Evaluation of River Basin Management Alternatives for the Bear River Migratory Bird Refuge

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Abstract

The supply of water is imperative when addressing wetland issues because water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface, which directly affects the habitat of priority bird species. For this reason, the primary objective of the Bear River Migratory Bird Refuge (BRMBR) relates to the management and manipulation of target water levels for wetland units. However, a review of the historical flows to the BRMBR indicates that the quantity of flow during summer months (i.e. July, August, September) are on average below the delivery targets. During these periods, the BRMBR resorts to an adaptive management strategy, prioritizing bird species and focusing efforts (water diversions) to maintain the respective wetland habitats of these species. In order to improve the success of all habitats, which improves overall bird species occupation in the BRMBR, water management strategies must be developed to better secure water deliveries during these months. For this reason, this report develops four metrics to rate the performance of deliveries to the BRMBR, and investigates three management alternatives and how they affect these metrics. In addition, this report looks at how implementing these alternatives affect the water supplied to three other stakeholders in the basin, the Bear River Canal Company, PacifiCorp, and the City of Logan, UT. The modeling of the alternatives was conducted in the Water Evaluation and Planning (WEAP) model for the Lower Bear River system. Analysis of the alternatives with respect to the performance metrics of the BRMBR and affects to the aforementioned stakeholders reveals that the construction of a new reservoir named Above Cutler on the Bear River just upstream of the existing Cutler Reservoir is the best alternative for increasing flows to the BRMBR. In addition, this alternative is also favorable to the three other stakeholders, making it an all around beneficial option. The second most beneficial alternative is an Urban Conservation alternative (where municipal and industrial demand in the basin is decreased by 25%). Lastly, an alternative of increasing the storage of an existing reservoir, an alternative called Hyrum Addition, is beneficial to most of the BRMBR metrics, but hurts other stakeholders in the basin, and thus is worse for the basin than the current basin scenario and is not recommended.

1 Introduction

The Bear River Migratory Bird Refuge (BRMBR) is a sanctuary for native bird species managed by the U.S. Fish and Wildlife Services. The BRMBR was established in 1928 and to this day operates under a singular conservation mission to “administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife and plant resources and their habitats within the United States for the benefit of present and future generations of Americans” (US DOI, 2004). The BRMBR is approximately 74,000 acres and is located directly upstream of the 112,000 acre Bear River delta (Figure 5, Appendix). Within the BRMBR, 29,259 acres are managed as freshwater wildlife habitat (US DOI, 2004). This area takes the form of many land use types that are designed to benefit a diversity of wetland plants and migratory bird species that depend on them. In conjunction with the non-watered lands, the BRMBR provides feeding, breeding, and resting habitat for more than 260 bird species (Downard, 2010).

The BRMBR area is situated near the Bear River delta of the Great Salt Lake. The Bear River Basin, located in northern Utah, southeast Idaho, and southwest Wyoming encompasses an area of 4.8 million acres (US DOI, 2004). A map of the river basin and the location of the stakeholders considered in this report is shown in Figure 6 of the Appendix. With 500 miles of flow from its origin in the Uintah Mountains to the Great Salt Lake, the Bear River is noted for being the longest flowing river in the western hemisphere that doesn’t reach the ocean. Of the water supplied to the Bear River, 60% comes from the Bear River Mountain Range in the form of spring snowmelt. The region is in the rain shadow of the Cascade and Sierra Mountain Ranges resulting in a semiarid climate that on average provides 12.5 inches of precipitation to the BRMBR annually. Therefore, each year’s winter snowpack is crucial for recharging the Bear River and maintaining flows throughout the dry summer months.

The BRMBR’s primary water right is of 1,000 cfs from the Bear River (UT DWR, 2010). This accounts for 93% of all the water the BRMBR has a right to (Table 5 and Table 6, Appendix). However, since many user groups in the region made claims to Bear River water prior to 1928, the BRMBR is referred to as a junior appropriator, and thus is subject to having their water rights cut off first when shortages occur. In essence, even though the BRMBR has a legal right to 1,000 cfs of water from the Bear River, there is no guarantee water will always be available. Unfortunately, this occurs most years due to the BRMBR’s primary source delivering far lower quantities than the BRMBR needs in the late summer months (i.e. July, August, September), corresponding to the peak irrigation season (Figure 7, Appendix).

The objectives specific to the BRMBR relate to the management or manipulation of target water levels of wetland units to foster desired species occupation with primary attention to the needs of priority bird species. This includes the maintenance, recovery and enhancement of plant and wildlife values. However, problems exist within the wetlands that need to be addressed to meet the objectives of the BRMBR. These challenges, among acquiring target environmental flows, include the revival of pre-flood (1983-1988) populations of nesting waterfowl species, control of noxious and invasive species abundance (post-flood), and reduction of pest fish species (carp) that occupy some wetland units (US DOI, 2004).

Not all objectives of the BRMBR can be met on an annual basis. The maintenance, recovery, and enhancement of plant and wildlife within the BRMBR are dependent on water availability; primarily from the Bear River, which may be unobtainable in drier years. Due to the variability in annual flows to the BRMBR, managers have developed an adaptive management strategy that prioritizes certain species and wetland units when shortages occur. Adaptive management is an iterative decision making method that uses monitoring to assess system performance and continually adjusts the actions taken to respond to uncertainty. The goal of this strategy with the BRMBR is to formulate future policies based on what is learned from effects of previous management efforts and protect the resilience of the ecosystems (Allen et al, 2011).

The BRMBR uses water to manage species diversity by creating several habitats that attracts different plant and animal communities. The description and area of these habitats are shown in Table 1. Wetlands within the BRMBR are managed by a series of dikes and canals that impound and transport the water to individual wetland units. In total, the BRMBR has 26 units divided by 96 miles of dikes (Downard, 2010). This allows the BRMBR managers to control the depth of water for individual units, which creates a variety of wetland habitats to accommodate priority bird species needs. In order to maintain good water quality in the units managers seasonally drain them in a process called drawdown. This is a beneficial practice that helps mitigate the spread of diseases (i.e. avian botulism) and restores a more natural hydroperiod (i.e., the period in which a soil area is waterlogged) in wetlands (Downard, 2010). A constraint to this, however, is the seasonal timing of the drawdown, which may disrupt the benefits of this practice depending on how quickly near future water deliveries can recharge these units.

