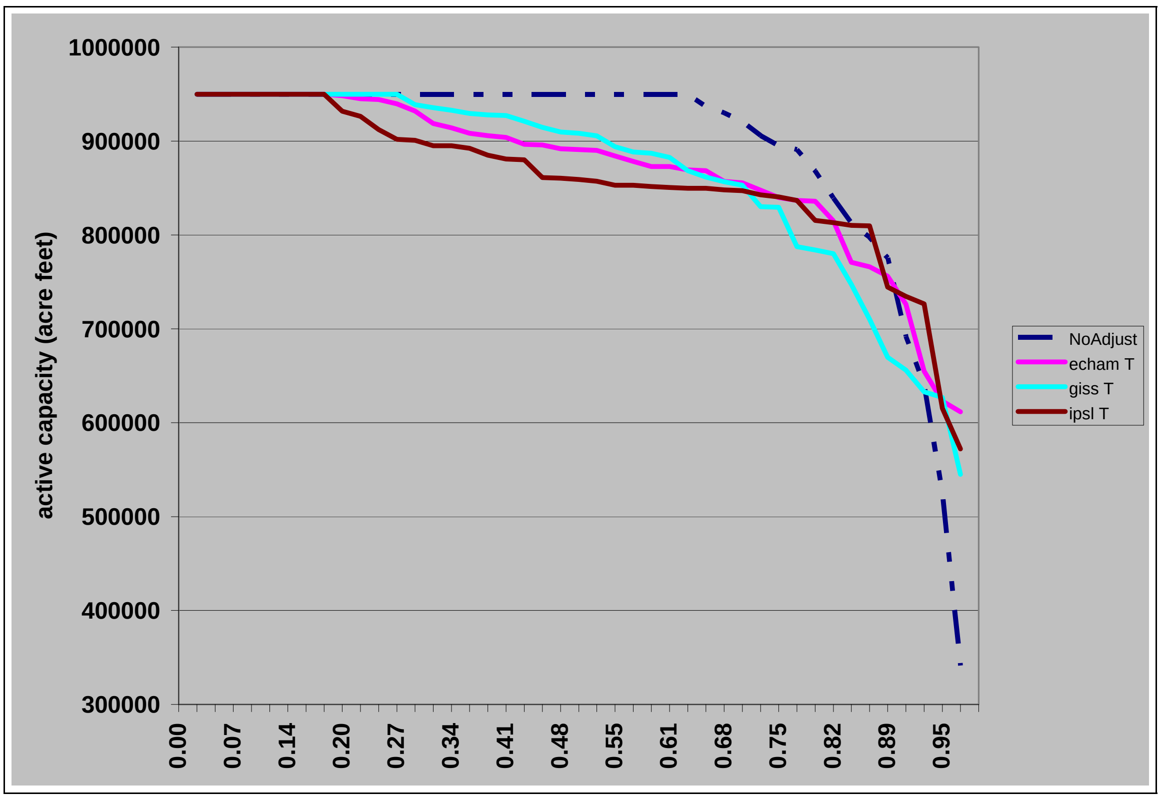

Figure 11. Planning Study: Probability of refill of system reservoirs (Anderson Ranch, Arrowrock and Lucky Peak) for the No Adjustment Scenario (dotted blue line) and the three climate change scenarios which apply temperature adjustments only.

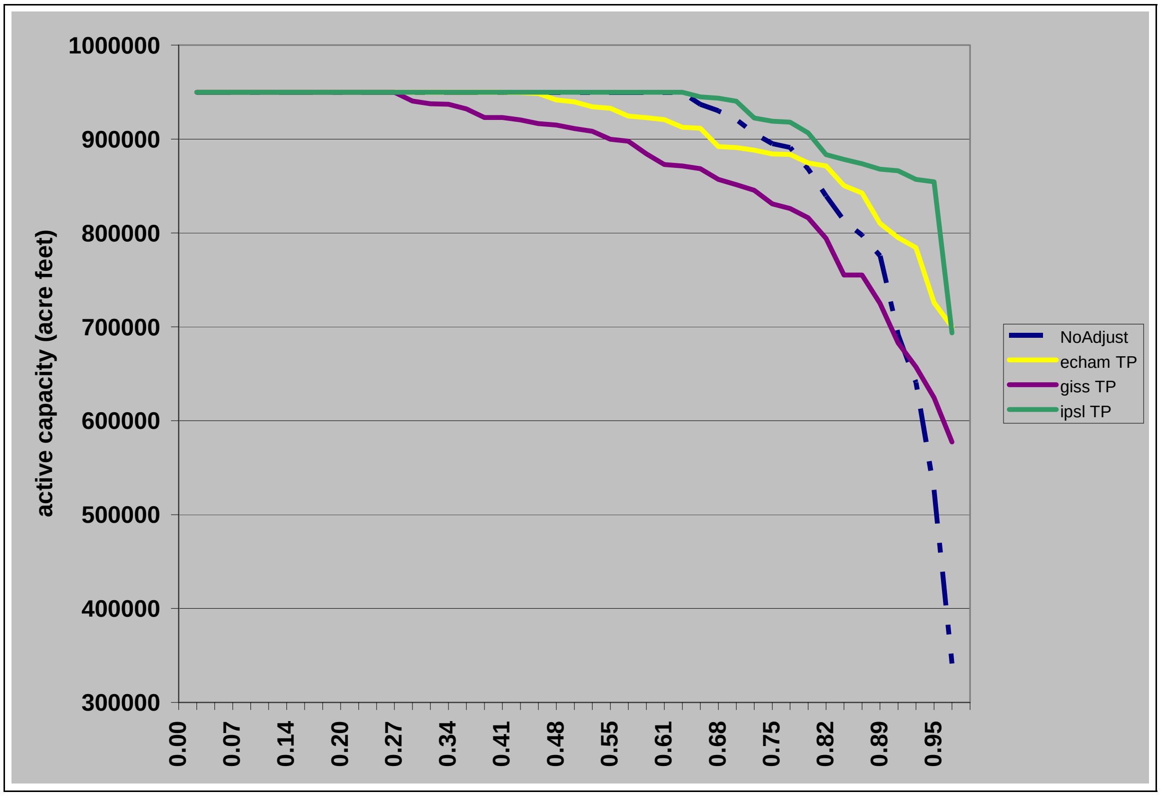

Figure 12. Planning Study: Probability of refill of system reservoirs (Anderson Ranch, Arrowrock and Lucky Peak) for the No Adjustment Scenario (dotted blue line) and the three climate change scenarios which apply both temperature and precipitation adjustments.

3.2.4 Boise River Contributions to Salmon Augmentation

The Boise River contributes to flow augmentation for salmon at Milner Dam. This version of the Planning model requests flow augmentation in July and August and in dry years, flow augmentation can begin as early as June. Flow augmentation in the Boise basin is provided by uncontracted storage space in Lucky Peak Reservoir, rented storage from Water District 63 rental pool, and the use of power head space in Anderson Ranch Reservoir. Space which has been applied to augmentation in the previous year is flagged as ‘last to fill’.

Flow augmentation, based on the assumptions described above, is reduced in the climate change scenarios by up to 2,340 acre feet at the mean, out of a possible 40,700 acre-feet annually. But, more importantly, flow augmentation is increased in the very dry years (refer to values above the 85th percentile in Figures 13 and 14).

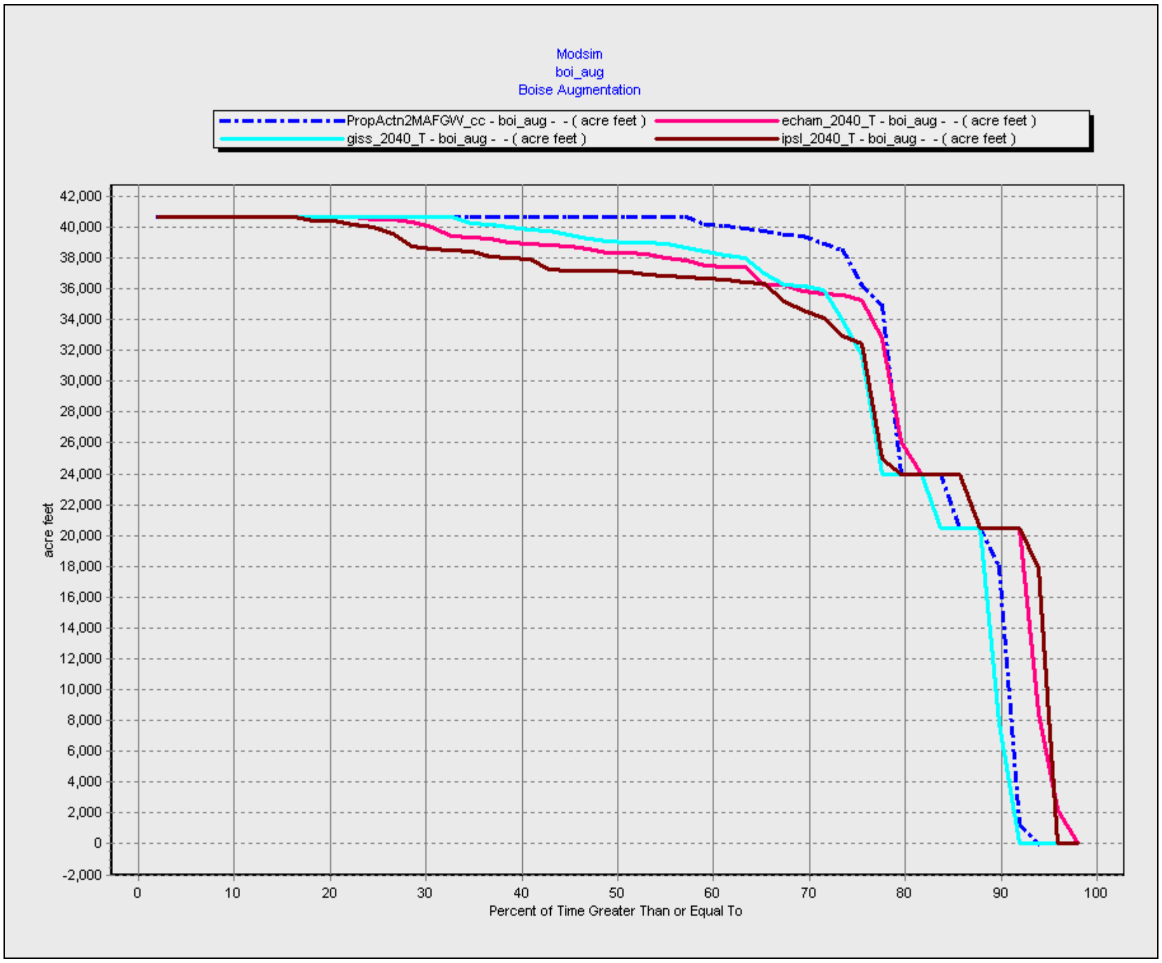

Figure 13. Planning Study: Boise River annual contributions to salmon augmentation for the No Adjustment Scenario (dotted blue line) and the three climate change scenarios which apply temperature adjustments only.

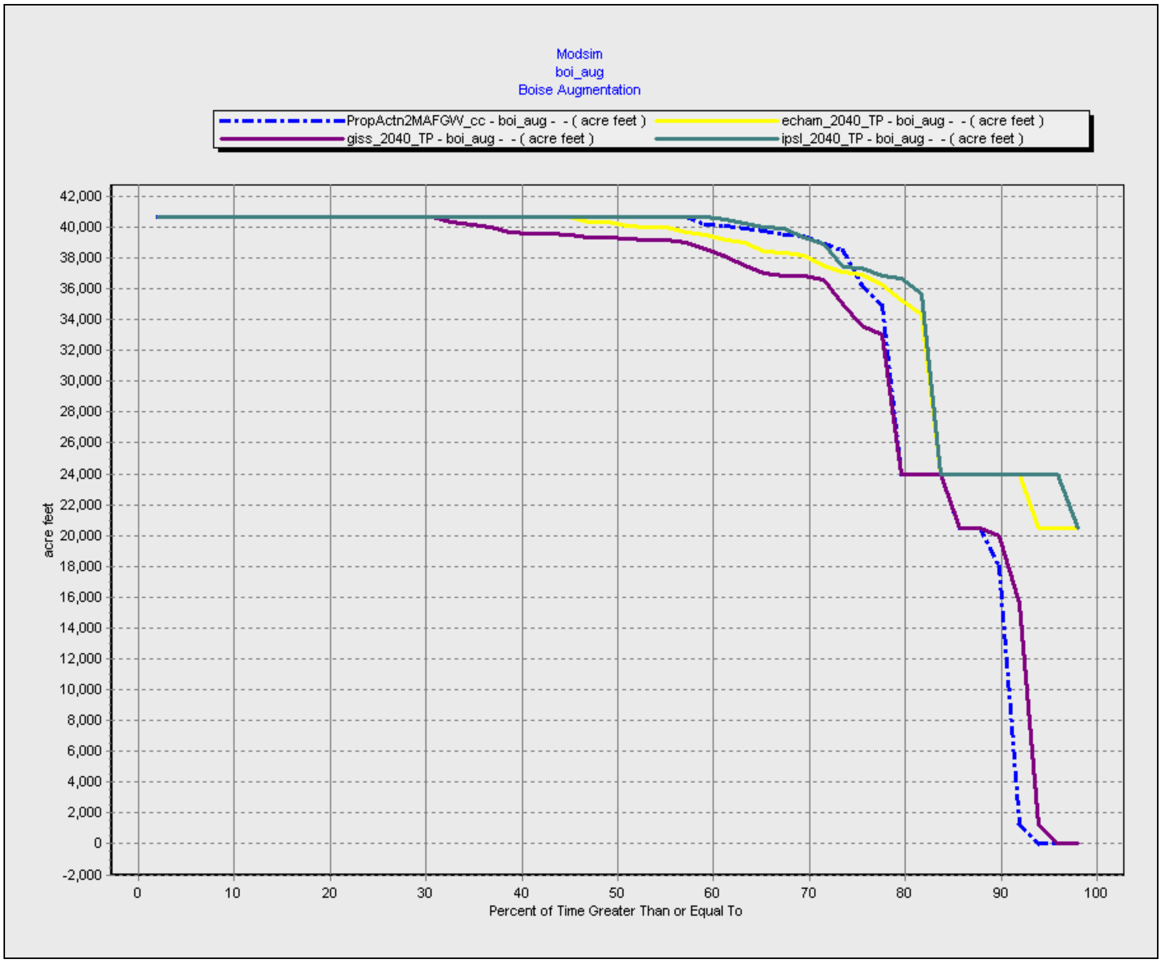

Figure 14. Planning Study: Boise River annual contributions to salmon augmentation for the No Adjustment Scenario (dotted blue line) and the three climate change scenarios which apply both temperature and precipitation adjustments.

3.2.5 Regulated Streamflows below Lucky Peak

Idaho Fish and Game has recommended preferred minimum release targets from Lucky Peak Dam. These informal targets are met in all climate change scenarios. Table 2 shows Idaho Fish and Game preferred minimum releases throughout the year.

Figures 15 and 16 show the median of average monthly releases from Lucky Peak Dam. January through May the average monthly discharge below Lucky Peak Dam is greater in the climate change scenarios than the No Adjustment Scenario and does not drop below 240 cfs at the median. In June through December, the average monthly discharge is less in the climate change scenarios, but does not drop below the preferred minimum releases at the median.

Table 2. Idaho Fish and Game preferred minimum releases from Lucky Peak Dam.

Idaho Fish and Game Preferred Minimum Releases[4]		
Date	Flow	Purpose
January 1 – February 28	240	fish rearing
March 1 – March 14	4500	waterfowl nesting
March 16 – June 30	1100	rainbow trout spawning and waterfowl nesting
July 1 – September 30	240	fish rearing
October 1 – November 30	240	brown trout spawning
December 1 – December 31	240	fish rearing

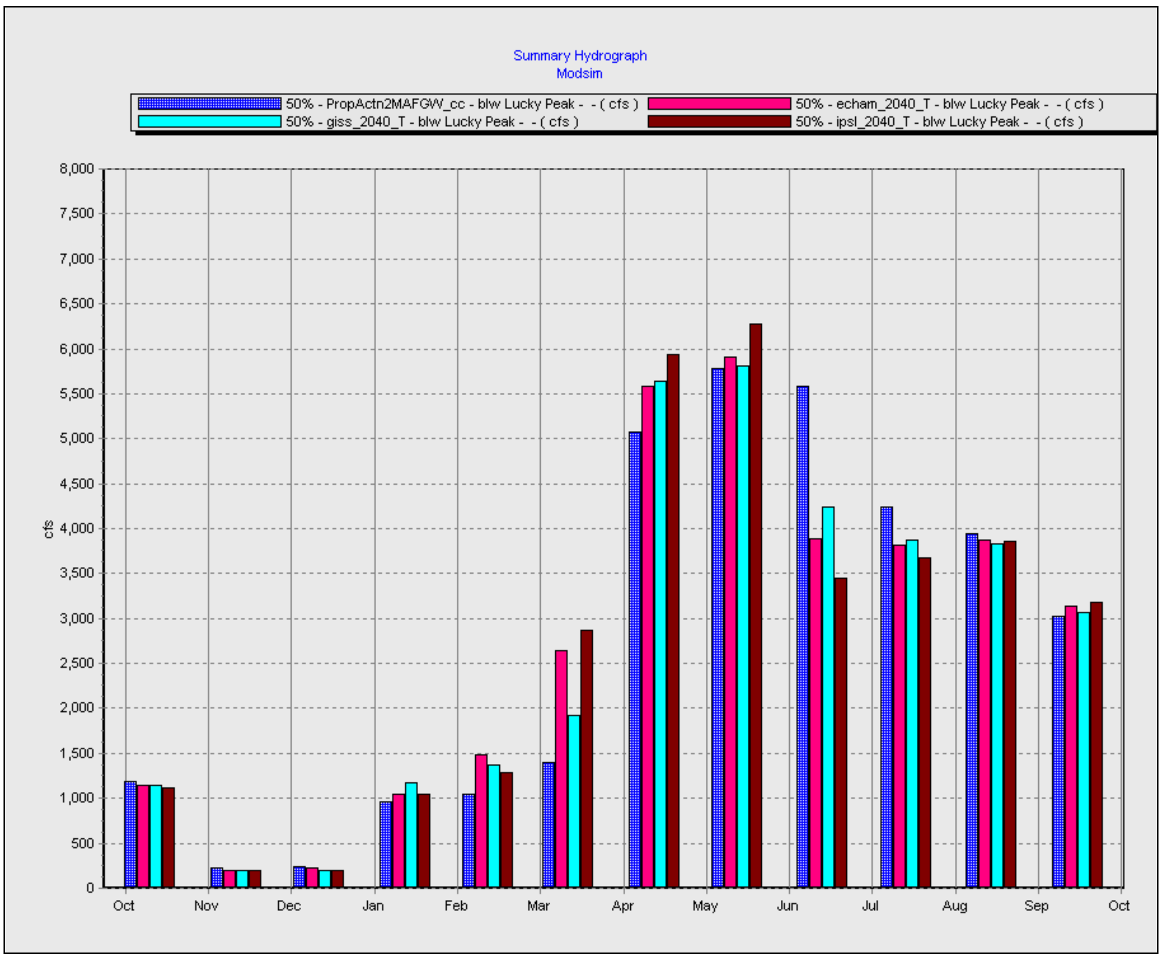

Figure 15. Planning Study: Median values of modeled average monthly discharge below Lucky Peak Dam for the No Adjustment Scenario (dotted blue line) and the three climate change scenarios which apply temperature adjustments only.

