Evaluating Reservoir Operation Rules to Improve Hydropower Production and Reduce Unmet Water Demands in the Bear River Basin Using the Water Evaluation and Planning (WEAP) System

Course Project Report

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1. Abstract

This study evaluates the effectiveness of updating reservoir operations for the Soda, Grace, and Oneida reservoirs along the Bear River in southeastern Idaho. These reservoirs are currently owned and operated by the PacifiCorp Electric Company. The primary purpose of these reservoirs is to supply downstream water demand, protect against flooding events, provide a source of recreational use, and produce hydro generated electricity.

Despite the wide range of use, these three reservoirs are not performing as well as they could. The current implemented reservoir operation is to supply immediate downstream water demand at the cost of potential storage and greater hydroelectricity generation. We believe there is a potential for greater performance for these reservoirs by making adjustments to their operation metrics.

We have found that by altering the release policy of these reservoirs it is possible to increase potential hydropower generation by 55% or alternatively further decrease downstream water demand by (-)0.26% for all demand sites. This is possible via a combination of reservoir operations including 1) changing the amount of water that is considered inactive for water demand, 2) the volume of water that is constrained below a specific level, 3) by adopting a seasonal change in demand priority that increases storage during the refill period.

Our provided alternatives in reservoir operation were designed in mind with the goal of increasing hydroelectricity generation and lowering unmet water demand. This report provides a detailed description of how we came to these conclusions and how they can be included into the reservoir practice. We feel confident that our solutions are a benefit for the PacifiCorp Electric Company and strongly recommend that they be implemented.

2. Introduction

The Bear River Basin (Fig. 1) covers an area of about 7,465 square miles of Idaho, Utah and Wyoming, and contains 470,000 Acres of crop and pasture land (Morse & Tasumi, 2000). The Bear River has several major tributaries, including Little Bear River, Blacksmith Fork, Malad River, Weber Surplus etc. Major demand sites in the basin include Bear River Canal Company (BRCC), Bear River Migratory Bird Refuge (BRMBR), Cache Valley Agriculture, New Cache Valley Municipal, Logan City and Weber basin project (Utah Division of Water Resources, 2011). The basin has 10 reservoirs; four active, and six inactive. There are three cascading reservoirs (in series) named Soda, Grace and Oneida located in Idaho along the northern part of the basin. These three reservoirs are part of a privately owned hydropower production, operated by the PacifiCorp Electric Company. The three reservoirs are capable of generating 77 Megawatt (MW) of clean energy with contribution from Soda, Grace and Oneida as 14 MW, 33MW, and 30 MW (PacifiCorp 2016).

However, these hydroelectricity generation rates do not always achieve their target mark because of various natural and management related issues, such as non-optimized reservoirs operation rules, low flow in the Bear River, the river's water commitments to downstream demand sites etc. This reports aims to analyze the performance of the system of the three mentioned reservoirs under various reservoir operating policies in terms of the hydropower production capability, and the ability to improve downstream water supply. This report summarizes release policies of the three reservoirs in tandem to increase hydropower production and decrease unmet demand.

2.1. Project Objective and Performance Metrics

The objective specific to the project is to evaluate and recommend reservoir operational policies to improve hydropower generation and decrease unmet water demand for downstream users. This will include suggestions on the weight of reservoir parameters such as reservoir filling priority, top of buffer, buffer coefficient, etc. to improve hydropower production, or to decrease downstream demand sites' unmet water demand.

WEAP has a comprehensive array of parameters that can represent results for various needs. Two such results- '*Hydropower Generation*' (in Megawatt-hour) and '*Unmet Water Demands*' (in Acre-foot) will be used as performance metrics for this project. The recommend reservoir operation rules will be evaluated upon these two metrics. For example, if a certain operation rule raises the *Hydropower Generation* value, that rule is considered desirable for improving hydropower production. Similarly, if an operating rule brings down the *Unmet Water Demand*, then that rule is considered desirable for decreasing the unmet water demand of the system.

2.2. Water Right Restrictions and Excluded Demand Sites

The water rights of PacifiCorp involve a long history dating back to the early 1800s. According to Bear River Settlement Agreement Explanatory Statement (2002), the original water right was transferred from Sugar Company to PacifiCorp under conditions that the PacifiCorp must supply an allocated value of water to various demand sites in the region. In order to fully understand this water right, demand site data and conditions for four major demand sites (Last Chance Canal Company, U&I Sugar Company, West Cache Irrigation Company and Cub River Irrigation Company) and multiple other smaller demand sites are required. However, the availability of such data are not present, as there is no clear indentation of recorded data. Instead, this project will skip the water right portion altogether for this report.

Similarly, the river inflow data to the three reservoirs are all considered the same, with no inflow or outflow from or into the river in between the three reservoirs. Despite these assumptions, the authors believe that the recommendation hold true, because the recommendations, in general, are independent to the magnitude of inflow. They are only dependent on the seasonal changes in flow, which is accounted for in the Bear River headflow data used in the model.

Figure 1 Bear River Basin in Idaho, Wyoming and Utah (source: http://waterrights.utah.gov/)

Table 1 Quantified Bear River Basin Demand Sites and Their Priorities

Priority	Name	Use Type	Downstream to the three reservoirs?
2	Bear River Canal Company	Irrigation	Yes
3	Bird Refuge	Irrigation	Yes
5	South Cache Existing	Irrigation	Yes
8	New Cache County	Municipal	Yes
8	Logan	Municipal	Yes
20	Weber Basin	Municipal	Yes

Note: Restrieved from *Water Evaluation and Planning (WEAP) Lab Exercise Lower Bear River, Utah* (p. 4), by D. Rosenberg. 2016