The water needs of wetlands in the Bear River Basin were originally determined by modeling done by the Utah Division of Water Rights, which calculated the amount needed to manage salinity and water loss. Improvements to the model were made by the USFWS in the 1990s, which took into account water depths for different habitat types, salinity, losses from evapotranspiration and seepage, and volumes needed for flushing (Downard, 2014).

Table 1. Wetland units within the Bear River Migratory Bird Refuge

Habitat	Area (acres)	Description
Wetland Marshes	29,259	Account for the Refuge's largest water needs. Varying water levels are used to dictate the types of plants and animal communities for individual units of this type.
Saltair Mudflat	38,064	Habitat consisting of highly saline soils and nearly barren of vegetation. Management of the vegetated mudflats requires the area to be inundated with up to 2 inches of surface water during seasonal high river flows or heavy precipitation.
Wet Meadow	374	Habitat consisting of primarily sedges and rushes.
Riparian Habitat	45.5	Stream bank habitat along the Bear River channel.
Alkali Knolls	522	Abrupt mounds consisting of forbs, grasses, shrubs, and bare ground.

Alkali Bottoms	973	Similar vegetation to the knolls, the bottoms low-lying characteristic provides nesting for waterfowl species.
Salt Meadows	2,625	Heavily vegetated communities that consist of sedges, rushes and saltgrasses.
Dikes and Levees	791	Primarily for impoundment of water within units. These also provide a vegetation community, which is dominated by forbs.

Forecasting the water availability to the BRMBR occurs on an annual basis. Each year the BRMBR develops a Habitat Management Plan that describes how the water will be managed within the wetland units (US DOI, 2004). The decisions are based on the anticipated water supply, which is provided by the annual Natural Resources Conservation Service (NRCS) water supply outlook. The NRCS supplies extensive data in regards to winter snowpack water equivalent, soil moisture, precipitation, and reservoir storage in respect to historical minimums, maximums, and averages. However, the quantity and timing of water delivered to the BRMBR can still be uncertain each year. In order to make the most informed decisions, staff biologists at the BRMBR use an adaptive management strategy along with bird survey data and previous water and vegetation management strategies to determine a course of action. The BRMBR has constructed general management goals that the refuge continually seeks to reach, which are listed in Table 2 below. However, when water availability is lacking not all goals can be accomplished and the BRMBR must prioritize wetland units so that it maximizes migratory bird habitat and puts the water rights of the BRMBR to the most critical and beneficial use. Therefore, obtaining greater water security will allow the BRMBR to meet more of its goals and thus is of great interest.

Table 2. Management tasks of high water use habitat units

Habitat	Management Tasks	Constraint
Wetland Marshes	Managing salinity levels by flushing units with fresh water	Timing and quantity of water from the Bear River
Saltair Mudflat	Spring drawdown	Risk of not being able to refill in summer
Wet Meadows	Maintain water supply and prescribe grazing	Timing and quantity of water from the Bear River
Streambanks	Treat tamarisk to obtain rich native plant communities.	Cost of treatment chemicals and equipment

It is critical that BRMBR managers explore options that ensure water security for the BRMBR in the future, due to current regional changes in water demands posed by growing populations and subsequent transitions of agricultural lands to developed urban land. The implementation of structural or non-structural applications can be used to maintain or increase the security of water but comes as a monetary cost to the BRMBR or as a social cost of conflict among other water user groups. It is important to note that the BRMRB has once sought to acquire more water via a federal reserved water right claim. However, the Refuge was unsuccessful in obtaining more water and the action resulted in a negative backlash from other stakeholders. Therefore, the BRMBR must take into consideration the affects their proposed alternatives have on neighboring user groups.

This poses a current need to find and alternative solution that increases water security for the BRMBR and is also socially beneficial. This project addresses three questions pertaining to the evaluation of three alternatives designed to increase the water security to the BRMBR: (1) What alternative provides the greatest increase for water security of the BRMBR based on the defined performance metrics. (2) Do the alternatives designed for the BRMBR have social acceptance (i.e. mutually beneficial outcomes). The methods implemented herein illustrate how each alternative was chosen and evaluated and presents an analysis of the modeled results that provide resolution the questions posed. The documentation used in the literature review, model instances, and calculation workbooks, can be found on the project's GitHub repository (Mihalevich and Pratt, 2016).

2 Methods

2.1 Performance Metrics for Evaluating Alternatives

There are many areas of concern in the creation and management of ideal habitat for the priority species including water levels and flows, water quality (salinity and stagnation), vegetation composition and density, invertebrate composition and population, and invasive species management. Most of these habitat variables depend on water quantity, meaning that successful management of the many important habitat variables is greatly enhanced when there is no shortage of available water. The ideal water volumes needed by the wetland units have been quantified by the Utah Division of Water Rights and are shown in Table 3 below. The water needs of wetlands in the Bear River Basin were originally determined by modeling done by the Utah Division of Water Rights, which calculated the amount needed to manage salinity and water loss. Improvements to the model were made by the USFWS in the 1990s, which took into account water depths for different habitat types, salinity, losses from evapotranspiration and seepage, and volumes needed for flushing (Downard, 2014).

Table 3. Monthly delivery targets for the BRMBR

Month	Target Delivery (ac-ft)
Jan	-
Feb	4,258
Mar	60,884
Apr	59,181
May	61,309
Jun	46,843
Jul	50,240
Aug	43,002
Sep	54,497
Oct	42,150
Nov	3,406
Dec	-

The Stockholm Environment Institute's Water Evaluation and Planning (WEAP) software is used to evaluate the unmet deliveries to the stakeholders in the basin (SEI, 2016). Because WEAP uses a mass balance approach for determining deliveries, the water targets and deliveries are easily integrated into the WEAP model. Therefore, our evaluation will focus on water volumes, specifically in achieving deliveries equal to or greater than the summer water delivery targets set by the BRMBR.

Performance metrics were implemented as a means to measure the success of the alternatives tested. Four metrics for the BRMBR were developed, all being a function of water deliveries and water demand. These metrics include reliability, resilience, vulnerability, and monthly weighted bird use. Three of the four metrics (reliability, resilience, and vulnerability) were formulated from Loucks, and adapted to the BRMBR using a monthly time step (Loucks, 2005). The metric of monthly weighted bird use was created specifically for the BRMBR based on finding during the literature review. The four metrics are each explained in turn.