[4] Operations Manual for the Mid-Snake and Upper Snake River, U.S. Department of the Interior, Bureau of Reclamation, Pacific Northwest Region, July 2000.

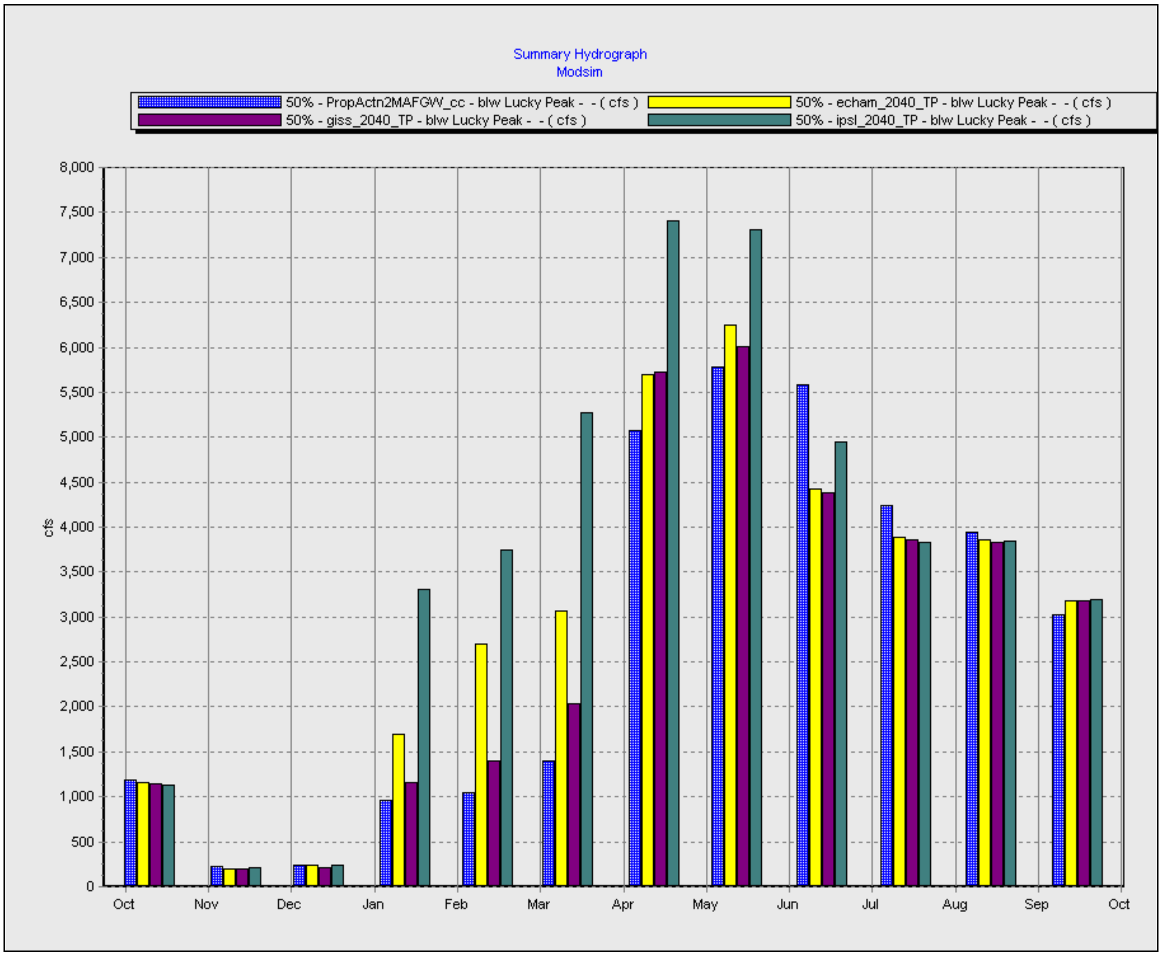

Figure 16. Planning Study: Median values of modeled average monthly discharge below Lucky Peak Dam for the No Adjustment Scenario (dotted blue line) and the three climate change scenarios which apply temperature and precipitation adjustments.

3.3 Flood Risk Study

3.3.1 Flood Risk Study Results Summary

The Flood Risk Study demonstrates an increased risk of winter and early spring flooding due to climate change. With climate change the entire hydrograph shifts, so that not only the peak arrives several weeks earlier, but the hydrograph starts receding earlier, too. So the existing rules are too late in evacuating the reservoirs, reaching maximum drawdown, and starting to fill.

Early peak inflows due to climate change will make it more difficult to manage river flows through Boise prior to April 1, the date for maximum space evacuation. Existing winter space requirements November through December are not aggressive enough to prepare for the increased volume of water arriving from January through March.

Balancing flood control with refill will be more challenging with climate change. Good volume forecasts and a knowledge of early peaking may produce reliable refill under the climate change. But runoff due to precipitation is more difficult to predict than that produced by snow accumulation and melt, so volume forecasts are likely to be less reliable. Currently reservoir drawdown begins about the time forecasts are prepared on January 1 when approximately 40 % of snow has accumulated. Operators may not be able to justify halting December fill operations when not much snow has accumulated and future precipitation is uncertain.

To prepare to manage Boise system reservoirs under climate change, Reclamation will need to:

- revise forecast methods,
- adjust rule curves to reflect the observed trends towards earlier runoff,
- increase winter space requirements, and
- start earlier drawdown

3.3.2 Modeled Current Practice Flood Operations

This section describes the current practice flood operations which were incorporated in the Flood Risk Study simulations.

3.3.2.1 Initial Conditions

For daily operations studies, each year was modeled independently using identical starting conditions. This provided a consistent assessment of the success of applying current operating rules. The initial conditions for these studies were the historic reservoir contents from November 1, 2000, which represents the median November 1 conditions since 1980. Higher initial conditions would likely produce a greater inability to meet winter space requirements and a greater likelihood of flooding January 1 through March 31.

3.3.2.1 Operating Rules, Model Assumptions and Results

The space requirements, rules and practices incorporated in the Boise Operations model and documented in the Corps of Engineers Water Control Manual[5] are described below.

3.3.2.1.1 Forecasts

Reservoir regulation for the Boise System for flood control and refill is based on forecasts of expected runoff volumes prepared by Reclamation operators, the Northwest River Forecast Center and the U.S. Army Corps of Engineers. Forecasts from the current date through July 31 are generated about every 2 weeks starting on January 1 and continue through the spring. Early forecasts may be significantly different from the runoff that eventually is realized, but forecasts generally improve as the season progresses. The progression of improving forecasts allows some opportunity for operators to correct and adjust operations through time. However, forecasts in the Boise Operations model are perfect forecasts, giving the model considerable advantage over real-world operators in determining release strategies. For this reason, study results

[5] Water Control Manual for Boise River Reservoirs, Walla Wall District, U.S. Army Corps of Engineers, April 1985.

should be viewed as providing nearly the best possible control, given the existing operating rules.

3.3.2.2.1 Winter Space Requirements

During November 1 through March 1 the minimum flood control spaces described in Table 3 are required. The space requirements are intended to protect against flooding resulting from rapid snowmelt and rainfall on frozen ground.

Table 3. Winter Space Requirements

Projects	Minimum Space Requirements (acre feet)	Duration
Anderson + Arrowrock + Luck Peak	300,000	Nov 1 through Dec 31
Arrowrock + Lucky Peak	165,000	Nov 1 through Dec 31
Lucky Peak	50,000	Nov 1 through Mar 31

Water in excess of these space requirements is evacuated with the intent to not exceed the maximum allowable discharge at Boise River at Glenwood gage, the control point used in addressing flooding in the Boise metropolitan area. The Water Control Manual sets the maximum allowable discharge at 6,500 cfs. Flood warnings are issued at 7,000 cfs. For the purposes of this study (and based on experience during high spring streamflows of April 2006), the model uses 7,200 cfs as the allowable maximum flow at Glenwood. Modeled discharge is allowed to exceed 7,200 cfs only when space is not available.

A minimum of 55% of the total winter flood control requirement during January through March is held in Arrowrock and Lucky Peak combined, with no less than 50,000 acre feet of space in Lucky Peak. The model is allowed to violate the shared space requirement if discharge at Glenwood Bridge would exceed 7,200 cfs otherwise.

The model uses November 1, 2000 starting conditions which provide 608,000 acre feet of space or 308,000 acre feet in excess of the space requirement. This is reasonable and reflects that Reclamation's reservoirs are usually drawn down at the end of irrigation season. The modeled space available by January 1 is shown in Figures 17 and 18. The No Adjustment (historic inflows) and climate change scenarios provide the required 300,000 acre feet of space on December 31, with the exception of the IPSL TP Scenario which violates the space requirement about 5% of the time. However, the climate change scenarios which use temperature adjustments provide from 6,500 to 25,000 acre feet less space on January 1 than the No Adjustment Scenario. The climate change scenarios which use both temperature and precipitation adjustments provide from 11,800 to 44,500 acre feet less space on January 1. Therefore, even though the winter space requirements are met, the climate adjusted scenarios are less prepared to control high inflows after January 1.

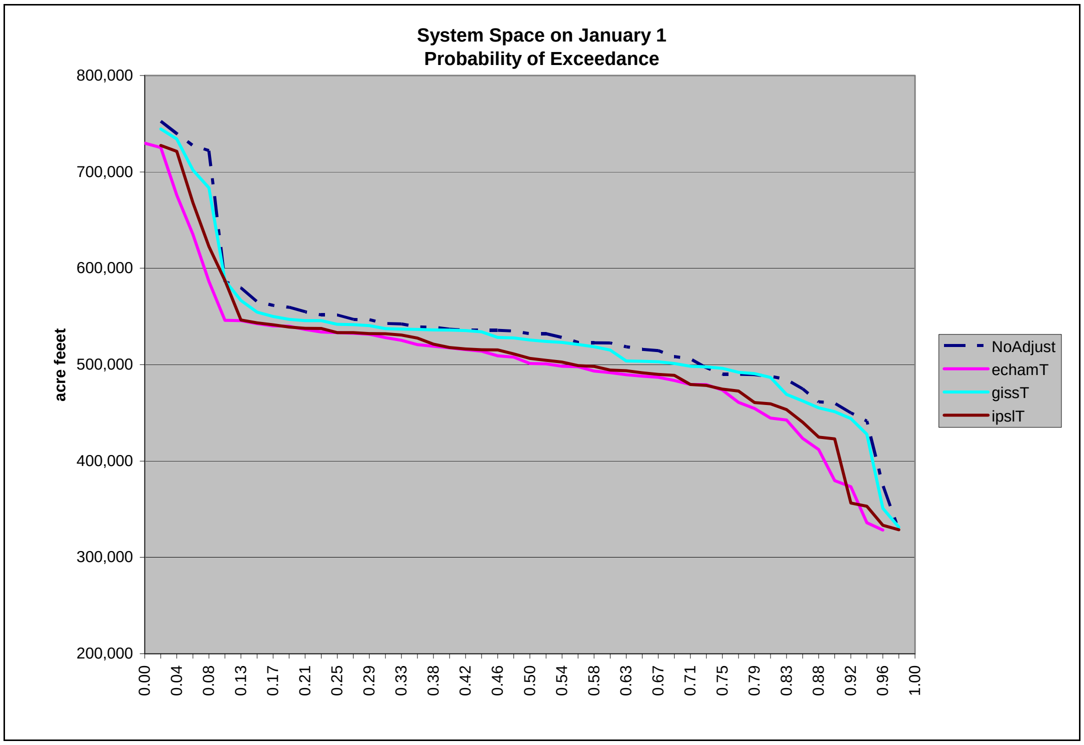

Figure 17. Flood Risk Study: Modeled space available on January 1 for the No Adjustment Scenario (historic inflows) and the three climate change scenarios which adjust temperature only.

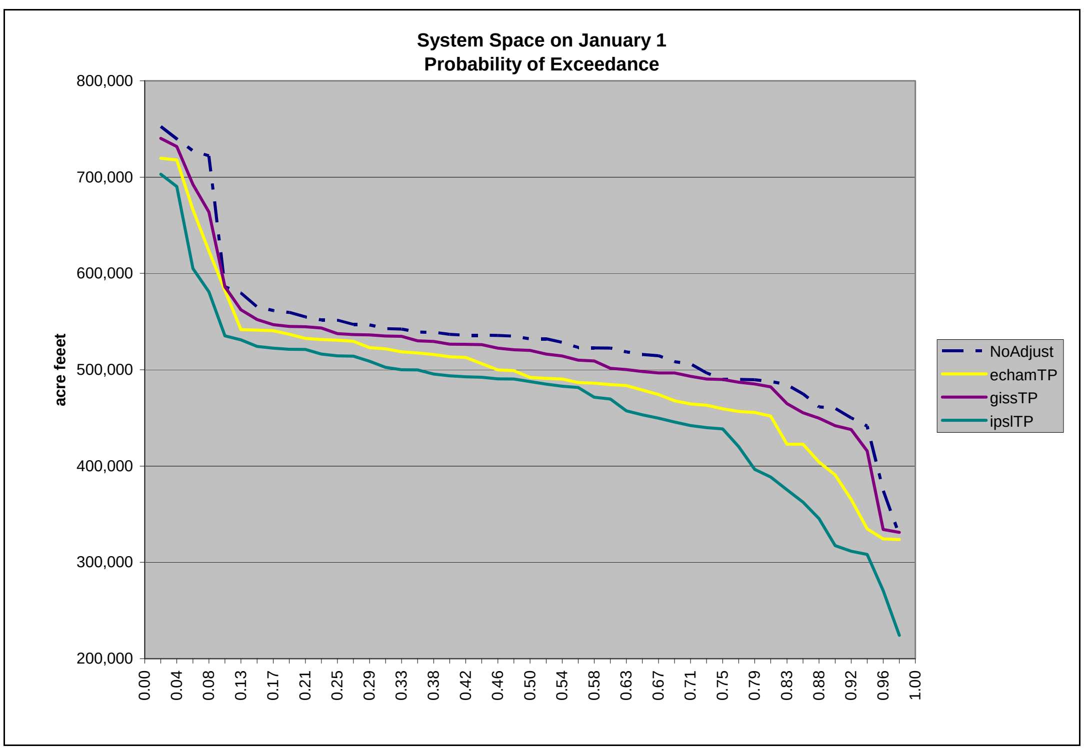

Figure 18 Flood Risk Study: Modeled space available on January 1 for the No Adjustment Scenario (historic inflows) and the three climate change scenarios which adjust temperature and precipitation.

3.3.2.3.1 Spring Evacuation Requirements

From January 1 through March 31 space is evacuated. The model attempts to not violate the 7,200 cfs restriction at Glenwood gage to prepare for the forecasted flood streamflows resulting from melting snow packs. The active snowmelt season currently begins about the first 2 weeks in April, so rule curves are used determine a space requirement on April 1 in anticipation for future runoff. Under climate change scenarios, however, runoff starts a steep rise as early as the first of February.

For consistency between scenarios, the Boise Operations model employed perfect forecasts. That means that reservoir operators are assumed to know with certainty the expected future runoff volume and shape of the runoff. In reality, the forecasted volume may have significant errors. That means that the model predicts less flooding than may occur with real-world forecasts.

Operators employ volume forecasts for the period 'now' through July 31. However, as the forecasts progress through time, it is necessary to estimate what portion of that forecast enters the system prior to April 1 and what portion enters after April 1, so that an April 1 target can be determined from the rule curves. The Boise Operations model uses perfect forecasts, so it is completely successful in determining how much water arrives before and after April 1. But real-world operators are not so fortunate. The Water Control Manual provides some guidelines in the form of projection equations for every 2 week period prior to April 1. Since these equations were developed using regressions on data from years 1895 through 1980, they under predict inflows prior to April 1 and over predict inflows after April 1 significantly for each climate change scenario. The equations appear to fail similarly for the No Adjustment Scenario (historic inflows), starting as early as the 1970's. Appendix C includes charts which show the differences between the prediction equations and the inflows for each scenario. Operators may not necessarily rely on the prediction equations, but the equations are based on the same data used to develop the rule curves and space requirements, so the charts in Appendix C also provide insight into how the existing rule curves and space requirements do not successfully anticipate the timing and volume of runoff with climate change.

3.3.2.4.1 Refill Requirements

From April 1 through July 31 snowmelt runoff is expected to refill the flood control spaces. The minimum flood control spaces and space distributions which govern the rate of refill are based on volume forecasts, flood control rule curves, space distribution rules among the three reservoirs, and projections of 15 day inflow volumes. At all times, discharge at Glenwood should not exceed 7,200 cfs. The ability of the system to refill depends on the successful determination of the April 1 space requirement. Because the model understands perfectly the inflow volumes which will enter the system after April 1, the study results provide the most successful refill operations possible. After April 1, the model relies on forecasts every 2 weeks, and flooding at times occurs when inflows spike outside of the 2 week forecast window.

Results from the Boise Operations model indicate good refill capabilities for the given starting conditions and perfect forecasts (Refer t o Figure 19). Refill occurs about three weeks earlier in the climate change scenarios. For all climate change scenarios studied the ability to refill the three system reservoirs is improved. But this improved refill capability has several causes and liabilities: in high water years system space requirements are not met and the system runs dangerously full and at risk. Perfect forecasts keep this risk in check, but real-world operations would not. In many low water years the NWSRFS model produces higher unregulated streamflows in the climate change scenarios than the No Adjustment Scenario. Since, space requirements of low water years do not force evacuation, the system is able to capture the additional water and consequently fill the system more successfully.

Both the Planning Study and the Flood Risk Study produce moderately to very successful refill. But the refill probabilities differ between the Planning and Flood Risk Studies because:

1) The initial conditions of the Flood Risk Study are November 1, 2000, contents for each year, which corresponds to average historic conditions, whereas the Planning Study simulation runs continuously from water year 1949 through 1997.
2) The Flood Risk Study does not simulate augmentation, minimum streamflows and irrigator response as dynamically as the Planning Study; and
3) The Planning Study uses less detailed space evacuation rules than the Flood Risk Study. The Planning Study's space evacuation is calibrated to historic operations for similar storage conditions and forecasted inflows. The Flood Risk Study's space evacuation is based strictly on operating rules from the Water Control Manual.
4) In some years, the Flood Risk Study can not create enough space to meet the April 1 space requirement because of its strict adherence to rules, putting reservoirs at higher risk but in a better position to refill.