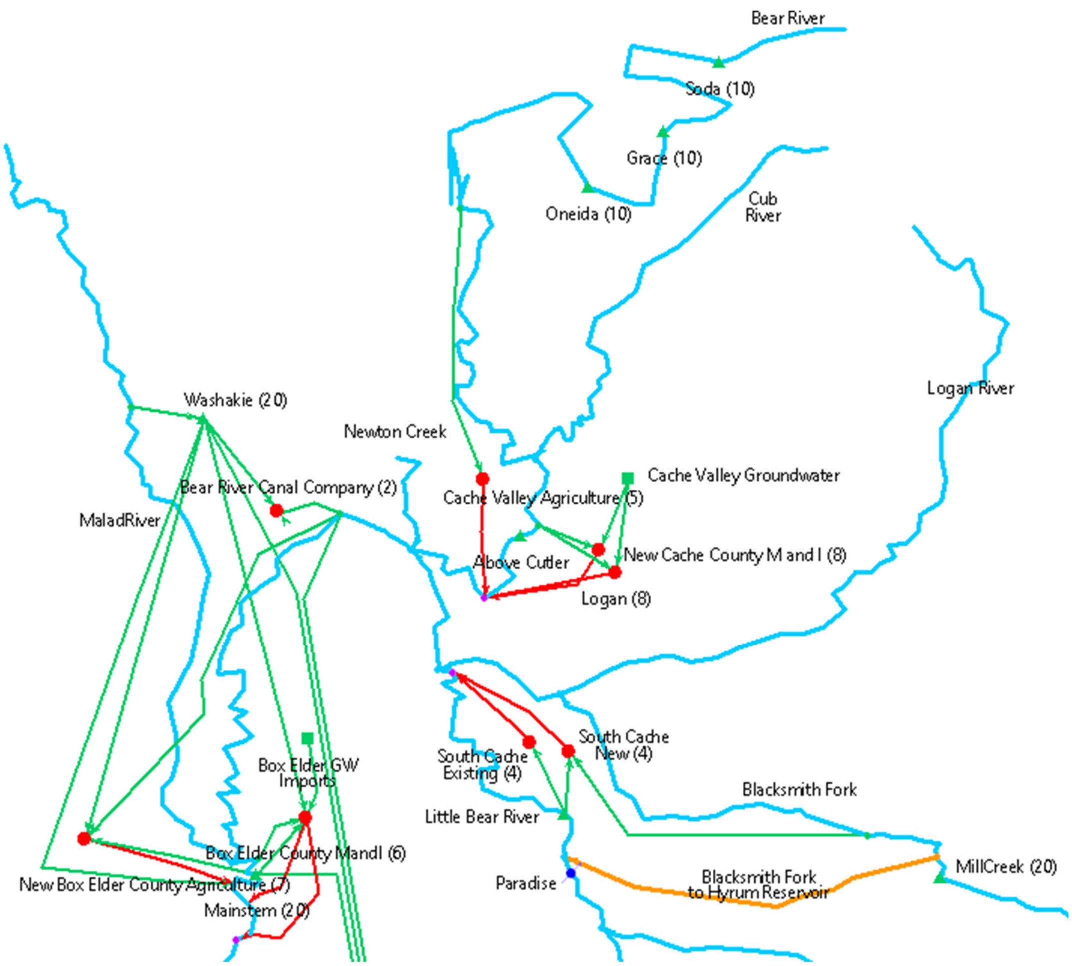

Figure 2 WEAP model schematic of the Bear River Basin.

3. The WEAP Model

3.1. Introduction to WEAP Model

The WEAP system, developed by the Stockholm Environmental Institute in 1988, is a software package for planning and managing water supply. It operates on the basic principle of mass-balance and allocates water based on the priorities specified for the system components such as the demand sites, reservoirs, and environmental flows (SEI, 2007). WEAP has been used in numerous water resources studies throughout the world, including the Aral Sea (Raskin et al., 1992); Upper Chattahoochee River Basin, Georgia (Johnson, 1994); South Africa (Levite et al., 2003); Sacramento River, California (Purkey et al., 2008); Austin, Texas; Portland, Oregon; and Philadelphia, Pennsylvania (Huber-Lee et al., 2005).

WEAP partitions reservoir storage into zones (Figure 3 Definition of the operation zone parameters required by WEAP (Adapted from SEI, 2007).). The Flood Zone is reserved to capture flood flows, while the Conservation Zone defines water storage to meet the full delivery requirements of urban, agricultural, hydropower, or other demand sites that draw from the reservoir. Should reservoir storage drop into the Buffer Zone, water deliveries are cut back below the full delivery amount. This cutback amount is specified by the buffer coefficient which determines the fraction of water in the buffer zone to be released. Users can enter the reservoir zone levels and buffer coefficient value in WEAP to create model scenarios representing different reservoir storage and release operations and simulate the associated results such as deliveries to and shortages at demand sites (SEI, 2007).

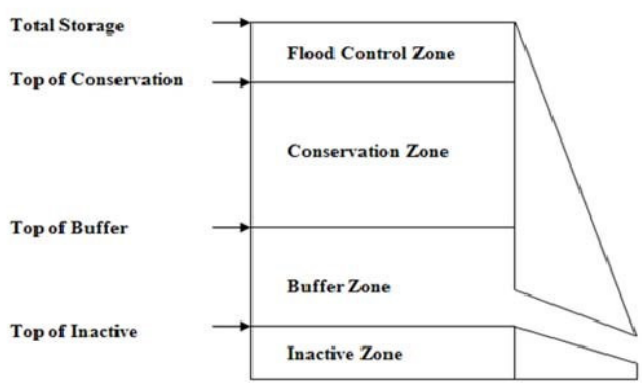

Figure 3 Definition of the operation zone parameters required by WEAP (Adapted from SEI, 2007).

3.2. Existing WEAP model

The WEAP model for the Bear River basin used in the class CEE 6490, 2016 taught by Dr. David Rosenberg & Dr. Steve Burien (Rosenberg GitHub, 2016) was upgraded by the addition of the three reservoirs; Soda, Grace and Oneida. The final WEAP model (Figure 2) used contains some demand sites, rivers and reservoirs whose values are not entered, and hence are inactive. The WEAP model contains 10 reservoirs (four active, and six inactive) and 11 demand sites (have been assigned monthly demand), 10 river flows (five of whom with assigned flow values).

A service area is a group of canals or diversions that serve agricultural or urban users and is alternatively referred to as a "demand site" in WEAP. The WEAP model allocates water among service areas based on priorities (Table 1). For example, the WEAP model gives the Bear River Canal Company the highest priority in the basin because it has the highest priority of 2, which is highest of all the demand sites that exist in the model.