Reliability is a measure of the dependability of the system, and is defined as the number of months with satisfactory performance over the total number of months used in the analysis, as shown in equation 1 below.

$$Reliability\ (\%) = \frac{number\ of\ satisfactory\ months}{total\ number\ of\ months} \qquad (1)$$

Resiliency is a measure of the likelihood for a system to bounce back from an unsatisfactory state. It is calculated as the number of months a *satisfactory* performance followed an *unsatisfactory* performance, divided by the total number of months with *unsatisfactory* performance.

$$Resiliency\ (\%) = \frac{\#\ of\ satisfactory\ months\ following\ an\ unsatisfactory\ month}{total\ number\ of\ unsatisfactory\ months} \qquad (2)$$

Vulnerability is the average magnitude of unmet demand when the performance is *unsatisfactory*. It is calculated as the sum of the unmet demands in acre feet divided by the number of months with *unsatisfactory* performance.

$$Vulnerability\ \left(\frac{acre\ ft}{failure}\right) = \frac{\sum monthly\ unmet\ demands}{total\ number\ of\ unsatisfactory\ months} \qquad (3)$$

Weighted monthly bird use (WMBU), was created in this project specifically for the BRMBR to allow emphasis on seasonal species occupation in the BRMBR. The purpose of this metric is to rate the performance of deliveries based on the number of bird species that will benefit from meeting the target deliveries. This metric is valuable because due to the migratory nature of many of the wetland bird species, some months at the BRMBR have higher species occupancy than others, therefore shortages in these months affects a greater number of species. The bird species found at the BRMBR for each month is shown in Figure 1, collected from the 2004 Bear River Habitat Management Plan (US DOI, 2004).

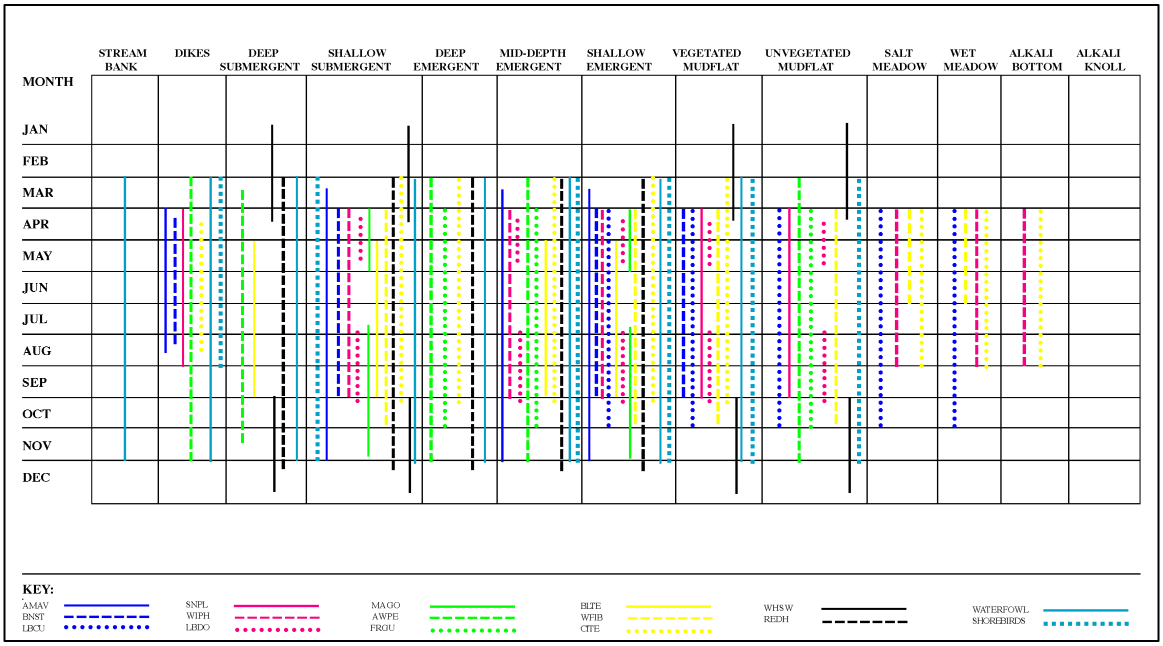

Figure 1. Bird species occupancy for BRMBR habitats throughout the year.

The weight for each month is calculated as the number of species occupying the BRMBR in that month divided by the sum of species counts for all months in the time frame. The equation for the monthly weight is shown in equation 4 below, where MSU_t is the monthly species count.

$$Weight\ of\ Month_t\ (WM_t) = \frac{MSU_t}{\sum MSU} \tag{4}$$

To calculate the weight of January, for example, from the figure there are four species found at the BRMBR during this month, and there are 22,304 species counts in the time frame of October 1965 through September 2006. Therefore, the weight for every January is 4/22,304, or 0.00018. From the figure it is shown that there are actually less species at the BRMBR in June and July than in April and May or August and September. Therefore, April and May as well as August and September have a larger weight, as more bird species are affected by shortages.

The weighted monthly bird use is defined as the sum of the product of the percentage of demand that is met for each month and the weight given to that month, as shown in equation 5 below.

$$Weighted\ Bird\ Use\ Metric = \sum\left(\frac{Demand_t - Unmet\ Demand_t}{Demand_t} * WM_t\right) \tag{5}$$

These performance metrics were applied to the results of the model simulations for each of the alternative, which are explained in the next section.

2.2 WEAP Modeled Structural and Non-Structural Management Alternatives

Two structural and one non-structural alternative management strategies that have been mentioned in UDWR reports were chosen in this project to be modeled in WEAP and compared with the performance under the current river basin scenario, called the “reference”. The alternatives affect the various stakeholders differently based on their location in the watershed, the timing of unregulated stream flows in the basin, and the water right priority of the stakeholder. The water right priorities used in WEAP were provided in a class handout titled WEAPPrimer-LowerBearRiver-v2, and is included in Table 7 in the Appendix.