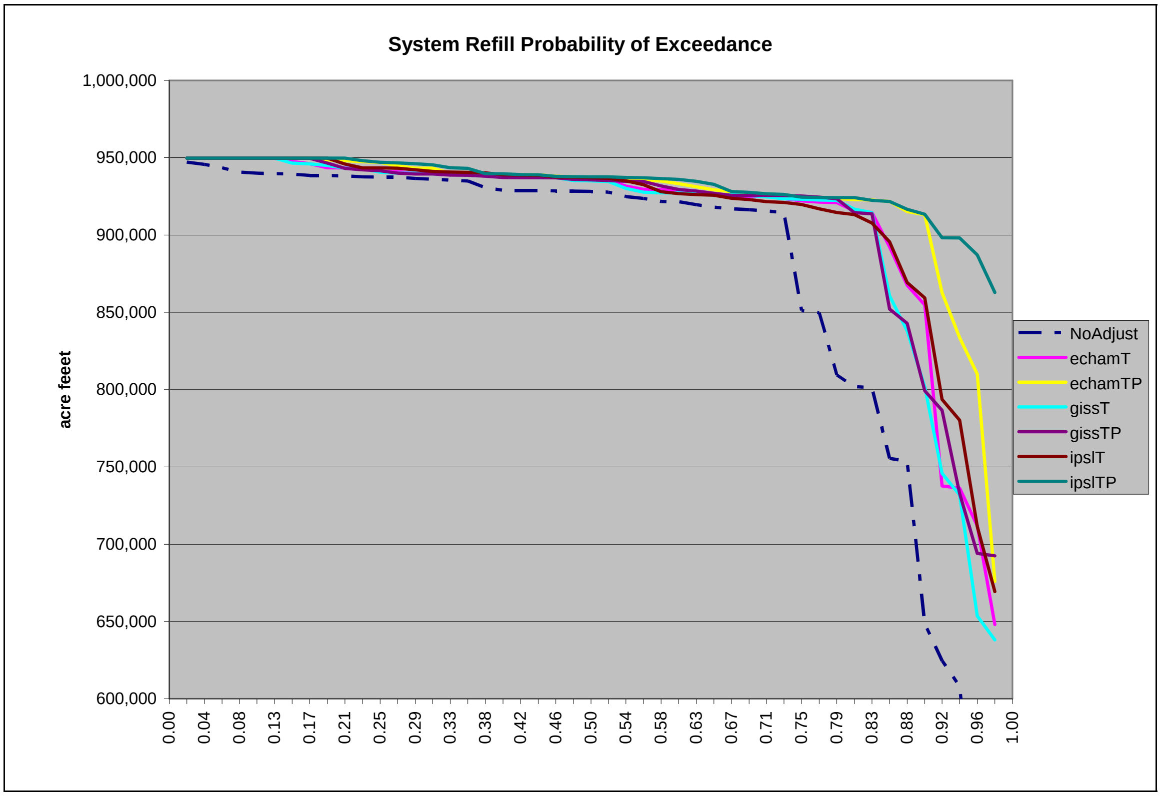

Figure 19. Flood Risk Study: Probability of Refill using starting conditions of November 1, 2000 for each year of study for the No Adjustment Scenario and all six climate change scenarios. Starting conditions correspond to average historic conditions.

3.3.2.1 Simulation Results of Current Practice Flood Operations Under Climate Change

The winter space and spring evacuation requirements for the Boise Project that are in place today produce winter and early spring flooding more frequently for the climate change scenarios than for the No Adjustment Scenario (historic inflows) (selected years and scenarios are shown in Appendix D). The winter space requirements prior to January 1 do not provide enough buffer for regulation January 1 through March 31. The early peaking of system inflows associated with climate change brings so much water into the system prior April 1, that successful drawdown by April 1 can not be achieved without making releases which create frequent flooding at Glenwood Bridge (discharge in excess of 7,000 cfs) January 1 through March 31.

The winter space requirements, rule curves and April 1 target date for maximum drawdown were originally determined using historic inflows from 1890 through 1986. Consequently, the space requirements and rule curves underestimate inflows prior to April 1 and overestimate inflows after April 1.

The existing rule curves force occasional flooding after April 1 in the climate change scenarios, but, for the most part, that is due to the increased variability in inflow. In the high precipitation scenarios, the inability to meet an April 1 target produces flooding after April 1.

Unlike real-world operations, this study uses perfect volume forecasts, so the model was able to anticipate reduced inflows after April 1 and draw down the reservoirs only enough to guarantee refill in the spring, resulting in successful refill operations. This demonstrates that good volume forecasts and an understanding of earlier peaking and recession will result in good refill capabilities under climate change.

3.3.2.1.1 Modeled Flood Events

Regulated streamflows for the Boise River at Glenwood Bridge are indicators of successful flood control operations. Flood stage at Glenwood Bridge is 7,000 cfs. The maximum allowable discharge in the model is 7,200 cfs. The flood control space requirement in the reservoirs was modeled as more important than the 7,200 cfs flood flow at Glenwood. This means that modeled streamflows were allowed to go above flood stage if flood control space requirements (necessary to capture larger snowmelt streamflows later in the spring) were not being met. With the exception of the IPSL scenarios, the simulation studies show that current flood operations and perfect forecasts produce flood control at Glenwood that is successful in most years. Tables 4 and 5 on pages 32 and 33 summarize the modeled flood events. Flood events are defined here as discharge in excess of 7,200 cfs on any given day and more than 1,000 acre feet in any single control period (January through March or April through July) at Glenwood Bridge Ten years out of the 49 years studied are potential flood years. Selected years and scenarios are described below.

3.3.2.2.1 Flooding Prior to April 1

Flooding prior to April 1 occurs in the climate change scenarios because inflow volumes arrive earlier than anticipated by the flood control rule curves and target dates. No flooding prior to April 1 occurs in the No Adjustment Scenario (historic inflows) for all years of the study (1949-1996), so the rule curves and target dates are successful for historic inflows. However, in the climate change scenarios the discharge at Glenwood Bridge from January 1 through March 31 is more likely to exceed flood stage in an attempt to meet an April 1 target.

The Echam TP Scenario for 1982 is an example of flooding prior to April 1. Water year 1982 experienced very high inflows in December and mid February through March and again after April 1. The No Adjustment and Echam TP scenarios for 1982 can be compared using Figures D1 and D2 in Appendix D. In the No Adjustment Scenario, the discharge at Glenwood Bridge does not exceed 5,500 cfs January 1 through March 31 and its space requirement is met within 3,000 acre feet on April 1. In the Echam TP Scenario, inflows are greater prior to April 1 and discharge remains at about 7,200 cfs to evacuate space for it's April 1 space requirement, which it fails to meet by about 6,000 acre feet.

3.3.2.3.1 Flooding After April 1

Flooding after April 1 occurs in the No Adjustment Scenario (historic inflows) in 5 out of the 48 years studied, but not in 1996. All the climate change scenarios, except Echam T, experience flooding after April 1 in 1996. Water year 1996 experienced high inflows in

December and later through July. Figures D3 through D6 in Appendix D can be used to compare the No Adjustment, GISS T, IPSL T and IPSL TP scenarios for 1996.

In the No Adjustment Scenario, the April 1 target was successfully met within 3,000 acre feet, discharge at Glenwood Bridge started at about 6,600 cfs in early April and declined to 3,800 cfs by mid-May, and the system reached its maximum fill of 937,606 acre feet on July 12.

In the GISS T Scenario, the April 1 target was also successfully met within 3,000 acre feet. The space requirement for the GISS T Scenario was 208,000 acre feet less than the No Adjustment Scenario, because less water was expected after April 1. The discharge at Glenwood Bridge started above flood stage at 7,200 cfs in April and declined to 3,800 cfs by mid-May. The system reached its maximum fill of 930,159 acre feet on June 19, three weeks earlier than the No Adjustment Scenario. Here, the early April flooding was caused by an inflow spike in early April which inflated the 2 week forecast and caused flood stage releases from Lucky Peak.

In the IPSL T Scenario, the April 1 target was successfully met within 3,000 acre feet. System storage remains higher than the No Adjustment Scenario starting in November because space requirements did not force otherwise. The April 1 space requirement was 420,000 acre feet less than the No Adjustment Scenario. The discharge at Glenwood bridge started above flood stage at 7,200 cfs in April, again in response to an inflow spike which inflated the 2 week forecast. The system reached its maximum fill of 940,465 acre feet on June 18, slightly higher and three weeks earlier than the No Adjustment Scenario.

The IPSL TP Scenario produces serious control problems April through July. (Remember, the IPSL TP Scenario features average temperature increases of 2.5 degrees C and precipitation increases of 9%). The April 1 space requirement was missed by 285,000 acre feet even though discharge at Glenwood Bridge remained above the flood stage at 7,200 cfs January through March. Discharge spiked to 8,800 cfs in late April and did not drop below 7,000 cfs until early June. System storage remained high because space requirements could not be met and the system reached its maximum fill of 949,800 acre feet on April 25 leaving the system dangerously full and without space to control downstream discharge. (Note that runoff in 1996 was high but not extraordinary. The 1996 historic January through July runoff volume was 4th highest in the past 26 years).

Table 4. Modeled flood events for the No Adjustment Scenario (historic inflows) and the climate change scenarios which apply temperature adjustments only. Flood events are discharge in excess of 7,000 cfs on any given day and more than 1,000 acre feet in any single control period (January through March or April through July) at Glenwood Bridge.

Scenario	year	flood events prior to April 1		flood events after April 1	
No Adjust		*Number of Days*	*Max cfs*	*Number of Days*	*Max cfs*
	1952	0	--	0	--
	1956	0	--	0	--
	1958	0	--	7	7200
	1965	0	--	29	7200
	1969	0	--	0	--
	1971	0	--	31	7200
	1974	0	--	1	7076
	1982	0	--	0	--
	1986	0	--	8	8640
	1996	0	--	0	--
Echam T		*Number of Days*	*Max cfs*	*Number of Days*	*Max cfs*
	1952	0	--	4	7907
	1956	0	--	0	--
	1958	0	--	9	7200
	1965	0	--	13	7200
	1969	0	--	12	7200
	1971	0	--	13	7200
	1974	0	--	3	7956
	1982	0	--	0	--
	1986	0	--	11	8255
	1996	0	--	0	--
GISS T		*Number of Days*	*Max cfs*	*Number of Days*	*Max cfs*
	1952	0	--	2	8301
	1956	0	--	3	7119
	1958	0	--	10	7200
	1965	0	--	15	7200
	1969	0	--	0	--
	1971	0	--	14	7200
	1974	0	--	1	8002
	1982	0	--	0	--
	1986	0	--	11	8351
	1996	0	--	9	7200
IPSL T		*Number of Days*	*Max cfs*	*Number of Days*	*Max cfs*
	1952	0	--	32	7200
	1956	0	--	14	7200
	1958	0	--	7	7200
	1965	1	7002	0	--
	1969	0	--	33	8168
	1971	87	7200	15	7200
	1974	0	--	4	7194
	1982	0	--	0	--
	1986	0	--	11	7641
	1996	0	--	10	7200

Table 5. Modeled flood events for the No Adjustment Scenario and the climate change scenarios which apply both temperature and precipitation adjustments. Flood events are discharge in excess of 7,000 cfs on any given day and more than 1,000 acre feet in any single control period (January through March or April through July) at Glenwood Bridge.

Scenario	year	flood events prior to April 1		flood events after April 1	
No Adjust		*Number of Days*	*Max cfs*	*Number of Days*	*Max cfs*
	1952	0	--	0	--
	1956	0	--	0	--
	1958	0	--	7	7200
	1965	0	--	29	7200
	1969	0	--	0	--
	1971	0	--	31	7200
	1974	0	--	1	7076
	1982	0	--	0	--
	1986	0	--	8	8640
	1996	0	--	0	--
Echam TP		*Number of Days*	*Max cfs*	*Number of Days*	*Max cfs*
	1952	0	--	3	7122
	1956	0	--	8	7200
	1958	0	--	10	7200
	1965	39	7200	21	7200
	1969	0	--	12	7344
	1971	90	7200	46	7200
	1974	0	--	2	8223
	1982	45	7200	0	--
	1986	0	--	11	8339
	1996	0	--	9	7200
GISS TP		*Number of Days*	*Max cfs*	*Number of Days*	*Max cfs*
	1952	0	--	6	7164
	1956	0	--	6	7200
	1958	0	--	10	7200
	1965	0	--	15	7200
	1969	0	--	12	8059
	1971	0	--	14	7200
	1974	0	--	15	8102
	1982	0	--	0	--
	1986	0	--	11	8143
	1996	0	--	9	7200
IPSL TP		*Number of Days*	*Max cfs*	*Number of Days*	*Max cfs*
	1952	2	7200	13	7792
	1956	89	7200	31	7200
	1958	0	--	10	7200
	1965	90	7200	43	7200
	1969	0	--	32	7934
	1971	90	7200	52	9022
	1974	90	7200	35	7250
	1982	90	7200	37	7200
	1986	0	--	16	8308
	1996	90	7776	48	8813

3.4 Suggestions for Further Study

The Flood Risk Study provides an initial assessment of future climate change and illustrates the possible consequences of taking no action to prepare for altered streamflows. Future studies should investigate approaches to mitigate for the effects of climate change. Revised flood control rules, increased channel capacity at Glenwood Bridge, additional flood control space in the existing reservoirs, and new storage could be explored.

The volume forecasts for the Flood Risk Study are perfect forecasts, giving the model considerable advantage over real-world operators in determining release strategies. For this reason, study results provide nearly the best possible control, given the existing operating rules. The use of imperfect forecasts would provide results which may be more applicable to the real-world.

The maximum drawdown determined by rule curves for an April 1 target date needs to be re-evaluated. Rule curves which utilize an earlier target date could be developed. Some optimization packages, like PEST and CSUDP, could be used in context with the existing Boise Operations model to develop revised operating rules and rule curves.

A scaling approach using streamflow adjustment multipliers might account for the differences described between the NWSRFS baseline runoff and historic streamflows (refer to Section 2.3) and should be evaluated. The streamflow adjustments would then be defined as:

$$\Delta Q = Q_{\text{NWSRFS climate change}} / Q_{\text{NWSRFS baseline}}.$$

The Planning and Flood Risk Studies applied temperature and precipitation results from the IPCC climate models which are average values for the whole of the Pacific Northwest. The Climate Impacts Group is currently downscaling IPCC temperature and precipitation results to areas as small as the Boise basin which will account for topographic and other local effects. These values should be available by the end of 2008. This assessment should be updated to reflect these improved values.

The Planning Study applied diversion requests based on historic response to similar hydrologic conditions. Better information is required to appropriately consider how diversions will actually respond to climate change.

The NWS model applied to develop streamflows from temperature and precipitation projections may not accurately describe the system outside of calibration conditions, and may, in fact, overestimate higher streamflow events[6]. Additional studies and models should be pursued to calibrate and evaluate simulated streamflows.

Selection criteria for the global climate simulations should be investigated.

[6] telephone conversation with Dr. David Raff, hydrologist, U.S. Bureau of Reclamation, July 9, 2008.

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APPENDIX A. NWSRFS Model Calibration

DRAFT TECHNICAL MEMORANDUM

Calibration Check of NWSRFS Forecast Streamflows for the Boise Basin

PREPARED FOR: Lesa Stark

PREPARED BY: Leslie Stillwater

DATE: May 29, 2007 (revised)

MODEL VERSIONS:

BoiseGains_v8, NWS_baseHistoric_v8

The National Weather Service River Forecast System model (NWSRFS) was used to develop daily baseline natural streamflows for the Boise basin, starting on October 1, 1949, and running through September 30, 1997[7]. Although a perfect calibration would be impossible, the NWSRFS model should yield baseline natural streamflows which, for the most part, match Hydromet's unregulated streamflows calculated from observed streamflow and storage values.

The daily baseline natural streamflows from the NWSRFS model were aggregated to monthly values and compared to monthly unregulated streamflows. The comparison demonstrates acceptable calibration of the NWSRFS model for the purposes of the monthly Climate Change model studies.[8]

One source of the differences between the NWSRFS natural streamflows and unregulated flows could be differences in the calculation of evaporation. Total system evaporation above Lucky Peak Dam is on the order of 25,000 acre feet annually.

The NWSRFS modeled values are shown in red ('NWS_baseHistoric_v8') and the unregulated values are shown in blue ('BoiseGains_v8') in the following graphs.

[7] The NWS River Forecast Center provided the baseline data sets to run NWSRFS, May 14, 2007.
[8] Streamflow adjustments developed from a comparison of two NWSRFS model runs, baseline and climate change, will be applied to the monthly unregulated streamflows to create a MODSIM model scenario for Climate Change.

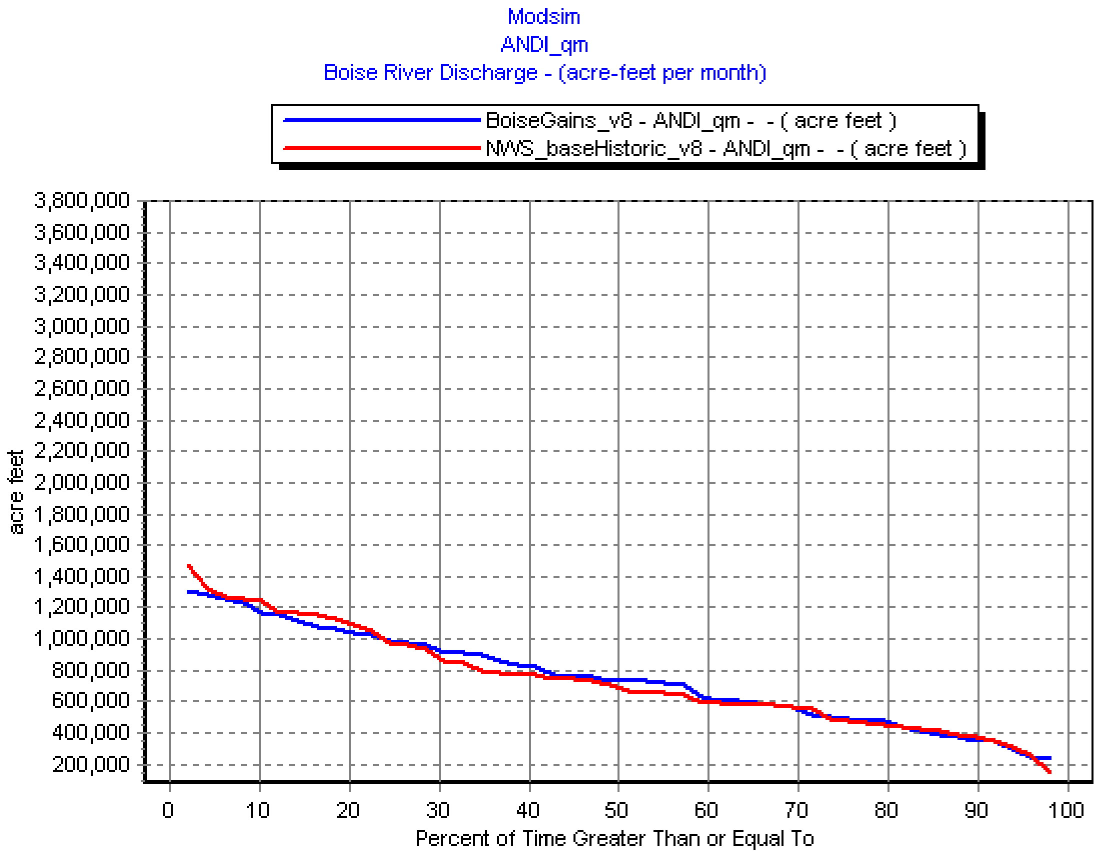


Figure A1. <u>Total annual discharge at Anderson Ranch Dam.</u> The total annual (October – September) discharge at Anderson Ranch Dam is about 41,000 acre feet lower for the NWSRFS modeled streamflows (red) than the unregulated streamflows (blue) at the 50 percent exceedance level.