3.3. Supply and Resources (Rivers)

There are 10 major tributaries of Bear River in the model. Out of the 10 rivers, the historical streamflow values for only five have been assigned in the model. They include Bear River headflow, Little Bear River, Blacksmith Fork, Weber Surplus and Malad River. The streamflow data ranges from October 1966 to November 2007.

3.4. Demand sites

There are 11 demand sites in the model; Bear River Canal Company, Bird Refuge, Cache Valley Agriculture, New Cache Valley Municipal, Logan City, South Cache Existing, South Cache New, Weber Basin, Box Elder County Municipal, and New Box Elder County Agricultural. However, the data for only six of them (Bear River Canal Company, Bird Refuge, Cache Valley Agriculture, New Cache Valley Municipal, Logan City and Weber basin project) are used (Table 1).

3.5. Reservoirs Data

Much of the data for the three reservoirs that this project considers were obtained from the bear river settlement agreement paper (*Bear River Settlement Agreement*, 2002). Additional data that was not possible to gather was instead assumed and/or estimated, which will be explained in the *Assumption* section below. Most of the data will change from scenario-to-scenarios. However, these changes will remain constant to a set of data considered for the base case (the Reference scenario) and is summarized in the Tables (Appendix A, B and C), which are summarized according to the WEAP sections below.

3.5.1. Physical Data

The storage capacity for the three reservoirs (Soda, Grace and Oneida) are 16300, 320 and 1080 Acre-feet respectively (PacifiCorp 2016). Initial storage values pre-project to the original WEAP were model considered 0 and inactive. The volume-elevation curve for all three reservoirs was estimated based on the shape of similar curve obtained for other reservoirs in the nearby system. They were constructed based on the storage capacities and water level when the reservoirs are full and empty (Appendix D). It is to be noted that the minimum elevation for the three reservoirs were assumed because of data unavailability. For the net evaporation, monthly variation in evaporation rate was accounted, as seen in Appendix E. Because the three reservoirs were spatially closely located, evaporation loss rates for all three were assumed to be the same. Remaining data in the physical tab was left to default.

3.5.2. Operational Data

The Top of Inactive, Top of Buffer, Top of Conservation and Buffer Coefficient values are left to default in the reference case. However, different combinations of these reservoir elements are tested against the performance metrics in different scenarios to find the release policy that works best. These will be discussed later in the Model Testing section.

3.5.3. Hydropower Data

In the Hydropower tab, the maximum turbine flow value used for Soda, Grace and Oneida were 2624, 2880 and 3290 cubic feet per second (CFS) respectively. The tailwater elevation for the three dams were assumed to be 5641, 4870 and 4760 feet respectively (PacifiCorp 2016). The tailwater elevation is necessary to determine the head difference, and hence hydropower generation. But, care must be taken to estimate the tailwater elevation for two main reasons: a) the tailwater elevation of one reservoir cannot be lower than the highest water elevation for the immediate downstream reservoir, and b) the tailwater elevation selected determines the hydropower generation value. Inappropriate values for tailwater elevation can mean too little or too much hydropower generation value, one that deviates too much from the true value. Hence they were assumed to make the output hydropower generation equal to the existing 14 MW, 33 MW and 30 MW generation under the 86% efficiency respectively. The generating efficiency of 86% was chosen because all three reservoirs have Francis turbine units, whose average efficiency is around 86% (Francis turbine, 2016). The hydropower priority was left at 10 for all three reservoirs.

3.5.4. Priority Data

The reservoir filling priority for the three reservoirs was left at 10 for the reference case. As with other parameters, different values of priority were tested in the different scenario to analyze the performance of the system in terms of the stated performance metrics.

3.6. Assumptions

- *Tailwater elevations*: Assumed different values for the three reservoirs to match real power production potential for each, using the standard hydropower production formula:

$$Power\ Produced = \frac{\eta * (water\ surface\ elev - tailwater\ elevation) * Q}{1.81 * 1000}$$

Where *Power Produced* is the megawatt value (Ex: 14 MW for Soda), *Q* is design discharge in cfs, *water surface elev* is the maximum water surface level when the reservoir is full, *tailwater elevation* was back calculated using this formula.

- *Exclusion of Multiple Demand Sites:* Multiple demand sites in the region around PacifiCorp's three reservoirs were excluded due to inadequate data. These sites include Sugar Company, Last Chance Canal Company, Cub River Irrigation Company, West Cache Irrigation Company and more.
- *Evaporation Rate*: Evaporation rate was assumed to vary monthly, and the values are shown in Appendix E. The rate for all three reservoirs was assumed the same as the table in Appendix E, because they are located close to each other and weather conditions were assumed to be the same.
- *Volume- Elevation Curve:* Volume-Elevation curve and relation used in the model for the three reservoirs are as shown in Table 2 (below). These values were estimated by assuming similar curve shape as the Idaho reservoir that was in the existing WEAP model. Rate of change in volume for the new volume-elevation curve was assumed the same as the existing reservoirs. The known value of reservoir maximum and minimum water surface elevation, and the storage capacity was used.
- *Refill and Drawdown Period*: Refill period was assumed to be Oct-March, and drawdown as May-Nov. These values were based on the historical mean river flow for each month.
- *Headflow for the Bear River:* The streamflow for each of the reservoirs was assumed the same as the headflow for Bear River used in the class model. This neglected the possible diversion and inflow of water in between the reaches, and hence the streamflow is probably not accurate. However, this will not affect the objective of the project too much since project is about looking at improving or seeing relative change in hydropower production and improving unmet water demand, and this actual magnitude of flow does not make much difference.

4. Model Testing

4.1. **Reference Scenario**

The below results were evaluated using two performance metrics: 1) hydropower generation in megawatts-hour, 2) unmet water demands in acre-foot. The results were found using the following methods: 1) changes in reservoir operation and release policy, 2) changing the priority of energy production demand with respect to water delivery demand. Most of the following results are compared to what is called the "Reference" scenario, as this comparison illustrates the greatest differences in results.