Alternative 1: New “Above Cutler” Reservoir

There have been numerous proposals by the UDWR to develop additional storage capacity on the Bear River. The Bear River Development Act, passed by the Utah State Legislature in 1991, gives four development approaches to increase the available supply of the Bear River, one of which is building new reservoirs in the Bear River Basin (US DOI, 2004). The plan estimates that there is currently 250,000 acre-feet of Bear River water that remains to be developed for Utah (i.e. not for Idaho or Wyoming), and of this nearly 190,000 acre-feet will require new storage. One of six reservoirs currently being proposed is the “Above Cutler” reservoir, which would be located just above the existing Cutler Reservoir on the Bear River in Cache County (UT DNR, 2014). To determine how the reservoir would affect the four stakeholders of concern in this analysis, the reservoir was added to the WEAP model on the Bear River in its proposed location between the New Cache County M&I diversion and New Cache County M&I point of return flow to the river, as shown in Figure 2. To model the reservoir evaporation losses, the evaporation rate for each month was included the reservoir input data, along with the reservoir storage volume to surface area. This data was taken from the ILO-4 course assignment and was originally collected by Dr. Rosenberg directly from the UDWR (Rosenberg, personal communication, March, 2016; Rosenberg, 2016). The reservoir operating rules are set to control water releases by the Standard Linear Operating Procedure (SLOP), with the *top of inactive* storage, *top of buffer*, and *buffer coefficient* set to 2,000 ac-ft, 15,000 ac-ft, and 1 respectively. The *top of inactive* storage is the water volume that cannot be spilled because it is below the discharge from the reservoir. The *top of buffer* is the reservoir volume where the delivery is less than the demands, and the *buffer coefficient* is the hedging policy, which when equal to 1 means that the release is not restricted. The reservoir is considered to be dual purpose for water supply as well as flood control, so the *top of conservation* storage (the reservoir storage volume at which operators begin to spill) is set to 36,342 ac-ft for the months of high spring runoff and potential flooding (April, May, and June) and 51,342 ac-ft for all other months, as required in ILO-4.

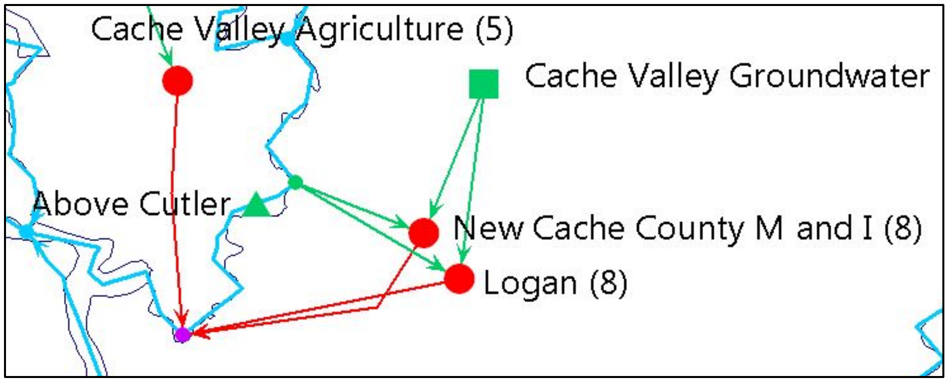

Figure 2. WEAP model of the proposed Above Cutler reservoir

Alternative 2: Increase Storage Capacity of Hyrum Reservoir

The second alternative to be modeled in WEAP is an increase in storage capacity of the Hyrum reservoir, a potential solution to low summer water deliveries that has been proposed by the BRMBR and is currently being explored by the U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation (US DOI, 2004). The proposal calls for an increase in the storage pool of 50,000 ac-ft, which would yield 24,200 ac-ft to the BRMBR in July and August, allowing the BRMBR to maintain an additional 8,000-10,000 acres of wetlands (US DOI, 2004). Without extensive alterations to the existing WEAP model, a simple storage addition to the existing Hyrum reservoir is not possible because the addition would make the additional water stored available to other users in the basin. A solution to this is to model the addition as a new and separate reservoir (which is called Hyrum Addition in the model) in parallel to the existing Hyrum reservoir with a single transmission line to the BRMBR. The schematic is shown in Figure 3 below. No evaporation losses or volume elevation curve was included in the Hyrum Addition reservoir input, because these are already accounted for in the existing Hyrum reservoir. The new transmission line to the BRMBR was placed as second priority to the transmission line representing the diversion from the Bear River adjacent the BRMBR, which means that water will only flow from the Hyrum Addition reservoir to the BRMBR if the demand cannot be met by the Bear River diversion.

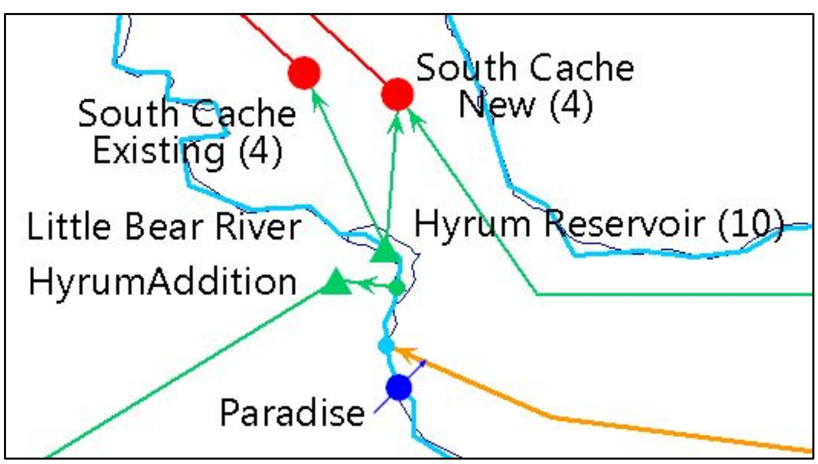

Figure 3. WEAP model of the proposed Hyrum reservoir storage addition

Alternative 3: Urban Water Conservation

To consider the effect of a non-structural alternative to meet the water delivery targets of the BRMBR, an alternative involving the reduction of municipal and industrial (M&I) water use in the basin was modeled in WEAP as a third river basin management alternative in this project. The UDWR has set a goal of reducing the year 2000 gallons per capital per day (gpcd) by 25% by 2025 (Kolankiewics, 2014). To model this reduced consumption, the existing monthly demands of the Weber Basin Project, South Cache Existing, New Cache County M&I, and Logan demand sites were multiplied by 75% in the data input section of WEAP using the expression builder function.

2.3 Performance Metrics of Other Stakeholders in the Basin

The performance metrics for each stakeholder were chosen and defined by each group to specifically represent their respective stakeholder. This was done in the same way to what has been illustrated in this project to measure the success of alternatives designed for the needs of the BRMBR. Stakeholder metrics for other groups were calculated with unmet demand data exported as Excel files from WEAP. An explanation of the other three group's metrics is provided in the following paragraph.

