Impacts on Bear Lake Storage under Alternative High-Runoff Management Operations

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DISCLAIMER

The model and results presented here are not PacifiCorp's operating policy for Bear Lake or the Bear River System but are a simplified interpretation of operations made by engineers and hydrologists from Idaho and Utah based on explanations from PacifiCorp hydrologists and study of the relevant legal documents and institutional guidelines. Alternative operations evaluated herein do not consider lake elevations beyond the physical maximum elevation of 5,923.65 feet. Overall, the model used for this analysis is a simplification of reality which relies on available data and professional judgment explained in *Joint Bear River Planning Model Development Report – Phase 1*. In this study, alternative Bear Lake operations are compared to results from an established baseline rather than to historical observations, though the Baseline relies on historic hydrologic data. For a comparison between the Baseline and historic data, see *Joint Bear River Planning Model Development Report – Phase 1*. Readers and policymakers should remember that the model is a tool, appropriate use of which requires acknowledgment of these simplifications and inaccuracies.

EXECUTIVE SUMMARY

The purpose of the *Impacts on Bear Lake Storage under Alternative High-Runoff Management Operations* study is to identify how much additional water could have been stored in Bear Lake between 1980 and 2018 if changes were made to the criteria by which PacifiCorp operates Bear Lake to reduce the risk of flooding on Bear Lake and on the Bear River below Bear Lake. Besides storage in Bear Lake, effects of altering operating policy are evaluated at other locations in the Lower Bear River system, including the Causeway, Gentile Valley, downstream of Oneida reservoir, downstream of Cutler reservoir, and inflow to Great Salt Lake. This executive summary provides a brief description of the study background, scenarios analyzed, key findings, model limitations, and recommendations for further study and model development.

Background

The Joint Bear River Planning Model, a new planning model for Bear Lake and the Lower Bear River, was developed in 2019 by staff from the Idaho Department of Water Resources, PacifiCorp, and Utah Division of Water Resources to simulate historic operations of the Lower Bear River system. The model starts at Stewart Dam and continues down to Great Salt Lake. The model includes interactions between Mud Lake and Bear Lake as well as tributary flows, agricultural diversions, and hydroelectric facilities downstream of Stewart Dam. The model is driven by observed hydrology from water years 1980 through 2018 and model rules designed to represent historic operations during this period. The model was reviewed by staff from the Wyoming State Engineer's Office and by David Neumann with the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) of the University of Colorado, Boulder. CADSWES is the developer of the RiverWare software that was used as the software platform for the new model

Analysis

More water could be stored in Bear Lake without exceeding the ordinary high water mark (OHWM) by changing the way Bear Lake is operated. Operational changes could be accomplished by raising the PacifiCorp March 31 Target Elevation (PTE) of Bear Lake. The PTE is used to create storage space in Bear Lake for managing high runoff in the Bear River. The main limitation on raising the PTE is the flow constraint through Gentile Valley. Raising the PTE significantly increases the risk of inundation in Gentile Valley but also increases the amount of physical water that can be stored in Bear Lake unless the target maximum flow in Gentile Valley is raised in conjunction with an increase in the PTE. Due to the flow limitation through Gentile Valley, even if the exact volume of spring runoff was known, there are times when insufficient space can be evacuated in Bear Lake to capture enough high-runoff to prevent downstream flooding. Because of this limitation, releases must begin before reliable forecasts are available to prevent flooding later in the year. This precaution occasionally results in lower available storage than would have been available if a higher flow rate were allowed through Gentile Valley. Gentile Valley is located below the Grace Bench where the Bear River flows through a narrow agricultural region roughly 14 miles long with a maximum valley width of 2 miles. The gradient of the river through the valley is gentle, dropping 7 feet per mile. The main agricultural products in the valley are livestock and hay. Some of this agricultural land used for these purposes is located within the floodplain. Currently, PacifiCorp has been largely successful in adjusting Bear Lake operations such that Bear Lake releases combined with inflow from tributaries below Bear Lake remain below 1,500 cubic feet per second (cfs) in the Bear River through Gentile Valley. At this flow rate, the Bear River channel is nearly full. Once the river flow exceeds 1,500 cfs agricultural land is at risk of being inundated. The only way to store more water in Bear Lake without exceeding the target maximum flow in Gentile Valley is to raise the target maximum flow, which could require an arrangement with landowners that allows for the occasional inundation of agricultural land.

This report presents the results of running the Joint Bear River Planning model under 39 scenarios in which the PTE and target maximum flow in Gentile Valley were adjusted from current operations. Table EX1 describes the 39 scenarios. The PTE range adjustment (PTEra) in column 1 represents the change in elevation from the current PTE of 5,918.0 feet. The second column shows the PTE used in the scenario. Columns 3 to 6 show a scenario index number for each of the scenarios. Note that Scenario 9 is referred to as the Baseline Scenario throughout the report. The Baseline Scenario represents the historical/current operation of Bear Lake in which the default PTE is 5,918.0 feet and the target maximum flow through Gentile Valley is 1,500 cfs. Table EX1 has four focus scenarios highlighted in yellow. The selection of the focus scenarios was based on performance criteria. These scenarios have the most favorable balance between flood risk and increased storage benefits.

All scenarios described in Table EX1 where run under two different simulation methods that make assumptions regarding use of stored water. The Continuous simulation method assumes none of the additional storage water is used, while the Yearly simulation method assumes all additional storage is used consumptively each year. Since no use has yet been assigned for the additional storage water, these two simulations methods cover the range of possible impacts. Notably the amount of storage available is not heavily impacted by simulation method.

The number of years in which the target maximum flow in Gentile Valley would have been exceeded during the 39-year simulation period from 1980 to 2018 is shown in Table EX2 for two periods: from January through March and from April to July. The period from January to March represents the winter flow period when peak flow events are limited to rain-on-snow situations. Exceedances of the target maximum flow during this period historically were caused by tributary inflows into the Bear River below Bear Lake being high enough to exceed the maximum flow target in Gentile Valley without any flow being released from above Bear Lake. These exceedances were most often caused by low elevation snowmelt due to a sudden thaw or rain-on-snow event. During these events, the outlet structure to Mud Lake is usually closed, stopping all flow entering Bear Lake and the Bear River above Stewart Dam from leaving the Bear Lake/Mud Lake complex.

By focusing on just the April to July runoff season, the second part of Table EX2 focuses on the period where the inundation of agricultural fields could potentially be prevented by changes to high-runoff management policy at Bear Lake. The red-shaded "4" in Table EX2 when the PTE range adjustment (PTEra) is 0.5 feet and the Gentile Valley target maximum flow (GVtmf) is 1,500 cfs indicates that if the PTE is raised by even 0.5 feet, with no change to the Gentile Valley target maximum flow, there would have been four more years with inundation than occurred under the baseline scenario. However, the PTE could be raised by 1.5 feet and still have no additional inundation beyond the levels that occur with a new target maximum flow of 2,000 cfs (focus Scenario 22). If the target maximum flow through Gentile Valley is raised to 2,600 cfs, the PTE could be raised to 2.5 feet without increasing inundation events beyond that which would occur at 2,600 cfs (Scenario 31). If the PTE is raised 3.0 feet (Scenario 35) and the target maximum flow in Gentile Valley is kept at 2,600 cfs, there would only be one additional year in which flows in Gentile Valley exceeded the 2,600 cfs limit and baseline peak flows. If the flow target is raised to 3,000 cfs, then there would be no additional years in which the 3,000 cfs flow target and baseline peak flows are exceeded.

Since 3,000 cfs was considered the maximum reasonable amount to raise the Gentile Valley maximum flow target, no scenarios were analyzed with the target maximum flow greater than 3,000 cfs. Raising the PTE by 3.5 feet, which would fill the lake to the OHWM in flood control years, would result in three more years of inundation beyond the target maximum flow of even 3,000 cfs. Based on these results, it seems infeasible to raise the PTE more than 3.0 feet. Additional analysis (in the Results section of this report) indicates that significant downstream increases in streamflow would occur at a PTE increase of 3.0 feet, therefore the optimal scenario appears to be Scenario 31 (PTE +2.5 feet with a Gentile Valley target maximum flow of 2,600 cfs).

Table EX1 – *Scenario index for the 39 alternative high-runoff management scenarios and Baseline Scenario used in this study. Scenario 9, the Baseline Scenario, representing historic operations is highlighted in gray and four focus scenarios (scenarios 22, 31, 35, 36) that were found to represent the optimal results are highlighted in yellow. PTEra represents the adjustment to the default PTE (and range) from current operations and the GVtmf.*

Scenario Indices					
PTEra (feet)	**Scenario Default PTE**	**GVtmf (cfs)**			
		1,500	**2,000**	**2,600**	**3,000**
+3.5	**5,921.5**	37	38	39	40
+3.0	**5,921.0**	33	34	**35**	**36**
+2.5	**5,920.5**	29	30	**31**	32
+2.0	**5,920.0**	25	26	27	28
+1.5	**5,919.5**	21	**22**	23	24
+1.0	**5,919.0**	17	18	19	20
+0.5	**5,918.5**	13	14	15	16
0.0	**5,918.0**	**9***	10	11	12
-0.5	**5,917.5**	5	6	7	8
-1.0	**5,917.0**	1	2	3	4

Table EX2 – *Number of target maximum flow and Baseline peak flow exceedances in Gentile Valley for the January to March and April to July seasons. Bold italics indicate the Baseline scenario; bold with yellow outline indicates focus scenarios. (the Baseline is the 0.0, 1,500 entry; Scenario 22 is the 1.5, 2,000 entry; Scenario 31 is the 2.5, 2,600 entry; Scenario 35 is the 3.0, 2,600 entry; and Scenario 36 is the 3.0, 3,000 entry).*

Gentile Valley									
PTEra (feet)	Scenario Default PTE	Number of years with winter (Jan-Mar) peak flow above baseline peak and well above target threshold.				Number of years with spring (Apr-Jul) peak flow above baseline peak and well above target threshold.			
		GVtmf				GVtmf			
		1,500	2,000	2,600	3,000	1,500	2,000	2,600	3,000
3.5	5,921.5	4	1	0	0	6	4	4	3
3.0	5,921.0	3	1	**0**	**0**	4	3	**1**	**0**
2.5	5,920.5	3	1	**0**	0	4	2	**0**	0
2.0	5,920.0	0	0	0	0	5	2	0	0
1.5	5,919.5	0	**0**	0	0	5	**0**	0	0
1.0	5,919.0	0	0	0	0	5	0	0	0
0.5	5,918.5	0	0	0	0	4	0	0	0
0.0	5,918.0	***0***	0	0	0	***0***	0	0	0
-0.5	5,917.5	0	0	0	0	0	0	0	0
-1.0	5,917.0	0	0	0	0	0	0	0	0

Key Findings

Timing of Water Availability – Additional storage water could only have been achieved in years when PacifiCorp needed to evacuate water from Bear Lake for high-runoff management. These years are shown in Figure EX1 as blue and red bars. In the 39 years of simulation, additional storage could only have been attained during the 15 years (38% of all years) of high-runoff management. Four of the high-runoff management years (10% of all years, shown by red bars in Figure EX1) were followed by years when releases were made exclusively for delivery of contracted irrigation water. There is an 80% chance a year with high runoff management will be followed by another year which will require high runoff management. There is only a 17% chance that the subsequent year will not require high runoff management.

Theoretical Volume of Water Available – The theoretical volume of additional storage available in the four years preceding dry periods, referred to as carry-over years and colored red in Figure EX1, is directly related to increases in the PTE. The term *theoretical* is used because this analysis is based on a perfect runoff forecast (i.e. the historic inflow between April and July was used to determine adjustments to PTE after January 1). This is significant because typically there is a large amount of uncertainty in the seasonal inflow forecast which is eliminated when using the historical inflow in place of a forecast. The average increase in storage during these four years would have been 58,000 acre-feet per 1.0-foot increase in the PTE if perfect runoff forecast information were available.

Table EX3 shows the average increase in storage for carryover years for each scenario. The average additional storage gained in carryover years ranges from -72,000 to 197,000 acre-feet across all 39 scenarios. When considering the average change during all high-runoff management years, the increased storage ranges from -50,000 to 109,000 acre-feet. Downstream flow constraints reduce the amount that the PTE can increase to between 2.5 and 3.0 feet. Without the additional study of flood risk in Gentile Valley, the optimal increase in PTE seems to be 2.5 feet. However, this could only have been achieved by raising the target maximum flow in Gentile Valley to at least 2,600 cfs.

A carry-over year is defined in this study as a year when releases were made for high-runoff management which was followed by a year when releases were made exclusively for the delivery of contracted irrigation water. A perfect runoff forecast is the observed spring runoff volume used in hindsight as a forecasted volume which is 100% accurate. A more detailed definition

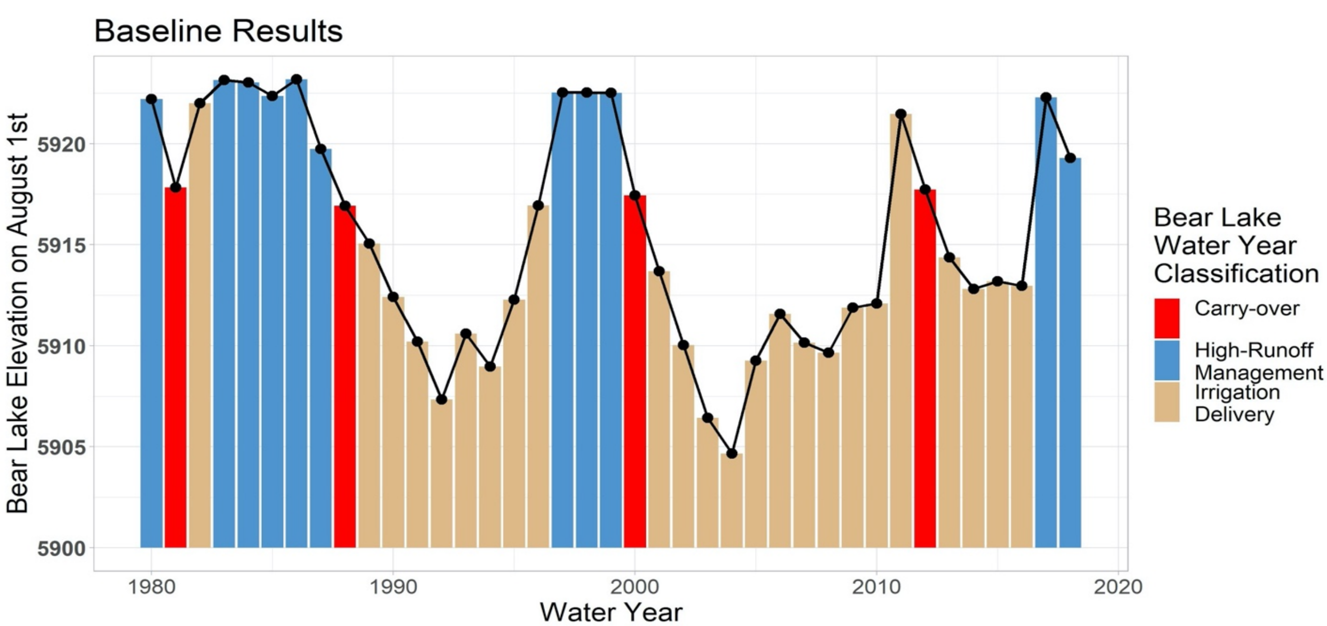


Figure EX1 – *Bear Lake elevation on August 1 of each year from the results of the Baseline simulation using the perfect forecast. Each water year has a bar color representing whether any releases were made for high-runoff management. Red indicates that the year was high-runoff management and the succeeding year was irrigation delivery.*

Table EX3- Comparison of mean increase in Bear Lake storage on August 1st during carry-over years for all 39 scenarios. Results from the Yearly simulation method and perfect forecast. Blue shading highlights increases whereas red shading shows a storage decrease. Focus scenarios are highlighted by yellow boxes. Units are thousands of acre-feet.

Bear Lake - Average additional volume on August 1st for carry-over years (TAF)					
PTEra	Scenario	GVtmf			
(ft.)	Default	1500	2000	2600	3000
3.5	5921.5	197	197	197	197
3.0	5921.0	168	168	168	168
2.5	5920.5	138	138	138	138
2.0	5920.0	111	111	111	111
1.5	5919.5	84	84	84	84
1.0	5919.0	57	57	57	57
0.5	5918.5	31	28	28	28
0.0	5918.0	0	-7	-7	-7
-0.5	5917.5	-25	-39	-40	-40
-1.0	5917.0	-46	-71	-72	-72

and explanation for using the perfect forecast is provided in the report.

Estimated Actual Volume of Water Available – It is important to remember that the volume of additional storage water available (as described in the above findings) is based on a perfect forecast of spring runoff. In actual operations, PacifiCorp does not know the volume of spring runoff and must rely on forecasts from the Natural Resource Conservation Service (NRCS) and/or Colorado Basin River Forecast Center to determine the PTE. The forecast can be either greater than or less than observed runoff. When the forecasted runoff is greater than the observed runoff, too much water may be evacuated from the reservoir, resulting in less water being stored than under the perfect forecast. In like manner, if less runoff is forecasted than actually occurs too little storage may be released from the reservoir. To prevent downstream flooding PacifiCorp may allow water in the reservoir to rise above the targeted maximum fill of the reservoir, known as the operational maximum elevation (5,922.5 feet), however PacifiCorp will not allow water to be stored above the OHWM at 5,923.65 feet.

Because the Joint Bear River Planning model has been configured to utilize any forecast, including historic forecasts, we performed an analysis on the effect of using historical forecasts. In place of a full uncertainty analysis, we compared the additional storage gained in

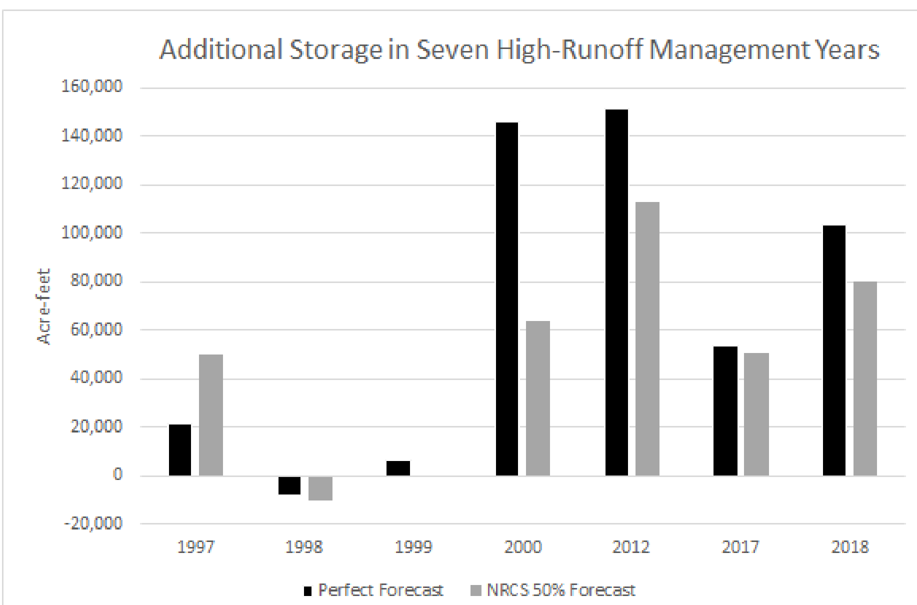


Figure EX2 – *Comparison of additional storage volume for seven high-runoff management years when Baseline storage in Bear Lake is subtracted from Scenario 31 storage using both the NRCS 50% probability of exceedance forecast (grey bar) and the perfect forecast (black bar).*

Scenario 31 with the perfect forecast to the storage gained using historic forecasts and found that the additional volume of stored water decreased considerably. However, this is based on only seven high-runoff management years for which historic forecasts were available.

Comparison of the additional storage gained when utilizing the perfect and historical NRCS forecasts is shown in Figure EX2 and indicates that the additional storage benefit which was identified using the perfect forecast would have been reduced when using a historic forecast that over-predicts runoff during a flood control year. The main takeaway is that the storage benefit is dependent upon the accuracy of the spring runoff forecast. Additional and more thorough analysis is needed to identify how much the expected theoretical volume would change if actual/historic forecasts were used.

Impacts of Proposed Changes on Diversions into Bear Lake – In most years, increases to the PTE would reduce the volume of water and the amount of time water is diverted from Mud Lake into Bear Lake. Raising the PTE means less water is evacuated for high-runoff management and less water is needed to refill the lake. Under the perfect forecast assumption, the reduction in flow through the Causeway for Scenario 31 would be around 600,000 acre-feet for the entire simulation period or an average reduction of 40,000 acre-feet per year for the 15 high-runoff management years.

Impacts on High Runoff through Gentile Valley – As described above, if the PTE is raised 2.5 feet and the target maximum flow through Gentile Valley is raised to 2,600 cfs, there are no peak flow events larger than observed under baseline conditions. However, the frequency and duration of flows up to 2,600 cfs increase relative to the baseline.

Impacts of Proposed Changes on Upstream Reservoir Storage – When the Bear Lake elevation is above 5,911.0 feet restrictions are lifted on upstream storage reservoirs and upstream reservoirs can store additional water. The maximum number of years in which Bear Lake would have remained above 5,911.00 when compared against the Baseline Scenario is shown in

Table EX4 – *The number of years in which the elevation of Bear Lake would have remained above 5,911.0 feet when compared against the Baseline Scenario.*

Bear Lake - Additional years above 5,911 feet from baseline (equivalent elevation).					
PTEra (feet)	Scenario Default PTE	GVtmf (cfs)			
		1,500	2,000	2,600	3,000
3.5	5,921.5	8.6	8.6	8.6	8.6
3.0	5,921.0	7.4	7.2	7.2	7.2
2.5	5,920.5	5.9	5.8	5.8	5.8
2.0	5,920.0	5.0	4.9	4.9	4.9
1.5	5,919.5	4.3	4.1	4.1	4.1
1.0	5,919.0	3.6	3.1	3.0	3.0
0.5	5,918.5	2.0	1.6	1.4	1.4
0.0	5,918.0	0.0	-0.5	-0.6	-0.6
-0.5	5,917.5	-1.1	-2.4	-2.4	-2.4
-1.0	5,917.0	-2.5	-4.0	-4.0	-4.0

Table EX4. Additional impacts from the proposed changes were not determined in this phase of modeling.

Impacts on Great Salt Lake – Impacts on Great Salt Lake from storing additional water in Bear Lake cannot be determined because no use for the additional storage volume was considered in this analysis. If all the additional storage water was used consumptively, then changes to inflow to Great Salt Lake would have ranged from an increase of 761,000 acre-feet to a decrease of 1,711,000 acre-feet over the 39-year study period, across all scenarios. Regardless of whether the additional water stored was used consumptively, the annual distribution of inflow would have been different, with higher inflow during a few wet years and lower flow during carryover years.

Trade-offs – The four focus scenarios have different effects on storage in Bear Lake, years the elevation of Bear Lake is above 5,911.0 feet, high flows downstream of Bear Lake, inflows to Great Salt Lake, and flow through the Causeway. Some of these effects can be compared in Table EX5, which numerically summarizes many key findings.

Table EX5 *– Comparison of the performance measures selected to estimate the impacts of changing historic high-runoff management operations to those defined by four focus scenarios. Units of each performance measure are included where they are not indicated by the name. Variable values defining each scenario are included. The simulation method, whether Yearly or Continuous, is also indicated. All results assumed a perfect forecast was available.*

Operations Scenario Variable Value			Performance Measure							
			Mean change in August 1 Bear Lake volume for carry-over years (TAF)	Change in total Bear Lake volume (TAF)	Additional years Bear Lake is above 5911	% Time above the GVtmf	High-Runoff impact index	Mean change in annual inflow to Great Salt Lake for carry-over years (TAF)	Change in total flow to Great Salt Lake (TAF)	Change in total volume through Causeway (TAF)
			Simulation Method							
PTEra (+ ft)	GVtmf (cfs)	Scenario	Yearly	Yearly	Continuous	Continuous	Continuous	Continuous	Yearly	Continuous
0.0	1500	Baseline	0	0	0	4.3%	0	0	0	0
1.5	2000	Scenario 22	84	455	4.1	2.5%	-3	-59	-458	-229
2.5	2600	Scenario 31	138	680	5.8	1.2%	-1	-96	-683	-605
3.5	2600	Scenario 35	168	1149	7.2	1.2%	2	-119	-1196	-637
3.5	3000	Scenario 36	168	1145	7.2	0.6%	3	-119	-1192	-607

Important Model Limitations

Storable Water Versus Useable Water – This study focuses on identifying how much additional water could be stored in Bear Lake each year. Most of the analysis relies on the use of the perfect forecast. However, policymakers should be aware that the present uncertainty in forecasts reduces the amount of water that would be stored under actual operations. In many back-to-back high-runoff management years, any additional storage benefit not used in the year it is accrued would likely be evacuated for high-runoff management the following year. Without knowing how, when, and where the additional storage water is used, policymakers should be aware that storable water is not the same as usable water. Future steps of analysis should include usability of additional storage.