As the name inclines, the reference scenario is the original model where no reservoir operations are put into use and the water priority matches those of other demand sites (around 10). In addition, the reference scenario contains the following information for the Soda, Grace, and Oneida reservoirs…

A. Storage capacity in ac-feet (16300, 320 and 1080 respectively)
B. Volume elevation curve (Appendix D)
C. Net evaporation (Appendix E)
D. A delivery priority (set to 10)
E. Maximum turbine flow in CFS (2624, 2880 and 3290 respectively)
F. Tailwater elevation in feet (5641, 4870 and 4760 respectively)
G. Plant efficiency set to 86% (based on Francis turbine units)

Each of the following scenarios will contain the above reference scenario information in addition to each element being tested. Scenarios testing storage elevation levels (Top of Buffer, Top of Inactive) of reservoir operation will use the bellow Table 2, which shows the volume-water surface elevation relationship of the three reservoirs.

Table 2 Volume Water Surface Elevation Relationship of Three Reservoirs

	Soda		Grace		Oneida	
Level	Volume (ac-feet)	Water surface Elevation (feet)	Volume (ac-feet)	Water surface Elevation (feet)	Volume (ac-feet)	Water surface Elevation (feet)
Level 9	0	5641	0	4921	0	4833
Level 8	654	5651	13	4931	437	4839
Level 7	1598	5661	31	4941	1067	4846
Level 6	2870	5671	56	4951	1915	4852
Level 5	4428	5681	87	4961	2956	4858
Level 4	6272	5690	123	4970	4186	4864
Level 3	8572	5700	168	4980	5722	4871
Level 2	12161	5710	239	4990	8117	4877
Level 1	16300	5720	320	5000	10880	4883

4.2. **Water Demand Priority Change for the Reservoirs Scenario**

We wanted to observe the influence that the priority number of water delivery to the three reservoirs has on the system. We ran simulations looking at the high outcome (setting priority to 1), the low outcome (setting priority to 99), and then a monthly variation outcome (setting the priority 1 for the months of Dec-March and 10 for April – October, see Table 3), who values were chosen as they correspond to the refill period and drawdown period of the system.

Table 3 Monthly Variation in Priority Value Scenario

Month	Priority Value	Month	Priority Value
Oct	10.0	Apr	10.0
Nov	10 .0	May	10.0
Dec	1.0	Jun	10.0
Jan	1.0.	Jul	10.0
Feb	1.0	Aug	10.0
Mar	1.0	Sep	10.0

Looking at Figure 4 we can see that the unmet water demand is greatly increased when the priority of filling the reservoirs is greater than the demand priority of the other sites (in this case 1) relative to the reference, which performed 2.68% higher than the reference scenario. In comparison, setting the priority to 99 did lower the unmet water demand compared to setting the priority to 1, but still performed worse than the reference scenario at an increase of 1.80%. Having a monthly-variation performed the best in respect to a change in unmet water demand, performing (-)0.51% less than the reference (which is good).

One would think that if the reservoir priority was set lower the unmet water demand for the rest of the system would go down, but these results show the opposite. This unexpected result is best explained in Figure 5, which shows the reservoir volume of the three reservoirs in question. When setting the priority to 1 the reservoirs were always full, but setting the priority low (to 99) means the reservoirs were never allowed to fill with water, which meant they were never allowed to store water for later delivery.

For hydropower generation, setting the priority to 1 for the reservoirs did produce the most hydropower, with an increase in 55.93% in performance than the reference. Using the monthly variation in water priority performed the second best in hydropower generation at 22.67% increase in performance. In contrast, setting the priority to a low demand of 99 resulted in a drastic decrease in performance by (-)36.65% to reference.

Figure 4 Change in Priority Unmet Water Demand. Note: Four scenarios are shown: 1) Reservoir priority set to 1, 2) Reservoir priority set to 99, 3) Reservoir priority set to Monthly Variation, 4) Reference Scenario.

Figure 5 Reservoir Storage Volume. Note: Four scenarios are shown: 1) Reservoir priority set to 1, 2) Reservoir priority set to 99, 3) Reservoir priority set to Monthly Variation, 4) Reference Scenario.

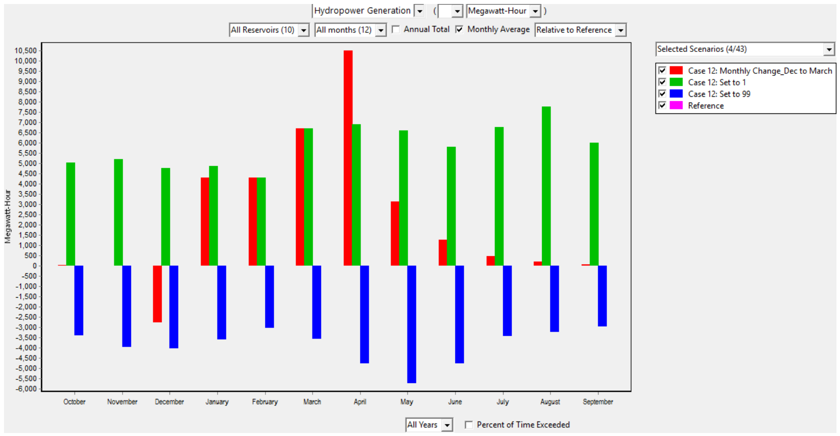

Figure 6 Change in Priority Hydropower Generation. Note: Four scenarios are shown: 1) Reservoir priority set to 1, 2) Reservoir priority set to 99, 3) Reservoir priority set to Monthly Variation, 4) Reference Scenario.

4.3. **Top of Inactive Volume Level Scenarios**

For testing the influence of the *Top of Inactive* reservoir operation element, we tested five different scenarios, each one setting the volume to the above described levels (Table 2) which were then compared them to the reference scenario. From Figure 7 and 8 we can see that setting the top of inactive to the reservoir capacity (level 1) has the greatest unmet water demand and hydropower generation results (increase by 2.68% and 55.93% to reference respectively). However, versus the lowest tested level (level 5) which did produce a beneficial unmet water demand at but also the lowest hydropower generation capacity of only a 27.63% increase in performance to the reference.

Figure 7 Change in Top of Inactive Level Unmet Water. Note: along with the Reference Scenario, there are an additional five scenarios shown in this figure. Each corresponding to a different level laid out in table 2.