The Logan city group used the same monthly reliability, resiliency, and vulnerability metrics and definitions as our group, and provided an Excel file for easy calculation of the said metrics with copying and pasting from the WEAP export file. The BRCC group used the performance metrics of reliability, resiliency, and vulnerability on an annual basis, and also provided an Excel file for easy copying and pasting of the unmet demand data. The BRCC considered the year's deliveries *unsatisfactory* if there was a single month out of the year with unmet demand, and *satisfactory* if no months of the year had unmet deliveries. The PacifiCorp group used the two metrics. The first metric is the total unmet demand of all four class stakeholders in the basin in units of acre feet. The second metric is total hydropower generation at the three reservoirs Soda, Grace, and Oneida in units of megawatt-hours. The unmet demand metric was possibly chosen because they wish to maintain a good reputation among the other stakeholders in the basin, but they are likely to be more motivated by the hydropower generation metric, which to them represents actual revenue. No spreadsheet was provided by the group, so we calculated these directly from the WEAP exported Excel file.

3 Results & Discussion

The tabular results for all group's performance metrics under the three alternatives and reference scenario are shown below in Table 4. The time frame used in the WEAP model was in time steps of "month" from October 1965 through September 2006. In the table, under the three alternatives the cell is green if the metric has the best improvement compared to the reference, is yellow if there is some improvement compared to the reference but not the best, is red is the metric is worse than the reference scenario, and is left white if there is no change compared to the reference scenario. This color coding serves as a visual aid to recognize the qualitative performance of the metrics for the three alternatives relative to the reference scenario.

Table 4. Performance metrics for each stakeholder metric under the reference scenario and each alternative.

Stakeholder	Performance Metric	Objective	Reference	Above Cutler Reservoir	Hyrum Addition	Urban Conservation
BRMBR	Weighted Monthly Bird Use (%)	Maximize	88.3%	91.7%	91.8%	88.8%
	Reliability (%)	Maximize	84.3%	88.2%	89.0%	84.8%
	Resilience (%)	Maximize	29.9%	34.5%	33.3%	30.7%
	Vulnerability (ac-ft/failure)	Minimize	25326	24502	25743	24846
BRCC	Reliability (%)	Maximize	85.0%	90.0%	85.0%	85.0%
	Resilience (%)	Maximize	100.0%	100.0%	100.0%	100.0%
	Vulnerability (ac-ft/failure)	Minimize	9871	8710	10039	9610
PacifiCorp	Hydropower Generation (MWh)	Maximize	183953	188902	183293	184396
	Unmet Demand (sum of monthly average, ac-ft)	Minimize	51897	37650	38304	49718
Logan City	Reliability (%)	Maximize	82.7%	87.2%	82.7%	82.7%
	Resilience (%)	Maximize	22.4%	25.4%	22.4%	22.4%
	Vulnerability (ac-ft/failure)	Minimize	1394	1392	1413	1380

As can be seen by the color trends in the table, for the Above Cutler reservoir alternative all stakeholder metrics except one improve over the reference scenario, and the one that does not improve (BRCC resilience) is at a maximum valve. Therefore, all four of the stakeholders would benefit from, and likely be supportive of, the proposed reservoir.

The Hyrum Addition reservoir alternative benefits four of the total performance metrics as compared to the reference scenario, but actually worsens four performance metrics as well. For the BRMBR the WMBU, reliability, and resilience metrics improve, but the vulnerability worsens slightly. The BRCC and Logan city groups each have metrics with no change but also have a poorer vulnerability, so they would be unlikely to be supportive of such an alternative. The PacifiCorp unmet demand metric improves but there hydropower generation metric worsens, so because they are likely to be more motivated by electricity sales than unmet demands of other demand sites in the basin, they are also unlikely to support the alternative. Thus, the Hyrum additional storage alternative is unlikely to gain acceptance with other stakeholders in the basin, although real world circumstances and pressure by the BRMBR would likely still advocate for such an alternative.

The urban conservation alternative (already a stated goal of the UDWR) benefited at least one metric of each of the four stakeholders, although not to the extent that the Above Cutler alternative did. Also, it did not negatively affect any of the metrics of the stakeholders. Perhaps of most importance, it improved the vulnerability metric of Logan city, the stakeholder most likely to be in opposition to such an alternative. Therefore, the urban conservation alternative, according to the model, is a promising alternative for all stakeholders in the basin.

Figure 4 shows the performance for each metric and each alternative for the BRMBR. The chart shows that the Hyrum Addition, Above Cutler, and Urban Conservation alternatives each increase the resilience, reliability, and weighted monthly bird use compared to the reference scenario. However, the vulnerability is actually worse (increases) for the Hyrum Addition compared to the reference scenario, while the Above Cutler and Urban Conservation alternatives improve (decrease) the vulnerability. The exact cause of the increased vulnerability is difficult to ascertain without a more disaggregated mass balance analysis of the river basin. Whether the increased vulnerability of the Hyrum Addition is worth the increase in the other three metrics is unknown without further investigation into the shortage costs associated with each unit of the BRMBR vulnerability.