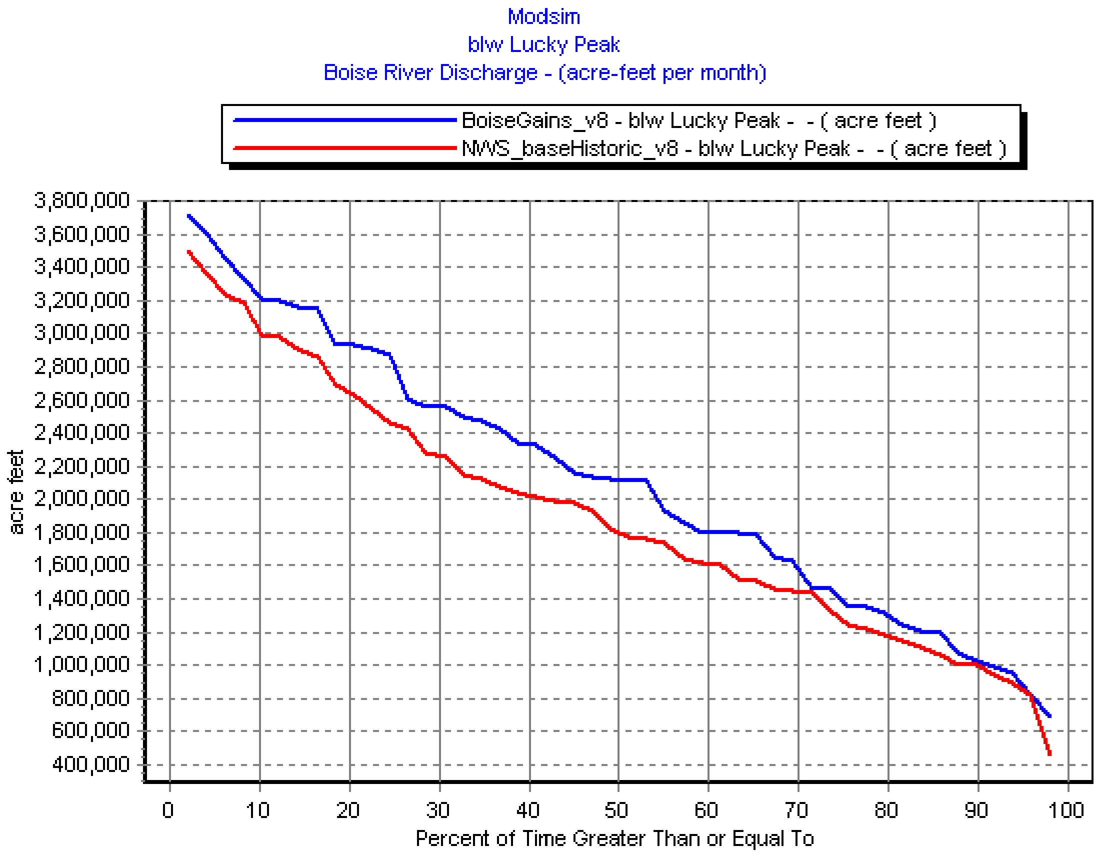


Figure A2. <u>Total annual discharge at Lucky Peak Dam.</u> The total annual (October – September) discharge at Lucky Peak Dam is about 319,000 acre feet lower for the NWSRFS modeled streamflows (red) than the unregulated streamflows (blue) at the 50 percent exceedance level.

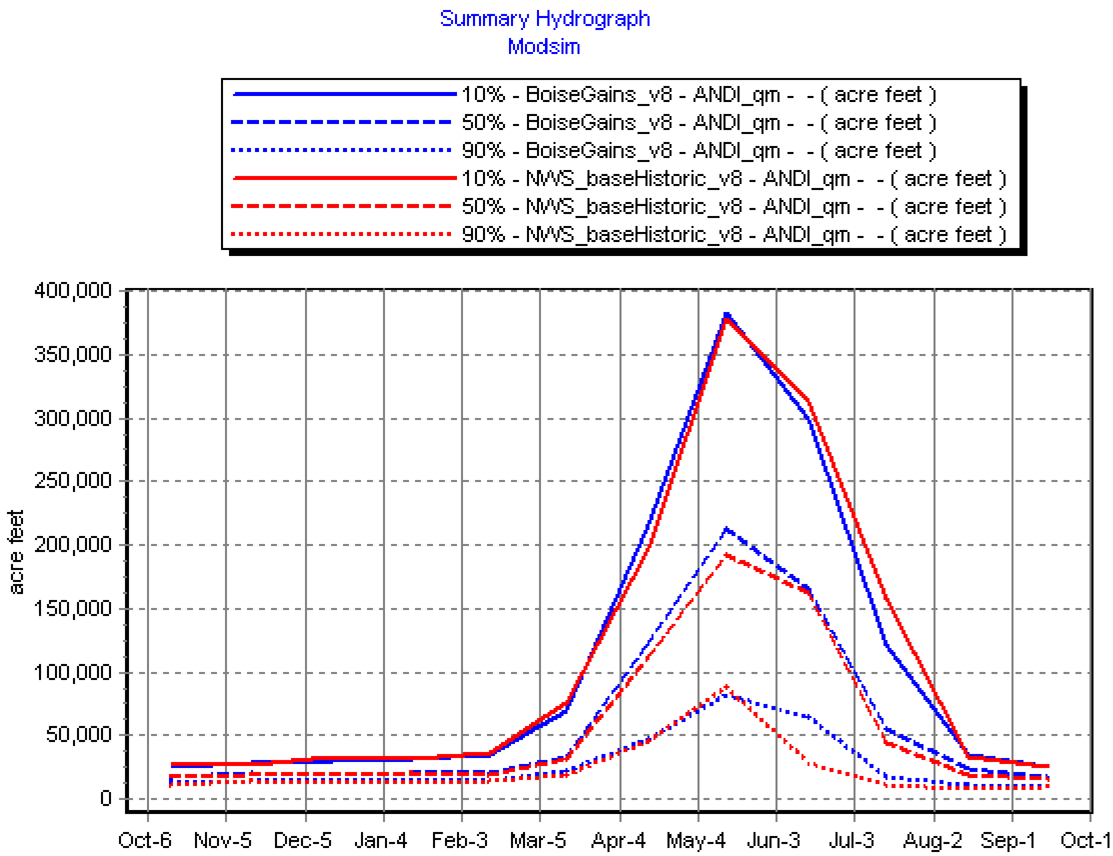


Figure A3. <u>Calibration at Anderson Ranch Dam.</u> The summary hydrograph shows NWSRFS modeled streamflows (red) and unregulated streamflows (blue) for the upper most calibration point in the system at Anderson Ranch Dam. Low flows (90 percentile) during June are about 35,100 acre feet lower for the NWSRFS modeled streamflows than for the unregulated streamflows (blue).

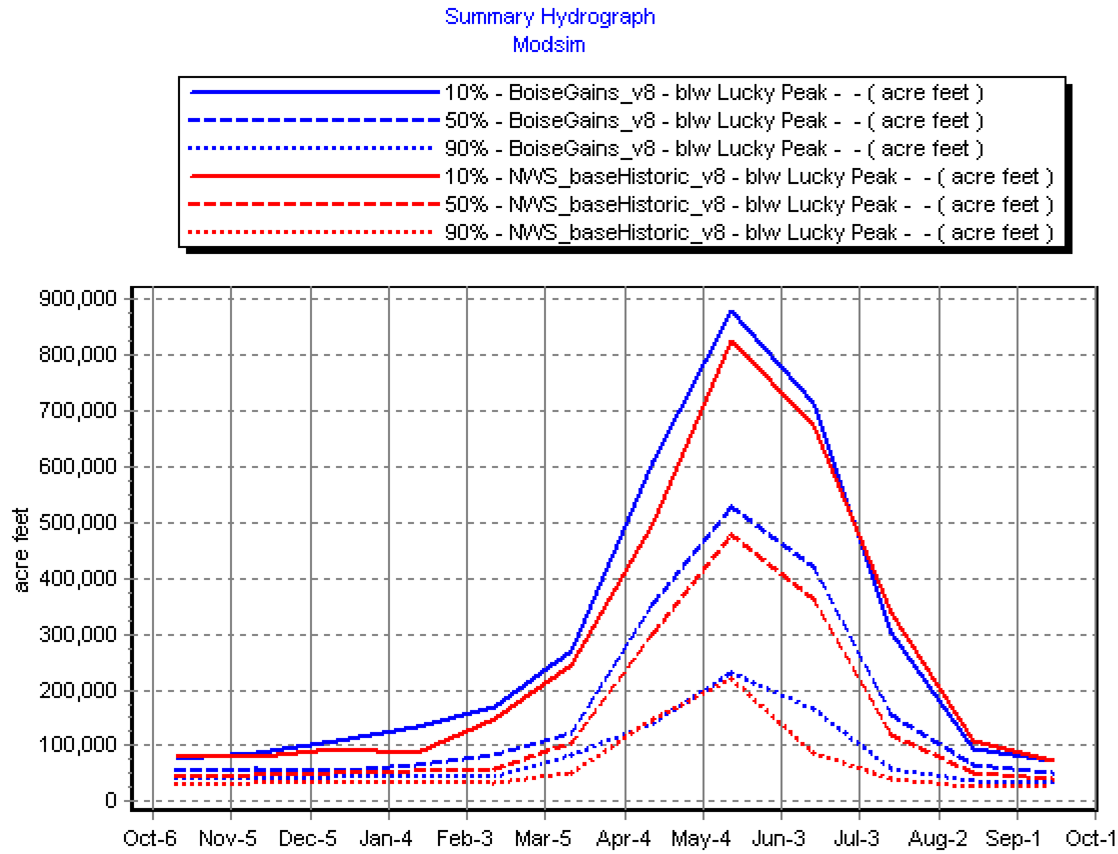


Figure A4. **<u>Calibration at Lucky Peak Dam.</u>** **The summary hydrograph shows NWSRFS modeled streamflows (red) and unregulated streamflows (blue) for the mid stream calibration point in the system at Lucky Peak Dam. Low flows (90 percentile) during June are about 78,500 acre feet lower for the NWSRFS modeled streamflows than for the unregulated streamflows (blue).**

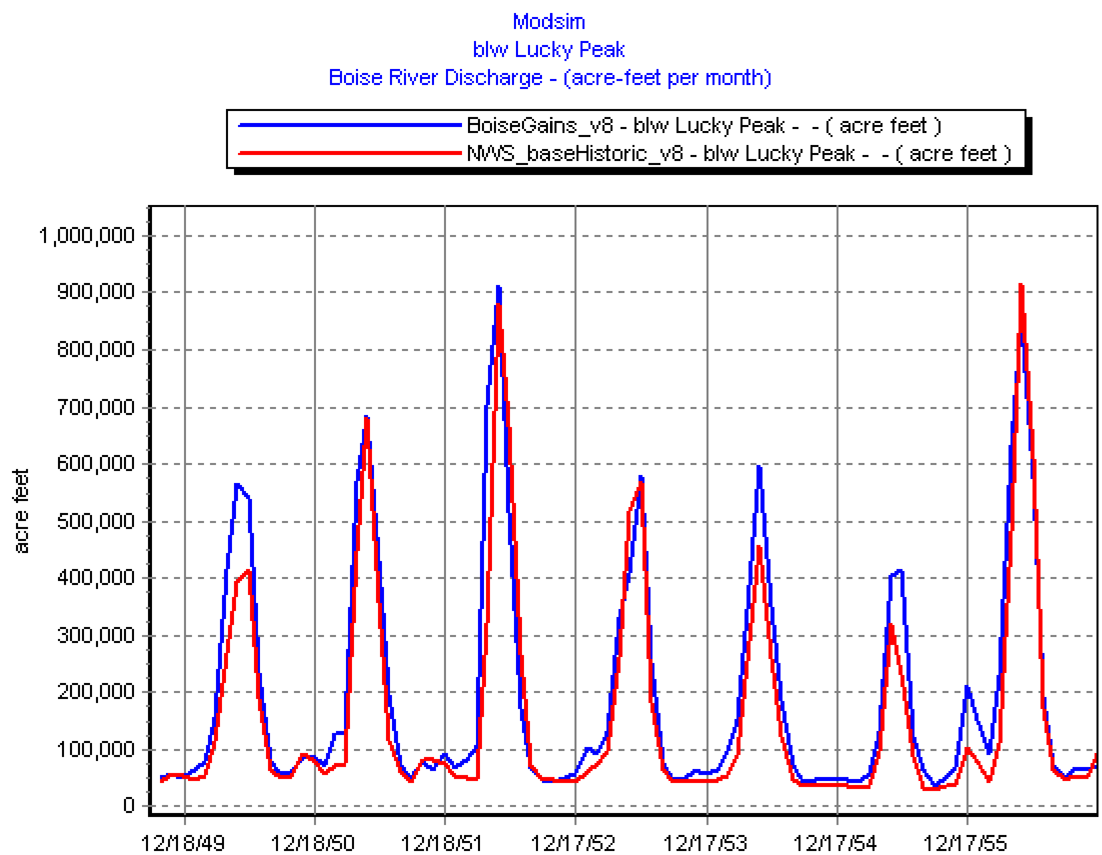


Figure A5. NWSRFS modeled streamflows (red) and unregulated streamflows (blue) for calendar years 1950 through 1956.

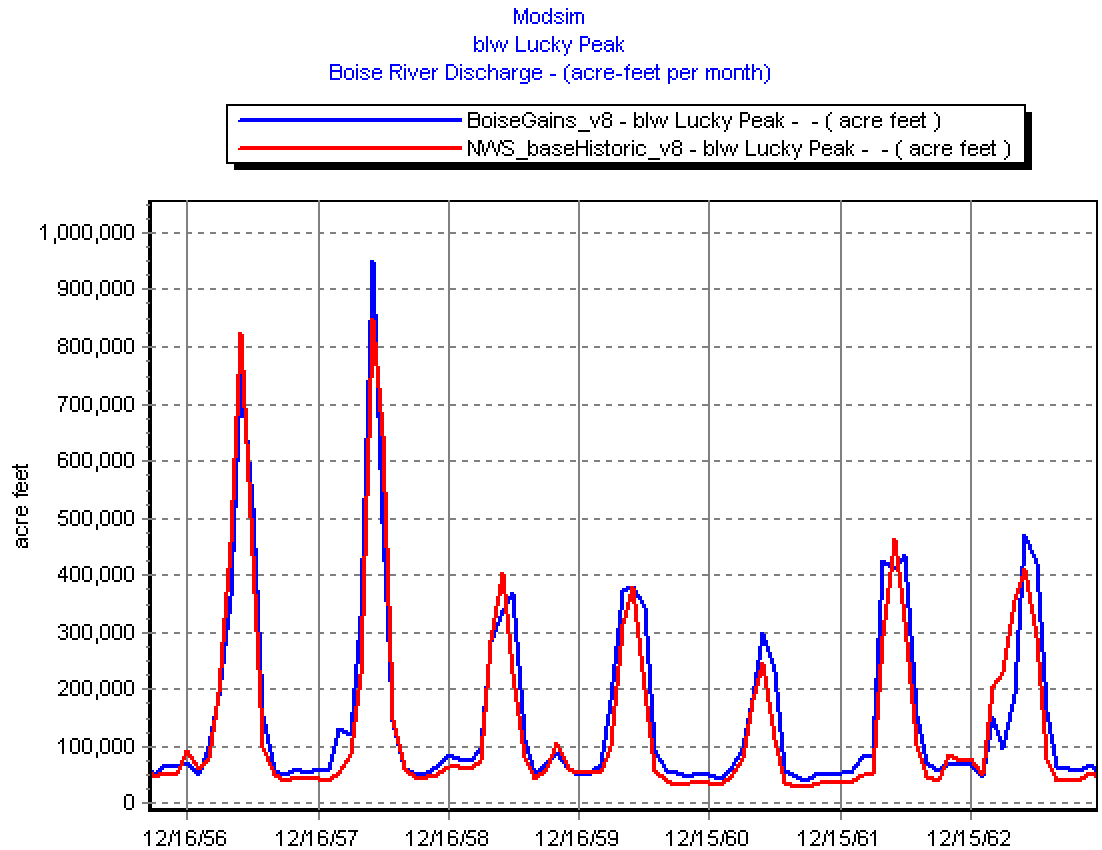


Figure A6. NWSRFS modeled streamflows (red) and unregulated streamflows (blue) for calendar years 1957 through 1963.