Current model only represents the Lower Division of the Bear River – The current version of the Joint Bear River Planning Model does not consider how changes in management of Bear Lake would impact the Upper Division and Central Division. When the elevation of Bear Lake falls below 5,911.0, reservoir storage upstream of Bear Lake in Wyoming and Utah is limited by the Bear River Compact. If changes in operations result in the elevation of Bear Lake remaining above 5,911.0 feet for a longer period, Wyoming and Utah might store more water upstream of Bear Lake. This could result in less flow entering the Lower Division and either decrease diversions or increase the amount of water released from Bear Lake. Decreasing the flow into the Lower Division would also impact water allocation in the Central Division, possibly leading to the earlier declaration of a drought emergency in some years. To analyze impacts across all three divisions, the model would need to be extended to the headwaters, include policies for "drought emergencies" that are part of the Bear River Compact and the 5,911.0 feet limitation on storage above Bear Lake. The expansion of the model above Bear Lake would be best carried out with aid from the Wyoming State Engineer's Office.

No Use of Additional Storage Water Modeled – Current allocation to contracted storage users in Bear Lake is determined based on PacifiCorp's policy adopted in the Bear Lake Settlement Agreement. The contract storage allocations are determined by the estimated spring peak elevation of Bear Lake based on information available on April 10th. In this model, we did not increase allocations to storage users or adjust diversions to account for the availability of more water in Bear Lake. In its current form, this model relies on historic diversions to drive demand for storage water from Bear Lake. Once available storage water is determined, policymakers and stakeholders will have to negotiate a method of accounting for additional storage water and determine potential uses for the additional water. Work to model potential uses of additional storage water is expected in a future study

Potential Future Actions

Potential efforts to continue the development of the model include on-going joint-use and maintenance to not allow it to fall into disuse. Significant effort should be expended to refine and perfect any future potential study questions. Improvements could be made to the model including updating data and five specific areas are detailed in the report. Finally, the States and PacifiCorp recognize that dissemination of information about the model and the study is very important. Hence, the States and PacifiCorp will give a presentation on both the Bear River model and this report to the stakeholders and at a Bear River Commission meeting.

REPORT

Introduction

Although numerous legal constraints have been put into place over the long history of river management, controversy continues to challenge regulators and users of the Bear River and Bear Lake water supply. In April 2017, at the annual Bear Lake Preservation Advisory Committee meeting, PacifiCorp presented preliminary ideas on how to increase Bear Lake storage without increasing the maximum elevation by modifying high-runoff management practices. After the presentation, PacifiCorp consulted with Idaho, Utah, and Wyoming on the concepts, but no agreements were reached. On March 23, 2018, the Idaho Water Resource Board and Utah Division of Water Resources filed two joint water right applications – one in Idaho and one in Utah – to appropriate 2,000 cfs of natural flow[1] and 400,000 acre-feet of storage to be diverted from the Bear River and stored in Bear Lake within the existing water level range. The applications assert that, if granted, the States will at a future time negotiate an agreement on how the additional storage will be apportioned between them. The Utah application is identified by Application No. 23-3972 and the Idaho application is identified by Application No. 11-7835.

These filings prompted signatories to the 2000 Operating Agreement for PacifiCorp's Bear River System (Idaho, Utah, Wyoming, and PacifiCorp) to investigate the development of a Bear River model to better assess future operations of the Bear River system and to identify alternative high-runoff management operations scenarios which could increase lake storage without increasing flood risk. Decision makers proceeded to assemble a technical group with members from Idaho, PacifiCorp, Utah, and Wyoming. The technical group drafted a study framework focused on questions identified by policymakers. To answer those questions, the technical group assembled a modeling group composed of hydrologists and engineers from Idaho, PacifiCorp, Utah, and CADSWES to develop the Joint Bear River Planning Model described in the *Joint Bear River Planning Model Development Report – Phase 1* (termed herein the "model report," which is in preparation). Responses to the policymakers' questions, arrived at through analysis of results from the model, are presented in this report

Study Questions

This report utilizes output from the Joint Bear River Planning Model to address six questions policymakers had in seeking to determine whether or not more water could be stored in Bear Lake by making changes to Bear Lake target elevations and increasing the Gentile Valley target maximum flow. Changing the practices by which high runoff is managed at Bear Lake would impact not only the storage within Bear Lake but also streamflow below the lake.

Policymakers asked the modeling group to address the following six questions:

1. How often could Bear Lake have stored additional water?
2. What volume of additional water could have been stored in Bear Lake (without increasing water levels above the Ordinary High Water Mark (OHWM))?
3. What would've been the effect on the Bear Lake equivalent elevation of 5,911.0 feet?

[1] Utah Division of Water Rights defines natural flow as the rate of water movement past a specified point on a natural stream from a drainage area for which there have been no effects caused by upstream diversion, storage, import, export, or return flow. The term is commonly defined this way in hydrologic and water rights contexts.

4. How would changes in high-runoff management have affected flows through Gentile Valley and downstream (below Oneida and below Cutler)?
5. How would additional storage in Bear Lake have impacted inflow to Great Salt Lake?
6. What would have been the effects on Mud Lake elevations and timing of discharge from Mud Lake to Bear Lake?

Bear River Background

Bear River has long been considered a rogue – at times untamable and always flowing with controversy. It makes five state line crossings through three states: Utah, Wyoming, and Idaho, resulting in a multitude of political, institutional, and legal challenges in river management and regulation. Beginning in the early 20th century, the river was regulated for hydropower by the diversion, conveyance, and storage of Bear River water into and out of Bear Lake by PacifiCorp and is considered one of the first multiple-use reclamation projects not financed by the federal government. For over 110 years, regulation of Bear River has provided (1) stable water supply for over 150,000 acres of irrigated farmland downstream of Bear Lake, (2) extensive high-runoff management benefits, (3) generation of hydroelectric power, (4) recreation opportunities at Bear Lake and along the Bear River, and (5) habitat enhancements for fish and wildlife.

Similar to other semi-arid western watersheds, the hydrology of the Bear River watershed is defined by a series of wet-dry cycles. Figure 1 compares the elevations of Bear Lake to the Standardized Precipitation and Evapotranspiration Index (SPEI, Vicente-Serrano, 2010) for the period between 1903 and 2018. The SPEI provides a measure of how precipitation and potential evapotranspiration differ from normal conditions. A value greater than 0.8 indicates a wet period (see the blue line in Figure 1) and a value less than -0.8 indicates a drought year (see the brown line in Figure 1).

The Bear River Basin has experienced extensive dry cycles over the past century. The first dry period of 1930-1935 was one of the worst, resulting in Bear Lake dropping to its lowest historical level of 5,902 feet in the fall of 1935. There is no active storage capacity in the lake when it reaches 5,902 feet, although below this

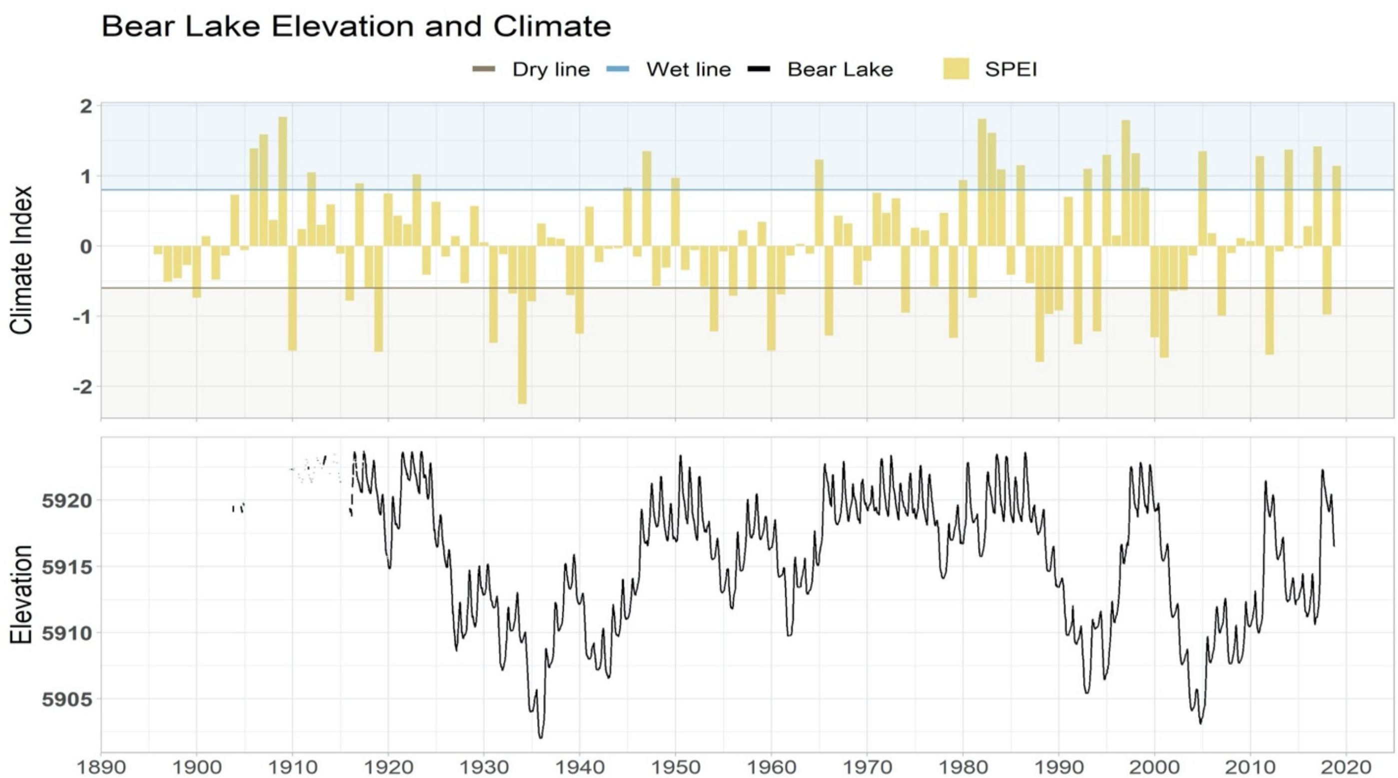


***Figure 1** - Historic Bear Lake elevations are represented by the black line. The SPEI winter drought index (Sept-March) is shown in gold. SPEI values above the blue line represent a wet year and values below the brown line represent dry year.*

elevation the lake volume is approximately 5.1 million acre-feet. This elevation remains the historical low-elevation benchmark. Dry periods in 1953-1955, 1958-1961, 1987-1992, 2000-2004, and 2012-2016 all resulted in Bear Lake elevations dropping to levels approaching the record low. Each of these periods was composed of 3 to 6 consecutive dry years during which PacifiCorp continued to deliver irrigation water to meet its contractual obligations.

The original Bear Lake Settlement Agreement[2] in 1995 first established an irrigation allocation schedule which reduces contractual deliveries as Bear Lake elevation decreases. This allocation schedule gradually decreases from 245,000 acre-feet when Bear Lake is above 5,914.7 feet down to zero when the spring maximum Bear Lake elevation is estimated to be 5,904.0 feet or lower.

Several periods of high runoff have resulted in litigation between landowners along the Bear River downstream of Bear Lake and PacifiCorp. PacifiCorp has acquired land along the Bear River to reduce risks caused by flooding and considers flood risk as part of its Bear Lake and Bear River operations management.

The Bear River Compact separates administration of the Bear River into three divisions (see Figure 2): the Upper Division (above Pixley Dam) includes parts of Wyoming and Utah, the Central Division below Pixley Dam and above Stewart Dam (where the river is diverted to Bear Lake) includes parts of Wyoming and Idaho, and the Lower Division which extends from Stewart Dam to Great Salt Lake, includes parts of Idaho and Utah.

This study considers only the Lower Division and only explicitly models changes to the operation of Bear Lake. Allocation of the natural flow and determination of Bear Lake storage use within the Lower Division is done with Bear River Interstate models, water rights accounting programs developed by Idaho, and Utah which each state runs independently. Note that irrigation storage reservoirs on tributaries of the Bear River and upstream of Stewart Dam on the Bear River are managed independently according to contracted needs associated with each, such as Newton Reservoir in Cache Valley and Woodruff Narrows Reservoir in Wyoming.

[2] The agreement currently in place is the Amended and Restated Bear Lake Settlement Agreement that was signed in 2004.

Figure 2 – Bear River watershed and key locations (denoted by red circles) noted in the report or where impacts due to alternative Bear Lake high-runoff operations are evaluated in this report. The base map also shows the three administrative divisions created by the Bear River Compact.

Approach

This section discusses the general approach taken to answer the policymakers' questions, which includes making important modeling assumptions, selecting performance measures to evaluate change, describing current system operations, defining operations scenarios, and running the model with two different methods of simulation

To begin answering the policymakers' questions, a computer simulation model was developed to replicate historical operations of the Lower Division Bear River system. The model is referred to as the Joint Bear River Planning Model because it was planned, built, and tested by engineers and hydrologists from Idaho, PacifiCorp, and Utah. It was developed using the model platform RiverWare with guidance from the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) that developed the software. RiverWare is an object-oriented reservoir operations software widely utilized in the water resource profession. The Bureau of Reclamation and Tennessee Valley Authority use RiverWare to manage some of the largest river systems in the United States. It is an ideal platform for operational decision-making, responsive forecasting, operational policy evaluation, system optimization, water accounting, water rights administration, and long-term resource planning. CADSWES was retained as a consultant on the project and provided valuable insight, key direction, and model review, assuring that modelers followed best practices.

The Joint Bear River Planning Model begins simulation on October 2, 1979 and runs each day until October 31, 2018. This 39-year study period was chosen for several reasons. It includes the wet period from the late 1970s to the early 1980s when high-runoff management was the most challenging in the historic record. It also contains two extended dry periods, including the second-longest dry period on record. Additionally, the model relies on historical streamflow, reservoir elevation, and irrigation diversion data for which records are nearly complete back to 1979.

To test river system impacts from a range of possible high-runoff operating policies, 39 management operations scenarios were defined then simulated with the model. Results from each scenario were compared against a Baseline, which represents current high-runoff management operations. The Baseline was made by adjusting the model rules to best replicate historic observations. The Baseline represents a simplified version of historic lake and river management, although differing in some ways from historical flows and lake elevations. PacifiCorp's current high-runoff management operations were translated by the modelers into computer code, referred to as "rules" in the RiverWare software. The rules were based on historic reservoir operations, as described in various legal and operational documents, and discussions with Carlyle Burton and Connely Baldwin regarding their experience operating PacifiCorp's facilities on Bear Lake and the Bear River. Mr. Burton was responsible for PacifiCorp's operation of the Bear River system from 1973 to 2003. Mr. Baldwin is currently responsible for Bear River reservoir operations at PacifiCorp. The rules are a simplification of the real-time decision-making process and actual facility operation. This study does not explicitly model irrigation diversions and demand, but rather utilizes historical irrigation diversion records for entities that divert from the Bear River below Bear Lake. All other diversions are implicitly included through the use of observed streamflow records.

Detailed descriptions of model development and a detailed comparison between the Baseline results and observed record of lake elevations and river flows are contained in the model report.

Key Modeling Assumptions

Assumptions were made to facilitate model development based on the questions being addressed, expert experience with the river system, professional judgment, and best modeling practices.

Four of the most important assumptions to keep in mind when interpreting the results are:

No additional releases from the Bear Lake system were made for contracted irrigation water or any other purpose than high-runoff management. Historic downstream irrigation diversions are used within the model to determine the timing and volume of releases from Bear Lake. No use for the additional storage water is assumed.

No changes to evaporation or conveyance losses were included in the model. Historic evaporation and conveyance losses are lumped in the local hydrologic inflows of each river reach. We acknowledge that changes in streamflow would have impacted conveyance losses within river reaches and that in scenarios where additional water could have been stored in Bear Lake the surface area of the lake would have been greater than it was under historic conditions. A larger surface area would result in greater evaporation and a smaller surface area would result in less evaporation. However, the marginal changes in evaporation due to changes in reservoir operations do not significantly alter the results of this study.

For example, the incremental increase in the surface area of Bear Lake from elevation 5,918.0 feet (69,187 acres) to 5,919.0 feet (69,565 acres) is 378 acres. Using detailed field measurements and energy balance calculations at Bear Lake in the early 1990s Amayreh (1995) determined that total annual evaporation is 24 inches per year (0.08 inches/day measured from March through October plus 0.04 inches/day estimated for November through February). Thus, the additional evaporation on the 378 acres gained from a 1-foot rise in the lake would be 756 acre-feet per year. An additional loss of this magnitude is small compared to the volume added. The additional loss would be 1.2% of the additional volume, (756 acre-feet out of 69,400 acre-feet of additional storage gain from 5,918.0 feet to 5,919.0 feet).

No further calculations were made to determine evaporative impacts on results because this assessment showed that large increases in volume result in small increases to the volume being evaporated. Moreover, the uncertainty in modeling lake volume is greater than 1.2%. Further discussion about this assumption as well as model uncertainties are presented in the model report.

Dates on which the target elevations are intended to be reached are fixed and unchanging between scenarios. In actual operations the dates, while generally around the same time each year, are flexible and based on a combination of multiple sources of information and expert judgment. Not having such sophistication, the model relies on specified dates that remain constant each year and through each scenario. For example, in the model high-runoff management always begins on August 1 and seeks to fill the lake by July 31. Variability in target dates and release start dates are aspects of high-runoff management operations that are not considered in the alternative operations scenarios explored in this study.

Perfect spring runoff forecasts are used to determine high-runoff management releases from January through July. Operations of the Bear Lake and Bear River system rely on streamflow forecasts rather than rule-curves[3]. The forecasts used in this report are based on historic observations and are referred to as perfect forecasts. In other words, there is no uncertainty in the estimated runoff volumes. The model has perfect foresight. This assumption eliminates the question of how errors in forecasts impact operations and allow the model user to determine the maximum storage that could be gained by a change in high-runoff management operations. We decided not to use the actual historic forecasts for several reasons. Older forecasts have more uncertainty than modern forecasts, forecasters are continually seeking to improve forecasts which means the forecast methods are also changing and the application of historic forecasts does not represent current forecast capability.

[3] A rule curve is a reservoir management tool used to set a desired reservoir elevation based strictly on the calendar date, regardless of hydrologic conditions.

Results from the use of the perfect forecast represent the maximum amount of storage benefit that could have been gained by a change in high-runoff management operations. In practice, perfect forecasting is unachievable so the storage benefit from changes in high-runoff management operations as reported here, are likely overestimated. A brief analysis using actual historic forecasts and synthetic imperfect forecasts was performed to provide a sense of the uncertainty in the estimated storage benefits.

Current System Operations

This section describes the guiding principles used for high-runoff operations with some discussion on how it was modeled. PacifiCorp currently operates Bear Lake consistent with applicable law, water rights, historic practices, and numerous agreements "with the use of water for hydropower generation being incidental to the other purposes for which the water is being released." (*Agreement Regarding the Bear River System*, 1999). In this report, current system operations are referred to as the Baseline Scenario which is described more in the model report.

PacifiCorp Target Elevation

For high-runoff management operations, PacifiCorp determines the elevation of Bear Lake to be achieved, if possible, on March 31 of each year. Setting and adjusting the target elevation, known as PacifiCorp Target Elevation (PTE)[4] is consistent with both PacifiCorp's operation of Bear Lake since the 1970s and the 2000 Operating Agreement for PacifiCorp's Bear River System. The PTE may range from as low as 5,916 feet during projected high runoff conditions to 5,920 feet during projected low runoff conditions. Under normal conditions, PacifiCorp sets the PTE at 5,918 feet. PacifiCorp has established the PTE to balance long-term contractual obligations for Bear Lake storage water with flood control operations.

Generally, PacifiCorp sets the PTE at the end of the irrigation season and updates the PTE at least monthly until March 31 of the following year. If the lake elevation is greater than 5,918 feet during the irrigation season and irrigation demand for storage water is not enough to reach 5,918 by the end of the irrigation season, releases of storage water may be initiated for high-runoff management in August or late July. Adjustments may be made to the PTE to accommodate changing conditions, including weather forecasts, downstream constraints, uncertain irrigation demands, variations in runoff from month to month, and other operational constraints. In January, PacifiCorp adjusts the PTE as needed (within the 5,916 to 5,920 feet elevation range) PacifiCorp considers forecasts of spring runoff provided by the Natural Resources Conservation Service (NRCS) and the Colorado Basin River Forecast Center (CBRFC). Both federal agencies provide official monthly forecasts and unofficial daily forecasts that help PacifiCorp staff adjust the PTE throughout the pre-runoff and runoff periods. Local inflow to Bear Lake and Mud Lake can be significant; however, no official forecasts are provided for this runoff volume which increases the uncertainty of total spring runoff. Table 1 summarizes the different PTEs and corresponding effective and target dates.

Table 1 – Model Baseline Bear Lake target elevations with their associated name, active period, target date, and condition that sets them. Note the Default and Operational Max have no conditions because they are singular values set for the full range of effective dates each year. The (PTE) Range Min and (PTE) Range Max are, respectively, 2 feet less than and 2 feet greater than the Default PTE.

Name	PTE	Effective Date	Target Date	Condition
Default	5918.0	Aug - Dec	Jan 01	NA
Range Min	5916.0	Jan - Mar	Mar 31	Spring runoff forecast
Range Max	5920.0			
Operational Max	5922.5	Apr - Jul	Jul 31	NA

[4] PTE is explicitly defined in the agreements as the "PacifiCorp Target Elevation."

If the elevation of Bear Lake is below the PTE from the end of the irrigation season to March 31 of the following year, releases are curtailed until the lake is predicted to reach the PTE or releases are necessary for flood control. "Except in emergencies, PacifiCorp will not release water from Bear Lake when the elevation is below the PTE unless consistent with flood control operation." (*2000 Operations Agreement for PacifiCorp's Bear River System*)

Once the high runoff period begins, PacifiCorp uses forecast information to store available inflow up to its operational maximum of 5,922.5 feet. The operational maximum is set in the model at 1.15 feet below the OHWM to provide freeboard in case spring runoff is greater than predicted. Although Bear Lake does not have a constructed spillway, the policy is to treat the OHWM of 5,923.65 feet as the maximum permissible elevation. The OHWM is the historic maximum elevation and conventionally accepted as the physical maximum capacity of Bear Lake. This was established in the 2000 Agreement Regarding the Bear River System and is the jurisdictional limit defining the lakebed, which is owned and administered by the states of Utah and Idaho.

Gentile Valley Target Maximum Flow

The Gentile Valley is a narrow stretch of agricultural land along the Bear River between Grace, ID and the Oneida Narrows. Hay and pasture land are the two major land uses. Because some of this agricultural land is located within the floodplain, there is a risk of inundation. In addition, several automobile bridges are thought to constrict streamflow. The current target maximum flow in Gentile Valley of 1,500 cfs is a significant constraint in high-runoff management below Bear Lake. A few hydrologic calculations are presented here to illustrate.

During the study period (water years 1980 to 2018), the median flow into the system above Gentile Valley (combined flow in the Rainbow Inlet Canal, from Bear Lake and Mud Lake watersheds, and tributaries between Bear Lake and Gentile Valley) was 560 cfs between October and March. A flow constraint of 1,500 cfs leaves an allowable average maximum discharge of 940 cfs from the Lifton Pumping Station or maximum evacuation of 171,080 acre-feet during those months. Over the same period, the tenth percentile flow into the system above Gentile Valley was 1,150 cfs. At this flow, the Lifton Pumping Station would be restricted to an average discharge of 350 cfs. Due to this limited rate at which Bear Lake can be drawn down to provide flood control space in the lake, releases from the lake for high-runoff management often begin on August 1 to be able to evacuate adequate space to reach the March 1 PTE.