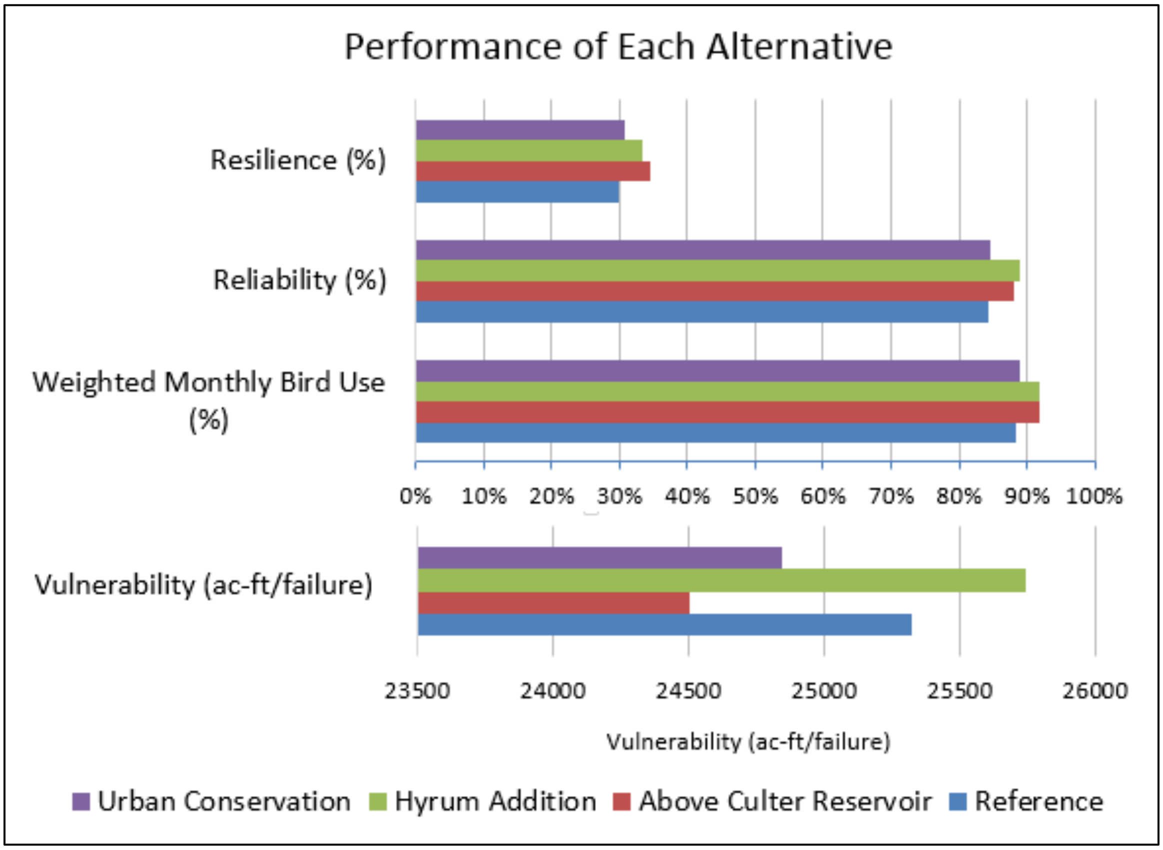

Figure 4. Performance of the BRMBR for each alternative

Among all stakeholders evaluated in the project the "Above Cutler" reservoir alternative accounted for a majority of best scoring performance metrics across all groups. Urban conservation also provides benefits or no change from the reference for most of the stakeholder metrics. The addition of storage in Hyrum reservoir would likely result as a negative option among all of the stakeholders, as most would incur a negative performance from the reference. In addition, the BRMBR is also less likely to go forward with the Hyrum reservoir alternative based on the vulnerability results, as mentioned earlier. Therefore, the construction of a new reservoir on the Bear River above the existing Cutler reservoir is likely to have the most social acceptance and mutually beneficial outcomes among the stakeholders evaluated in this project.

4 Conclusion

The BRMBR must develop alternatives to ensure the quality of wetland habitats that are essential for maintaining and promoting priority bird species occupation. The deliveries of water to the BRMBR is a major factor for accomplishing this due to the nature of soil development and the types of plant and animal communities living in the soil and on its surface that characterize the types of habitat and can be effected by changes in water supply and coverage. Therefore, alternatives designed at decreasing the unmet demands to the BRMBR, especially from the Bear River can improve the performance of the BRMBR. After evaluation of three alternatives based on the performance metrics developed to characterize the success, the "above Cutler" alternative would provide the greatest securities of water to the BRMBR. Furthermore, this alternative is highly advantageous among the other stakeholders evaluated in this report, as is provides a positive increase in performance for each group.

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Appendix

Map of the BRMBR.

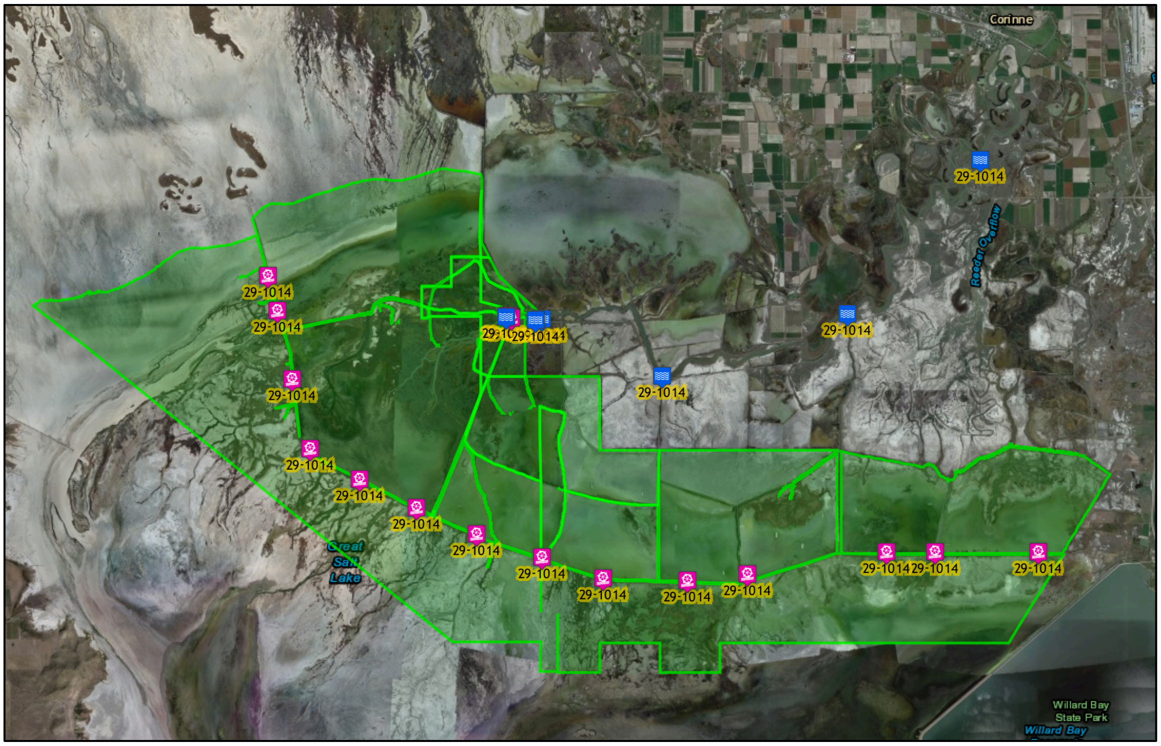

Figure 5. Online screen shot of the BRMBR depicting the management units. Taken from the Utah Division of Water Rights website.

Map of the Bear River Basin with approximate locations of stakeholders evaluated in this report.