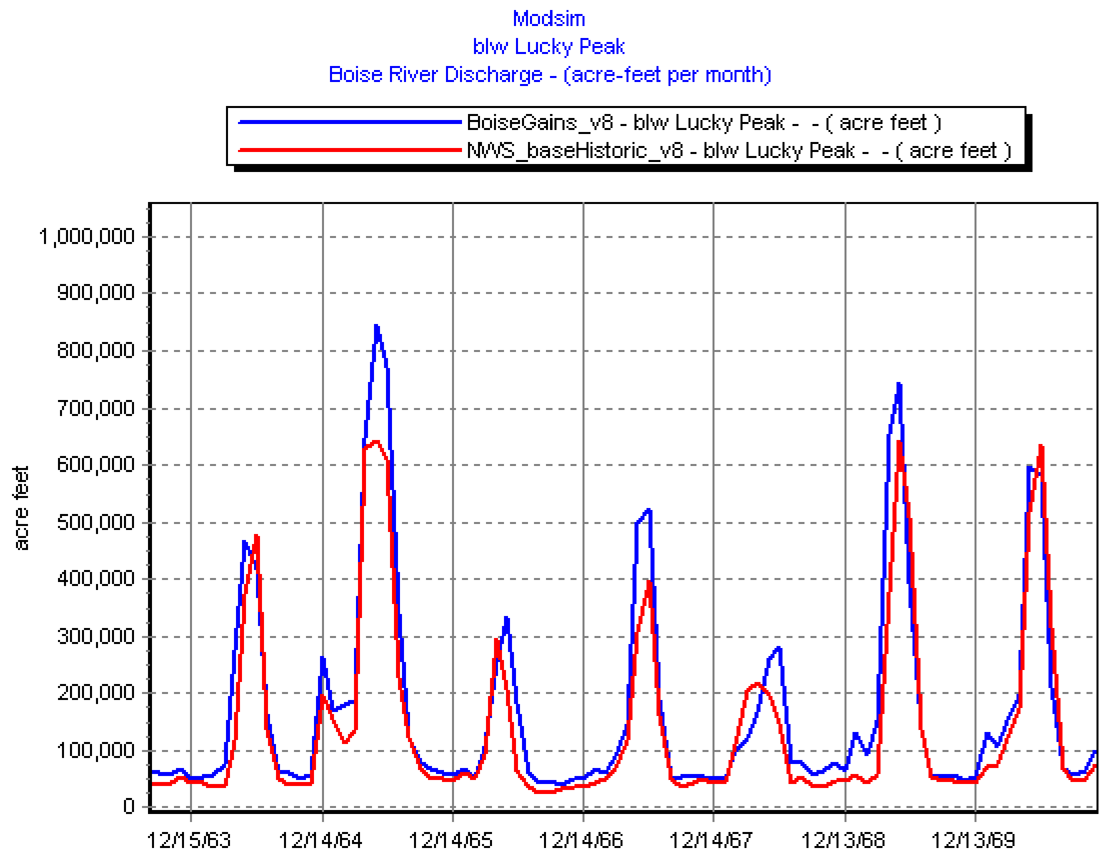


Figure A7. NWSRFS modeled streamflows (red) and unregulated streamflows (blue) for calendar years 1964 through 1970.

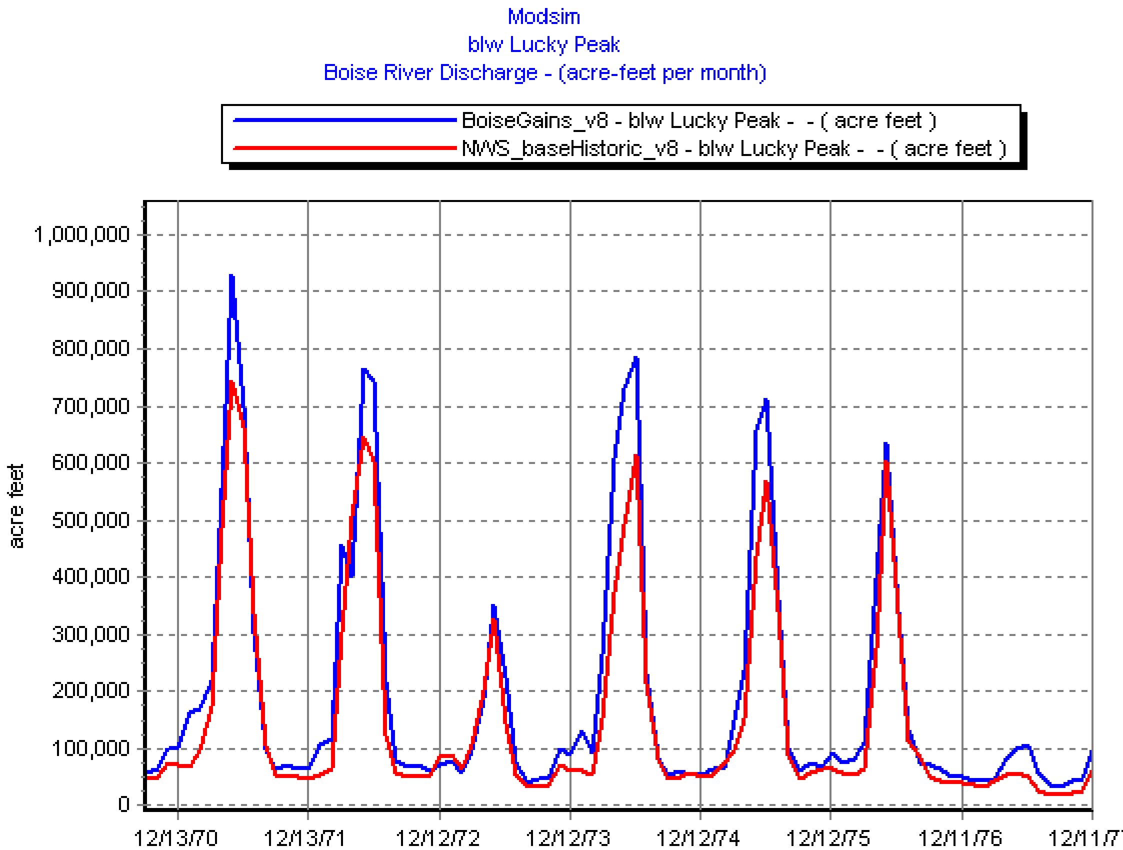


Figure A8. NWSRFS modeled streamflows (red) and unregulated streamflows (blue) for calendar years 1971 through 1977.

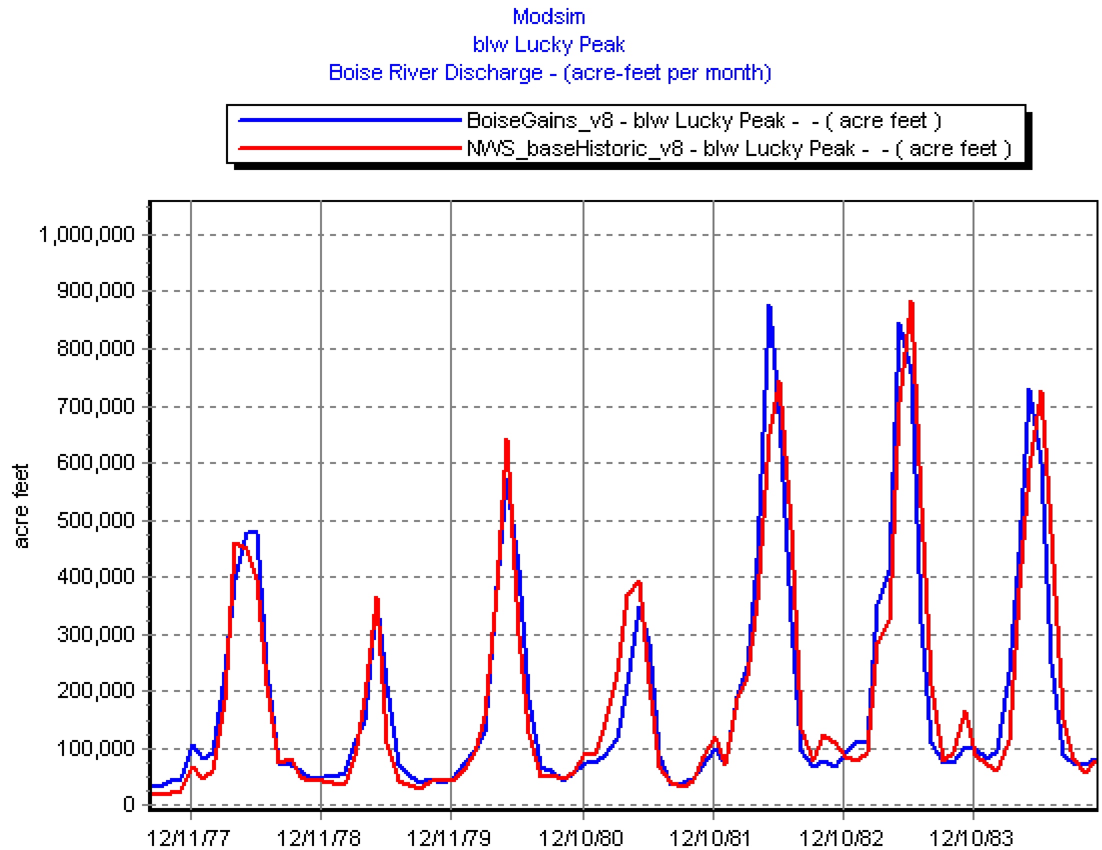


Figure A9. NWSRFS modeled streamflows (red) and unregulated streamflows (blue) for calendar years 1978 through 1984.

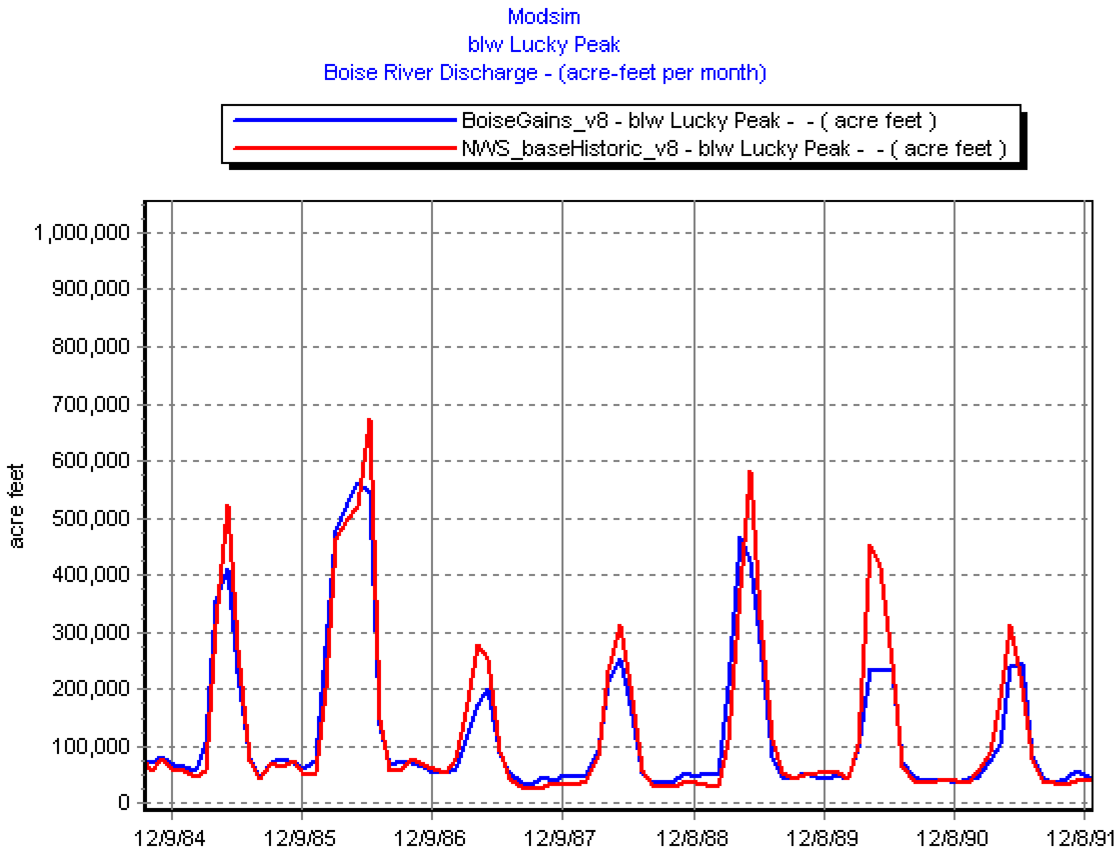


Figure A10. NWSRFS modeled streamflows (red) and unregulated streamflows (blue) for calendar years 1985 through 1991.

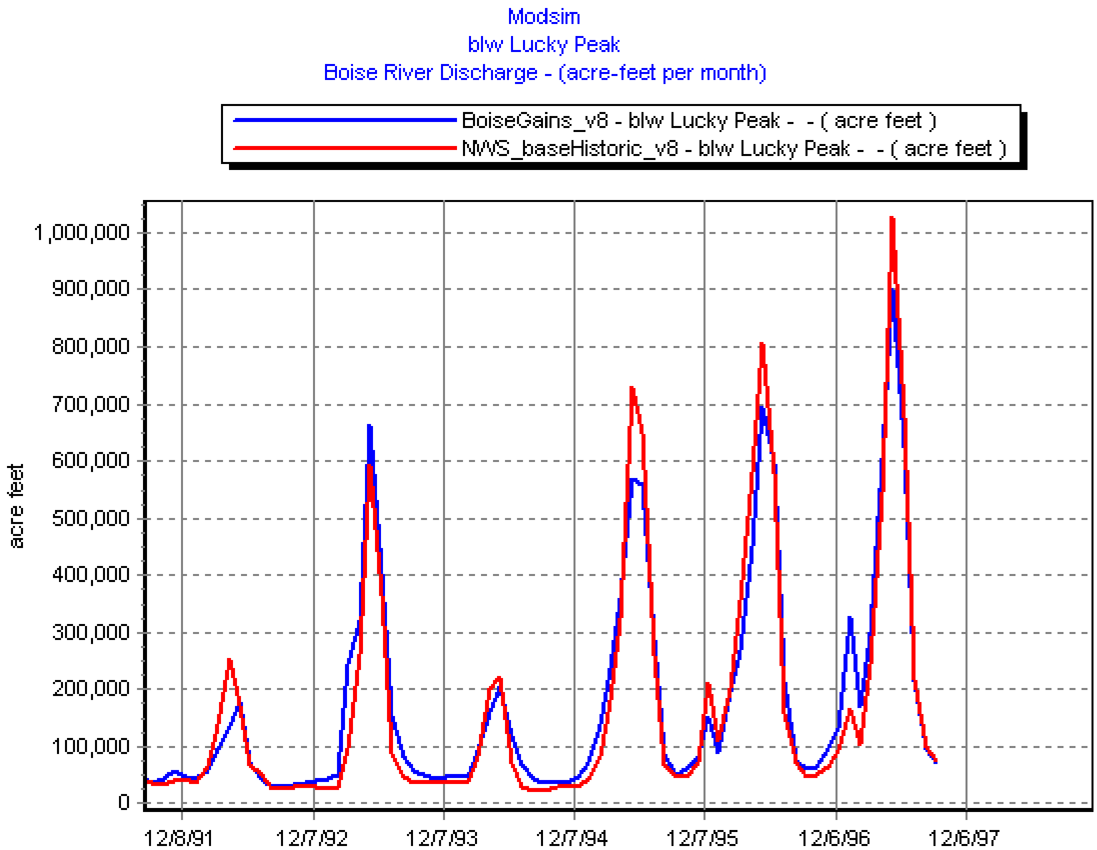
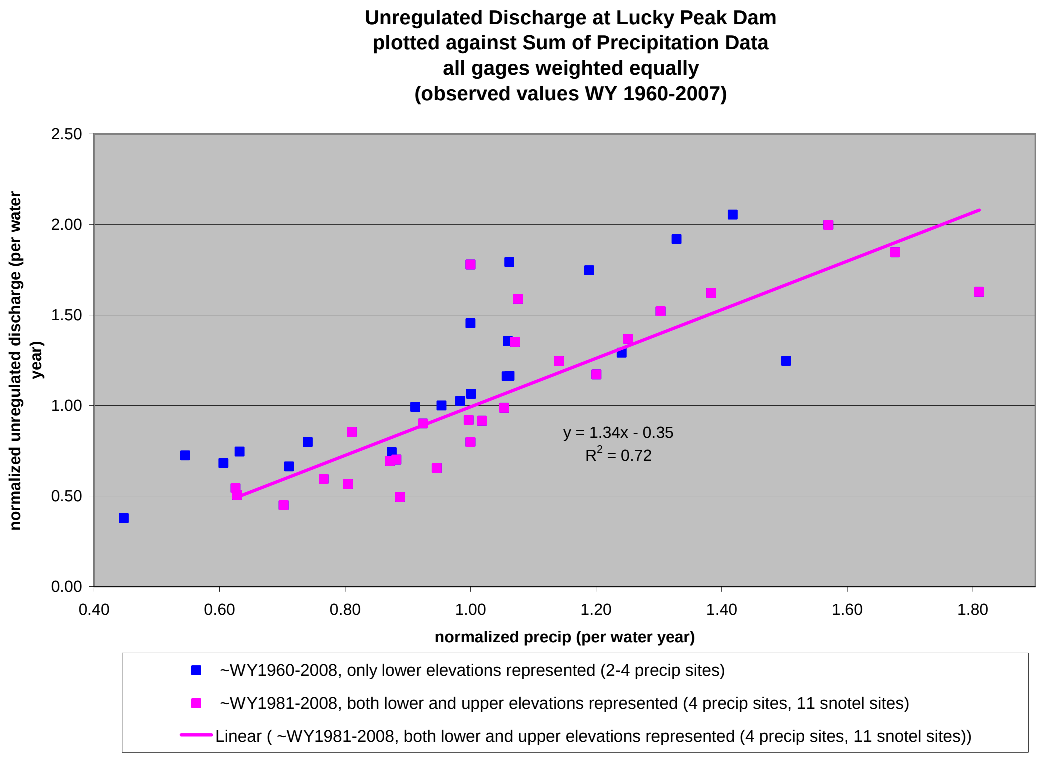


Figure A11. NWSRFS modeled streamflows (red) and unregulated streamflows (blue) for calendar years 1992 through 1997.

Appendix B. Observed Precipitation and Unregulated Discharge



B 1. The normalized annual unregulated discharge at Lucky Peak Dam plotted against normalized annual combined precipitation at Anderson Ranch Dam, Arrowrock Dam, Atlanta, Idaho City. Vienna Mine, Trinity Mountain, Moores Creek Summit, Galena Summit, Jackson Peak, Prairie, Atlanta Summit, Banner Summit Dollarhide Summit, Garfield Ranger Station, and Graham Guard Station for water years 1960 – 2008, when available. Each station was weighted equally. Normalized values were calculated by dividing the annual value by the average annual value for the period of record. A casual inspection indicates that normalized discharge increases faster than normalized precipitation (the slope is greater than 1.0).

APPENDIX C. Inflow Projection Equation Errors

The Water Control Manual provides projection equations to assist operators in determining what portion of the volume forecast will enter the system prior to April 1 and what portion will enter after April 1. Projection equations are provided for every two week period from January 1 through March 31. The following projection equation is intended to produce the January 1 through March 31 volume forecast from the January 1 through July 31 volume forecast. The forecast errors produced in applying this equation are shown in the charts below. The projection equation is:

$$Y = 68.792 + 0.129677\ X$$

where Y is the projected inflow volume (1,000 acre feet) expected during January 1 through March 31 and X is the forecasted runoff volume (1,000 acre feet) corresponding to the volume forecast period of January 1 through July 31. The standard error for the regression equation is 72,473 acre feet. The projection and standard error were developed using 1895 through 1980 data.