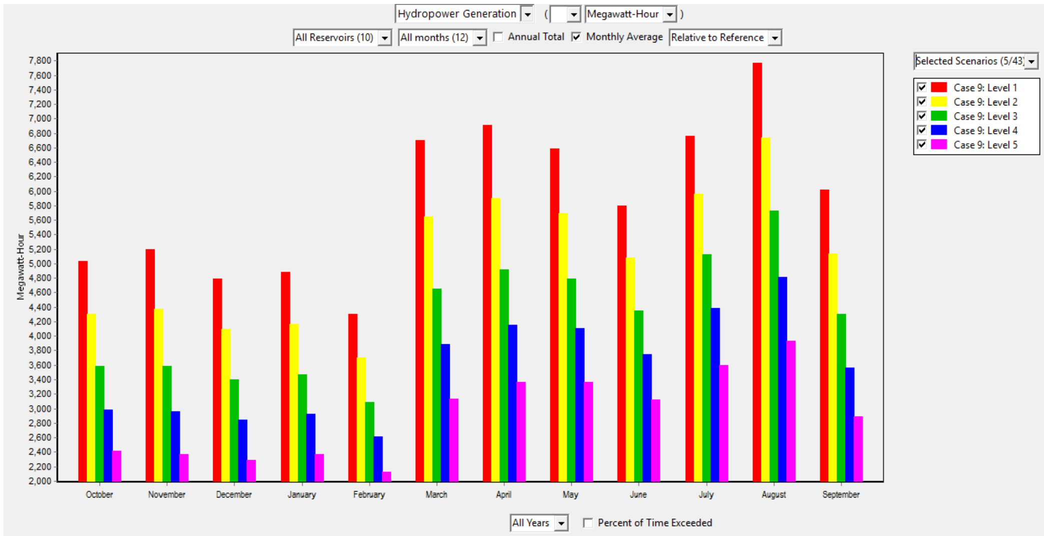

Figure 8 Change in Top of Inactive Level Hydropower Generation. Note: along with the Reference Scenario, there are an additional five scenarios shown in this figure. Each corresponding to a different level laid out in table 2.

4.4. Top of Buffer Volume Level & Buffer Coefficient Scenarios

For testing the *Top of Buffer* and corresponding *Buffer Coefficient* value, a total of 25 different scenarios were prepared, each set to a specific level of reservoir volume (levels 1 - 4, as can be seen in the Table 2) and with a range of buffer coefficients values (1.0, 0.75, 0.50, 0.25, 0.1). A Buffer Coefficient value of 1.0 means that release from the reservoir is not restricted, whereas the smaller value of 0.1 means the release is restricted down to only 10% of normal.

Results for the 20 scenarios can be seen in Figure 9 and 10. As the level and buffer coefficient value decrease the unmet water demand increases. Where the highest change occurs at level 1 with a coefficient of 0.1 at a 1.42% increase in unmet demand and 8.36% more hydropower generated. The lowest change occurs at level 4 with a coefficient of 1.0, with a 0.0 % increase in unmet demand and a 0.0% more hydropower generated.

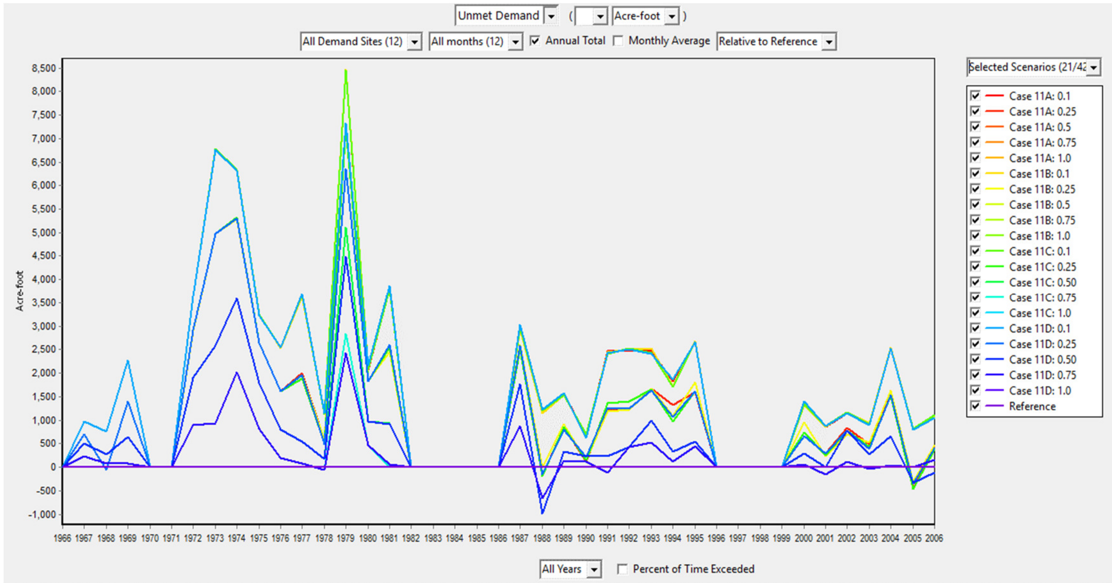

Figure 9 Change in Top of Buffer Level and Buffer Coefficient Unmet Water Demand. Note: along with the Reference Scenario, there are an additional 25 scenarios shown in this figure. Each corresponding to a different level laid out in table 2, and a different buffer coefficient value (1.0, 0.75, 0.50, 0.25, 0.1).