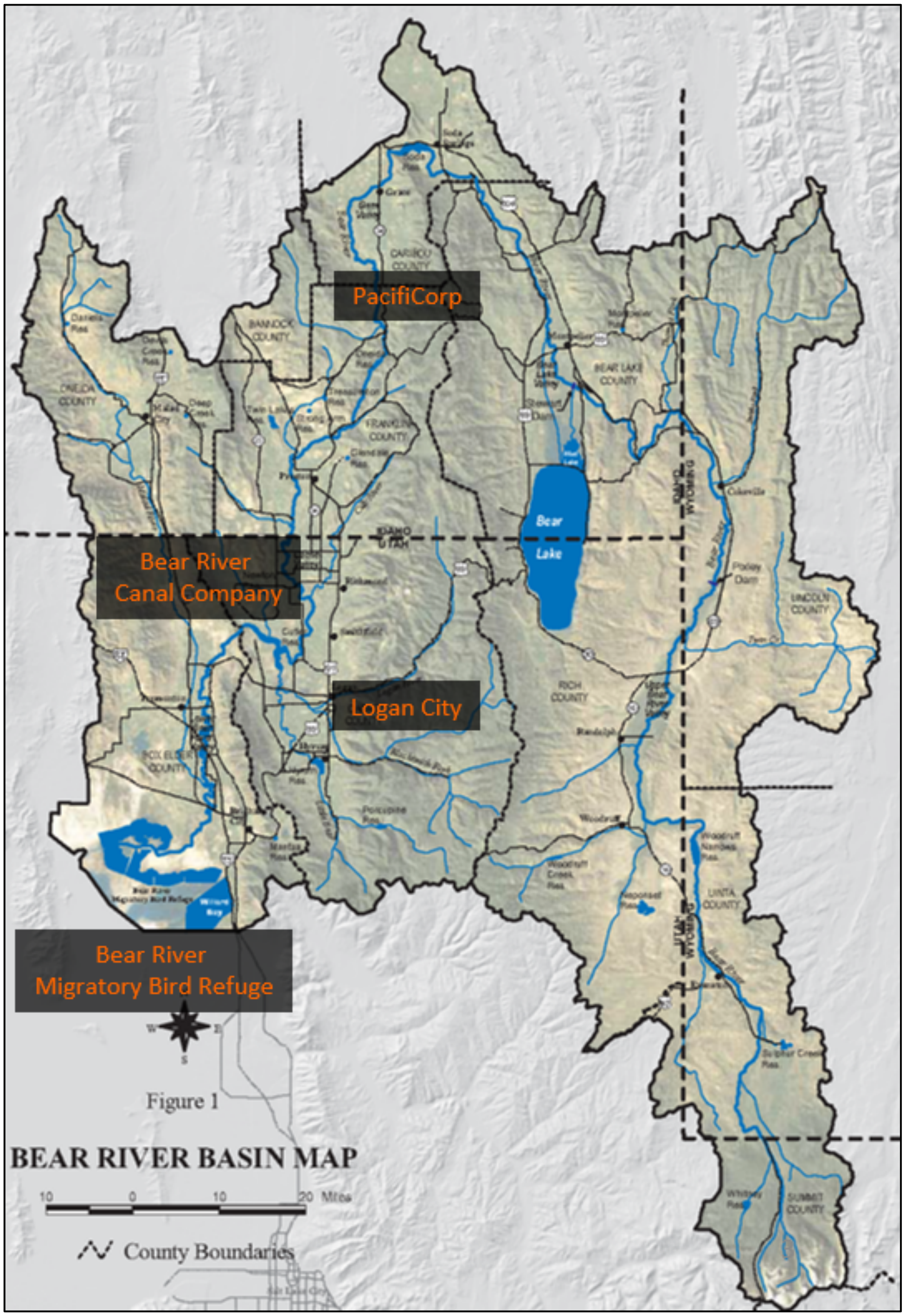

Figure 6. Map of the Bear River Watershed

Water Rights, Source, and Allocated Flow of the BRMBR. Primary Bear River Water Rights are in Bold.

Table 5. Water Rights of the BRMBR

Primary Right Holder	Water Right number	Source	Allocated Flow	Point of Diversion
Paul W. and Mary V. Nelson J.T.	29-3172	Stauffer-Packer Spring	1.04 cfs	SURFACE
John Robert Reese Trustee	29-951	Perry Spring Stream	1.0 cfs	SURFACE
USA Fish &Wildlife Services	29-1919	Unnamed Stream	2.4 cfs	SURFACE
USA Fish and Wildlife Services	29-973	Unnamed Stream	2.4 cfs	SURFACE
Grace G. White Trust and LeRoy Clark White Family Trust	29-936	Dan Walker Spring	3.06 cfs	SURFACE
Grace G. White Trust and LeRoy Clark White Family Trust	29-937	Perry Spring Stream	0.56 cfs	SURFACE
USA Fish & Wildlife Service	29-3061	Underground Water Drain (open)	0.002 cfs	POINT TO POINT
USA Fish and Wildlife Service	29-2622	Unnamed Spring Stream	0.015 cfs	POINT TO POINT
USA Fish and Wildlife Service	29-1697	Unnamed Spring Stream	1.0 cfs	SURFACE
Grace G. White Trust and LeRoy Clark White Family Trust	29-3060	Unnamed Spring	1.0 cfs	SURFACE
USA Fish and Wildlife Service	29-1915	Underground Water Drain	1.5 cfs	UNDERGROUND
USA Fish and Wildlife	29-1916	Underground Water Drain	2.0 cfs	UNDERGROUND
USA Fish and Wildlife Service	29-1914	Underground Water Drain	3.0 cfs	UNDERGROUND
USA Fish & Wildlife Services	29-1450	East Slough	7.37 cfs	SURFACE
USA Fish & Wildlife Service	29-3484	Black Slough	45.0 cfs	SURFACE
USA Fish and Wildlife Service	29-768	Underground Water Drain	1.59 cfs	UNDERGROUND
USA Fish and Wildlife Service	29-769	Underground Water Drain	1.114 cfs	UNDERGROUND
USA Fish & Wildlife Service	**29-3485**	**Bear River**	**15.9 cfs**	**SURFACE**
USA Fish & Wildlife Service	**29-3698**	**Bear River**	**2000.0 acre-feet**	**SURFACE**
USA Fish & Wildlife Service	29-3157	Unnamed Stream	0.002 cfs	SURFACE
USA Fish & Wildlife Service	29-770	Underground Water Well	0.01 cfs	UNDERGROUND
USA Fish & Wildlife Service	29-980	Surface Drains	0.5 cfs	SURFACE
USA Fish & Wildlife Service	**29-1014**	**Bear River**	**1000.0 cfs**	**SURFACE**
USA Fish & Wildlife Service	29-1165	Underground Water Well	0.011 cfs	UNDERGROUND
USA Fish & Wildlife Service	29-1330	Underground Water Well	0.134 cfs	UNDERGROUND