In the charts below, a negative value means the projection equation under estimates the inflow volumes which were projected to occur prior to April 1 and over estimates inflow volumes which were projected to occur after April 1

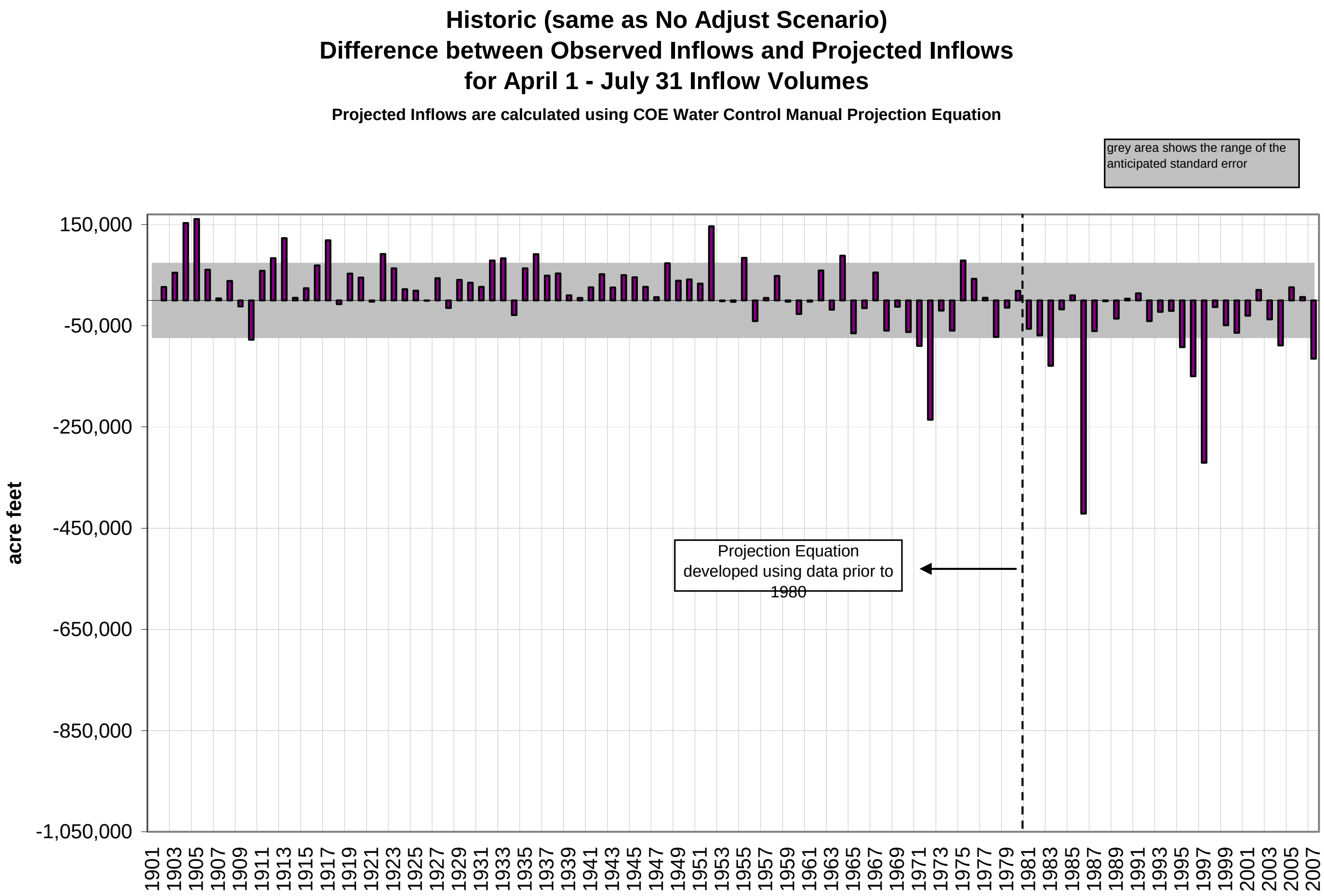


Figure C1. Historic Projected Inflow Errors. The No Adjust Scenario uses historic inflows. The values shown for each year are the volumes which were experienced during April 1 through July 31 minus the volumes for the same period as predicted using the projection equation applied on January 1. A negative value means the Projection Equation under estimates the inflow volumes which were to occur prior to April 1 and over estimates inflow volumes which were to occur after April 1. The grey area is the range of standard error anticipated when the projection equation was developed. For years 1949 through 1980 the error in the predicted volume is only infrequently outside of the standard error, so the projection equation is mostly successful. After 1980, the projection appears in error and outside of the anticipated standard deviation more frequently. Although the study period extends through 1996 only, this one particular chart extends the data through the present day to demonstrate a possible trend towards earlier runoff.

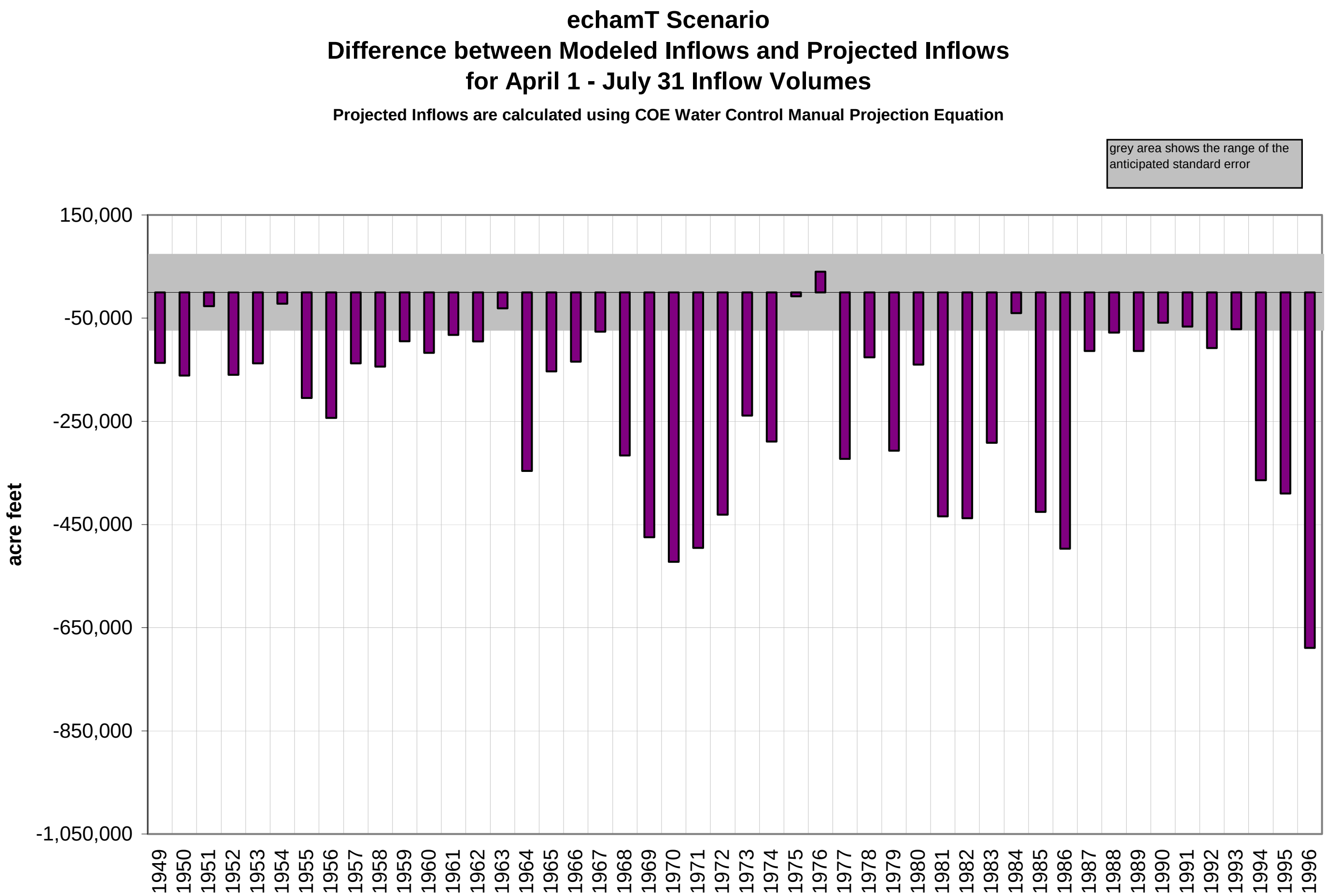


Figure C2. EchamT Scenario Projected Errors. The values shown for each year are the volumes which were experienced in the Echam T Scenario during April 1 through July 31 minus the volumes for the same period as predicted using the projection equation applied on January 1. The grey area is the range of standard error anticipated when the projection equation was developed. But it can be seen that the errors in the inflow estimates are much greater than the anticipated standard error. For the study period of 1949 through 1996, the error in the predicted volume is frequently outside of the standard error and is as large as negative 650,000 acre feet, indicating that for a given January 1 through July 31 forecast, the projection equations under estimate January 1 through March 31 inflow volumes by up to 650,000 acre feet and over estimate April 1 through July 31 inflow volumes by up to 650,000 acre feet.

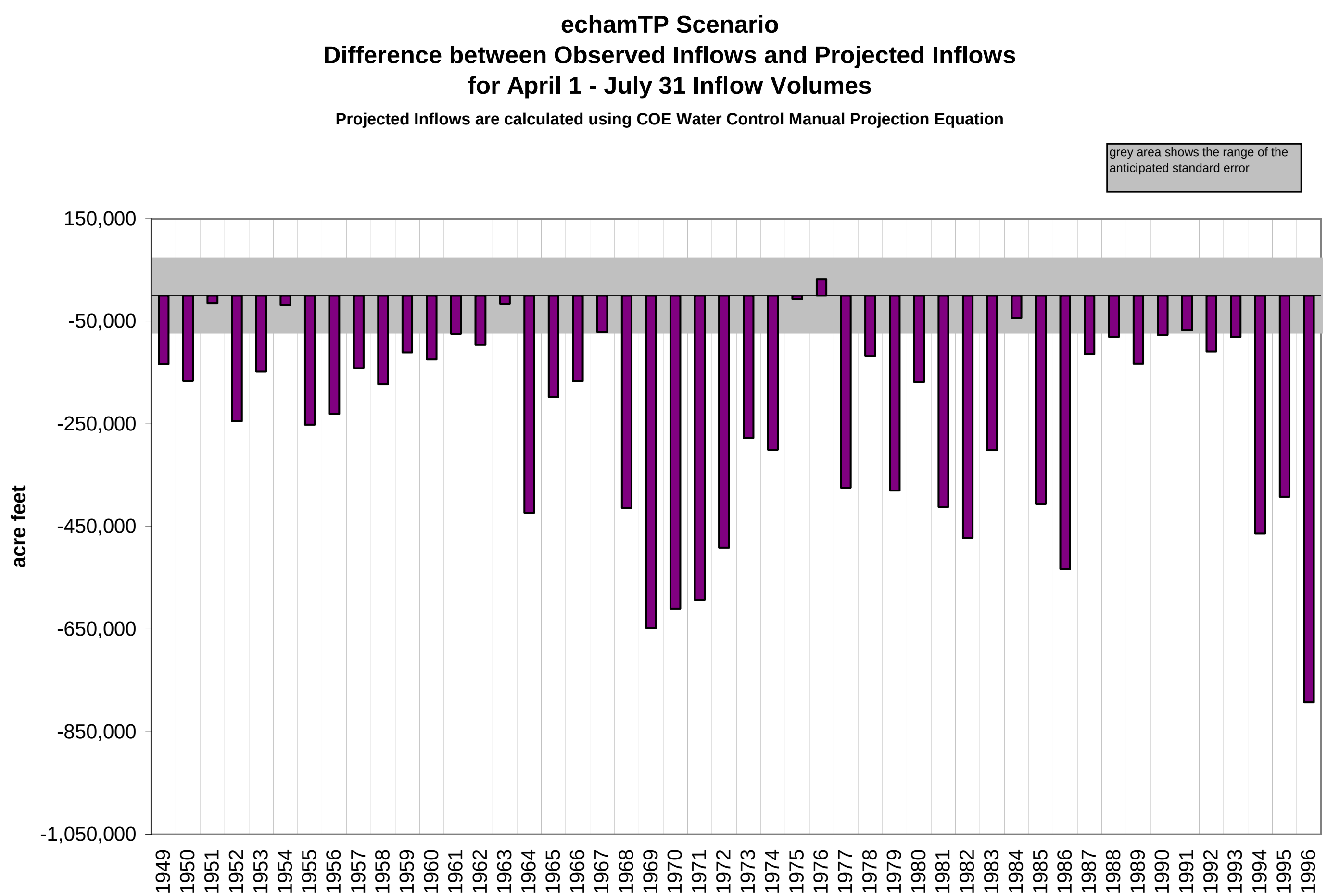


Figure C3. EchamTP Scenario Projected Errors. The values shown for each year are the volumes which were experienced in the Echam TP Scenario during April 1 through July 31 minus the volumes for the same period as predicted using the projection equation applied on January 1. The grey area is the range of standard error anticipated when the projection equation was developed. But it can be seen that the errors in the inflow estimates are much greater than the anticipated standard error. For the study period of 1949 through 1996, the error in the predicted volume is frequently outside of the standard error and is as large as negative 800,000 acre feet, indicating that for a given January 1 through July 31 forecast, the projection equations under estimate January 1 through March 31 inflow volumes by up to 800,000 acre feet and over estimate April 1 through July 31 inflow volumes by up to 800,000 acre feet.

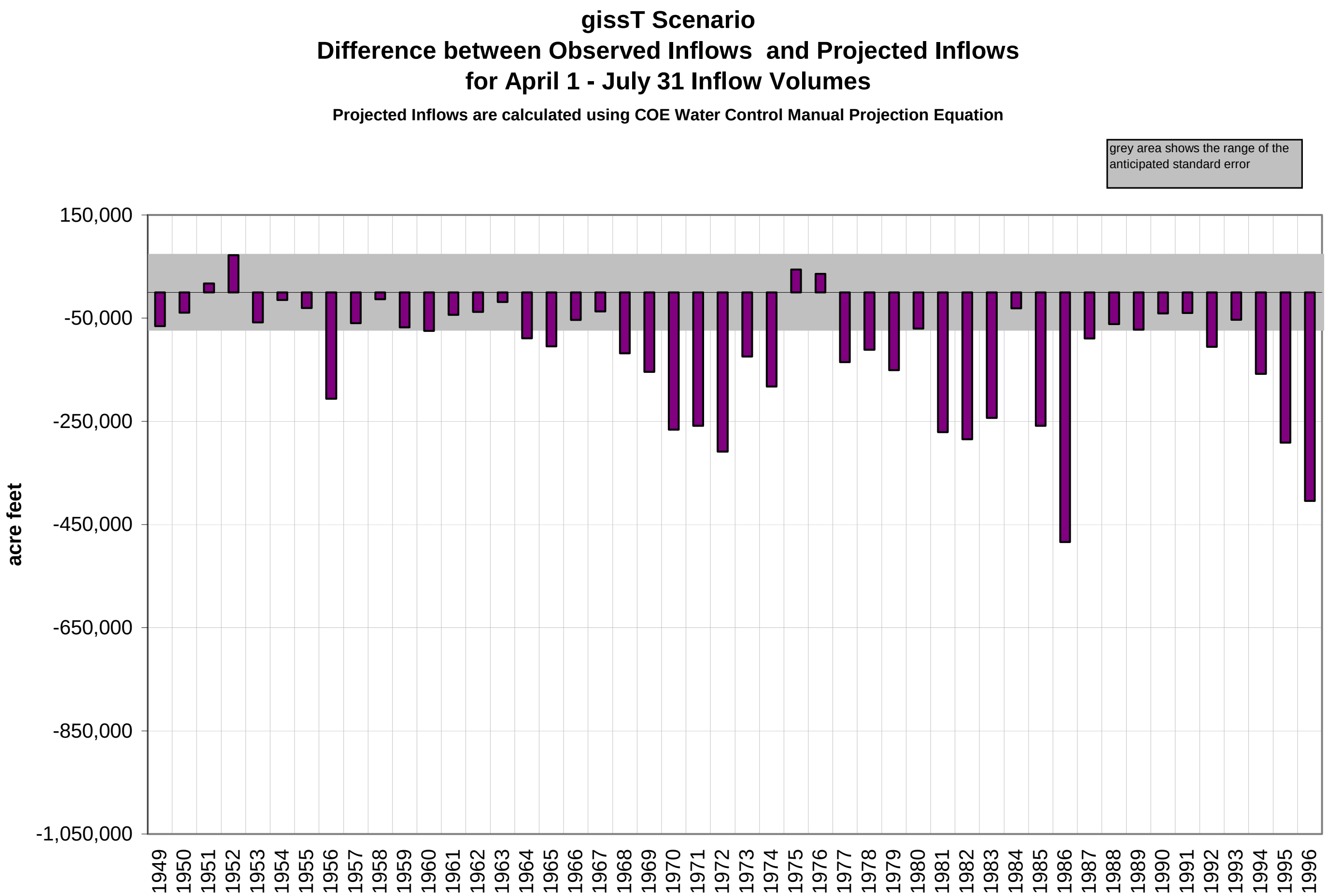


Figure C4. GISST Scenario Projected Errors. The values shown for each year are the volumes which were experienced in the GISS T Scenario during April 1 through July 31 minus the volumes for the same period as predicted using the projection equation applied on January 1. The grey area is the range of standard error anticipated when the projection equation was developed. But it can be seen that the errors in the inflow estimates are much greater than the anticipated standard error. For the study period of 1949 through 1996, the error in the predicted volume is frequently outside of the standard error and is as large as negative 475,000 acre feet, indicating that for a given January 1 through July 31 forecast, the projection equations under estimate January 1 through March 31 inflow volumes by up to 475,000 acre feet and over estimate April 1 through July 31 inflow volumes by up to 475,000 acre feet.