Sometimes the flow in Gentile Valley can exceed 1,500 cfs even when the Outlet Canal below Bear Lake is closed. Under those circumstances, the inundation of fields and pasture within Gentile Valley cannot be prevented by the regulation of Bear Lake.

The current target maximum flow in the Gentile Valley of 1,500 cfs is the most constraining factor in determining the time required to evacuate Bear Lake to create space that is needed to reduce flows in the Bear River during times of high runoff. Relaxing this constraint allows Bear Lake to be evacuated more quickly. A relaxation of this constraint would require an agreement between landowners and PacifiCorp to allow land to be inundated during the period of high-runoff management. Other opportunities for increasing flow through Gentile Valley might include removing possible channel constrictions, dredging the channel, and establishing off-channel short-term regulation reservoirs.

Alternate High-Runoff Management Operations Scenarios

The two main variables considered in the alternative high-runoff management operations scenarios are the Gentile Valley target maximum flow and the PTE of Bear Lake. Limiting the analysis to only these two variables was decided prior to initiating the study. In this section, we describe how these two variables are modified to estimate the resulting impacts to the system in order to answer the study questions.

Gentile Valley target maximum flow (GVtmf) – This variable ranges in the scenarios from the Baseline value of 1,500 cfs up to 3,000 cfs which is 400 cfs greater than the maximum turbine discharge at the Soda hydropower dam. A value greater than the maximum discharge of 2,600 cfs is included to determine if there could be added value by increasing the target maximum flow beyond the maximum turbine discharge at Soda.

PTE range adjustment (PTEra) – This variable shifts the entire Baseline PTE range up or down for use in a scenario. Under current operations the default PTE is 5,918 feet with a range of 2 feet on either side; the corresponding PTEra is 0.0 for the Baseline. For example, increasing the PTEra by +1.0 foot would change the range of the current PTEra of [5,916 to 5,920] to [5,917 to 5,921] with 5,919 becoming the default PTE for that scenario.

The PTEra is lowered by 1.0 foot to show the impacts of a more conservative high-runoff management policy. The upper limit of the scenarios is a PTEra of +3.5 feet, which increases the upper limit of the PTE range from the Baseline elevation of 5,920.0 to 5,923.5, which is 0.15 feet below the Bear Lake OHWM. Additionally, when the PTEra is +3.5 feet, the April-July target elevation is adjusted to match the maximum range of the PTE to 5,923.5. This Operational Maximum is otherwise set to the Baseline value of 5,922.5 when the scenario maximum range of the PTE is 5,922.5 (i.e. when the PTEra is +2.5) or lower.

Values range from -1 to +3.5 feet for the PTEra and 1,500 to 3,000 cfs for the GVtmf. Each scenario has an assigned index number that serves as a scenario identifier for the range of scenarios evaluated as shown in Table 2. This combination of variable values resulted in 39 alternative operational scenarios. The Baseline scenario was also evaluated and is shown as Scenario 9* in Table 2 (it is referred to as "Baseline" for this report). The limits on these ranges were selected based on physical, policy, and reasonability limitations.

Plots, tables, and performance measures showcase the Baseline and select focus scenarios, as described in the next section, to answer the questions. Where practical, results are shown for all scenarios.

***Table 2** – Range of scenarios considered with numbers in the table showing the scenario index numbers used in this report. Note that for each PTEra, the corresponding scenario default PTE is shown. The focus scenarios are highlighted in yellow and the Baseline is highlighted in grey.*

Scenario Indices					
PTEra (feet)	Scenario Default PTE	GVtmf (cfs)			
		1,500	2,000	2,600	3,000
+3.5	5,921.5	37	38	39	40
+3.0	5,921.0	33	34	**35**	**36**
+2.5	5,920.5	29	30	**31**	32
+2.0	5,920.0	25	26	27	28
+1.5	5,919.5	21	**22**	23	24
+1.0	5,919.0	17	18	19	20
+0.5	5,918.5	13	14	15	16
0.0	5,918.0	**9***	10	11	12
-0.5	5,917.5	5	6	7	8
-1.0	5,917.0	1	2	3	4

Performance Measures

Performance measures are numerical values drawn from scenario results used to evaluate effects on the river system resulting from alternative high-runoff management operations. The goal of developing performance measures is to synthesize and condense information in ways useful to stakeholders and policymakers. Although useful, performance measures can be difficult to define. The modeling team has come to a consensus about which are informative, useful, and communicable. Performance measures were computed for every scenario then used to screen initial scenarios to identify focus scenarios.

Performance measures form the basis for evaluating trade-offs of different operations scenarios and are essential to quantifying impacts from those alternative operations.

The performance measures used to compare scenarios to the Baseline in this report include:

- Mean change in Bear Lake volume on August 1 of carryover years in thousand acre-feet
- Change in total Bear Lake volume over the 39-year simulation in thousand acre-feet
- Additional years Bear Lake is above the equivalent elevation of 5,911.0 ft.
- Percent of time streamflow through Gentile Valley is greater than the target maximum flow
- High-Runoff impact index which sums results of maximum flow target exceedances each year
- Mean change in annual inflow to Great Salt Lake for carry-over years in thousand acre-feet
- Change in total volume to Great Salt Lake in thousand acre-feet
- Change in total volume through Causeway in thousand acre-feet

Two Simulation Methods

The impacts on storage in Bear Lake, timing, and flow into Bear Lake from Bear River, and inflow to Great Salt Lake are greatly affected by how, when, and where the additional storage water is used (which may include remaining in Bear Lake). Two different methods of simulation are employed which handle holdover storage in Bear Lake differently and thus provide an idealized range of impacts.

While the benefits of additional water stored are similar in Bear Lake for both methods, impacts to downstream locations differ between the two. Analysis of results from the two methods allows us to better understand the effects from holdover storage by isolating changes each year.

Continuous simulation method – This method does not allow use of the additional stored volume and carries that volume over from year to year until it is evacuated for flood control. The purpose of this method is to determine how much total water could be stored in Bear Lake on August 1 including carryover from the previous year which may or may not be released due to high-runoff management operations.

Yearly simulation method – This method returns the storage volume of Bear Lake to the Baseline volume on August 1 when high-runoff operations begin for the next year and the default PTE is used to determine releases. Resetting the volume of Bear Lake to the Baseline is equivalent to assuming all additional storage water would be utilized. The purpose of this method is to determine how much additional water could be stored in Bear Lake on August 1 in any given year, ignoring annual carryover storage of the additional storage volume.

Answers to Study Questions

In this section, the outcomes of simulating different operating scenarios under historic hydrology and diversions are compared against a simulation of historic lake operations (the Baseline scenario). Results are distilled into performance measures which are defined in each subsection below. Graphs, tables, and text are presented for each question to provide the information needed by policymakers.

Focus Scenarios

Results are shown for all scenarios where practical, but in some cases, only results for scenarios 22, 31, 35, and 36 are shown. These were selected based on values of two performance measures, one "benefit" measure, and one "cost" measure. Briefly, a simple graphical cost-benefit analysis was performed comparing the benefit of additional storage in Bear Lake to the "cost" of impacts on high-runoff in the Gentile Valley and in reaches below Oneida and below Cutler reservoirs. In Gentile Valley, one of these impacts is the frequency of inundation of agricultural land. The performance measures are explained more fully in sections that answer Questions 2 and 4 in the Results section of this document and the cost-benefit analysis is explained in the Trade-Offs section.

In answering the study questions, we give more attention to Scenario 31 throughout this report for the sake of brevity when graphs and discussion of a single scenario suffice to make the point. The selection of Scenario 31 is based on professional judgment and is shown later in the Trade-Offs section to be an optimal point among the scenarios evaluated.

Question 1. How often could Bear Lake have stored additional water (without increasing water levels above the OHWM)?

Because the study focuses on how changes to high-runoff management could increase storage in Bear Lake, the only years in which additional volume could have been stored in Bear Lake are in years where high-runoff management was necessary. Fifteen of the 39 years in the study were managed for high-runoff, the rest were controlled by irrigation deliveries. Four of the years in which additional volume could have been stored were followed by a year during which high-runoff management was unnecessary. We classified each water year in the study period as either an irrigation delivery, high-runoff management, or carryover year. A carryover year is a year with high-runoff management followed by a year where releases were controlled by irrigation delivery. Distinguishing the carry-over years from the rest of the high-runoff management years is important because any additional volume stored during the carry-over year could be utilized over multiple dry year.

The three classifications are defined as follows:

Irrigation delivery year: A year in which releases from Bear Lake were made exclusively for delivery of contracted irrigation water.

High-runoff management year: A year in which storage is evacuated from Bear Lake for high-runoff management purposes. Note that this classification does not mean that storage releases for high-runoff management were not used for irrigation. In high-runoff management years, storage may be released solely for irrigation purposes during some portion of the irrigation season.

Carry-over year: A special type of high-runoff management year when the subsequent year is classified as irrigation delivery. This year represents a transition from high-runoff management to a year (or years) during which lake releases were made exclusively for irrigation delivery. Classifications for each water year are shown in Figure 3, which provides a quick understanding of how Bear Lake was operated from 1980-2018. Of the 39 years simulated, 15 are classified as high-runoff management which means 38% of the time was spent in high-runoff management mode. The remaining 62% of the time, or 24 years, were exclusively irrigation delivery. There were 4 periods of irrigation delivery which lasted 1, 8, 11, and 4 years (an average of 6 years). Carry-over years are

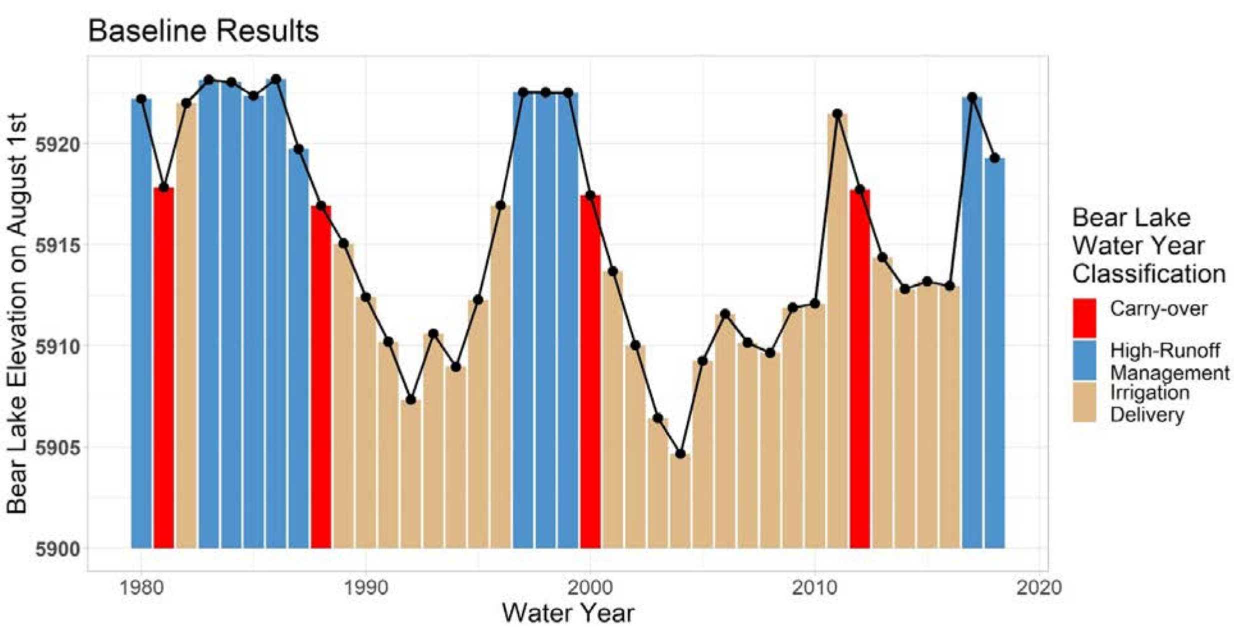


Figure 3 - Plot of Bear Lake elevation on August 1st of each year from the results of the Baseline simulation using the perfect forecast. Each water year has a representative bar colored according to the classification of whether any releases were made for high runoff.

indicated by the red bars in Figure 3. Table 3 also provides a breakdown of the types of years during the study period. These are years in which changing high-runoff management operations could have had the greatest impact since they are years transitioning from high-runoff management to irrigation delivery. A year in which releases from storage are made for high-runoff management prior to entering a dry period is when the potential advantage to reduce those releases may be the most important. Four of the high-runoff management years were carry-over years. 1982 was a carry-over year which occurred during a wet period and was followed by a single year of irrigation delivery.

***Table 3** - Summary of water year classifications and percentage of occurrence during the simulation study period.*

	Bear Lake Baseline	Percent of Total
Simulation period	39 years	
High-Runoff Management	15 years	38%
Carry-over	4 years	10%
Irrigation Delivery	24 years	62%
Number of dry periods	4	
Mean length of dry periods	6 years	

The historic record of Bear Lake water surface elevation allows us to classify types of water years back to 1920 based on analysis of the simulation period just discussed. Instead of using the purpose for which releases were made in the model simulation, we classify years with an August 1 lake elevation greater than 5,917.0 as high-runoff management. This elevation was selected based on observation of elevations in Figure 3. Figure 4 plots the August 1 elevation of Bear Lake for each year in the 99-year record with its yearly classification. Note that in this elevation-based classification scheme, the carry-over year of 1981 is not included as it was in Figure 3.

Based on historic lake operations and according to this classification scheme, if the present year were known to be a high runoff management year, then there is a 17% chance that the next year will be irrigation delivery. This percentage is fairly low because of a past tendency to experience recurring high runoff management years. In other words, the percentage indicates an 80% chance that a high runoff management year will be followed by another high runoff management year. Figure 4 shows that all of the high runoff management years except for a few occurred in groupings of four or more. Without knowing the classification of the present year, there is a 7% chance that a high runoff management year comes which will then be followed by an irrigation delivery year. Meaning that in the past 100 years this ordered pairing of a high runoff management to a carry-over year has occurred seven times, three of which happened during the 39-year model simulation period. Throughout the period of record, the carryover years are regular and evenly spaced except for the 1930s drought.

Based on another assessment done using watershed climate (rather than lake elevation), the chance of two consecutive high runoff management years is 20%. The difference between the 80% high runoff management years (using lake elevations) and the 20% (using basin hydrology) demonstrates the combined effects from both lake management and low demand for supplemental storage during wet years. When the lake is managed for high-runoff management there is a high chance that the next year will also be managed that way. Current operations permit the lake to remain relatively high. Large reductions in the lake level for irrigation delivery made in years after a carry-over year have the most profound impact on lowering the elevation of the lake. Essentially, the frequency at which Bear Lake could have stored more water is directly related to the goal of the overall operations which attempts to balance the risk of flooding with the risk of reducing storage prior to entering a dry period. High-runoff management is an important consideration because historically the chance of wet-wet year pairings (33%) is much higher than wet-dry year pairings (7%). Furthermore, if the current year were wet and managed for high runoff then there would be an 80% chance that the following year will also be managed for high runoff, compared to a 17% chance that during the subsequent year no releases are made for that purpose.

If the PTE were higher, additional water could have been stored in Bear Lake during what were high-runoff management years. Impacts on high runoff in Bear River downstream of Bear Lake associated with storing the additional water are discussed in the section which answers Question 4. Trade-offs between additional storage and high runoff impacts are presented in the Discussion section. Much of the additional storage will be nullified when another high-runoff management year necessitates its release. Moreover, this answer is complicated by changes to downstream flow constraints because increasing the flow capacity would have reduced storage in some years, for some scenarios.

Based on results from Scenario 31, between 1980 and 2018, additional water could have been stored during 7 of the 15 high-runoff management years, with the greatest volume being stored on each of the 4 carry-over years. Results found 4 of the 15 years would have had less storage than the Baseline. It would have been possible to store more water during all 15 years if the PTEra were high enough. The last year of simulation, 2018, is classified as a high-runoff management year since water year 2019 is not included in the study. Historically, during the 99 years of record that were analyzed outside of the model, the lake was in a high-runoff management regime for 41 years. We estimate that 18 of those could possibly have been able to store more water, 7 of which were carryover years.

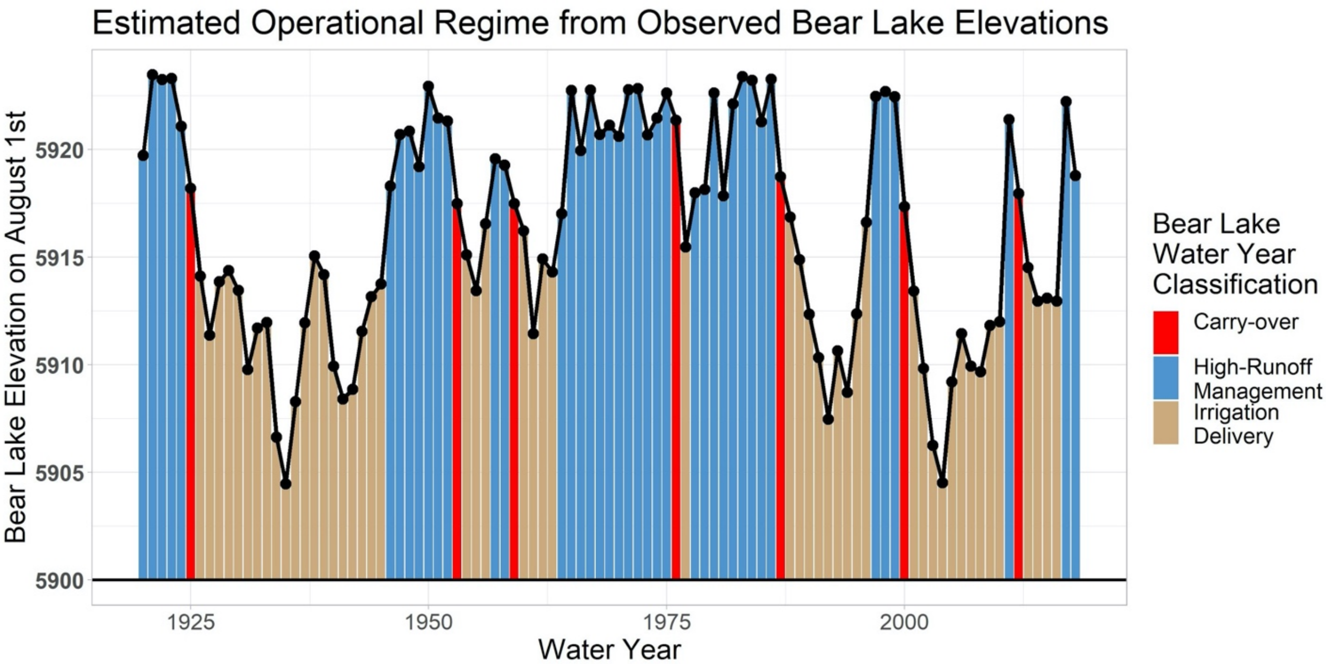


Figure 4 - Time series plot of historical measurements of Bear Lake elevation on August 1st. from 1920 - 2018. Years above elevation 5,917.0 are categorized as high-runoff management (wet) whereas years below are categorized as irrigation delivery (dry). Wet years which are succeeded by dry years are colored red indicating their value as potential for storage carry-over into a dry period. Probabilities of interest are displayed in the gray box.

Question 2. What volume of additional water could have been stored in Bear Lake (without increasing water levels above the OHWM)?

The Joint Bear River Planning Model was utilized to determine the additional volume of water that could have potentially been stored in Bear Lake under 39 high-runoff management scenarios. The additional storage volume was determined by comparing the modeled storage in the reservoir to the modeled storage in the Baseline scenario. Two simulation methods were utilized to determine the range of additional water that could have been stored in Bear Lake. These two simulation methods represent two extremes in the utilization of additional Bear Lake Storage Water. At the time of this report, no use had yet been determined for the additional water stored in Bear Lake. Policymakers wanted to understand the timing and volume of potential of increased storage water in Bear Lake before negotiating the management and usage of the new storage water. Therefore, the model does not make any changes to historic water use.

In the first simulation method, referred to as the Continuous simulation method (see Figure 5), all the additional water stored in Bear Lake is held in the reservoir and carries over into the following year. This water is evacuated only if high-runoff management necessitates it in the following years. In the second simulation method, known as the Yearly simulation method (see Figure 6), all of the additional storage in the reservoir is removed instantaneously on August 1, when the new high-runoff management season begins. In other words, all additional storage that year would have been utilized and none carried over for the next season. During years without high runoff management, the Yearly method matches the Baseline Scenario. While neither simulation method is completely practical, together they provide limits on the amount of additional water that could have been stored in Bear Lake by changing the two parameters in the high-runoff management policy.

Table 4- *Comparison of mean increase in Bear Lake storage on August 1st during carry-over years for all 39 scenarios. Results from the Yearly simulation method and perfect forecast. Blue shading highlights increases whereas red shading shows a storage decrease. Focus scenarios are highlighted by yellow boxes. Units are thousands of acre-feet.*

Bear Lake - Average additional volume on August 1st for carry-over years (TAF)					
PTEra (ft.)	Scenario Default	GVtmf			
		1500	2000	2600	3000
3.5	5921.5	197	197	197	197
3.0	5921.0	168	168	168	168
2.5	5920.5	138	138	138	138
2.0	5920.0	111	111	111	111
1.5	5919.5	84	84	84	84
1.0	5919.0	57	57	57	57
0.5	5918.5	31	28	28	28
0.0	5918.0	0	-7	-7	-7
-0.5	5917.5	-25	-39	-40	-40
-1.0	5917.0	-46	-71	-72	-72

Table 5 *- Comparison of mean increase in Bear Lake storage on August 1st during high-runoff management years (includes carry-over years) for all 39 scenarios. Results from the Yearly simulation method and perfect forecast. Blue shading highlights increases whereas red shading shows a storage decrease. Focus scenarios are highlighted by yellow boxes. Units are thousands of acre-feet.*

Bear Lake - Average additional volume on August 1st for high-runoff management years (TAF)					
PTEra (ft.)	Scenario Default	GVtmf			
		1500	2000	2600	3000
3.5	5921.5	109	108	107	107
3.0	5921.0	83	79	77	77
2.5	5920.5	56	50	46	45
2.0	5920.0	47	42	39	37
1.5	5919.5	35	31	26	24
1.0	5919.0	23	15	10	9
0.5	5918.5	12	0	-6	-7
0.0	5918.0	0	-17	-23	-24
-0.5	5917.5	-9	-32	-37	-37
-1.0	5917.0	-16	-45	-49	-50

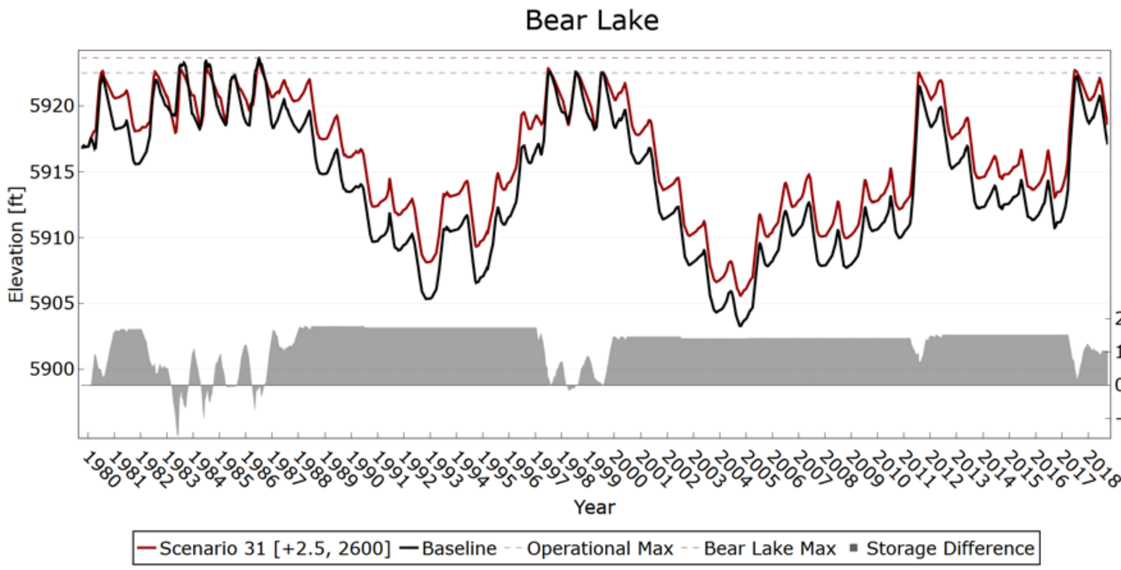


Figure 5 - Comparison of daily Bear Lake elevations between the Baseline simulation and Scenario 31 using the Continuous method and perfect forecast. Daily volumetric differences between the two are graphed along the secondary vertical axis.