USA Fish and Wildlife Service	29-3668	Salt Creek	2468.1267 acre-feet	SURFACE
USA Fish & Wildlife Service	29-3825	Stauffer-Packer Spring	1.04 cfs OR 4.0 acre-feet	SURFACE
USA Fish & Wildlife Service	29-3824	Underground Water Drain	1.0 cfs OR 40.0 acre-feet	SURFACE
USA Fish and Wildlife Service	29-1637	Surface Water	132.88 acre-feet	SURFACE

Note: Data gathered from the Utah Division of Water Rights (2009) online database. Water right numbers for the BRMBR were obtained from Downard, 2010. Water right listed where USA Fish USA Fish & Wildlife Service are not primary water right holders indicate shared water right use with USA Fish & Wildlife Service being a secondary or tertiary water user on that right.

Monthly Water allocations of the BRMBR by water right.

Table 6. Water allocations for the BRMBR by month and water right number (ac-ft) and total monthly allocated water.

Month	Water Right Number			Total Allocation (ac-ft)
	29-3485	29-3698	29-1014	
Jan			5938	5938
Feb			8202	8202
Mar			61380	61380
Apr			59400	59400
May	976	750	60077	61803
Jun	472	250	35120	35842
Jul			56978	56978
Aug			40868	40868
Sep	472	200	59400	60072
Oct	976	400	27424	28800
Nov	944	400	8987	10331
Dec			1997	1997

Note: Data gathered from the Utah Division of Water Rights (2009) online database. Water right numbers for the BRMBR were obtained from Downard, 2010.

Box and whisker plot of the monthly Bear River flows at Corinne Station, Oct. 1949 through Dec. 2015.

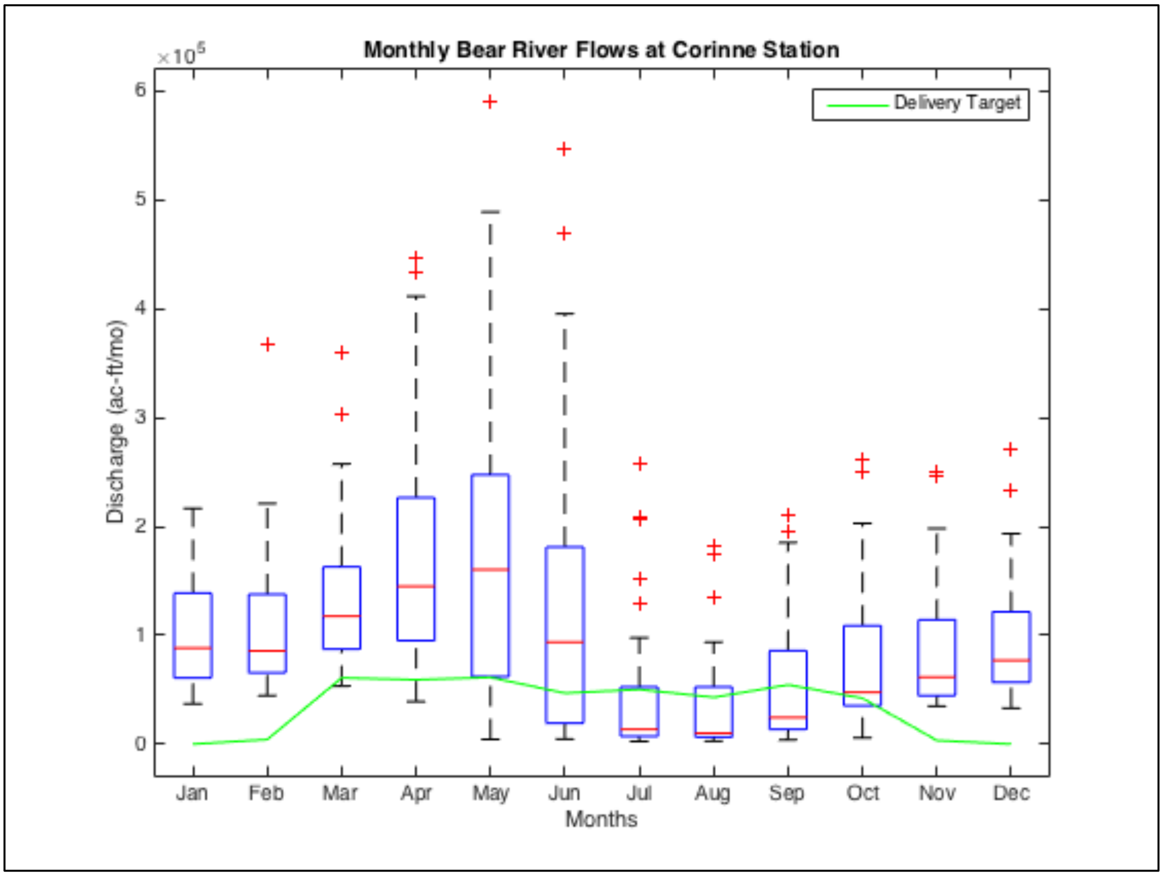

Figure 7. Monthly Bear River Flows at Corinne Station

Bear River Basin demand sites priorities used in the WEAP model.

Table 7. Bear River Basin Demand Site Priorities

Priority	Service Area No.	Name	Use Type	Demand Quantified
Included in WEAP Model				
2	1	Bear River Canal Company	Irrigation	Yes
3	2	Bird Refuge	Environmental	Yes
4	8	South Cache Existing	Irrigation	Yes
4	9	South Cache New	Municipal	No
8	3	Cache Valley New	Municipal	No
5	4	Cache Valley Irrigation	Irrigation	No
6	6	New Box Elder County	Irrigation	No
7	7	Box Elder County	Municipal	No
21	5	Wasatch Front	Municipal	No
20	11	Weber Basin	Municipal	Yes
Excluded from WEAP Model				
NA	10	Idaho	Irrigation	No