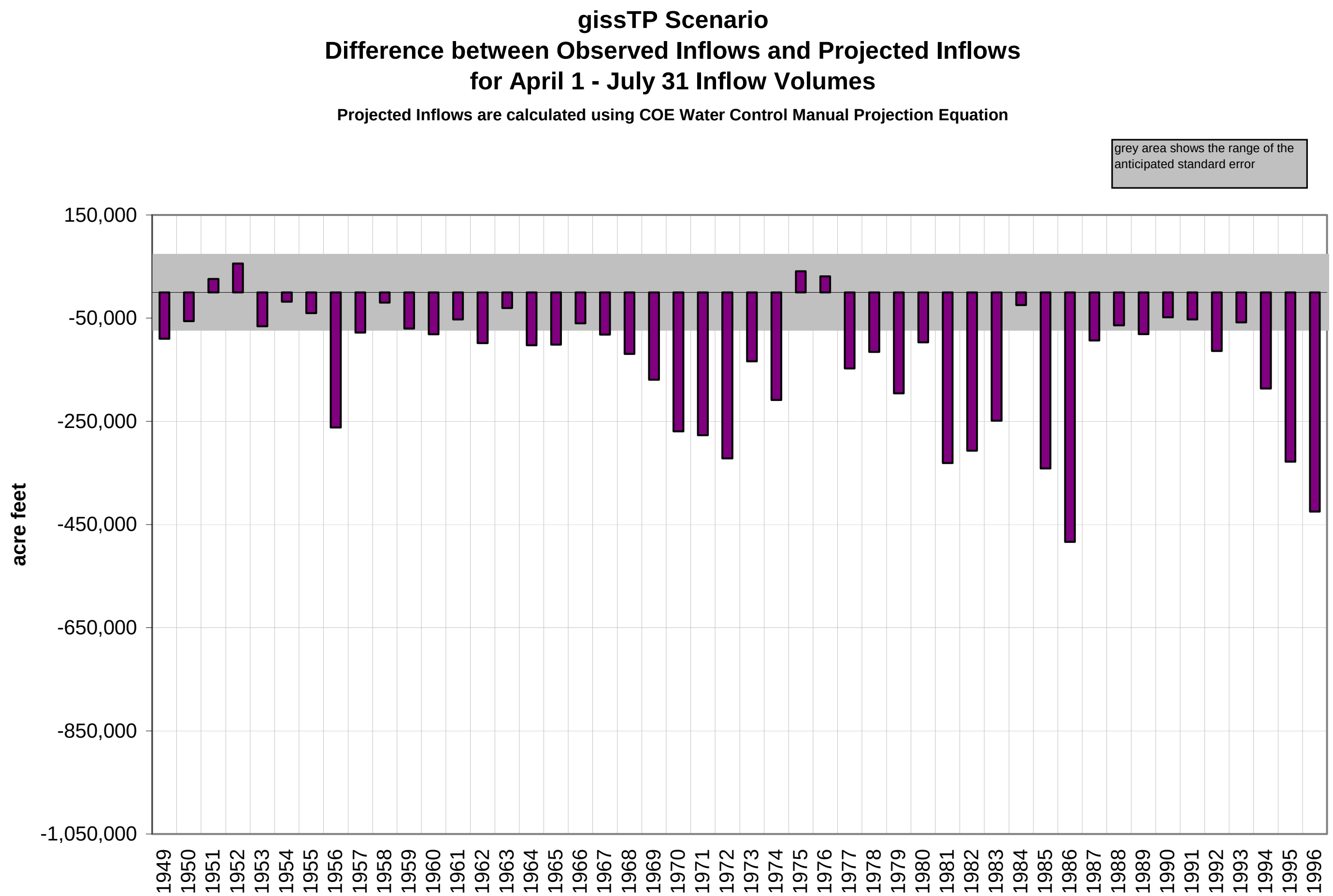


Figure C5. GISS TP Scenario Projected Errors. The values shown for each year are the volumes which were experienced in the GISS TP Scenario during April 1 through July 31 minus the volumes for the same period as predicted using the projection equation applied on January 1. The grey area is the range of standard error anticipated when the projection equation was developed. But it can be seen that the errors in the inflow estimates are much greater than the anticipated standard error. For the study period of 1949 through 1996, the error in the predicted volume is frequently outside of the standard error and is as large as negative 475,000 acre feet, indicating that for a given January 1 through July 31 forecast, the projection equations under estimate January 1 through March 31 inflow volumes by up to 475,000 acre feet and over estimate April 1 through July 31 inflow volumes by up to 475,000 acre feet.

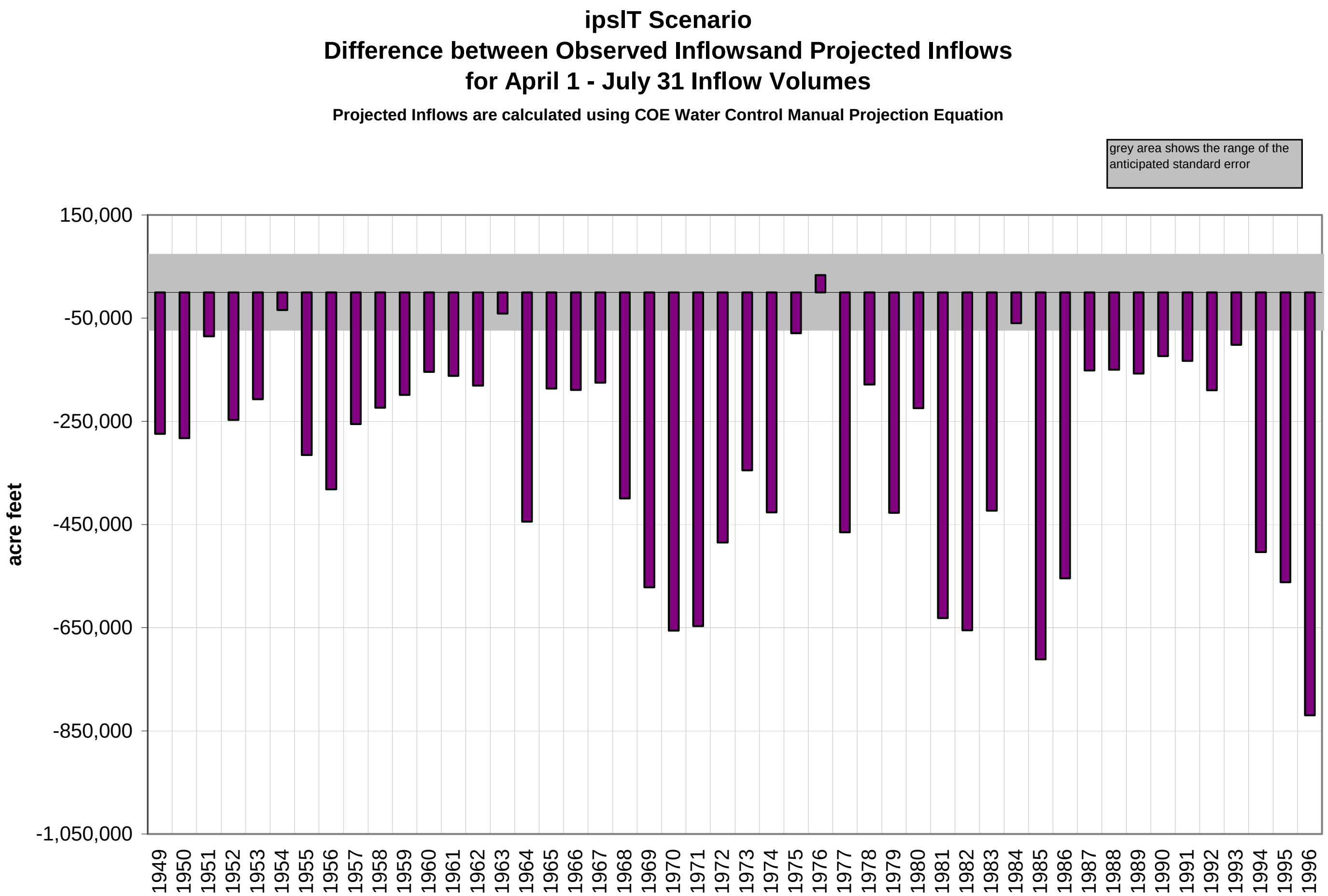


Figure C6. IPSL T Scenario Projected Errors. The values shown for each year are the volumes which were experienced in the IPSL T Scenario during April 1 through July 31 minus the volumes for the same period as predicted using the projection equation applied on January 1. The grey area is the range of standard error anticipated when the projection equation was developed. But it can be seen that the errors in the inflow estimates are much greater than the anticipated standard error. For the study period of 1949 through 1996, the error in the predicted volume is frequently outside of the standard error and is as large as negative 850,000 acre feet, indicating that for a given January 1 through July 31 forecast, the projection equations under estimate January 1 through March 31 inflow volumes by up to 850,000 acre feet and over estimate April 1 through July 31 inflow volumes by up to 850,000 acre feet.

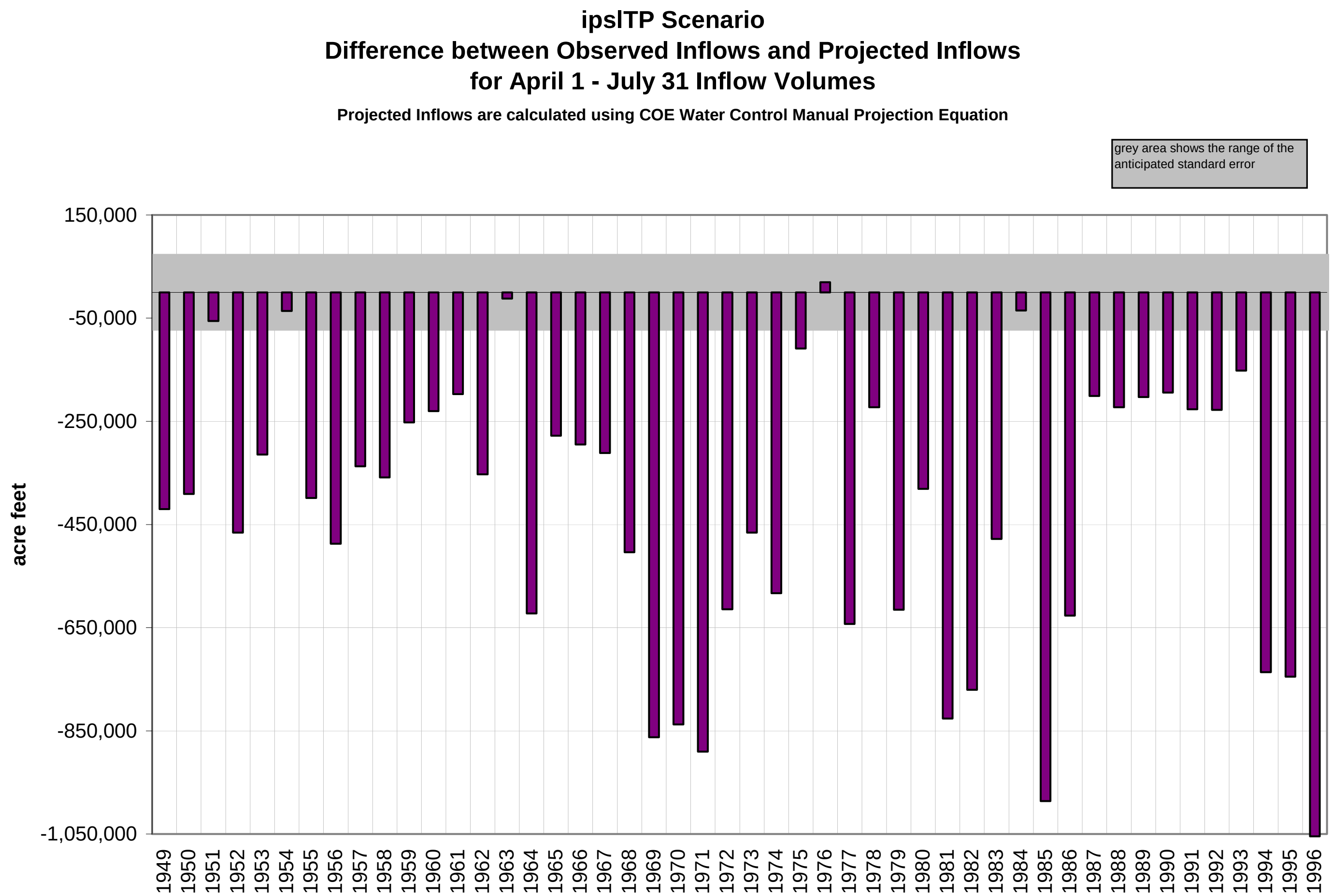


Figure C7. IPSL TP Scenario Projected Errors. The values shown for each year are the volumes which were experienced in the IPSL TP Scenario during April 1 through July 31 minus the volumes for the same period as predicted using the projection equation applied on January 1. The grey area is the range of standard error anticipated when the projection equation was developed. But it can be seen that the errors in the inflow estimates are much greater than the anticipated standard error. For the study period of 1949 through 1996, the error in the predicted volume is frequently outside of the standard error and is as large as negative 1,000,000 acre feet, indicating that for a given January 1 through July 31 forecast, the projection equations under estimate January 1 through March 31 inflow volumes by up to 1,000,000 acre feet and over estimate April 1 through July 31 inflow volumes by up to 1,000,000 acre feet.

Appendix D. Selected Flood Risk Study Results

The following graphs show selected Flood Risk Study Results for water years 1982 and 1996. The solid red line is discharge at the Boise River at Glenwood Bridge (BIGI). Discharge less than 7,000 cfs at Glenwood Bridge is considered successful flood operation. The solid blue line is total system inflow above Lucky Peak Dam, including gains to Anderson Ranch and Arrowrock Reservoirs. The black dashed line is the total system storage (Anderson Ranch, Arrowrock and Lucky Peak storages combined). Look for a drawdown in system storage to meet target space requirements on April 1, a change in discharge at Glenwood Bridge on January 1 in response to receiving the first volume forecast of the season, and a change in discharge after April 1 in response to filling.

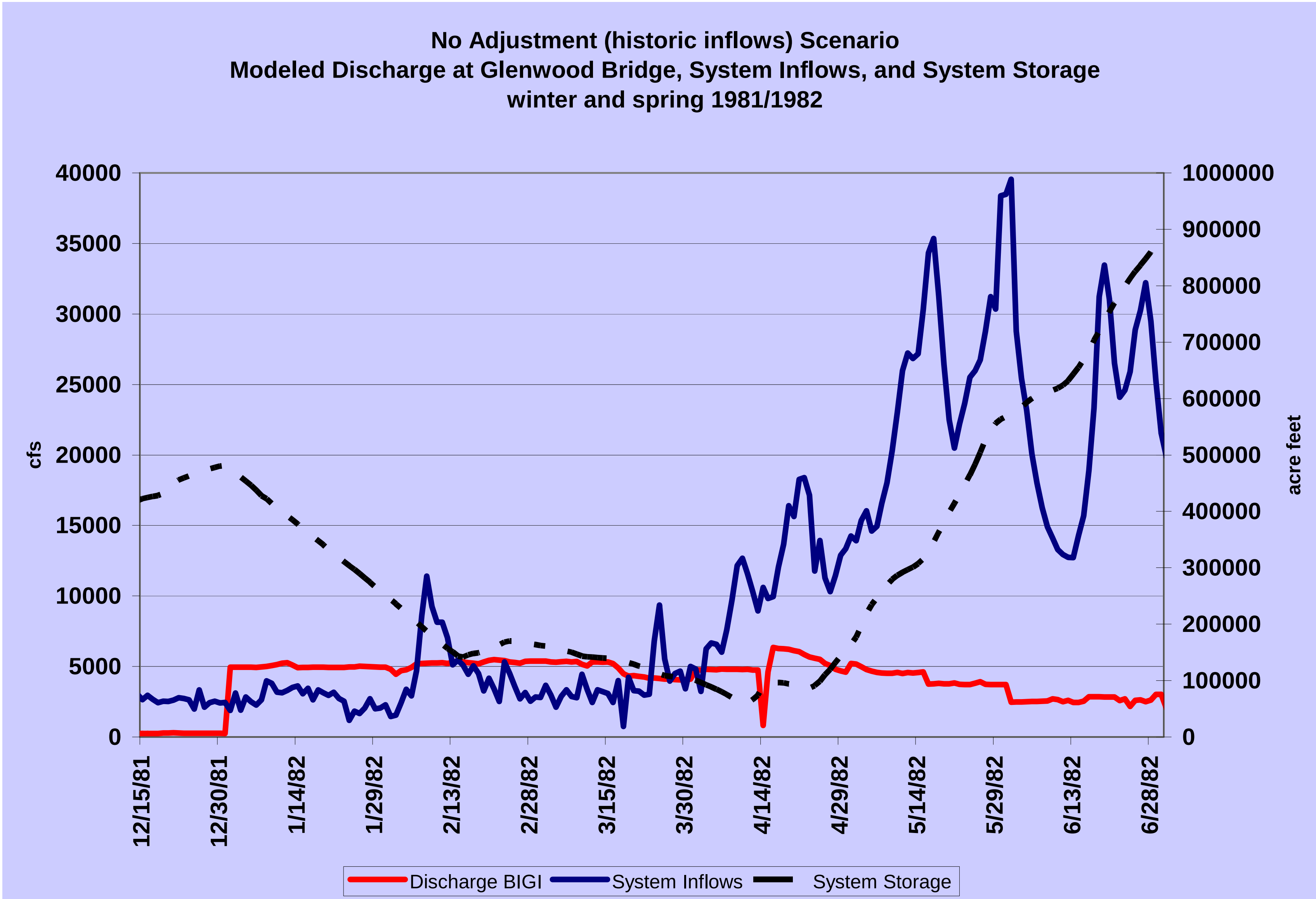
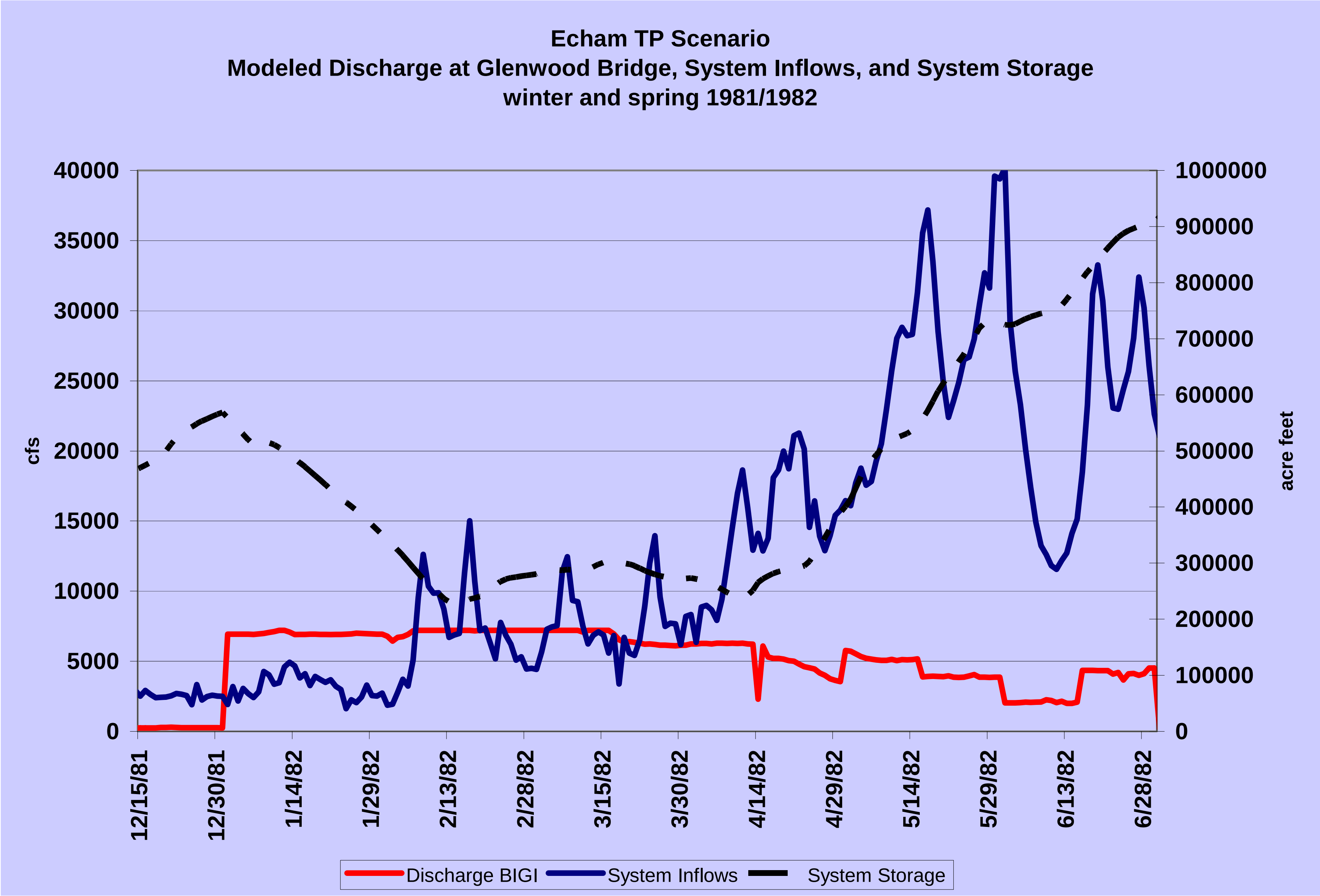