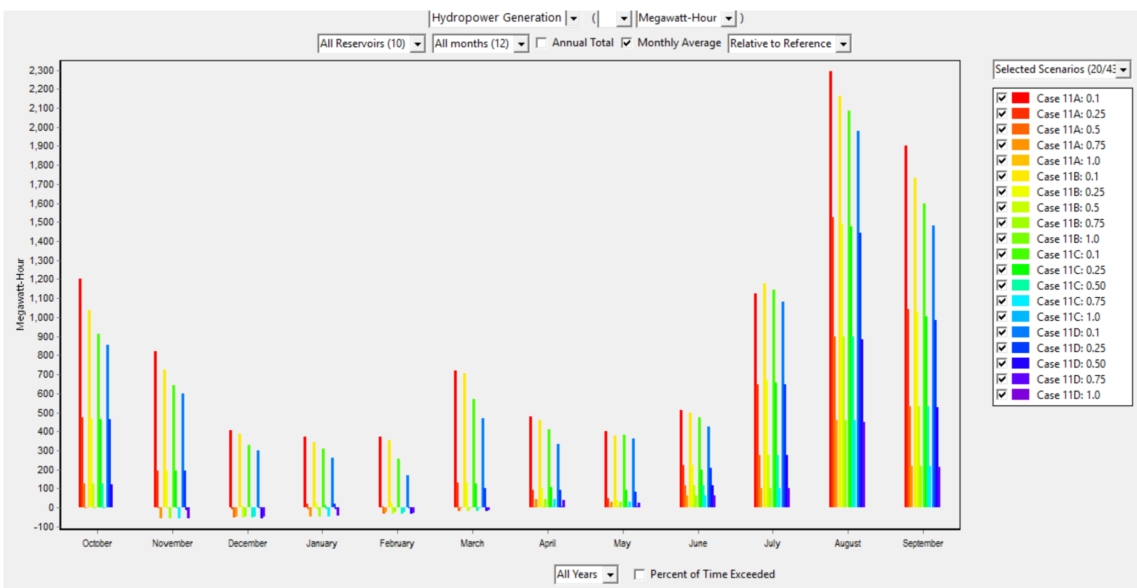

Figure 10 Change in Top of Buffer Level and Buffer Coefficient Hydropower Generation. Note: along with the Reference Scenario, there are an additional 25 scenarios shown in this figure. Each corresponding to a different level laid out in table 2, and a different buffer coefficient value (1.0, 0.75, 0.50, 0.25, 0.1).

From Figures 9 and 10 it can be hard to distinguish the difference in influence that the Top of Buffer level and Buffer Coefficient reservoir elements have had on the system. Figures 11 and 12 show the sum of the annual results of figures 9 and 10, with hydropower generation plotted against unmet water demand. Both figures show the same results, but differ in their manner of sorting. Figure 11 was sorted by Top of Buffer level (Table 2), while Figure 12 was sorted by coefficient value. According to these two figures, the influence that the Top of Buffer level has on the model is almost minuscule versus the amount of influence the Buffer Coefficient value has had. This is particularly noticeable around the left hand side of Figure 11, where it is impossible to distinguish between the Top of Buffer level results. These two plots show that no matter where you set the Top of Buffer level, the results will vary little. Whereas the strongest aspect is going to be the selection of the Buffer Coefficient value.

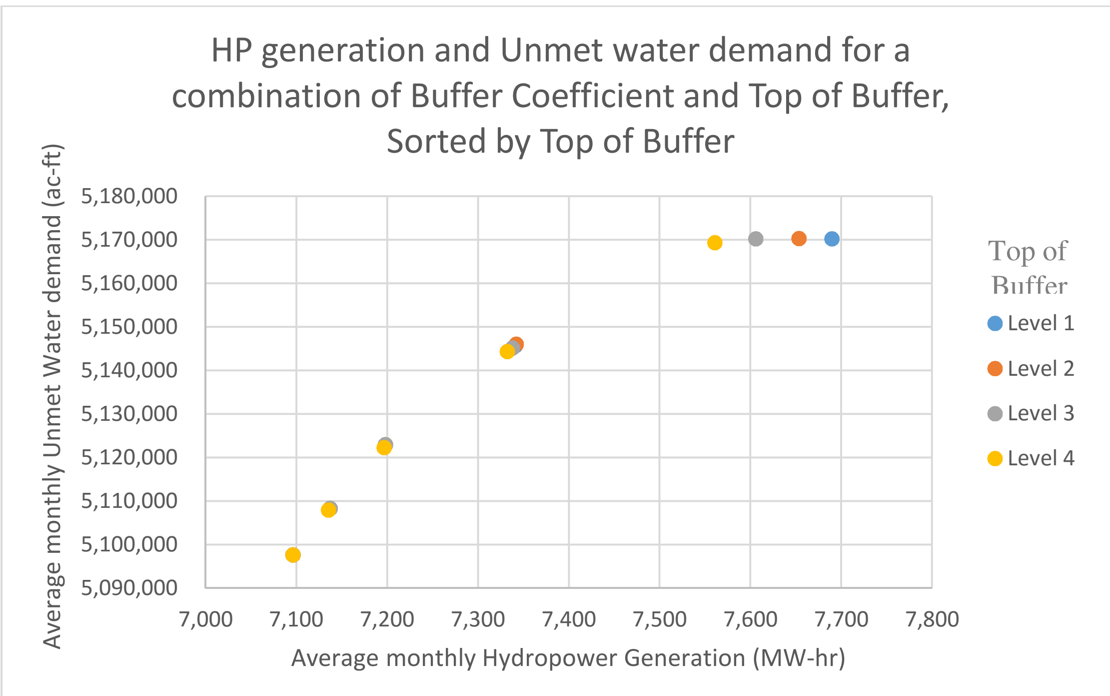

Figure 11 Plot of Hydropower (HP) generation and Unmet water demand for a combination of Buffer Coefficient and Top of Buffer. The graph has been labelled by Top of Buffer Level value ranging from Level1 to Level4. These levels, as described earlier, represent the fraction of total reservoir storage capacity taken as the value for Top of Buffer.