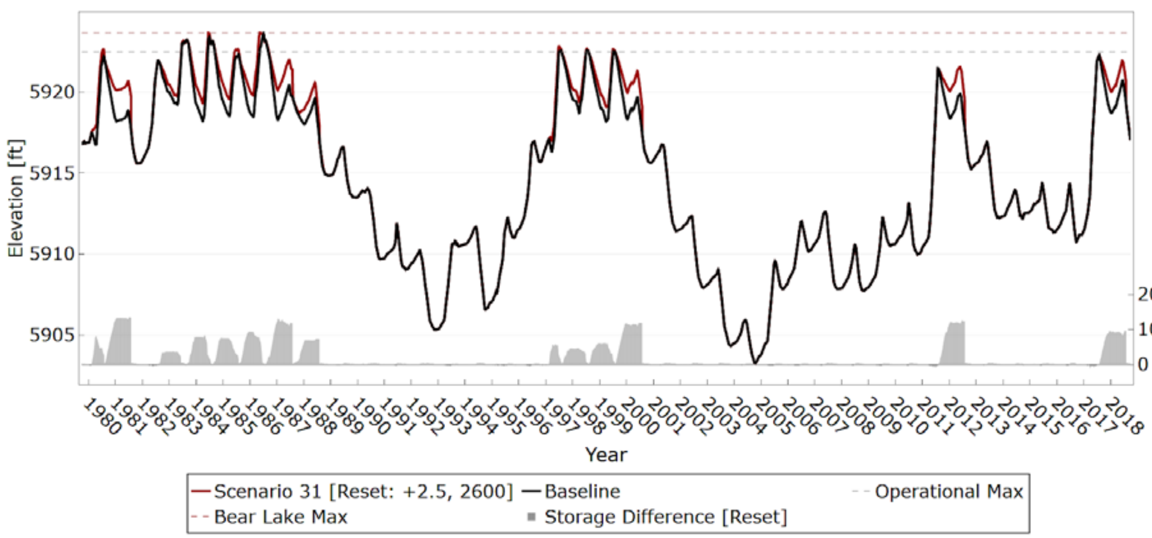


Figure *6 – Comparison of daily Bear Lake elevations between the Baseline simulation and Scenario 31 using the Yearly method and perfect forecast. Daily volumetric differences between the two are graphed along the secondary vertical axis.*

Simulation results of average additional volume on carry-over years for all scenarios computed using the Yearly method are shown in Table 4. As can be seen in Table 4, the average additional storage volume is closely associated with adjustments to the PTE. Each increase of 1.0 foot in PTE increases the average annual volume on carry-over years by 58,000 acre-feet. GVtmf has little impact on average annual storage volumes. GVtmf is directly related to the inundation risk in Gentile Valley. An increase in GVtmf reduces inundation risk.

Simulation results of average additional volume on all high-runoff management years for all scenarios computed using the Yearly method are shown in Table 5. Again, the average additional storage volume is closely associated with adjustments to the PTE. The average storage available is lower when including all years when additional water could have been stored.

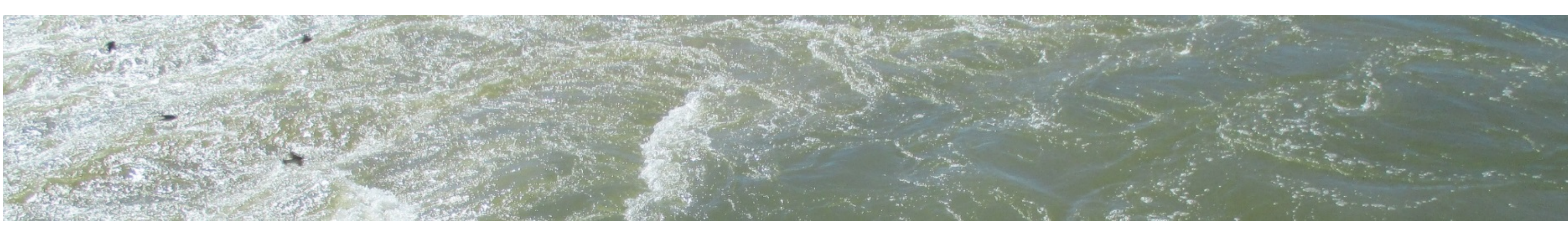
Each increase of 1.0 foot in PTE increases the average annual volume on high-runoff management years by 31,000 acre-feet. GVtmf has more impact on annual storage volumes the set of high-runoff management years includes years when more water could have been evacuated to hit the PTE.

The storage benefits gained in Scenario 31 using the Yearly simulation method are shown in Figure 6 which compares the storage in Bear Lake under Scenario 31 versus the storage in Bear Lake under Baseline simulation. Figure 6 presents daily values of the two Bear Lake elevations for the full simulation period together with the volumetric differences between the two curves. Most of the additional storage occurs in carry-over years. In 1987 and 1988 as the climate was shifting from a wet to a dry phase, there appeared to be additional storage water in both years. However, it should be noted that if all the water stored in 1987 was not used that year, some of the additional water may have been spilled when space was evacuated in Bear Lake to capture runoff in 1988. The difference in volume between Scenario 31 and the Baseline, was typically less or negative during high-runoff management years. Potentially some of the additional volume in Bear Lake on a carryover year could be utilized over multiple ensuing dry years until a wet cycle commenced that would result in excess storage being released for high-runoff management purposes.

The potential benefit of additional storage during dry periods is illustrated more clearly by the Continuous simulation method. One possible benefit of additional storage water would be to spread its use over a period of dry years when releases would not be made for high-runoff management. If a downstream use for the additional storage water had been modeled, then the brown bars in the irrigation delivery years (shown in Figure 3) would decline at the rate of the proposed new storage demand. Both simulation methods clearly show that for Scenario 31 there were 7 years when additional water could have been stored. Results from the two methods are approximately equivalent for high-runoff management years. For Scenario 31, using the Yearly method, the mean increase during all 15 high-runoff management years (which include the 4 carry-over years) would have been 46,000 acre-feet. This value is diminished by the decrease in storage which would have occurred during the mid-1980s. The mean increase during carry-over years using the Yearly method would have been 138,100 acre-feet, a volume lower than that computed using the Continuous simulation method (161,600 acre-feet).

Just as with the Continuous simulation method, the. Yearly simulation method shows years that would have had increased storage and others with decreased. The decreased storage occurs because increases to GVtmf over the baseline allows adequate space to be evacuated from Bear Lake for flood control space, which prevents or decreases the risk of inundating agricultural land downstream of Bear Lake. Higher releases allow the Bear Lake elevation to reach the targeted PTE which under the Baseline simulation (and actual practice) were unachievable because of downstream target maximum flow constraints.

Another way to measure the change in storage is to consider the total cumulative increase during all 39 years using the yearly simulation method. The total additional storage on August 1 is summed for every year of the simulation and presented in Figure 7 for the four focus scenarios. Scenario 22 (PTEra = 1.5 ft., 2000 cfs) had the lowest total increase with 455,000 acre-feet. Scenario 31 (PTEra = 2.5 ft., 2,600 cfs) included 690,000 acre-feet of additional storage. No advantage in total additional storage is attained between Scenario 35 and Scenario 36, in which the PTEra is 3.0 feet for both scenarios, but the GVtmf increases from 2,600 to 3,000 cfs, respectively.



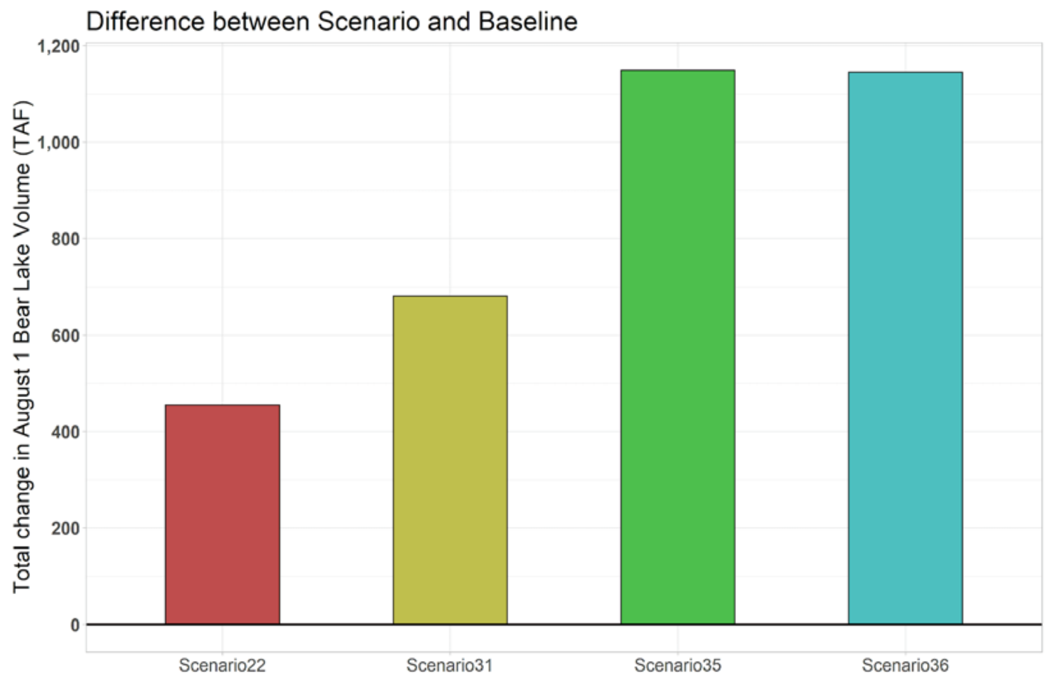
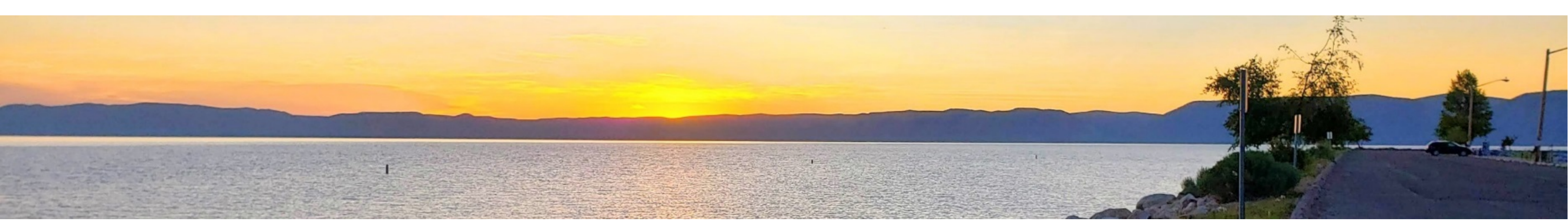


***Figure 7** – Changes to total storage in Bear Lake on August 1st summed over the 39-year simulation period for the different operation policies represented in the focus scenarios using the Yearly simulation method and perfect forecasts.*



Insight from Using Actual Historic Forecasts

It is important to remember that the additional volume represented in the above analysis is based on the use of perfect forecasts. When the model is run with historic forecasts, which sometimes fall above and below the volumes utilized for the perfect forecast, additional volume changes vary from those predicted by the perfect forecast. In actual operations, PacifiCorp does not know the volume of spring runoff and must rely on forecasts from the Natural Resource Conservation Service (NRCS) and/or Colorado Basin River Forecast Center to determine the PTE. The forecast can be either greater than or less than observed runoff. This section compares the additional storage resulting from use of historic forecasts and perfect forecasts for the Baseline Scenario and Scenario 31.

The key target elevations for the Joint Bear River Planning Model are shown in Table 6 for the Baseline and Scenario 31. On August 1st the PacifiCorp Target Elevation (PTE) is set for a default value. During the forecast period during the months of January through March the PTE is set in a range between the Min and Max values based on the forecasted runoff. The PTE is set based on the volume of space that needs to be evacuated below the operational maximum so that adequate space is available in the reservoir to capture the April to July forecasted runoff. During extremely wet winters with significant snowpack the PTE is pushed to the minimum value to maximize available storage space to capture the spring runoff, while during drought years the PTE is pushed to the maximum value to increase the likelihood of filling the reservoir during the spring runoff.

Once the flood control space has been evacuated and the PTE achieved on March 31, the Operational Max (Op. max) is set to 5,922.5 in both scenarios, leaving a "freeboard" of 1.15' to reach a maximum reservoir capacity of 5,923.65. The elevation 5,923.65 is the designated original high water mark (OHWM) or Bear Lake maximum content. During the flood control years of the late 1990s, when the Baseline Scenario and Scenario 31 are run with a perfect forecast the model tries and succeeds in filling Bear Lake to the operational max at the end of the runoff period. Likewise, when both the Baseline and Scenario 31 are run with the historic forecast, because the forecasts under-predicted runoff in the late 1990s (more runoff arrived than was anticipated) storage was pushed above the operational max toward the OHWM. The differences in storage between the Baseline and Scenario 31 were small (see Figure 8) under both forecast conditions in these years because the scenarios share the same fill target. Insight into the impacts of historical forecast uncertainty on the additional storage volume is gained by using the historic NRCS 50% probability of exceedance forecast, which was used in place of the perfect forecast. Although PacifiCorp considers all available information on hydrologic conditions and available forecasts to determine how much space to evacuate in Bear Lake, the use of the 50% probability of exceedance forecast is suitable for the planning purposes of this study. Although reservoir operations were modeled using other exceedance

***Table 6** - Comparison of the reservoir elevation targets between the Baseline and Scenario 31 used in comparing results of the prefect and historic forecasts.*

	Min.	Default	Max.	Op. max	OHWM
Baseline	5916.0	5918.0	5920.0	5922.5	5923.65
Scenario 31	5918.5	5920.5	5922.5	5922.5	5923.65
Time Period	Jan-Mar	Aug-Dec	Jan-Mar	Apr-Jul	

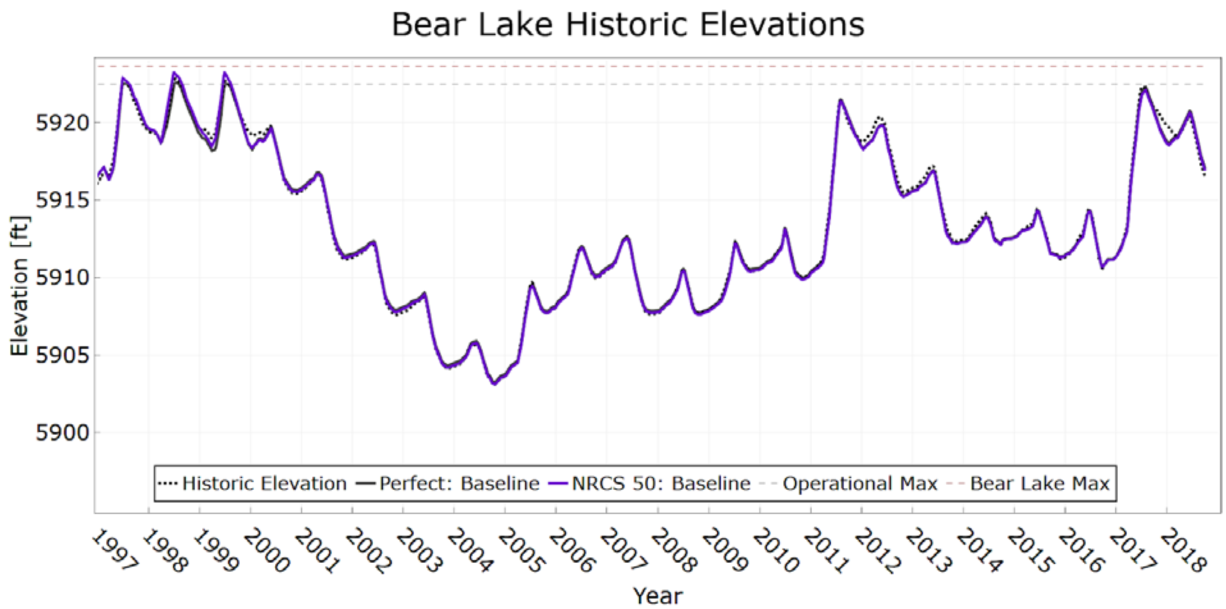


Figure 8 *- Bear Lake historic reservoir elevation (dotted line) compared against the Baseline Scenario for the perfect forecast (black line) and NRCS 50% (dark purple) probability of exceedance forecast.*

probabilities, the NRCS 50% exceedance forecast was utilized in this study, because the reservoir elevations generated by use of NRCS 50% exceedance forecast were found to most closely match both the historic reservoir elevations and the simulated baseline with the perfect forecast, as shown in Figure 9.

Reservoir elevations are compared in Figure 9 from the Baseline and Scenario 31 for the perfect forecast and NRCS 50% probability of exceedance forecast based on the Continuous Simulation Method. The additional storage volumes attained during high-runoff management years from 1997 - 2018 when using the NRCS 50% exceedance forecasts were generally less than the additional storage volume attained when using the perfect forecasts (see Figure 10).

There are three carryover years in which significant storage could have been gained under Scenario 31: 2000, 2012, and 2018. In 2000, use of the perfect forecast indicates that 146,300 acre-feet of additional storage could have been gained under Scenario 31. However, when the NRCS 50% probability of exceedance forecast is utilized only 63,800 acre-feet of additional storage gained. This additional volume is 45% of the storage added with a perfect forecast. This storage difference is due to an over-prediction of runoff. The runoff volume forecasted by the NRCS 50% exceedance forecast was 240,000 acre-feet on January 1st and changed little by April 1st when it was 202,000 acre-feet. Comparatively, the actual runoff volume was 49,500 acre-feet. Such a large over-forecast resulted in significant space being evacuated in Bear Lake that could not be filled during the runoff period.

Differences between forecasted and actual runoff volumes were much lower in 2012 and 2018. In 2012, the NRCS 50% probability of exceedance forecast was 130,000 acre-feet on January 1st and 70,000 acre-feet on April 1st. The actual runoff was 36,700 acre-feet. In 2018 the January forecast started at 145,000 acre-feet on January 1st and reduced to 110,000 acre-feet on April 1st. The actual runoff was 85,500 acre-feet. Because the over-prediction of runoff was less in 2012 and 2018 than in 2000, the additional storage in the Bear Lake came closer to reaching the additional storage attained under the perfect forecast. The additional storage in 2012 using the historic forecast was 77% of the additional storage volume predicted with the perfect forecast, and the additional storage in 2018 using the historic forecast was 76% of that achieved using the perfect forecast. Because the actual flow was less than the forecast in these three carryover years, the additional storage volume predicted by the perfect forecasts is greater than the additional storage volume predicted by the historic forecast.

In addition to the three carryover years, there were four additional high-runoff management years in the study period: 1997, 1998, 1999, and 2017. Figure 10

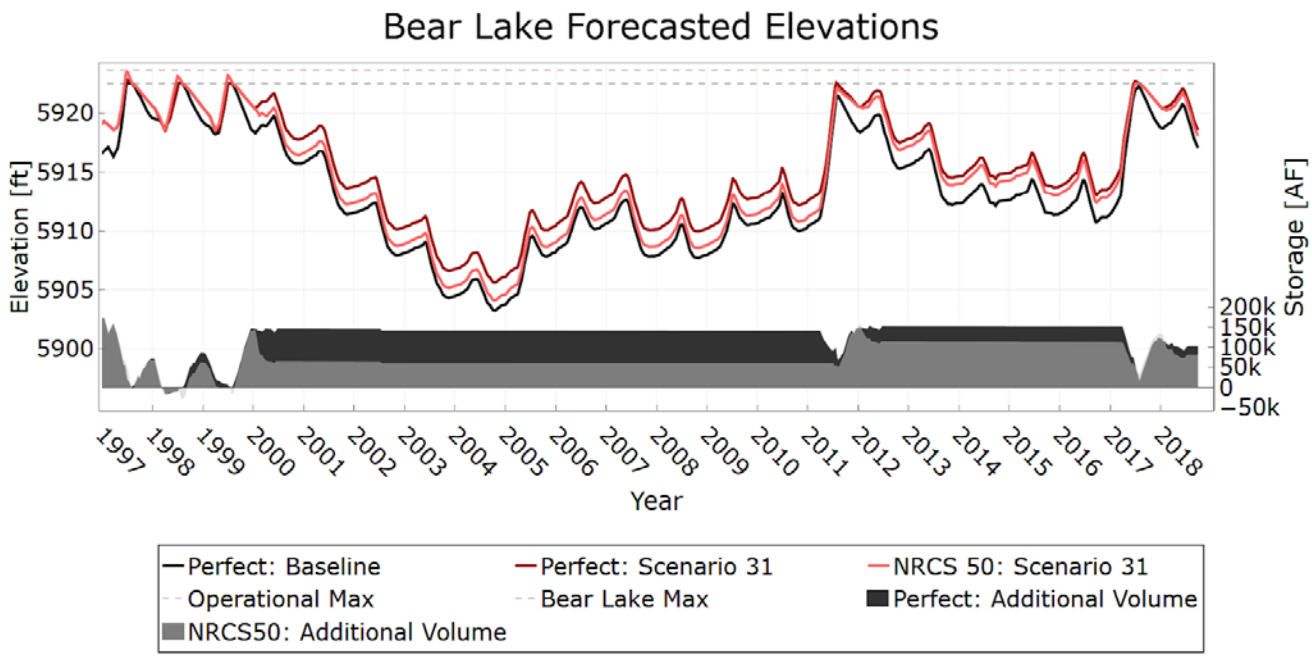


Figure 9 *- Comparison of Bear Lake elevations between the Baseline and Scenario 31 when the model is run using the perfect forecast (black line for the Baseline Scenario and dark red line for Scenario 31) and the NRCS 50% probability of exceedance forecast. The volume of additional storage in Scenario 31 is shown as light grey for the perfect forecast and dark grey for the NRCS 50% probability of exceedance forecast.*

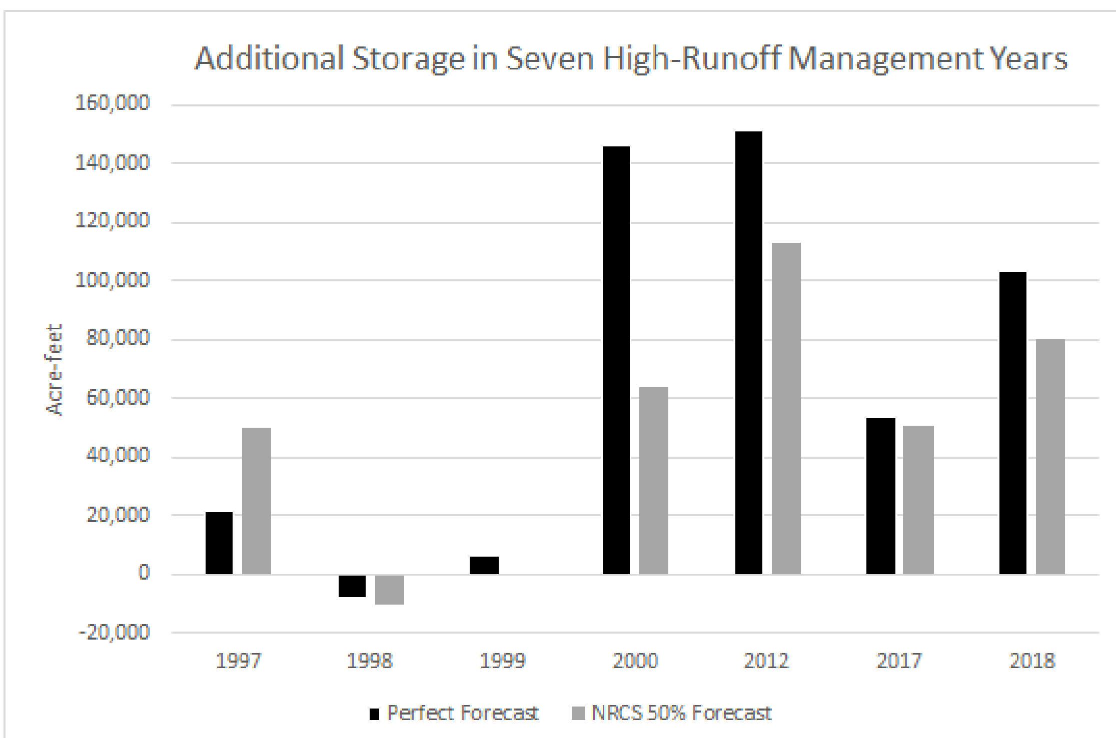


Figure 10 *- Comparison of additional storage volume for seven high-runoff management years when Baseline storage in Bear Lake is subtracted from Scenario 31 storage using both the NRCS 50% probability of exceedance forecast (grey bar) and the perfect forecast (black bar).*

shows the difference in additional storage between the perfect and historic forecasts in the seven high-runoff management years between 1997 and 2018. Because the 2017 forecast came close to the perfect forecast, the additional storage values predicted using both forecasts are nearly identical. In 1997, the NRCS 50% probability of exceedance forecast under predicted runoff by 23,000 acre-feet, which resulted in more storage being attained under the historic forecasts as compared to the perfect forecast. In 1998 and 1999, storage differences between the two forecasts were minimal.