No Adjustment (historic inflows) Scenario
Modeled Discharge at Glenwood Bridge, System Inflows, and System Storage
winter and spring 1981/1982
cfs
acre feet
40000
35000
30000
25000
20000
15000
10000
5000
0
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
12/15/81
12/30/81
1/14/82
1/29/82
2/13/82
2/28/82
3/15/82
3/30/82
4/14/82
4/29/82
5/14/82
5/29/82
6/13/82
6/28/82
Discharge BIGI
System Inflows
System Storage

Figure D 1



Echam TP Scenario
Modeled Discharge at Glenwood Bridge, System Inflows, and System Storage
winter and spring 1981/1982
cfs
acre feet
40000
35000
30000
25000
20000
15000
10000
5000
0
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
12/15/81
12/30/81
1/14/82
1/29/82
2/13/82
2/28/82
3/15/82
3/30/82
4/14/82
4/29/82
5/14/82
5/29/82
6/13/82
6/28/82
Discharge BIGI
System Inflows
System Storage

Figure D 2

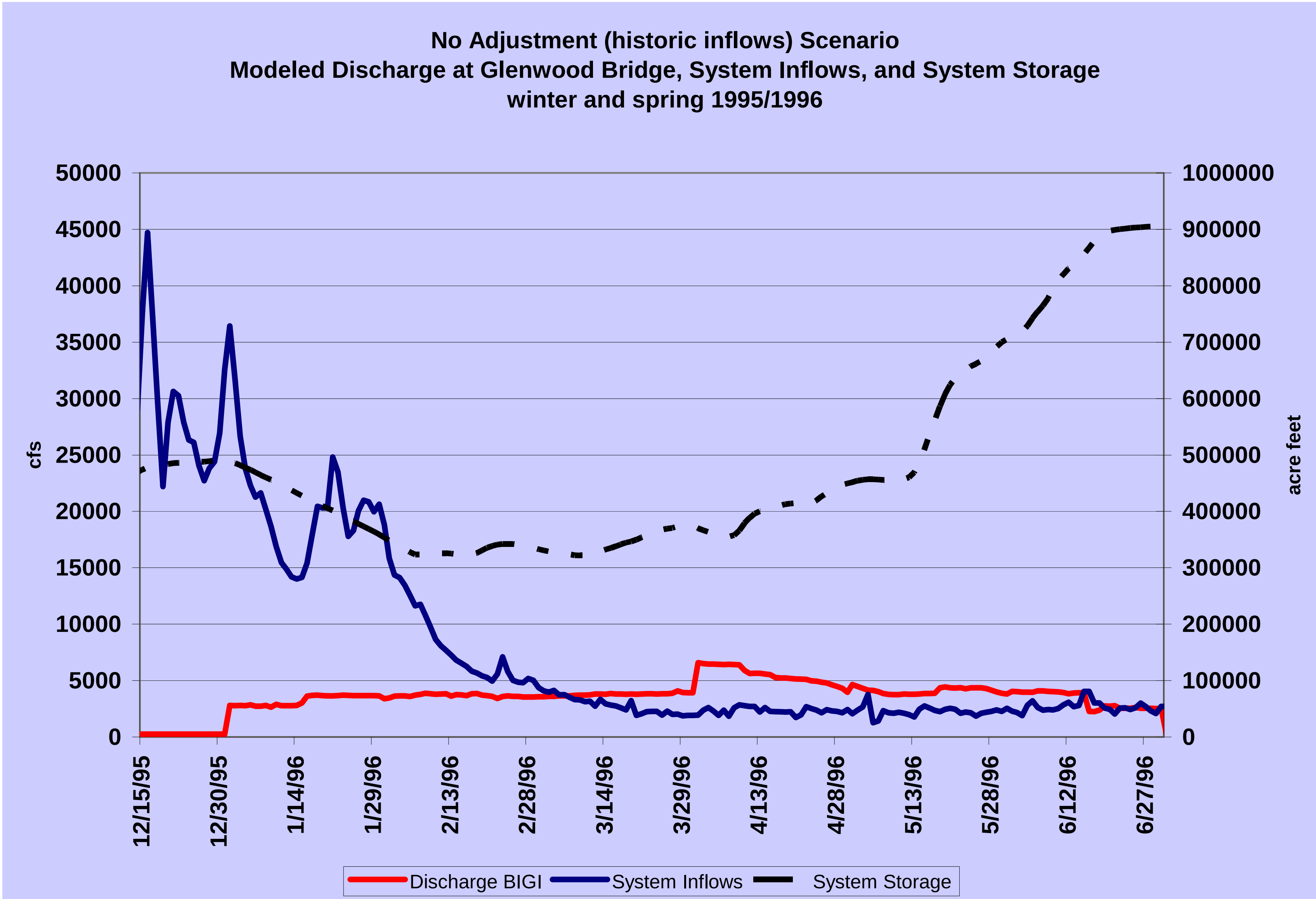

No Adjustment (historic inflows) Scenario
Modeled Discharge at Glenwood Bridge, System Inflows, and System Storage
winter and spring 1995/1996
cfs
acre feet
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
12/15/95
12/30/95
1/14/96
1/29/96
2/13/96
2/28/96
3/14/96
3/29/96
4/13/96
4/28/96
5/13/96
5/28/96
6/12/96
6/27/96
Discharge BIGI
System Inflows
System Storage

Figure D 3

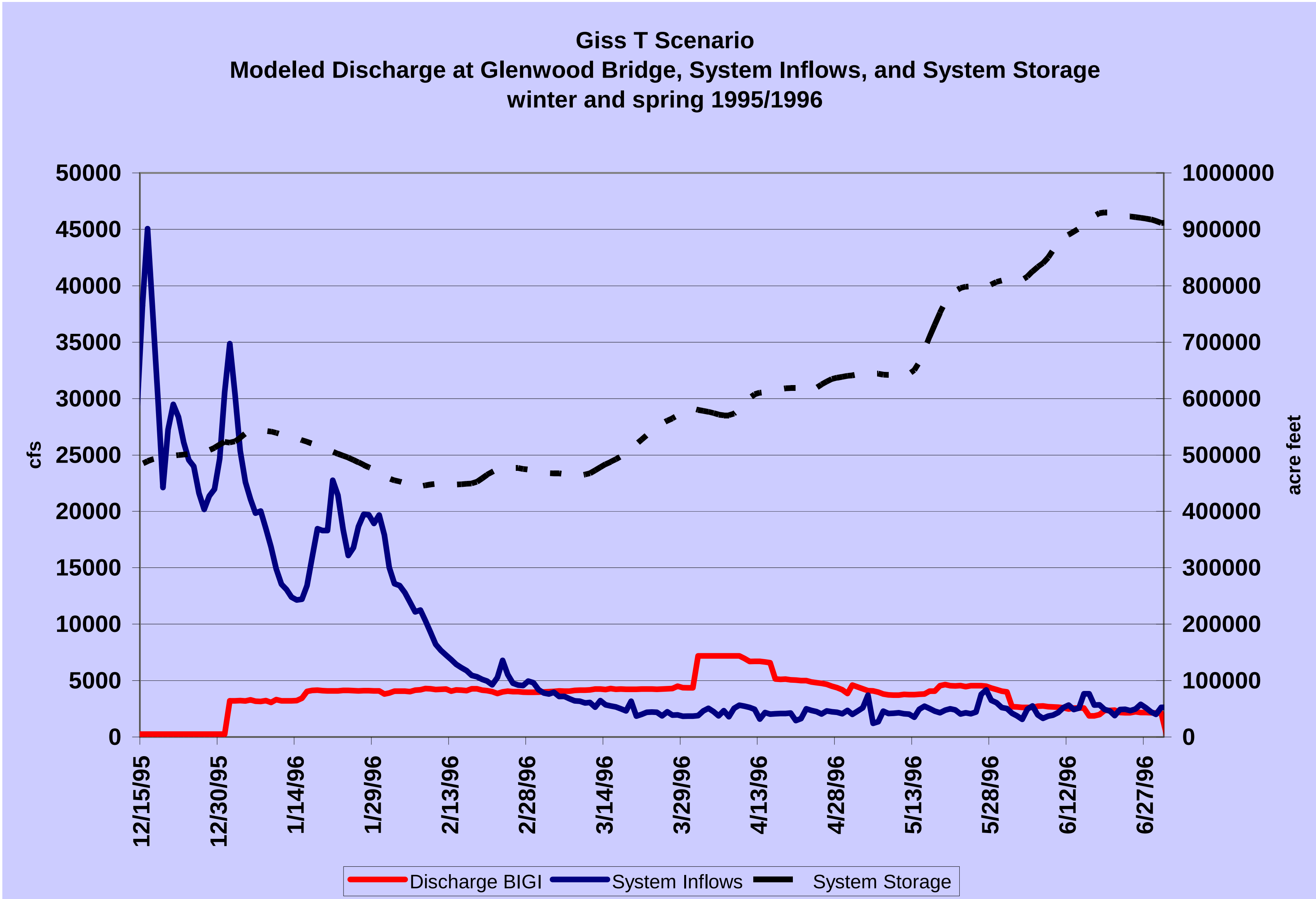

Giss T Scenario
Modeled Discharge at Glenwood Bridge, System Inflows, and System Storage
winter and spring 1995/1996
cfs
acre feet
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
12/15/95
12/30/95
1/14/96
1/29/96
2/13/96
2/28/96
3/14/96
3/29/96
4/13/96
4/28/96
5/13/96
5/28/96
6/12/96
6/27/96
Discharge BIGI
System Inflows
System Storage

Figure D 4

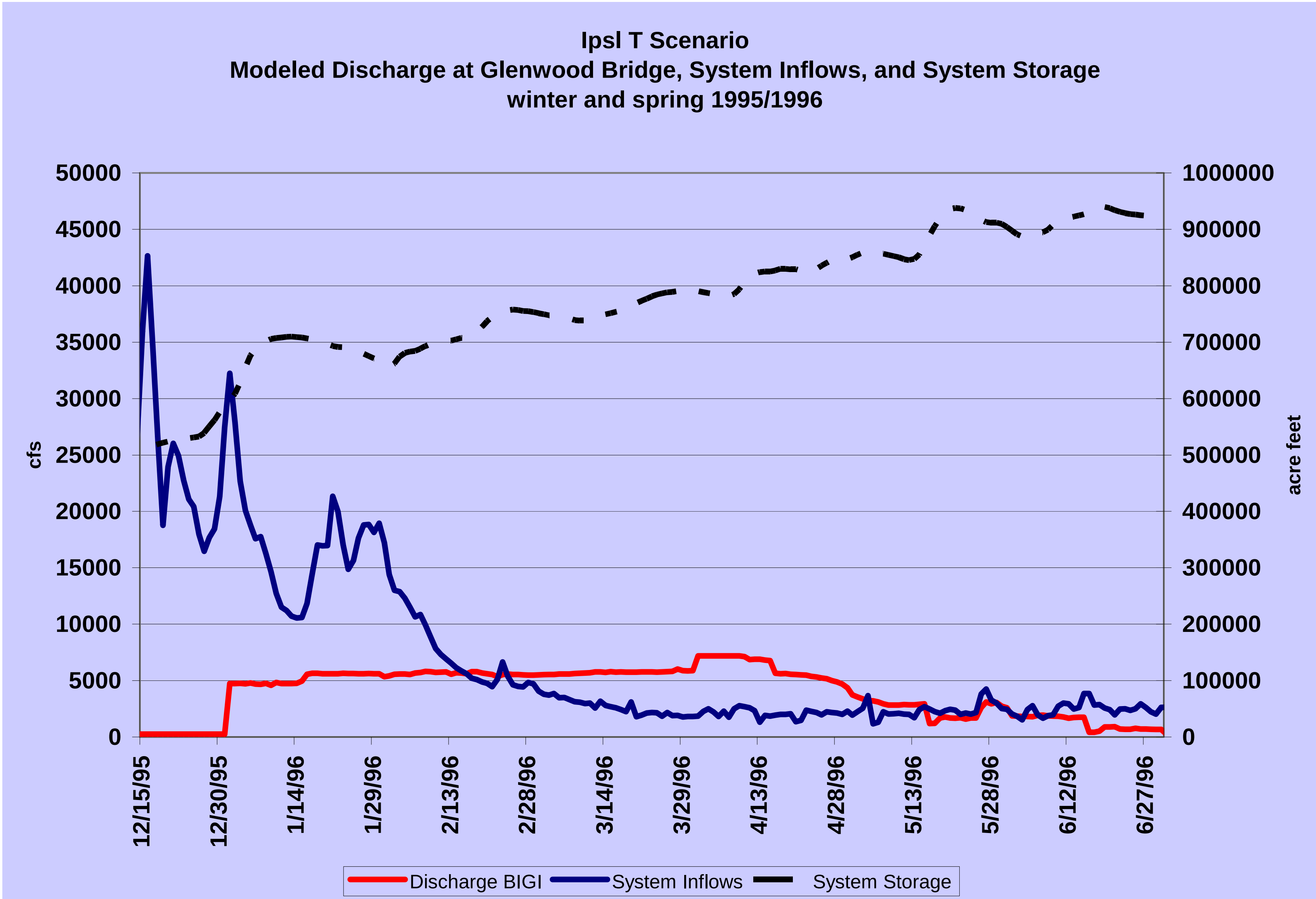

Ipsl T Scenario
Modeled Discharge at Glenwood Bridge, System Inflows, and System Storage
winter and spring 1995/1996
cfs
acre feet
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
12/15/95
12/30/95
1/14/96
1/29/96
2/13/96
2/28/96
3/14/96
3/29/96
4/13/96
4/28/96
5/13/96
5/28/96
6/12/96
6/27/96
Discharge BIGI
System Inflows
System Storage

Figure D 5

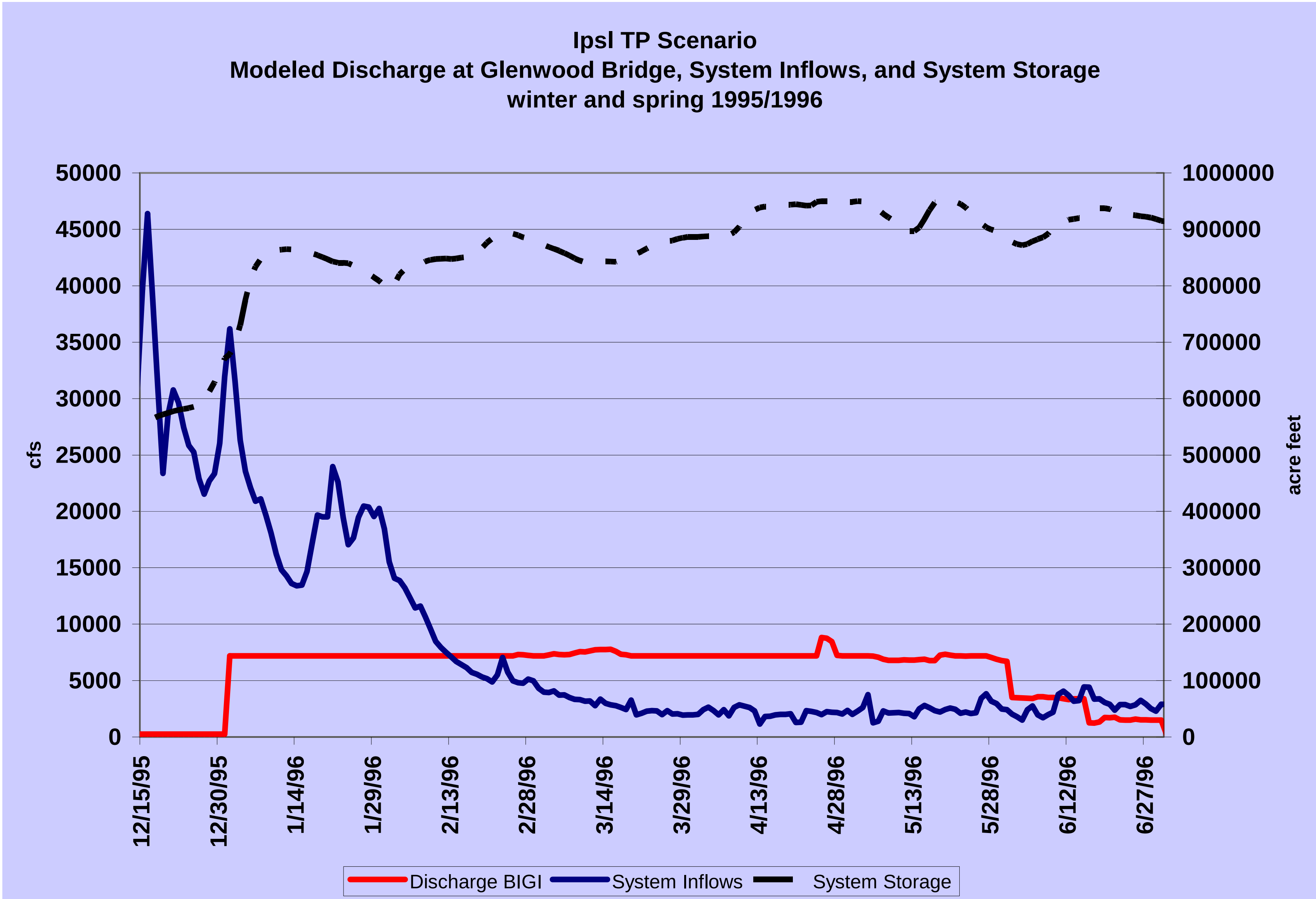

Ipsl TP Scenario
Modeled Discharge at Glenwood Bridge, System Inflows, and System Storage
winter and spring 1995/1996
cfs
acre feet
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
12/15/95
12/30/95
1/14/96
1/29/96
2/13/96
2/28/96
3/14/96
3/29/96
4/13/96
4/28/96
5/13/96
5/28/96
6/12/96
6/27/96
Discharge BIGI
System Inflows
System Storage

Figure D 6