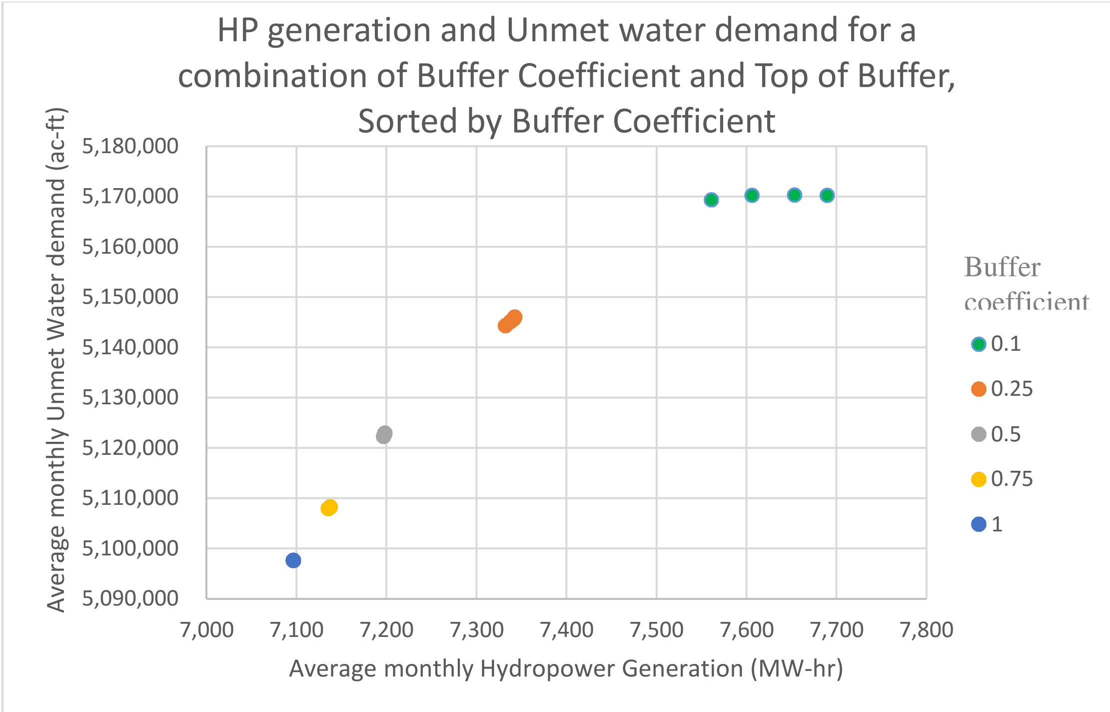

Figure 12 Plot of Hydropower (HP) generation and Unmet water demand for a combination of Buffer Coefficient and Top of Buffer. The graph has been labelled by Buffer Coefficient values. The buffer coefficient values represent the fraction of available water to release when the available water is below the demand value.

5. Recommendation – Alternative Solutions

The following recommendations were chosen based from the above tested scenarios. These recommendations break down to three possible solution alternatives in reservoir operation that either attempt to maximize hydropower generation or minimize unmet water demand. The first alternative solution will attempt to maximize hydropower generation (Alt 1), the second solution will attempt to minimize unmet water demand (Alt 2), and the third solution is combined favorite that tries to make the best of both results (Alt 3).

Figure 13 and Figure 14 show the WEAP model results of the above three mentioned alternative solutions. As can be clearly seen, Alt 1 produces the most hydropower generation (55.93% better than reference), but has the highest unmet demand (a gain of 2.63% in total to reference). Likewise, Alt 2 has the lowest and only beneficial unmet water demand, but has a lower hydropower generation capability. Alt 2 performs (-)0.26% better in unmet water demand and 27.63 % better in hydropower generation than the reference scenario. Alt 3, the combined alternative, performs 34.46% better in hydropower generation, but does raise the unmet water demand by 0.54% compared to reference.

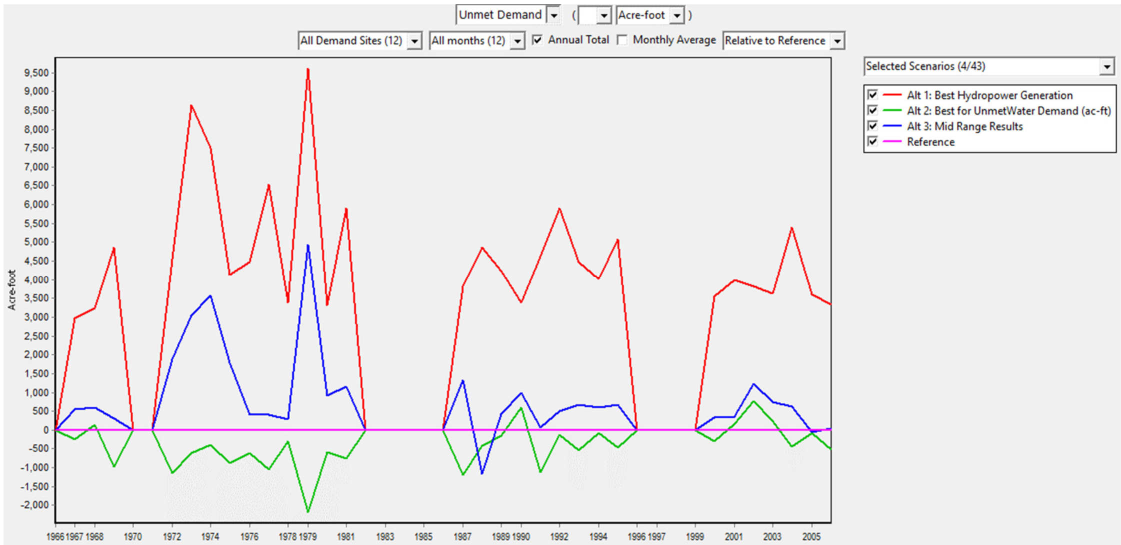

Figure 13 Alternative Solutions Unmet Water Demand. Note: Compared to the Reference Scenario. This figure shows three scenario results: 1) Best for Hydropower Generation, 2) Best for Unmet Water Demand, 3) Mid-Range Results, which is an author solution.