Comparison of the perfect and historical NRCS forecasts indicates that the additional storage benefit predicted by the historic forecasts during this time period is less than the additional volume achieved under perfect forecasts in 6 out of 7 years. However, 1997 provides a scenario when the amount of additional storage gained with an actual forecast could be greater than the additional storage gained through use of a perfect forecast.

Question 3. What would have been the effect on the Bear Lake equivalent elevation of 5,911.0 feet?

The Bear Lake equivalent elevation is that elevation which Bear Lake would reach if all water stored in Mud Lake was diverted into Bear Lake. This is a method to account for all water stored used in the procedure of determining a restriction for upstream storage.

The Bear River Compact[5] defines two types of storage upstream of Bear Lake: Original Compact Storage, which is indifferent to Bear Lake elevations, and Amended Compact Storage, which is only allowed when the Bear Lake equivalent elevation is 5,911.0 feet or higher. The restriction of storage could impact both Wyoming and Utah water users upstream of Bear Lake as some of the reservoirs that serve water users in both states rely heavily on amended compact storage for fill. Note that any additional storage upstream of Bear Lake would reduce the amount available for increased storage at Bear Lake by decreasing inflow to the Rainbow Inlet Canal, although the total upstream storage capacity (current and compact-allowed future) is small relative to Bear Lake. The benefit to reservoir storage upstream of Bear Lake is anticipated to be helpful in any negotiations which may involve the state of Wyoming or upper Utah users. Understanding this, there are two sub-questions:

How much more storage would have been possible upstream of Bear Lake (benefit to Upper Division users with storage reservoirs)?

Would the additional upstream storage have reduced water available for storage in Bear Lake?

At this time, the model simulations cannot quantitatively answer these questions but qualitative answers can be provided. Also, the two simulation methods each have caveats to consider:

The Continuous simulation method overestimates carry-over in dry years because it assumes none of the additional storage would have been utilized. The no-use assumption overestimates benefits to reservoirs above Stewart Dam.

The Yearly simulation method assumes no change to historic conditions in non-high-runoff management years because carry-over impacts are ignored and all additional storage is removed at the beginning of the next high-runoff management year. The August 1 lake elevations in the Yearly simulation and Baseline simulation are equal.

The Continuous simulation method shows the maximum benefits that could possibly have been attained and is used to describe the possible upstream benefits and reduced availability for Bear Lake storage. Table 7 below shows the difference in total time the Bear Lake equivalent elevation would have been above 5,911.0 feet between scenario and Baseline Bear Lake equivalent elevations for all scenarios using the Continuous simulation method and perfect forecast. Differences range from 4 years less for the reduced PTEra scenarios, up to 8.6 years more for the

Table 7 *- Additional time (in years over the 39-year simulation) Bear Lake equivalent elevation would have been above 5,911.0 compared to the Baseline using the Continuous simulation method and perfect forecast.*

Bear Lake - Additional years above 5,911 feet from baseline (equivalent elevation).					
PTEra (feet)	Scenario Default PTE	GVtmf (cfs)			
		1,500	2,000	2,600	3,000
3.5	5,921.5	8.6	8.6	8.6	8.6
3.0	5,921.0	7.4	7.2	7.2	7.2
2.5	5,920.5	5.9	5.8	5.8	5.8
2.0	5,920.0	5.0	4.9	4.9	4.9
1.5	5,919.5	4.3	4.1	4.1	4.1
1.0	5,919.0	3.6	3.1	3.0	3.0
0.5	5,918.5	2.0	1.6	1.4	1.4
0.0	5,918.0	0.0	-0.5	-0.6	-0.6
-0.5	5,917.5	-1.1	-2.4	-2.4	-2.4
-1.0	5,917.0	-2.5	-4.0	-4.0	-4.0

[5] The Amended Bear River Compact defines the equivalent elevation as the elevation Bear Lake would reach if all the contents of Mud Lake were theoretically transferred into Bear Lake.

increased PTEra scenarios. The bolded entries highlight the results for the focus scenarios.

The total amount of time is a helpful performance measure, but it is important to consider the historical context for specific years. It is also important to assess the time of year during which the equivalent elevation would have been above 5,911.0 because in some years the upstream storage may have been full. Within-year timing is an important consideration because available flows are typically significantly higher during spring runoff. Years and calendar days when a positive difference in the equivalent elevation between Scenario 31 and the Baseline occurred during spring runoff are shown in Figure 11. Years when no difference occurred are omitted.

Qualitative answers to the two sub-questions are obtained by comparing Figure 11 to information in relevant water year reports (personal communication March 26, 2020, Kevin Payne, Division 4 Water Superintendent in Wyoming). Even without explicitly considering the timing of when Bear Lake was above 5,911.0, Wyoming reservoirs[6] would not have had many opportunities to store additional water since the reservoirs either filled regardless of Bear Lake level restrictions or natural flow was sufficient to fill them. Only 3 of the 13 years "could have utilized some additional storage." Therefore, the additional time which Bear Lake would have been above 5,911 in Scenario 31 likely would not have significantly changed upstream storage nor would flows into Bear Lake have been reduced. While the other focus scenarios were not explicitly evaluated, Table 7 indicates that the qualitative answer would be similar to those of Scenario 31.

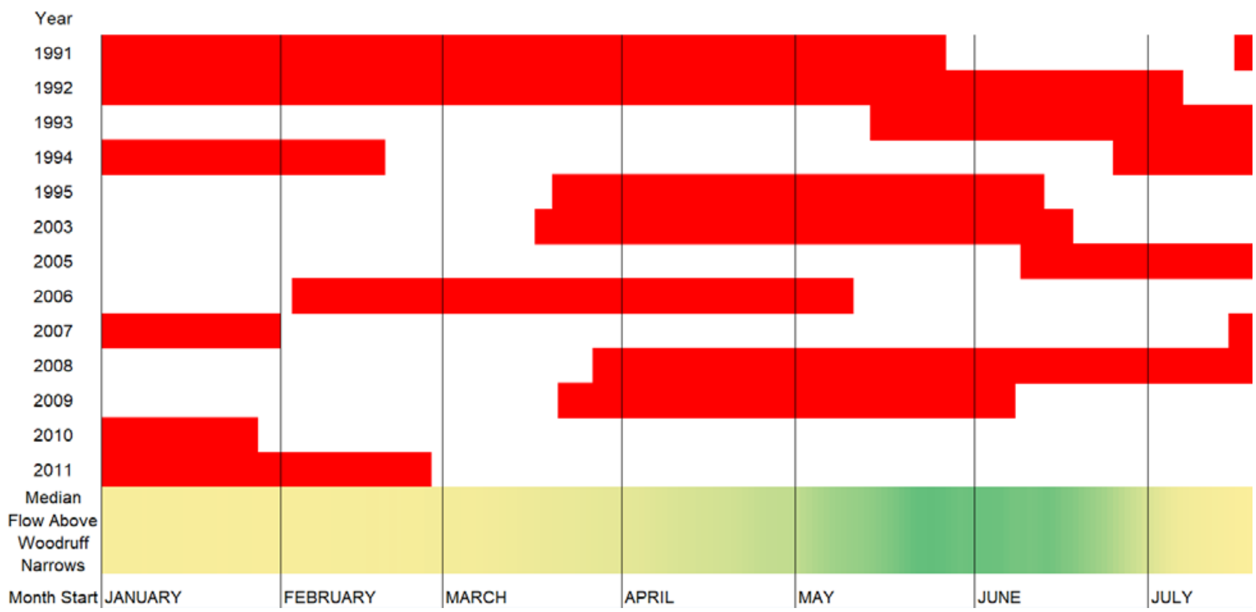


Figure 11 *- Red bars indicate days when Scenario 31 Bear Lake equivalent elevation is above 5,911.0 feet and Baseline is below. The color-graded bar at the bottom indicates intensity of runoff based on smoothed median historical daily flows. Higher streamflow is shaded green. Note that missing years (1996-2002, 2004, 1979-1990) resulted in no additional days above 5,911.0 feet in Scenario 31.*

[6] Upper division Utah reservoirs represent a smaller volume than the Wyoming reservoirs and Woodruff Narrows reservoir in Wyoming provides water to Utah users, but is accounted for as Wyoming storage.

Question 4. How would changes in high-runoff management have affected flows through Gentile Valley and downstream (below Oneida and below Cutler)?

Two complementary performance measures can be used to answer this question: 1) the duration of flows above location-specific target maximum flow thresholds and 2) seasonal peak flow rates. The duration of flows summarizes the impact across all daily flow values while the seasonal peak flow rates focus on the highest flow rates which are often indicative of maximum impact due to high runoff

Flow Duration

Flow durations for the Baseline and the focus scenarios (22, 31, 35, and 36) are shown in Figure 12. Each scenario has its own model threshold (the GVtmf highlighted in yellow), which was used for model operations in the corresponding scenario and resulted in a specific flow rate for each day of the simulation. The daily flow rate through Gentile Valley during the 39-year simulation is summarized by computing the percentage of time that each scenario's daily flow was above each of the 4 possible GVtmf values explored in this study (not just the GVtmf used for that particular scenario). This allows a broad analysis of the impact on the number of times that flows are above these thresholds.

Gentile Valley

Scenario 22 had a GVtmf of 2,000 cfs. Since flows were allowed up to 2,000 cfs the percent of time above 1,500 cfs would have increased by 5%, from 4.5% up to 9.5%. However, the total time that flows would have been above 2,000 cfs was 2.5%, nearly the same as the Baseline. Time spent above 2,600 and 3,000 cfs would have been reduced compared to the Baseline; this is a significant result that is similar for other scenarios: that the higher target maximum flow threshold (GVtmf) of the scenario reduces the duration of very high flows, reducing the impact of higher flows in exchange for more frequent flows up to the new, higher target maximum flow threshold.

Scenario 31 had a GVtmf of 2,600 cfs. Since flows up to 2,600 were allowed, the percent of time above both 1,500 and 2,000 cfs would have increased. Flows would have been above 2,600 cfs 1.2% of the time, compared to 1.7% during the Baseline. Total time

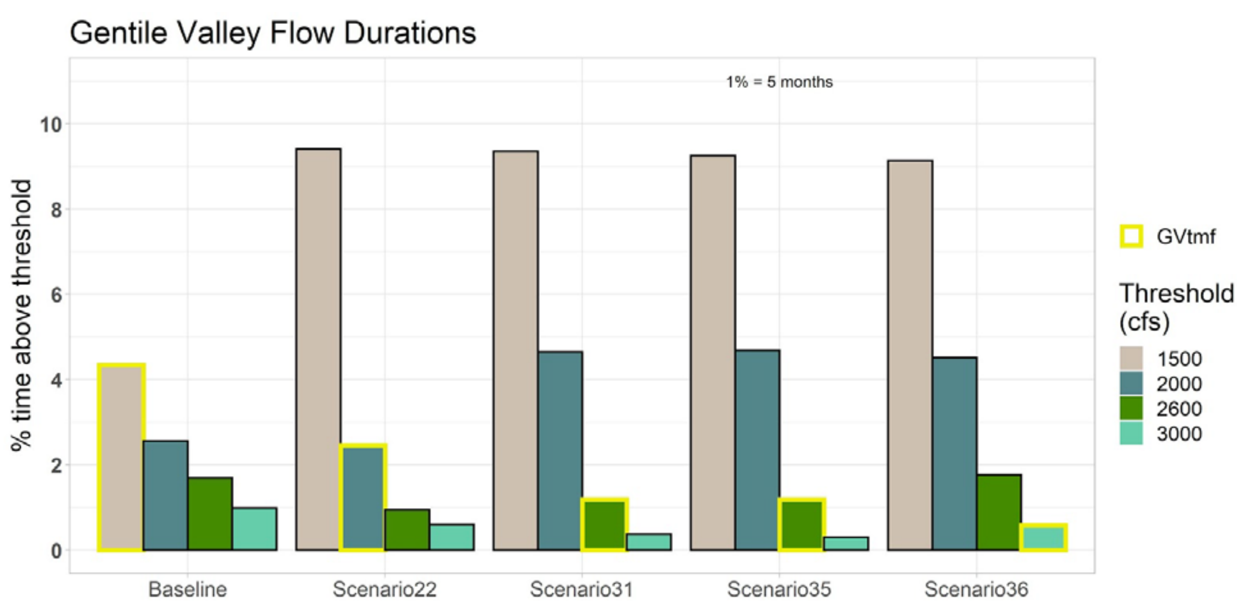


Figure 12 - Flow duration results for Gentile Valley inflows over the full simulation for all GVtmf thresholds used in the scenarios with results for the Baseline and the four focus scenarios. The value of the Gentile Valley target maximum flow (GVtmf) is highlighted. (Recall that the Baseline had a GVtmf of 1,500 cfs; Scenario 22 had a GVtmf of 2,000 cfs; Scenario 31 had a GVtmf of 2,600 cfs; Scenario 35 also had a GVtmf of 2,600 cfs; and Scenario 36 had a GVtmf of 3,000 cfs).

above 3,000 cfs would also have been reduced from the Baseline value of 1.0% down to 0.4%.

Scenario 35 also had a GVtmf of 2,600 cfs and the results are similar to those of Scenario 31.

Scenario 36 had a GVtmf of 3,000 cfs. Since flows up to 3,000 were allowed, the percent of time above both 1,500 and 2,000 cfs would have increased. Durations above 2,600 cfs would have been unchanged from the Baseline but would have been higher than the other focus scenarios. Similarly, time spent above 3,000 cfs would have been reduced compared to the Baseline but would have been higher than the focus scenarios.

All scenarios showed a reduction in the frequency of flows above 3,000 cfs when compared to the Baseline. Scenarios 22, 31, and 35 reduced the frequency of flows above 2,600 cfs, but Scenario 36 was unchanged from the Baseline for this flow rate. As expected, the frequency of flows above 1,500 cfs increased for all scenarios because the scenarios all had maximum flow targets higher than 1,500 cfs. Overall, the higher target maximum flow thresholds used in the focus scenarios (GVtmf) would have reduced the duration of very high flows thus reducing the impact of higher flows in exchange for more frequent flows up to the new, higher target maximum flow thresholds.

Oneida and Cutler Reservoirs

Similar analysis for flows downstream of Oneida and Cutler reservoirs were also determined. Of course, the same GVtmf value guides the scenario results at these locations, but since no changes to the target maximum flow thresholds are anticipated at these locations, only the current target maximum flow threshold is used for evaluating changes in flow duration. The target maximum flows at these locations were not used to govern releases from Bear Lake during model simulations. In other words, they do not have an impact on operations.

For the reach below Oneida, Figure 13 shows the flow duration results above 3,000 cfs. Only Scenario 22 reduces the duration above 3,000 cfs (from 1.8% to 1.5%), whereas the other scenarios increase it slightly (up to 2.1% and 2.2%). These are very modest increases in absolute terms and much smaller than observed for Gentile Valley. For the reach below Cutler, Figure 14 shows the flow duration results above 8,500 cfs. Scenario 22 is nearly the same as the Baseline (0.3%) scenarios 31 and 35 are 0.26%, slightly below the Baseline and Scenario 36 is 0.32%, slightly above the Baseline, but all changes are very small in magnitude.

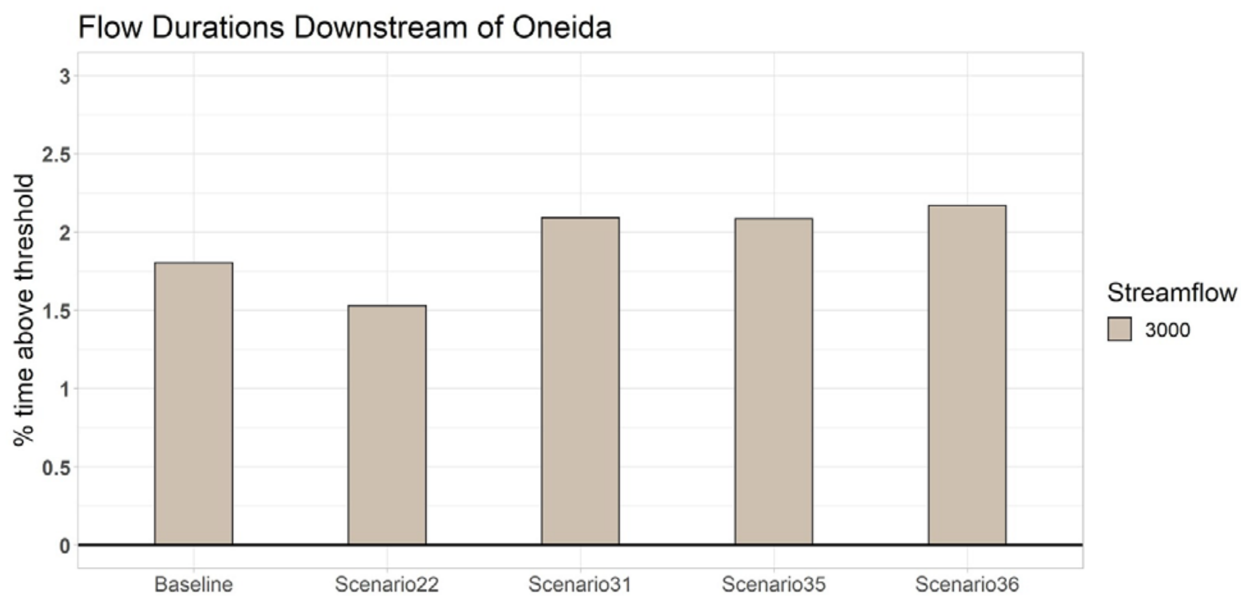


Figure 13 *- Flow duration results for Oneida over the full simulation for the GVtmf thresholds used in the scenarios with results for the Baseline and 4 focus scenarios.*

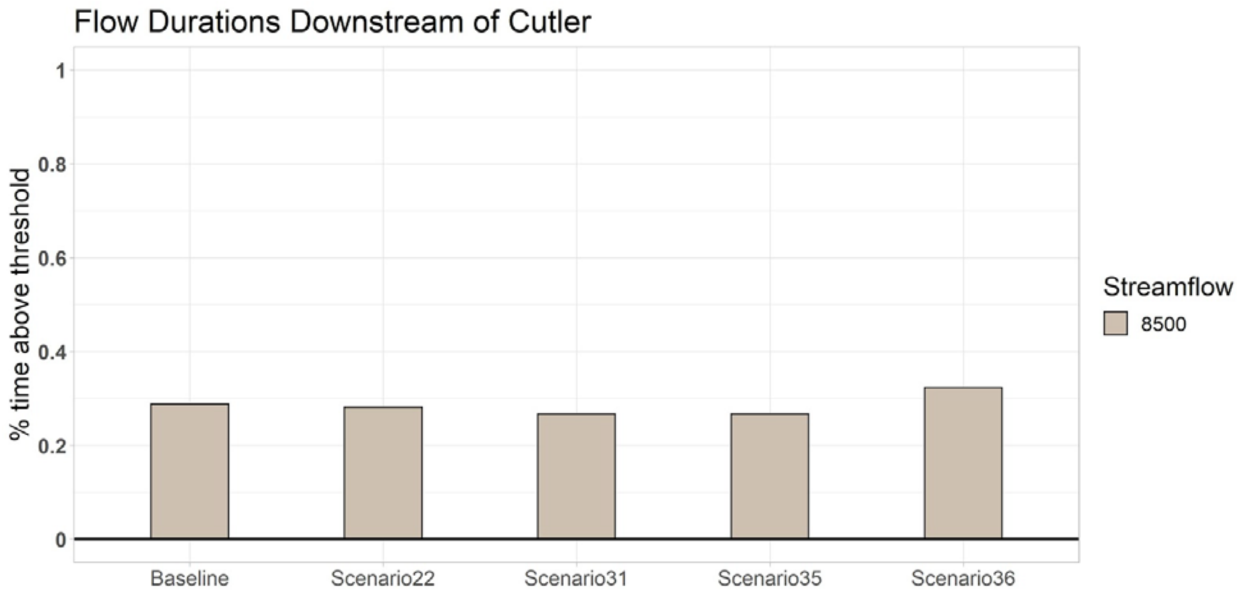


Figure 14 *- Flow duration results for Cutler over the full simulation for the GVtmf thresholds used in the scenarios with results for the Baseline and 4 focus scenarios.*

The results for below Oneida and below Cutler support the decision made in modeling to use only the Gentile Valley target maximum flow threshold to guide high-runoff management releases at Bear Lake. While the modeling rules only react to flows in the Gentile Valley reach, the exceedances of the other downstream target maximum flow thresholds are not greatly changed. Changes in peak flow and frequency are treated in the next.

Peak Flow Magnitude and Frequency

Another way to assess impacts to high runoff downstream of Bear Lake is to examine the magnitude of seasonal peak flows. Peak flow and frequency can be indicative of the maximum impact due to high runoff. Two seasons are considered, winter from January through March and spring from April through July. The other months (August through December) are the dry season with no significant historical peak flows. Winter peak flows are often natural events driven by runoff below Bear Lake that cannot be controlled. Spring peak flows are much more likely to be driven by high-runoff management being controlled at Bear Lake. However, winter peak flows may also be influenced by high-runoff management releases from Bear Lake. In some cases, downstream flows primarily driven by local runoff or reach gains (surface tributary inflow, groundwater inflow, and irrigation return flow) can be increased relative to the Baseline if higher Bear Lake releases are made in some of the scenarios as a result of the higher GVtmf.

An effective way to convey changes in peak flows resulting from changes to high-runoff management operations is to plot and compare seasonal peak flows from the scenarios and the Baseline.

To get numerical results to quantify the impact, there are two high-runoff performance measures (HRPMs) per Equation 1.

HRPM1 is the exceedance of the scenario target maximum flow threshold.

HRPM2 refines HRPM1 by counting only the scenario peak flows that also exceeded the corresponding Baseline peak flow. Both are evaluated in each season every year at all sites and presented in Table 8, but only the combined results and selected other numerical results are shown since the plots convey all of these values visually. Exceedances of the target maximum flow are the main consideration (HRPM1) while, ideally, no scenario would also exceed the peak flow modeled for the Baseline

$$\textit{High-Runoff Impact Index}_{Scenario} = \sum_{locations}\sum_{seasons}\left[(HRPM1_{Scenario} - HRPM1_{Baseline}) + HRPM2_{Scenario}\right] \qquad \text{(Equation 1)}$$

variables that represent existing high-runoff management at Bear Lake (HRPM2). Both are important and it is possible to have fewer exceedances of a target maximum flow which changes from scenario to scenario while still having some scenario's peak flow higher than the Baseline peak in a particular season in a given year. It is desirable to have as few exceedances of both as possible. As the target maximum flow increases, it is possible to exceed the higher threshold less often, but still exceed the peak flow of the Baseline case in some instances.

These two high-runoff performance measures to get a single value termed the high-runoff impact index for each scenario. The high-runoff impact index is the difference in HRPM1 between the scenario and the Baseline, added to HPRM2 for the scenario, summed over both seasons (winter and spring) and all three locations (Gentile Valley, downstream of Oneida and Cutler reservoirs)

Values of HRPM1 and HRPM2 and the high-runoff impact index for both winter and spring seasons for all 39 years for all three sites: Gentile Valley, Oneida, and Cutler are shown in Table 8. Note that the table shows the HRPM1 in the first 4 columns of the table and HRPM2 in the middle 4 columns of the table. The shading in the last 4 columns of Table 8 corresponds to the value of the high-runoff impact index with blue indicating fewer events than Baseline and red indicating more events than Baseline. An example of how the high-runoff impact index is calculated may be useful: The calculation for Scenario 31 (the 2.5; 2,600 entry in Table 8) is as follows: HRPM1 is 15 events, while the Baseline HRPM1 is 21 events. The difference is -6 events (15 - 21). HRPM2 for Scenario 31 is 5, so the high-runoff impact index is –1 (-6 + 5). (The table values are already summed over the locations and seasons).

To summarize Table 8, the Baseline (PTEra of 0.0 and GVtmf of 1,500) had 21 combined peak flow events above 1,500 cfs for Gentile Valley, 3,000 cfs for Oneida, and 8,500 cfs for Cutler. The bolded entries highlight the focus scenarios. For HRPM1, Scenarios 22 and 31 both had 15 exceedances of their respective thresholds while Scenarios 35 and 36 had 16 and 18, respectively. All scenarios had fewer exceedances than the Baseline.

When HRPM2 is considered, the scenario exceedances of the Baseline peak flow and the scenario target maximum flow, Scenario 22 has 3 peak flow events, while Scenario 31 has 5, Scenario 35 has 7 and Scenario 36 has 6. When the high-runoff impact index is calculated, Scenario 22 has 3 fewer events than the Baseline, while Scenario 31 has 1 less, Scenario 35 has 2 more and Scenario 36 has 3 more. The rest of

***Table 8** – High runoff performance measures (HRPM) for all seasons and locations combined. Bold italics indicate the Baseline scenario; bold and yellow outline indicates focus scenarios. (Recall that the Baseline is the 0.0, 1,500 entry; Scenario 22 is the 1.5, 2000 entry; Scenario 31 is the 2.5, 2,600 entry; Scenario 35 is the 3.0, 2,600 entry; and Scenario 36 is the 3.0, 3,000 entry).*

Gentile Valley, Oneida, Cutler Combined													
PTEra (feet)	Scenario Default PTE	HRPM1 Number of years with winter or spring peak flow well above target threshold.				HRPM2 Number of years with winter or spring peak flow above baseline peak and well above target threshold.				High-Runoff Impact Index - Net of HRPM 1 above baseline plus HRPM 2			
		GVtmf				GVtmf				GVtmf			
		1,500	2,000	2,600	3,000	1,500	2,000	2,600	3,000	1,500	2,000	2,600	3,000
3.5	5,921.5	26	19	18	19	22	16	12	11	27	14	9	9
3.0	5,921.0	23	19	**16**	**18**	17	12	**7**	**6**	19	10	**2**	**3**
2.5	5,920.5	23	19	**15**	17	17	11	**5**	6	19	9	**-1**	2
2.0	5,920.0	23	17	17	22	12	8	5	8	14	4	1	9
1.5	5,919.5	23	**15**	16	21	12	**3**	4	7	14	**-3**	-1	7
1.0	5,919.0	22	15	16	21	11	3	4	7	12	-3	-1	7
0.5	5,918.5	21	15	16	21	10	3	4	7	10	-3	-1	7
0.0	5,918.0	***21***	15	16	18	***0***	3	3	5	***0***	-3	-2	2
-0.5	5,917.5	21	15	16	15	0	3	3	3	0	-3	-2	-3
-1.0	5,917.0	21	15	14	15	0	2	3	3	0	-4	-4	-3

this section breaks out where and when these exceedances occurred among each location, season, and year.

Gentile Valley

The target maximum flow in Gentile Valley was a key variable in the model since Gentile Valley is the constraining reach limiting Bear Lake Outlet Canal releases. The flows in Gentile Valley result from a combination of uncontrollable natural reach gains below the Bear Lake Outlet Canal and the flow released through the Bear Lake Outlet Canal. In the model, the flow in Gentile Valley is compared to the scenario target maximum flow on a daily basis to inform, and in some cases reduce, the modeled flow in the Bear Lake Outlet Canal.

Winter (January-March) and spring (April-July) peak flows for Gentile Valley for the Baseline and focus scenarios are shown in Figures 15 and 16 with horizontal lines of matching color for the Gentile Valley target maximum flow value for the scenario. Note that all numerical values used for HRPM1, HRMP2, and the high-runoff impact index are derived from the information shown on these plots, so only selected numerical values will be shown.

Results for HRPM2, the number of seasonal peak flows above the target maximum threshold and above the Baseline peak flow for that season are shown in Table 9. Note that of the focus scenarios (bold font), only the spring peak flow in Scenario 35 (GVtmf of 2,600 and 2.5 adjustment increment) is higher than the Baseline. Also note that in each focus scenario, increasing the PTEra one more 0.5-foot increment significantly increases the number of exceedances that influenced the selection of the focus scenarios.

As seen in Figure 15, the Baseline moderately exceeds its target maximum flow of 1,500 cfs, but the other focus scenarios do not. In this and the following figures, the scenario peak flows overlap in many years (e.g., 1984, 1998,1999), but only the symbols shown in the legend are present.

Note that in Figure 16, only Scenario 35 had a peak flow greater than the Baseline and above that scenario's target maximum flow rate (1986). The peak flow exceeded that scenario's target maximum flow of 3,000 cfs in 1984 as well, but the Baseline peak flow that year was even higher, around 4,000 cfs. Oneida Reservoir. The operational target maximum flow below Oneida hydroelectric plant is 3,000 cfs. Flows only exceed this rate during high runoff events. Exceedances of the 3,000 cfs threshold during the 1980s high-runoff period resulted in no complaints of inundation or damage, and there are no defined areas or thresholds above which damage occurs. One issue of unwanted inundation pre-dating the very high flows of the 1983-86 period was resolved when PacifiCorp purchased the land that was inundated. Since then no other high-runoff issues have arisen.

Table 9 *- HRPM2 (number of target maximum flow and Baseline peak flow exceedances) for both seasons for Gentile Valley. Bold italics indicate the Baseline scenario; bold with yellow outline indicates focus scenarios. (Recall that the Baseline is the 0.0, 1,500 entry; Scenario 22 is the 1.5, 2,000 entry; Scenario 31 is the 2.5, 2,600 entry; Scenario 35 is the 3.0, 2,600 entry; and Scenario 36 is the 3.0, 3,000* entry).

Gentile Valley									
PTEra (feet)	Scenario Default PTE	Number of years with winter (Jan-Mar) peak flow above baseline peak and well above target threshold.				Number of years with spring (Apr-Jul) peak flow above baseline peak and well above target threshold.			
		GVtmf				GVtmf			
		1,500	2,000	2,600	3,000	1,500	2,000	2,600	3,000
3.5	5,921.5	4	1	0	0	6	4	4	3
3.0	5,921.0	3	1	**0**	**0**	4	3	**1**	**0**
2.5	5,920.5	3	1	**0**	0	4	2	**0**	0
2.0	5,920.0	0	0	0	0	5	2	0	0
1.5	5,919.5	0	**0**	0	0	5	**0**	0	0
1.0	5,919.0	0	0	0	0	5	0	0	0
0.5	5,918.5	0	0	0	0	4	0	0	0
0.0	5,918.0	***0***	0	0	0	***0***	0	0	0
-0.5	5,917.5	0	0	0	0	0	0	0	0
-1.0	5,917.0	0	0	0	0	0	0	0	0

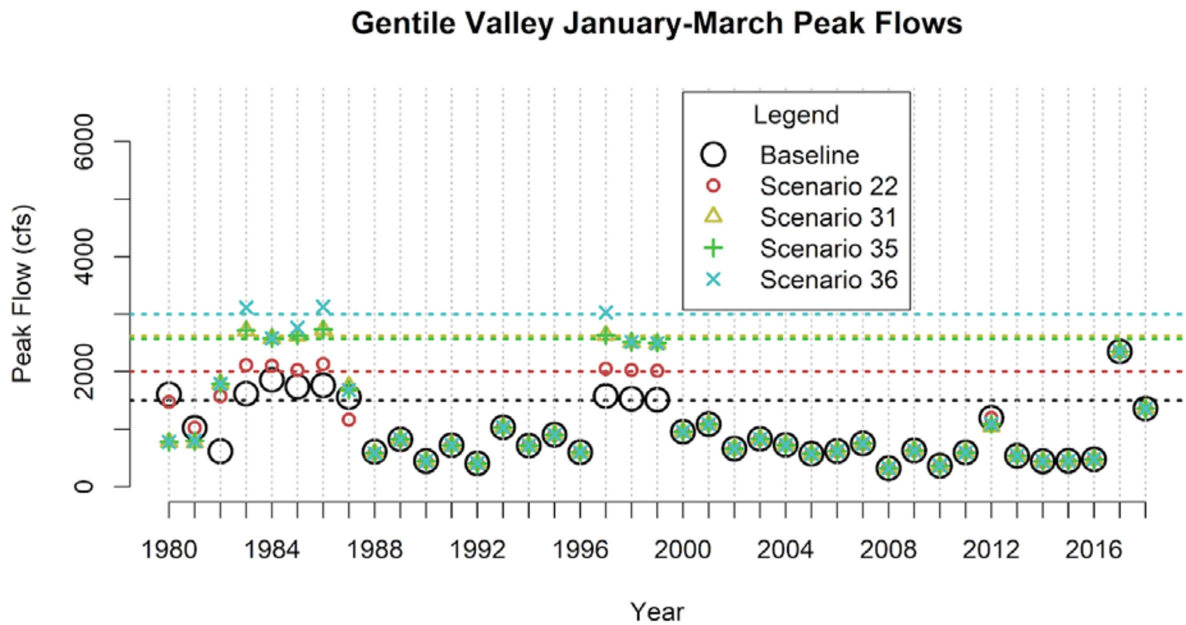


Figure 15 *- Winter (January-March) peak flows for Gentile Valley for the Baseline and focus scenarios with dotted horizontal lines indicating the respective target maximum flows using the same color as the symbol. Note that both Scenario 31 and 35 have the same target maximum flow of 2,600 cfs.*

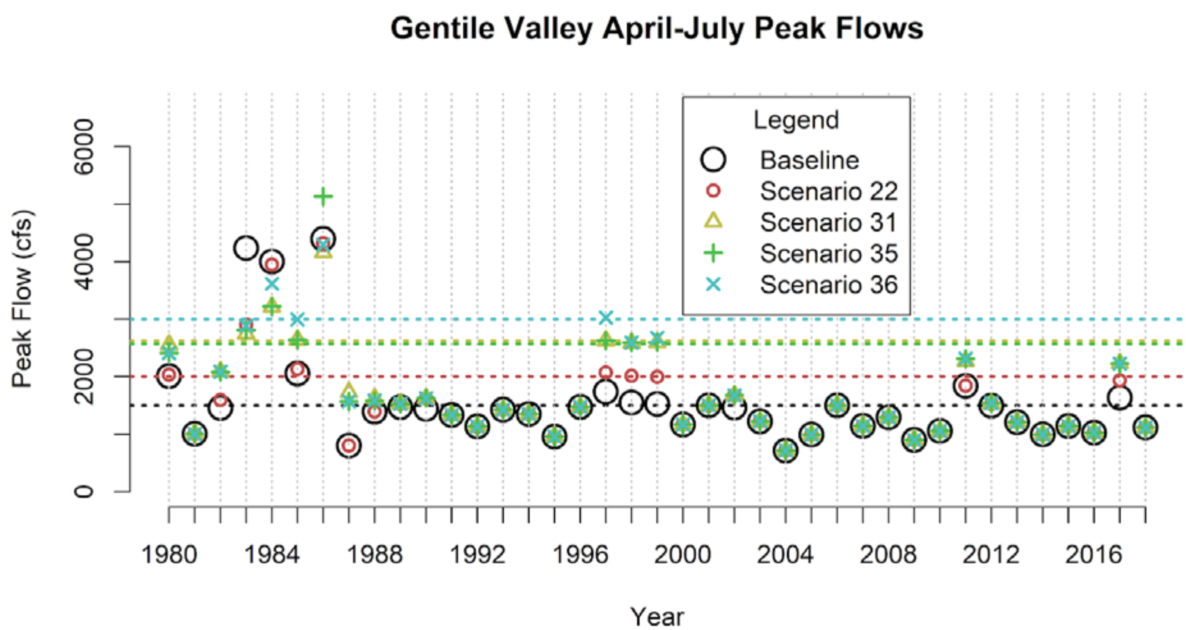


Figure 16 *- Spring (April-July) peak flows for Gentile Valley for the Baseline and focus scenarios with dotted horizontal lines indicating the respective target maximum flows using the same color as the symbol. Note that both Scenario 31 and 35 have the same target maximum flow of 2,600 cfs.*

Changes to the Gentile Valley target maximum flow thresholds can impact flow exceedances of the Oneida target maximum flow rate as observed in Figure 17. For example, the winter 1980s scenario peak flows are greater than the threshold and Baseline peak flow. However, these flow rates are less than the 1980s Baseline spring flow rates as shown in Figure 18 for each corresponding year. In both figures, other exceedances of the threshold occur in 1997 (winter and spring) and 2017 (spring) when the exceedance is more than the buffer of 150 cfs, but not by much. The numerical values of the HRPMs and high-runoff impact index for Oneida are similar to Gentile Valley and are not shown.

Cutler Reservoir

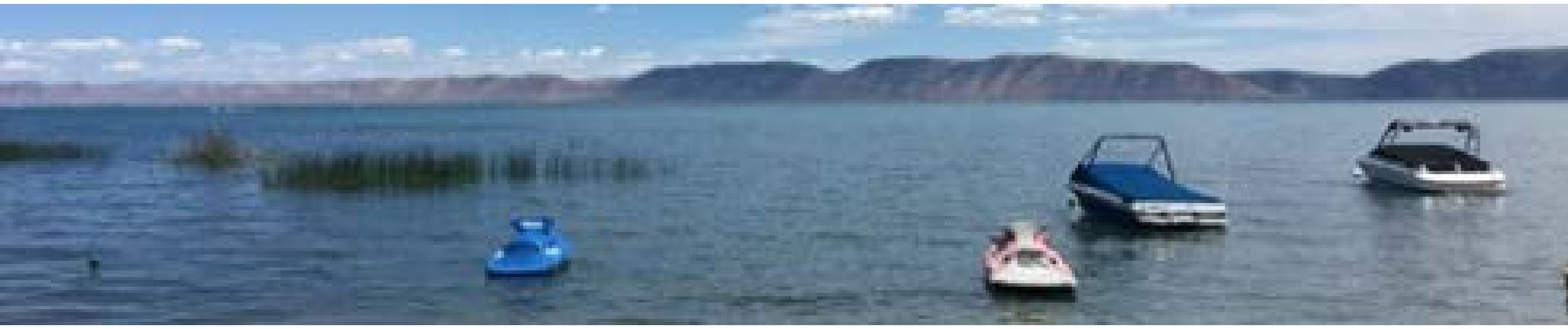
The high-runoff situation at Cutler is similar to Oneida and the model does not modify the Bear Lake Outlet Canal high-runoff release rate in response to flows below Cutler. Winter peak flows below Cutler are shown in Figure 19. Note that the 1986 high flow that resulted from rain-on-snow runoff from the unusually large snow cover in Cache Valley. All scenarios in 1986 resulted in higher Cutler peak flows due to Bear Lake Outlet Canal flows being released to meet Bear Lake March 31 target elevation (PTE). The peak flow rate below Cutler is higher in the scenarios because the higher Gentile Valley target maximum flow rate allowed a greater release rate at the Bear Lake Outlet Canal.

Spring peak flows below Cutler are shown in Figure 20. Note there are small increases in the scenario peak flow rates above the Baseline peak. Indeed, for HRPM1, the number of threshold exceedances for all focus scenarios is identical. Only one or two of the threshold exceedances were also above the Baseline peak flows, one for the winter season for all scenarios and one or two for the spring season. For HRPM2 and the high-runoff impact index, the values for the focus scenarios were similar to each other and do not help differentiate between the focus scenarios.

Discussion about Question 4

In summary, the peak flow changes for the focus scenarios for Gentile Valley rarely exceed the new higher threshold, and in only one case (for Scenario 35) is there an event worse than the Baseline peak flow for that year. For the reach below Oneida, while the winter 1980s peak flows exceed the winter Baseline peak flow, they are still lower than the corresponding spring season peak flows. Two other years (1997 and 2017) saw peak flows exceeding both the Baseline and the Oneida 3,000 cfs threshold, but the magnitude of the exceedance was not large. For the reach below Cutler, the magnitude of the single 1986 winter peak flow event was increased significantly, but the increase in magnitude for the spring 1983 and 1984 peak flow events was less.

The flow duration analysis showed that changes to flow duration for the reach below Oneida and the reach below Cutler were minimal due to the higher thresholds at those locations. The peak flow analysis is more insightful for those locations. However, for Gentile Valley, the higher target maximum flow thresholds reduced the duration of very high flows, reducing the impact of higher flows in exchange for more frequent flows up to those new, higher target maximum flow thresholds.



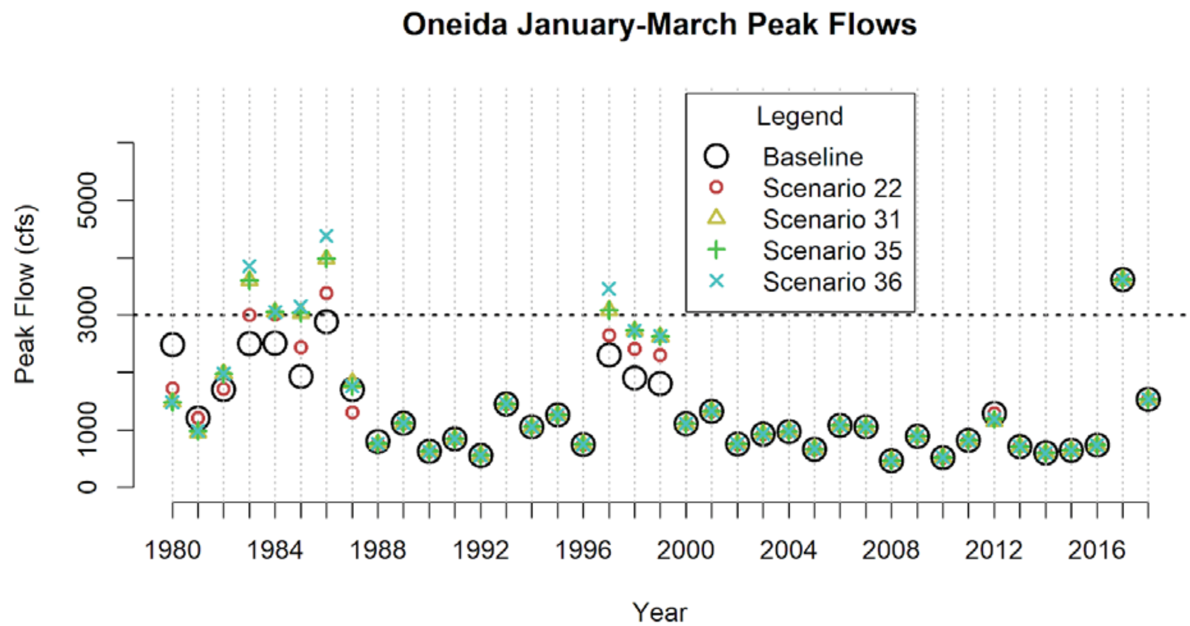


***Figure 17** – Winter (January-March) peak flows for Oneida for the Baseline and focus scenarios with a dotted horizontal line indicating the 3,000 cfs target maximum flow.*

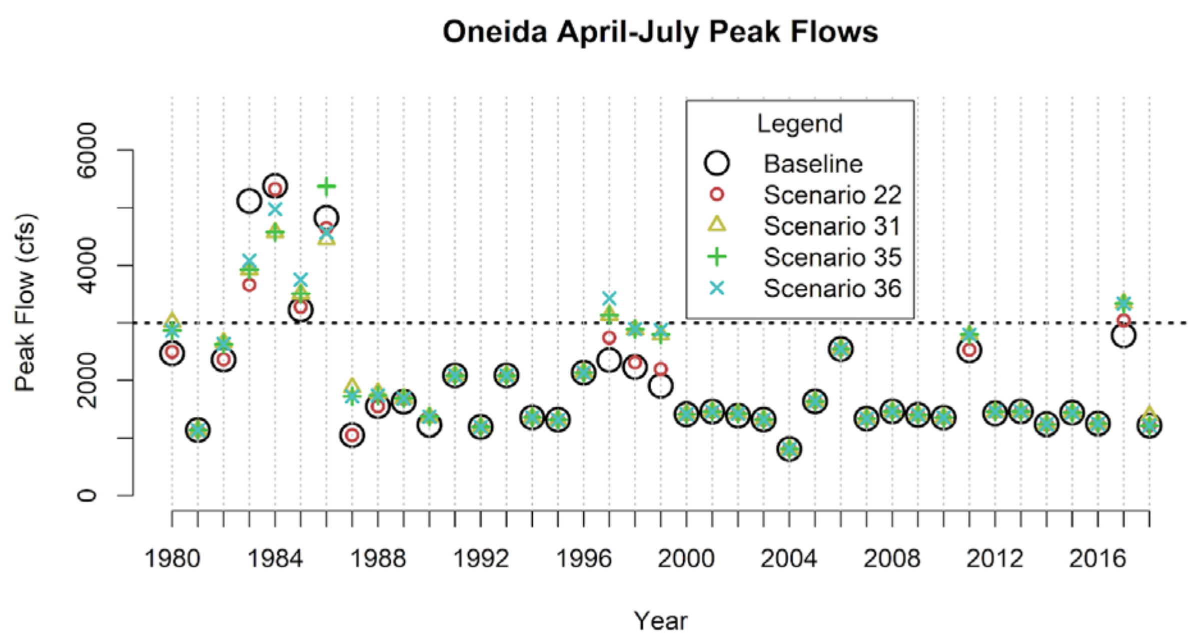


***Figure 18** – Spring (April-July) peak flows for Oneida for the Baseline and focus scenarios with a dotted horizontal line indicating the 3,000 cfs target maximum flow.*

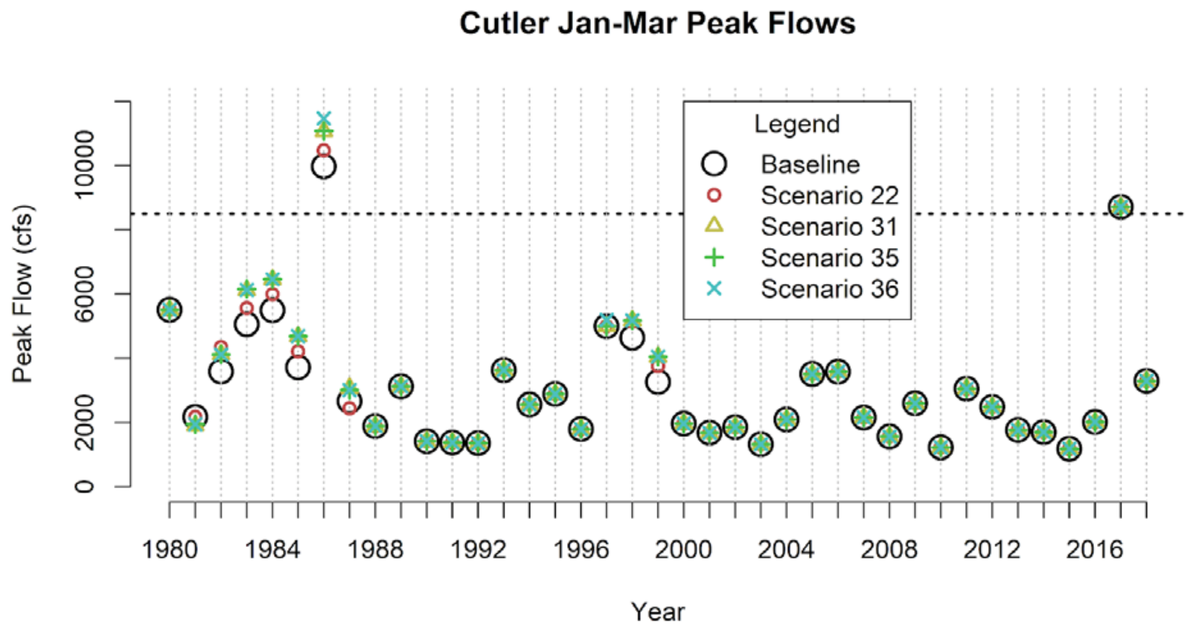


Figure 19 – Winter (January-March) peak flows for Cutler for the Baseline and focus scenarios with a dotted horizontal line indicating the 8,500 cfs target maximum flow.

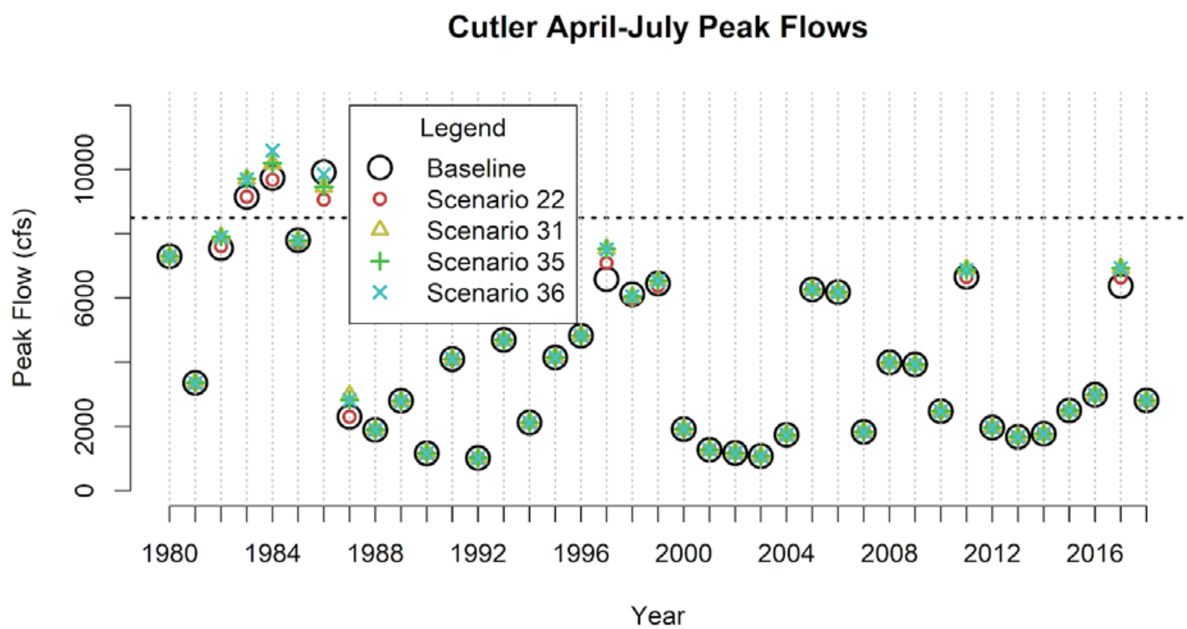


Figure 20 – Spring (April-July) peak flows for Cutler for the Baseline and focus scenarios with a dotted horizontal line indicating the 8,500 cfs target maximum flow.

Question 5. How would additional storage in Bear Lake have impacted inflow to Great Salt Lake?

The answer to this question provides approximate information concerning impacts on the flow of Bear River to Great Salt Lake as well. It is important to consider these impacts because Bear River is the largest tributary to Great Salt Lake which has tremendous economic, environmental, wildlife, and cultural importance to the region. Streamflow of the Bear River measured at the Corinne station is used to estimate flow reaching Great Salt Lake. Total annual streamflow volume (TAV) is computed for each model scenario and used herein as the performance measure of interest. Changes from the Baseline to the TAV are computed to assess impacts on the inflow from Bear River to Great Salt Lake. Wider-ranging impacts to Great Salt Lake and the surrounding ecosystem are not known nor discussed here.

Under the assumption that no new deliveries or losses occur from the Baseline, there would have been an average change of 0.0 acre-feet to inflow into Great Salt Lake over the simulation period for all scenarios. However, for several years, reductions and increases in volume do occur as shown in Figure 21. For Scenario 31, inflow to Great Salt Lake would have been reduced during 10 of the 15 high-runoff management years, with the most drastic changes occurring during the 4 carry-over years. However, the additional volume stored in Bear Lake is preserved until the following wet period, or high-runoff management year, when it is released. Because of this, Figure 21 shows 9 years of increased volume reaching Great Salt Lake, an average of 71,000 acre-feet. A reduction to inflow volume would have occurred during 11 years, an average of 58,000 acre-feet. The average reduction during

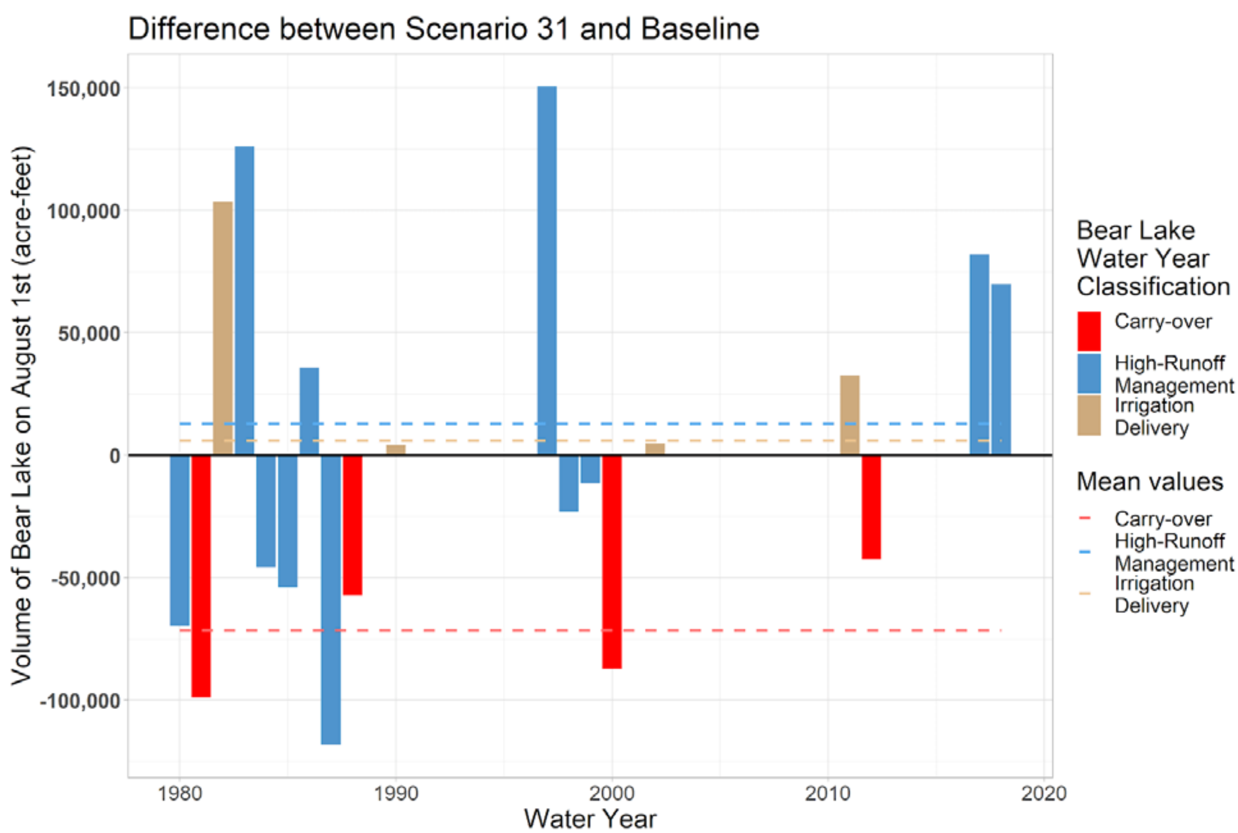


Figure 21 *- Bar chart showing the differences of the total annual inflow to Great Salt Lake between the Baseline and Scenario 31 using the Continuous simulation method and perfect forecast. The colors correspond to water year classifications. Mean differences for each classification group are shown as dashed lines.*

carryover years would have been 72,000 acre-feet. The average change over the entire period is 0.0 acre-feet, but the impacts vary throughout the 39-year period. Total cumulative changes in volume by scenario are shown in Table 10

There is a much larger effect on flows reaching Great Salt Lake when using the assumption that all new storage volume is removed from the system (using the Yearly simulation method). Results are shown in Figure 22. Rather than the overall impact being zero, there is an average reduction of 17,000 acre-feet. The total annual flow is reduced in 15 years, 13 of which are high-runoff management years. The mean reduction during carryover years is 96,000 acre-feet and the mean reduction for all high-runoff management years is 19,000 acre-feet. In addition to reductions every carryover year, there would have been reductions to inflow during two irrigation delivery years. Two years of increased inflow would have occurred during the wet years 1984 and 1987. Mean changes from the Baseline to the annual inflow into Great Salt Lake during carry-over years for all 39 scenarios are shown in Table 11.

Importantly, both methods of simulation show that reductions in streamflow entering Great Salt Lake from Bear River would have occurred during the majority of high-runoff management years. Using the Continuous method, no reductions would have occurred during irrigation delivery years. In fact, the reductions in volume occur only during wet years when such a reduction in the lower reaches of the river may have been an advantage. Though increased volume flowing into Great Salt Lake would have been beneficial in the years which came amidst the long dry period such as 2011 and 2017. Reductions are more drastic when using the Yearly method which assumes additional water is removed from Bear Lake to set it back to the elevation of the Baseline scenario. In this case, reductions do occur during delivery years and those occurring during carryover years are higher than results from the Continuous method.

Effects on Great Salt Lake and the lower reaches of Bear River cannot be adequately assessed without modeling how, when, and where the additional volume will be used as evidenced by showing results from the two simulation methods. Thereby, this analysis shows results at two extreme ends: what the effect would have been if all additional storage had remained in the lake and what it would have been had all the additional storage been directly and instantaneously withdrawn from the lake.

Table 10 *– Change in total volume flowing to Great Salt Lake (GSL) over the 39-year simulation. Units are thousands of acre-feet. Results for all scenarios using the Yearly simulation method and perfect forecast. Focus scenarios are highlighted. Red shading indicates decreases from the Baseline whereas blue shading represents positive change.*

Change in total flow to GSL (TAF)					
PTEra (ft.)	Scenario Default	GVtmf			
		1500	2000	2600	3000
3.5	5921.5	-1711	-1684	-1683	-1682
3.0	5921.0	-1256	-1221	-1196	-1192
2.5	5920.5	-816	-739	-683	-674
2.0	5920.0	-687	-631	-576	-558
1.5	5919.5	-518	-458	-380	-362
1.0	5919.0	-338	-219	-145	-126
0.5	5918.5	-178	12	110	123
0.0	5918.0	0	278	375	384
-0.5	5917.5	132	500	571	575
-1.0	5917.0	249	695	758	761

Table 11 *– Change in total volume flowing to Great Salt Lake (GSL) over the 39-year simulation. Units are thousands of acre-feet. Results for all scenarios using the Yearly simulation method and perfect forecast. Focus scenarios are highlighted. Red shading indicates decreases from the Baseline whereas blue shading represents positive change.*

Mean change in annual volume to GSL for carry-over years (TAF)					
PTEra (ft.)	Scenario Default	GVtmf			
		1500	2000	2600	3000
3.5	5921.5	-142	-142	-142	-142
3.0	5921.0	-119	-119	-119	-119
2.5	5920.5	-96	-96	-96	-96
2.0	5920.0	-77	-77	-77	-77
1.5	5919.5	-58	-59	-59	-59
1.0	5919.0	-39	-40	-40	-40
0.5	5918.5	-22	-21	-21	-21
0.0	5918.0	0	5	4	4
-0.5	5917.5	16	27	27	27
-1.0	5917.0	28	48	49	49

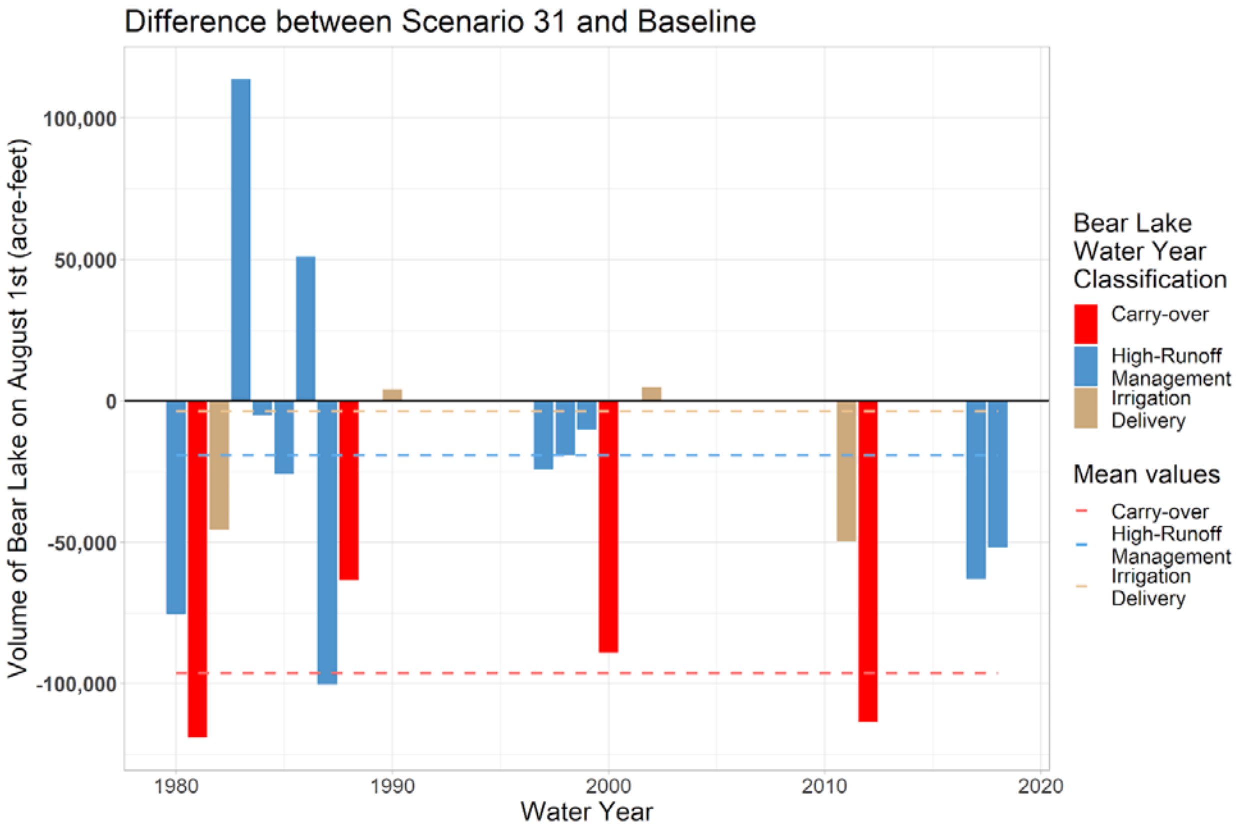
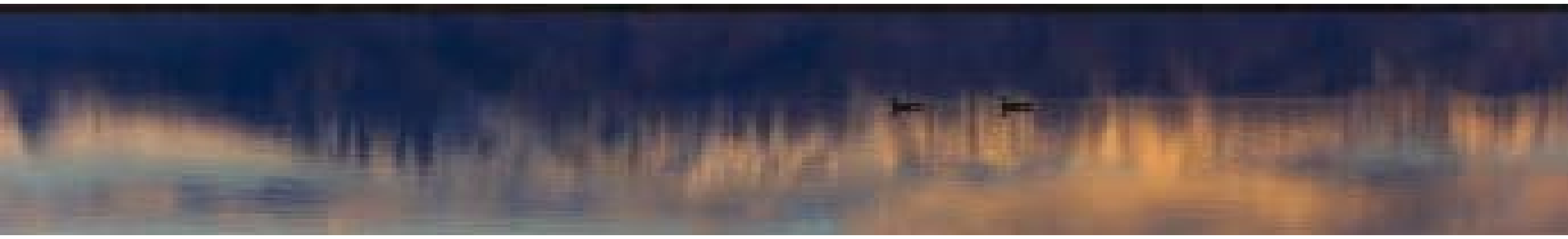


***Figure 22** - Bar chart showing the differences of the total annual inflow to Great Salt Lake between the Baseline and Scenario 31 using the Yearly simulation method. The colors correspond to water year classifications and the mean difference for each classification group are shown.*



Question 6. What would have been the effects on Mud Lake elevations and timing of discharge from Mud Lake to Bear Lake?

Mud Lake is the deepest portion of the Dingle Swamp and makes up most of the Bear Lake National Wildlife Refuge. Mud Lake is a complex, shallow lake used as a regulating basin for inflow and outflow between Bear River and Bear Lake. It is difficult to model Mud Lake elevations and storage content. However, the Baseline model does reasonably well simulating the inflow and outflow from Mud Lake. Inflows to the lake include the Rainbow Canal and the Lifton Pumping Station. The Rainbow Canal diverts almost the entire flow of the Bear River into Mud Lake. The Lifton Pumping Station moves water from Bear Lake to Mud Lake for downstream storage water deliveries. Outflow from Mud Lake occurs at the Outlet Canal and the Causeway. The Outlet Canal is controlled by a small dam called the Paris dike. The Causeway outlet structure releases water from Mud Lake into Bear Lake (see Figure 23).

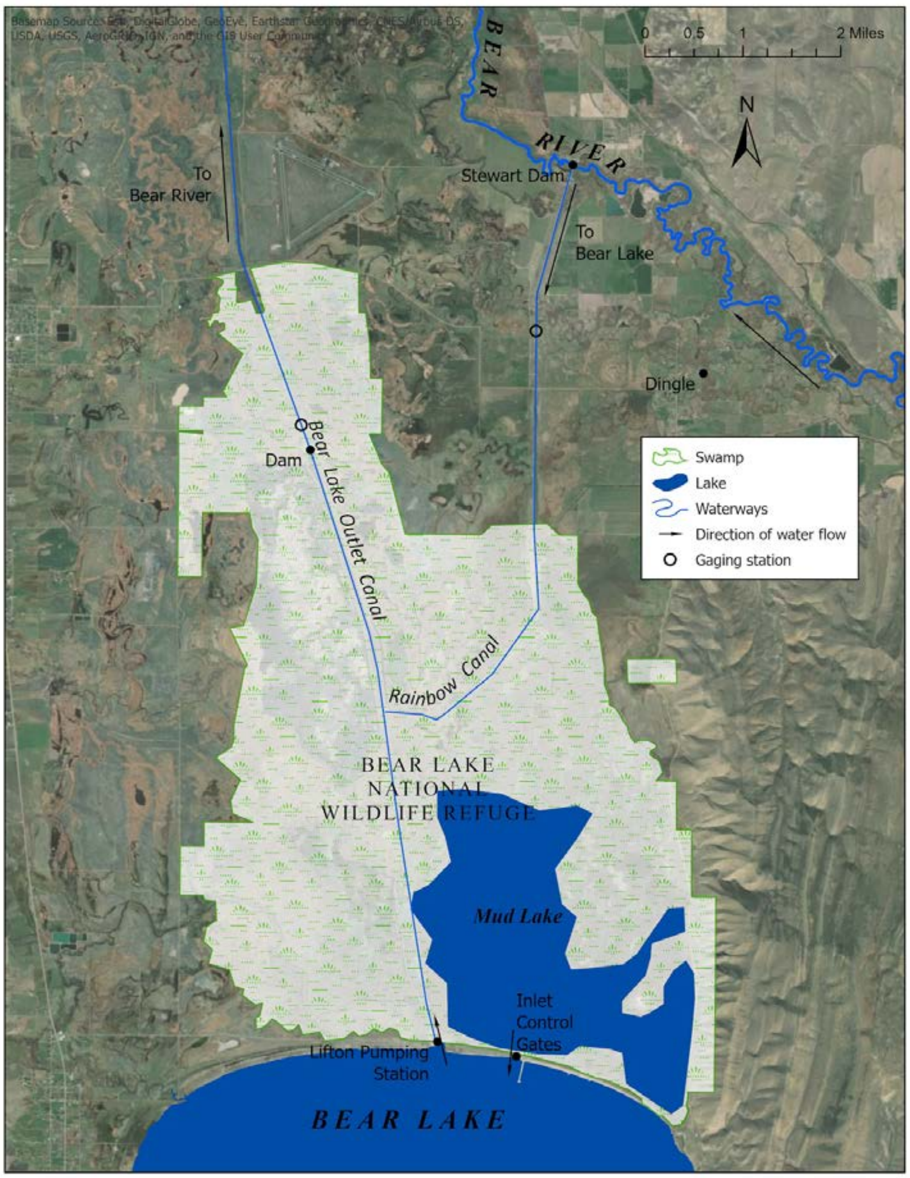


Figure 23 - Map of the showing the control structures and direction of flow within the Dingle Swamp/ Mud Lake Complex.

Volume through the Causeway

To investigate what the effects on Mud Lake elevations and timing of discharge from Mud Lake to Bear Lake would have been we compute the total volume flowing from Mud Lake to Bear Lake through the Causeway over the entire 39-year period. Table 12 tabulates the total increase of flow into Bear Lake. A negative value indicates less flow and a positive value indicates more flow. As shown in Figures 25 the decrease in inflow is least for Scenario 22 and about equal for the other focus scenarios 31, 35, and 36. In Scenario 31 the reduction in discharge from Mud Lake to Bear Lake is about 600,000 acre-feet over 39 years.

The decrease is 200,000 acre-feet when the Yearly simulation method is used. The reason for the decrease in Scenario 31 is that less water is evacuated from Bear Lake for high-runoff management purposes and therefore less water is needed to fill the lake. Only a few years (1983, 1988, and 1998) show a small increase in discharge from Mud Lake to Bear Lake. Diversions into Bear Lake are calculated to decrease by 200,000 to 600,000 acre-feet should the GVtmf be increased to 2,600 cfs and the PTEra be raised by 2.5 feet. A range is the best way to address this question since the Continuous simulation method overestimates the decrease of diversions into Bear Lake whereas the Yearly simulation, which removes the increased storage in Bear Lake at the beginning of August underestimates the decrease in diversions. Like the effects on Great Salt Lake and the lower reaches of Bear River, effects on volumetric flow through the causeway cannot be adequately assessed until a use is determined for the additional storage that is made available as evidenced by showing results from the two simulation methods.

***Table 12** - Change in total volume flowing through the Causeway over the 39-year simulation. Units are thousands of acre-feet. Results for all scenarios using the Continuous simulation method and perfect forecast. Focus scenarios are highlighted. Red shading indicates decreases from the Baseline whereas blue shading represents positive change.*

Change in total flow through the Causeway (TAF)					
PTEra (ft.)	Scenario Default	GVtmf			
		1500	2000	2600	3000
3.5	5921.5	-885	-743	-700	-663
3.0	5921.0	-800	-678	-637	-607
2.5	5920.5	-732	-636	-605	-595
2.0	5920.0	-658	-476	-380	-344
1.5	5919.5	-420	-229	-109	-71
1.0	5919.0	-246	-7	125	159
0.5	5918.5	-108	180	329	364
0.0	5918.0	0	336	482	516
-0.5	5917.5	94	446	603	639
-1.0	5917.0	158	538	709	752

Timing of Flow through the Causeway

Changes in the timing of diversion into Bear Lake depends on the runoff pattern. In the 1980s when multiple high-runoff management years came back-to-back, the peak discharge would have occasionally been greater in Scenario 31 and the timing would have occurred later in the year.

1983 for the Baseline and Scenario 31 simulated using both the Continuous and Yearly methods. In 1983, the Causeway would have been opened later in the year because a GVtmf of 2,600 cfs allows for higher flows downstream which shortens the evacuation period thus significantly reducing the amount of time that the target maximum flow would have been exceeded. Note that in 1983, diversions through the Causeway would have increased by 50,000 acre-feet in both the Continuous and Yearly simulations because more water had to be evacuated from Bear Lake.

In 1997, diversions into Bear Lake through the Causeway decreased for Scenario 31 by 139,000 acre-feet when applying the Continuous simulation method and by 33,000 acre-feet using the Yearly simulation. This can be seen in Figure 24 which compares hydrographs of discharge through the Causeway in 1997 for the Baseline and Scenario 31 simulated using both the Continuous and Yearly methods. Unlike conditions in 1983 the alternate high-runoff management operations successfully maintained flows in Gentile Valley under the target maximum. In Scenario 31, both the magnitude of the volume and rate of diversions into Bear Lake decreased and the timing of the diversions were slightly earlier in the year.

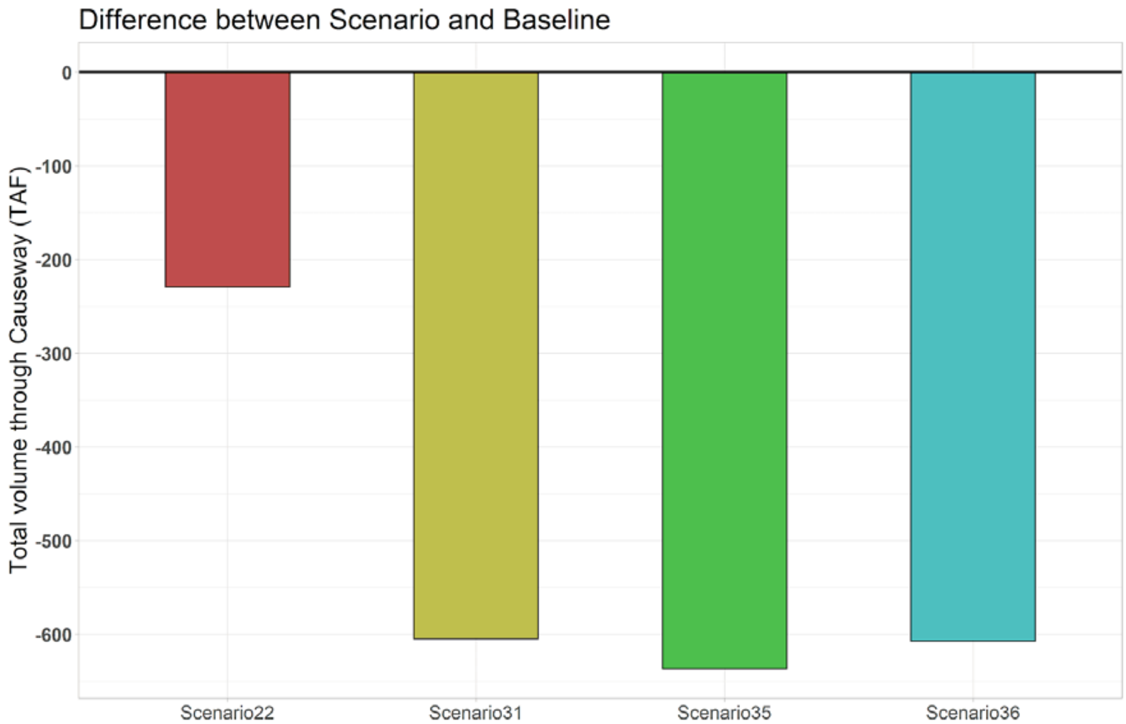
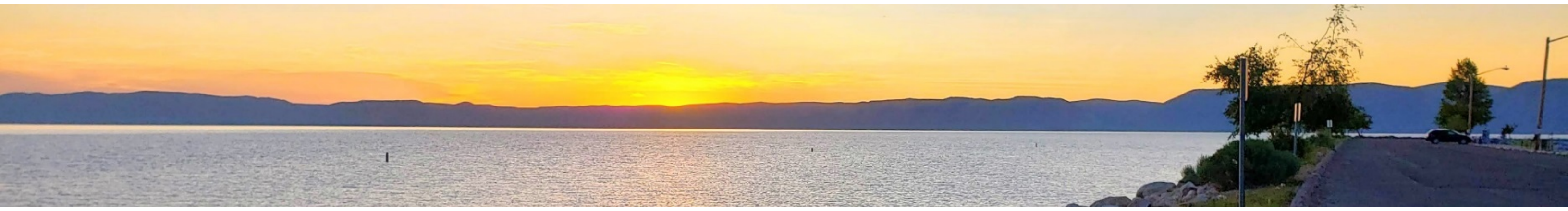


Figure 24 *- Change in total volume passing through the Causeway during all 39 years of simulation as compared to the Baseline operations. Values are shown in thousands of acre-feet for focus scenarios. Value computed using the Continuous simulation method.*



Discussion

In the previous section, impacts for each location of interest in this study were presented independent from impacts at other locations in the river system. This section considers the impacts together by assessing trade-offs or joint benefits at all locations, mentions related policy implications, and elaborates on the assumptions made for this study which must not be ignored when interpreting the results.

The impacts on storage in Bear Lake, timing and flow into Bear Lake from Bear River, and inflow to Great Salt Lake are greatly affected by how, when, and where the additional storage water is used. Not being our decision to make, we elected to use two different methods of simulation which provide the idealized range of impacts by assuming 1) no additional storage is used for any purpose, and 2) all additional storage in excess of the baseline is vacated from Bear Lake at the end of the runoff season.

General Findings

In the Baseline scenario, releases to manage high runoff were made 15 of the 39 years. Of the 15 years, 3 were of greatest import since they preceded dry periods lasting 4 years or longer. The operations scenarios defined in this study only consider alterations to aspects of high-runoff management. As a result, the maximum number of years in which additional water could have been stored is 15. Based on a longer period of record, we estimate a 7% chance that any two years will be a high-runoff management year followed by an irrigation delivery year. However, if the present year is known to be high-runoff management then the chance is 17% that the next year will be irrigation delivery, whereas the chance is 80% that the next year will be managed for high-runoff again. These probabilities evince a hesitancy to reduce releases for managing runoff based on the chance that the following year will be dry. Although, if the future looks more like the last 20 years, then there will be a lower probability of high-runoff management years and thus a greater importance to storage during a carry-over year.

During the 3 carry-over years, with perfect forecasts and using the Continuous method, the greatest additional average volume that could have been stored in Bear Lake ranges from -72,000 to 197,000 acre-feet per carry-over year across all scenarios. These volumes are well below the 400,000 acre-feet requested in the joint water right applications made by the states of Utah and Idaho.

Scenario 31 has been highlighted because it provides the maximum increase in storage without increasing downstream high-runoff impacts relative to the Baseline. There are 7 years in which additional water could actively have been stored. The Continuous method resulted in 25 more years when that stored water would have been available, but that is only because that water is not evacuated from Bear Lake except for high-runoff management. The average change in storage over all 15 high-runoff management years would have been 45,000 acre-feet. The average during carry-over years is higher than the runoff years because in this scenario the higher GVtmf allows for the lake to be drawn closer to the PTE during the 1980s than it was in the Baseline. During these same years, the change in storage is not always less than the Baseline, such as Scenario 35.

Additional volume does not equate directly to usable or deliverable water. Constraints on the usable water include Lifton pump capacity, demand, and annual availability. The Lifton Pumping Station has a capacity of 1,600 cfs. In some years, at the peak of the irrigation season, most of this capacity is utilized. If a use of the additional storage water was sought in this period, a study should be conducted on the timing and rate at which additional storage could be pumped through the Lifton Pumping Station. If use of additional storage was sought at the end of the irrigation season, there would be little constraint imposed by the capacity of the Lifton pumps.

Demand on the use of water during high-runoff management years to agricultural producers would be a limitation. Some of these high-runoff management years have wetter than normal spring and summer conditions that reduce crop water demand. Lastly, the annual availability of the additional usable water is limited. Any proposed domestic, commercial, municipal, or industrial uses would probably require some other water supply or a rationing of the storage across dry years to have the desired reliability.

The average increase at the end of carry-over years for Scenario 31 would have been between 138,100 and 161,600 acre-feet for the Yearly and Continuous methods, respectively. The cumulative change during all 39 years would have been 680,000 acre-feet, using the Yearly method and perfect forecasts. When using imperfect forecast information, the total increase may have been as little as 250,000 acre-feet over the 39-year period. A study of additional storage gained from 1997 to 2018 using actual forecasts indicates that the ability to store additional water in some years would be reduced significantly. For example, in the 2000 water year, the additional storage benefit with the perfect forecast was estimated at 146,000 acre-feet, but the benefit using the NRCS 10% exceedance forecast that year would have been only 16,000 cfs. The amount of storable water varies directly with the exceedance level forecast used to guide high-runoff management decisions (as represented by the NRCS 10%, 30%, and 50% exceedance forecasts).

Turning now to the Causeway results, the operations represented by Scenario 31 would have caused the total discharge through the Causeway into Bear Lake to decrease between 605,000 and 200,000 acre-feet for the Continuous and Yearly methods, respectively. For all scenarios, the range was 752,000 to -885,000 acre-feet using the Continuous method or 673,000 to -333,000 using the Yearly method. Changes to the timing of when the Causeway would have been opened or closed are mixed. Depending on the natural flow pattern of each year, at times the gates are opened earlier and at times later. The total time the gates are open is generally shorter. These results imply that the amount of sediment introduced to Bear Lake through the Causeway may be reduced in proportion to the increase in PTE.

Across all scenarios, Bear Lake would have been above the equivalent elevation of 5,911 feet between 4 years fewer and 8.6 years longer. In Scenario 31, the lake would have been above the equivalent elevation 5.8 years longer. Upstream reservoirs during those years would not have much opportunity to store additional water in upstream reservoirs, because they occurred during years when the amended compact storage allocations upstream of Bear Lake would have filled regardless of Bear Lake conditions (based on a qualitative examination of reports from the relevant years). Elevations of upstream reservoirs were not modeled in this study. If additional water were stored, then it would have the effect of reducing flows downstream including through the Rainbow Canal.

The number of downstream high-runoff events ranges from 4 fewer to 27 more than the Baseline. Raising the GVtmf increases the number of peak flows and durations up to the GVtmf but reduces the number of peak flows and durations above the GVtmf. Clearly, raising the GVtmf effectively changes the definition of a flood event so that at a GVtmf of 3,000 cfs the total time above this target threshold is 0.6%, compared to the Baseline which is 4.3% above the GVtmf of 1,500 cfs. It also has the effect of reducing the amount of time above the higher flow since the Baseline was 1% of the time above 3,000 cfs. There is a balance in the aim of policy on whether to allow more frequent low-level flooding or less-frequent high-level flooding. Bear Lake elevation and the PTE are important factors to achieving this balance. Nevertheless, modeling results convey the fact that downstream flood events occur despite having perfect foresight of spring runoff. The balance is more readily achieved when using perfect forecasts, though in real operations the considerable variability and uncertainty in forecasts of the spring runoff make achieving this balance more difficult.

Impacts on flow into Great Salt Lake depend greatly on the assumption of how the additional storage water is used. Using the Continuous method, there is no impact overall because additional water stored is eventually released. Changes to the annual inflow volume would have been affected. During carry-over years, the change in average flow reaching Great Salt Lake would have been 49,000 to -119,000 acre-feet for all scenarios and -96,000 acre-feet for Scenario 31 (Continuous method). However, if the additional storage were diverted upstream of Great Salt Lake then the overall change would be negative. The average change during carryover years would be 49,000 to -142,000 acre-feet for all scenarios and -96,000 acre-feet for Scenario 31 (Yearly method). Importantly, although many of the years of reduced inflow would have occurred during wet years, using the Continuous method, flows on the wettest years would have increased at times when such increase was not wanted (historically, when Great Salt Lake elevations were very high). During some irrigation delivery years, the inflow would have been reduced using the Yearly simulation method.

Trade-offs

It is important to recognize the trade-offs between storage benefit and high runoff impact for all 39 scenarios. This can be visualized through a graphical cost-benefit (or impact-benefit) analysis comparing the benefit of additional storage in Bear Lake to the “cost” or impact of high-runoff in the Gentile Valley and in reaches below Oneida and below Cutler reservoirs. The cost or impact is quantified by the High Runoff Impact index. A negative value for the High Runoff

Impact index indicates a decrease in impacts while a positive value indicates an increase in impacts. The benefit is quantified by the median increase in Bear Lake volume on August 1 of carry-over years. Figure 25 shows the trade-offs graphically. Flood risk increases to the right and additional storage increases toward the top. The Baseline is shown at the intersection of the zero-lines. For each scenario, shapes vary according to the GVtmf value while the color changes according to the PTEra. Note that the upper-left quadrant reflects the highest benefit with the least negative impact. Focus scenarios are surrounded by gray circles. Moving from bottom-left to top-right the circled focus scenario indices are 22, 31, 35, and 36. The focus scenarios fall along the upper envelope and straddle the dashed line showing that these scenarios maximize additional storage while minimizing impacts downstream.

Trade-offs between the focus scenarios are:

- Scenario 22 (GVtmf = 2,000 cfs & PTEra = 1.5): this scenario realizes the maximum carry-over benefit with the largest reduction in high-runoff impacts.
- Scenario 31 (GVtmf = 2,600 cfs & PTE = 2.5): this is the "optimal" scenario which still has a reduction in high- impacts, but has a greater carry-over benefit than the previous scenario.
- Scenarios 35 (GVtmf = 2,600 cfs & PTE = 3.0) and Scenario 36 (GVtmf = 3,000 cfs & PTE = 3.0): these scenarios marginally increase the carry-over benefit but result in high-runoff impacts greater than the current baseline.
- A few intuitive conclusions are confirmed by the results shown in Figure 25. Additional storage on carry-over years is most directly affected by raising the PTE whereas changing the GVtmf has no effect on storage when the PTE is also raised. This is

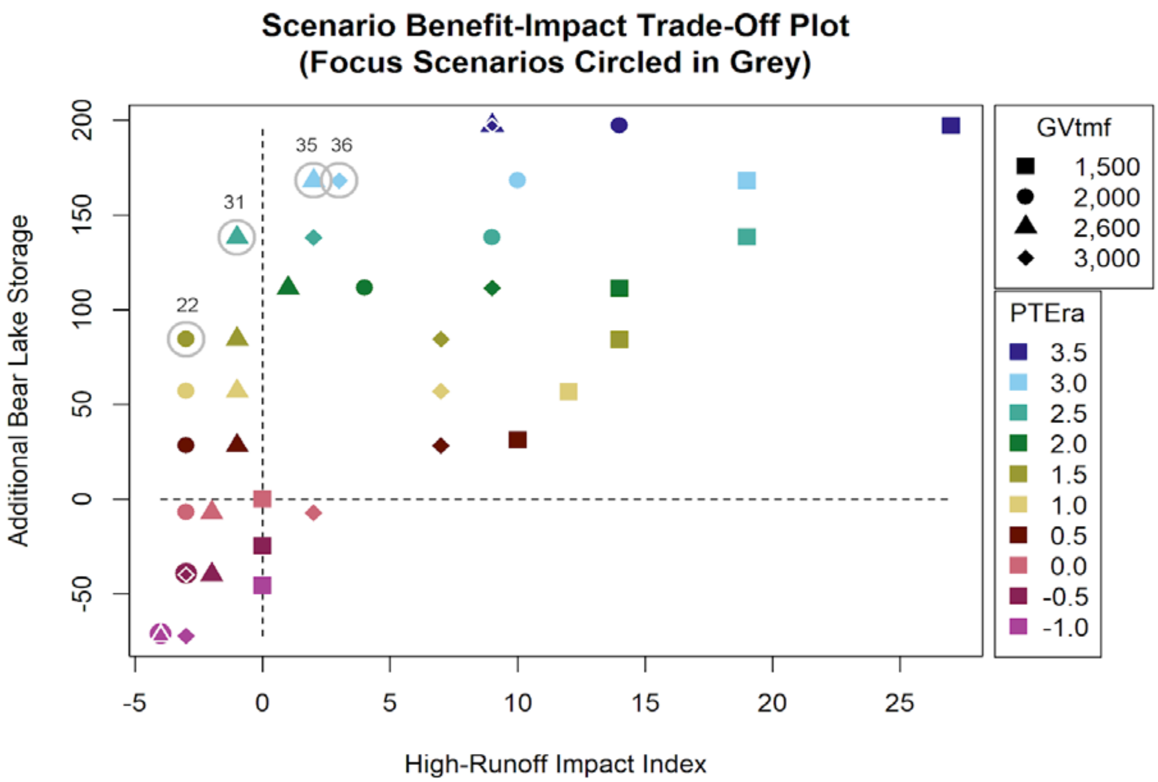


Figure 25 *– Demonstration of the trade-offs between scenarios of different high-runoff operations. One particular trade-off is shown: the High-Runoff Impact Index along the horizontal axis is compared to the median increase in Bear Lake volume on August 1st of carry-over years in thousands of acre-feet along the vertical axis. Each point represents 1 of 39 scenarios evaluated in this study. The point shape and color correspond to the Gentile Valley target maximum flow and the PTE range adjustment, respectively. The focus scenarios are labeled and highlighted by gray circles. Baseline values are at the intersection of the dotted, zero reference lines indicating no change to benefits or impacts. Overlapping points are outlined in white.*

shown in Figure 25 which shows each color (representing values of PTEra) falling along a horizontal line, indicating that storage remains the same despite changes to the GVtmf (represented by shapes). Likewise, lowering the PTE without changing the GVtmf reduces storage but has no impact on flooding. Changing the GVtmf has a direct impact on downstream flooding. Changing the GVtmf without increasing the PTE reduces storage because the system can more often achieve the target elevation. If the PTE is lowered, then any increase to the GVtmf significantly reduces flood impacts.

For these reasons, practically raising the GVtmf must coincide with raising the PTE. Raising the PTE without changing the GVtmf causes significantly higher flood impacts. Even with a modest increase in PTE of 0.5 feet, the high-runoff impact index increases by 10 if GVtmf remains at 1,500 cfs. The PTE could be raised up to 1.5 feet without adversely affecting downstream flooding only if the GVtmf is lifted to a flow between 2,000 - 2,600 cfs, represented by focus scenario 22 labeled in Figure 25. Raising the PTE further but keeping the GVtmf at 2,000 would result in considerable increases to downstream flooding. Above 1.5-foot increase, a GVtmf of 2,000 would cause higher flood impact than 2,600. Interestingly, an increase of PTEra to 2.5 feet with a GVtmf of 2,600 (Scenario 31) reduces the flood impact to below the Baseline while increasing the storage to 138,000 acre-feet. Beyond a 3.0-foot increase, a GVtmf of 2,600 and 3,000 cfs results in nearly the same increased impact on downstream flooding. An increase in PTE of more than 3.0 feet results in drastic increases to downstream flooding (the same as GVtmf of 1,500 and PTE increase of 0.5 feet).

Table 13 further elaborates on the on the trade-offs of the focus scenarios, to help policy makers compare the scenarios that were found to be optimal.

Additional storage during carryover years is not affected by the value of the GVtmf when the PTEra is more than 1.0 feet. Lowering the GVtmf limits additional storage only when the constraint is so low that it prevents adequate evacuation of storage to meet the PTE, mostly when PTEra is less than 1.0 feet. That is why an increased capacity downstream can reduce the volume available in Bear Lake unless the PTEra is raised high enough. We observe that in all cases, lowering the PTE reduces storage whereas raising the PTE increases storage, regardless of the downstream flow constraint.

The mean additional storage at the end of the runoff season during carry-over years increases approximately

Table 13 *- Comparison of the performance measures selected to estimate impacts of changing historic high-runoff management operations to those defined by 4 focus scenarios. Units of each performance measure are included where they are not indicated by the name. Variable values defining each scenario are included. The simulation method, whether Yearly or Continuous, is also indicated. All results assumed a perfect forecast was available.*

Operations Scenario Variable Value			Performance Measure							
			Mean change in August 1 Bear Lake volume for carry-over years (TAF)	Change in total Bear Lake volume (TAF)	Additional years Bear Lake is above 5911	% Time above the GVtmf	High-Runoff impact index	Mean change in annual inflow to Great Salt Lake for carry-over years (TAF)	Change in total flow to Great Salt Lake (TAF)	Change in total volume through Causeway (TAF)
			Simulation Method							
PTEra (+ ft)	GVtmf (cfs)	Scenario	Yearly	Yearly	Continuous	Continuous	Continuous	Continuous	Yearly	Continuous
0.0	1500	Baseline	0	0	0	4.3%	0	0	0	0
1.5	2000	Scenario 22	84	455	4.1	2.5%	-3	-59	-458	-229
2.5	2600	Scenario 31	138	680	5.8	1.2%	-1	-96	-683	-605
3.5	2600	Scenario 35	168	1149	7.2	1.2%	2	-119	-1196	-637
3.5	3000	Scenario 36	168	1145	7.2	0.6%	3	-119	-1192	-607

58,000 acre-feet per 1.0-foot increase in PTEra when perfect forecast information is available. However, in a more realistic case, perfect forecasts are unavailable and the increase would be changed. The direction and degree of change depends on the level of risk assumed in selection of the non-exceedance forecast of spring runoff and the accuracy of the forecast. Overestimated forecasts would lead to less additional storage whereas an underestimate would yield more.

By comparing proposed scenarios in this study, we gained a better-shared understanding of current operations of the Lower Division of the Bear River system. This study provides greater common knowledge of system operations and facilitate a collaborative assessment of effects from changing high-runoff management on the Bear River. This study has produced a planning model that can be adapted and applied to answer future questions

Potential Future Actions

This section identifies potential future modeling, analysis, and cooperation.

Continue cooperative development, maintenance, and refinement

The laudable effort of the States and PacifiCorp to cooperatively develop a river simulation model of the Bear River should not be overlooked. This was truly a collaborative effort! If the model is maintained, then it will continue to be of service for planning and collaboration within the watershed. The States and PacifiCorp desire to continue joint-use, maintenance, and development of the model so as not to allow it to fall into disuse.

The model used for analysis in this study was developed specifically to answer the questions addressed with an eye towards the future in developing the structure to allow model improvements. Future uses of the model can allow for better or different assumptions to be made if the States and PacifiCorp seek to answer additional questions.

Significant effort should be expended to refine and perfect any future potential study questions, because they form the backbone of the study process by defining purpose, providing direction, and giving clarity to the modeling team.

Modeling updates and potential study efforts

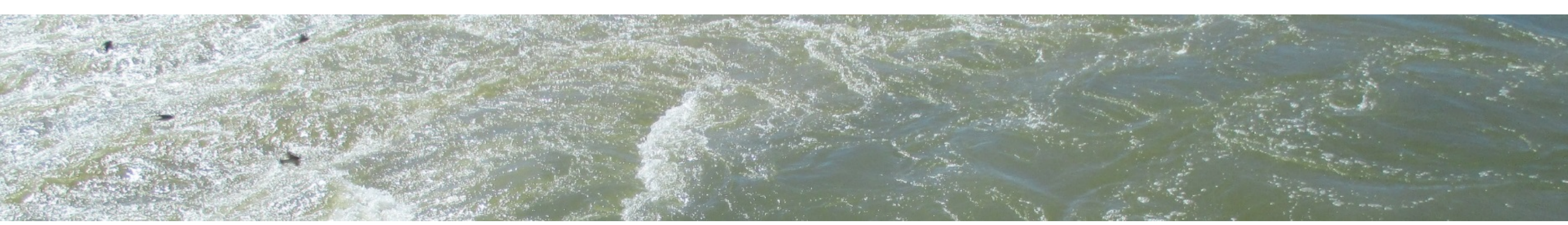
Improvements could be made to the model. One easy improvement is to update the model using data through the 2020 water year. This improvement requires little effort aside from simple data collection but would keep the model up-to-date and may spur development of tools to more readily update the model in the future. This improvement would also include updating any of the hydraulic data such as reservoir capacity tables.

Potential efforts to continue the development of the model include:

1. Adopt a Memorandum of Understanding between the States and PacifiCorp to jointly maintain the model and share updates, modifications, and improvements
2. Adding detail to specific river reaches, incorporating Extended Streamflow Prediction (ESP) forecasts, including reach gain forecasts, and building a software framework for ease of data updates and assimilation.
3. Incorporate water rights accounting into the model, seeking to duplicate the results of the existing interstate models below Bear Lake.
4. Determine the deliverable portion of the additional storable volume of water (without increasing reservoir water levels above the OHWM), based on system constraints such as pumping and existing irrigation delivery.
5. Determine how system performance and model results change under scenarios of greater uncertainty, such as with spring runoff forecasts of varying degrees of certainty or with a different hydrology (e.g., drier conditions).

Stakeholder Engagement

The States and PacifiCorp recognize that dissemination of information about the model and the study is very important. Hence, the States and PacifiCorp will give a presentation on both the Bear River model and this report to the stakeholders and at a Bear River Commission meeting.



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