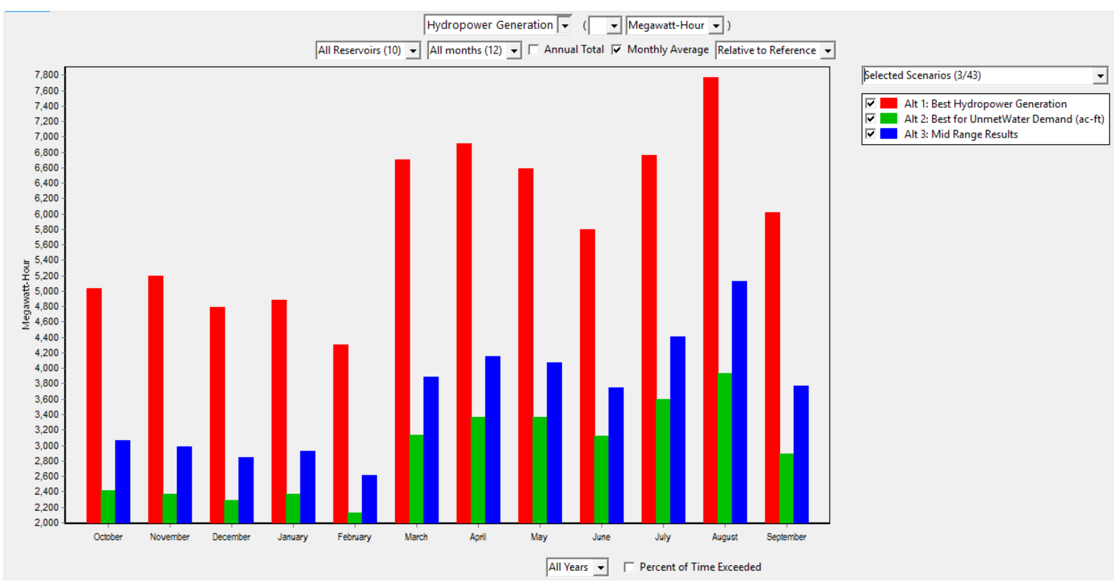

Figure 14 Alternative Solutions Hydropower Generation. Note: Compared to the Reference Scenario. This figure shows three scenario results: 1) Best for Hydropower Generation, 2) Best for Unmet Water Demand, 3) Mid-Range Results, which is an author solution.

6. Effects on other demand sites

The above three alternatives recommended by this project do improve hydropower and also decreases unmet water demand for the entire system. However, it is worthwhile to observe the direct impact of these alternatives on the other three demand sites under study in the class project; BRCC, BRMBR and Logan City. If these other demand sites performance improves, not only will the recommendations be better than their initial intention of improving hydropower and decreasing overall water demand, they will be better alternatives all around. However, if they bring negative effects to these sites, the recommended alternatives might have to be modified or used with an adverse effect in mind. Hence, let's look at the effect of the three recommended reservoir alternative policies on the three other demand sites selected by the other groups in the class.

i) Bear River Canal Company (BRCC)

The results for BRCC seem promising. Their Reliability has no significant changes in the three alternative suggested, however, there is a significant increase in the resiliency of the system. The resiliency increases from 66.7% to up to 71.4% under one of the alternative suggested (Alt 1), shown in the Table 4 below. The vulnerability of the system also reduces drastically, by 8.92% as seen in Appendix E. Hence, the reservoir release policies favor the BRCC demand sites to improve their performance as well.

Table 4 *Performance Metrics for the BRCC for the three recommended alternatives*

Scenarios	Reliability (%)	Resiliency (%)	Vulnerability (ac-feet)
Alt 1: Best Hydropower Generation	97.2%	71.4%	6530.3
Alt 2: Best for Unmet Water Demand	97.4%	69.2%	6767.5
Alt 3: Mid-Range	97.6%	66.7%	6960.2
Reference	97.6%	66.7%	7169.8

ii) Bear River Migratory Bird Refuge (BRMBR)

For the three recommended alternatives, the change in Weighted Monthly Bird Use is negligible, less than 0.6% decrease for the worst case, i.e. Alt 1, and 0.05% increase in Alt 2. Similarly, there is insignificant changes in reliability and resiliency as seen in the Table 5 below, compared to the reference scenario. These poor results are most likely due to the fact that the BRMBR is the furthest downstream demand site. At this point during the river's travel, most of the water has either already been distributed or lost. Some alternatives do have marginal improvements, while other have hurt the BRMBR performance metrics. In all, there seems to be next to negligible effect of all three recommended reservoir release policies on these sites (Appendix E).

Table 5 *Performance Metrics for the BRMBR for the three recommended alternatives*

Scenarios	Weighted Monthly Bird Use (%)	Reliability (%)	Resilience (%)	Vulnerability (Acre-feet)
Alternative 1: Best Hydropower Generation	85.02%	80.28%	29.90%	25544.0
Alternative 2: Best for Unmet Water Demand	85.64%	81.10%	27.96%	25567.1
Alternative 3: Mid-Range Results	85.49%	80.49%	30.21%	25031.3
Reference	85.59%	80.69%	29.47%	25120.7

iii) **Logan City**

Similar to the BRMBR, Logan City also has had negligible effects for the three recommended alternatives. There are insignificant changes in reliability and resiliency as seen in the Table 6 below, compared to the reference scenario. Unlike the BRMBR, Logan City is located further upstream, but still performs poorly under these alternatives. This might be the result of the demand priority of Logan City being lower than those of sites. BRCC, for example, has a priority of 2, versus Logan City's priority of 8. Some alternatives have had marginal improvements, while others have hurt the Logan City performance metrics. In all, there seems to be next to negligible effect of all three recommended reservoir release policies on these sites (Appendix E).

Table 6 *Performance Metrics for the Logan City for the recommended alternatives*

Scenarios	Reliability (%)	Resiliency (%)	Vulnerability (ac-feet)
Alt 1: Best Hydropower Generation	77.8%	26.6%	1379.4
Alt 2: Best for Unmet Water Demand	78.5%	26.4%	1361.4
Alt 3: Mid-Range	78.0%	26.9%	1363.0
Reference	78.3%	27.1%	1357.4

7. Model Access and Repository

This model and its results have been shared on the GitHub, with the link to it shown below. Any user interested in repeating these results may do so by following the link and the posted instructions on how to download and view the model results. https://github.com/CEE-6490-RiverBasinPlanning/Spring-2016/tree/master/PacifiCorp%20-%20Ryan%26Prasanna

8. Conclusion and Discussion

A WEAP model was prepared for the Bear River Basin where three reservoirs (Soda, Grace and Oneida) were included. Different operation policies were tested by creating over 31 scenarios in the WEAP model, and the results for these scenarios were used to identify the best management solution to improve hydropower production, and decrease the overall water demand of the entire system. Different values for Reservoir Release Priority, Top of Inactive, Top of Buffer & Buffer Coefficient were tested to see the effects each had on hydropower production and meeting water demands.

Three alternatives were recommended; the first to increase hydropower production, the second to decrease the unmet water demand, and the third being the authors choice that tried to include the best of both practices. The alternative suggested for increasing hydropower production (Alt 1) produced an 55.93% increase compared to the reference scenario. The alternative for best (least) Unmet water demand (Alt 2) could manage a 0.26% decrease in unmet water demand. The authors choice alternative (Alt 3) has an average 0.54% increase in unmet water demand, but still out performed the reference scenario with an 34.46% increase in hydropower production.

For the other demand sites, the release policies recommended here has had either negligible negative affect (less than 0.6% decrease in reliability or resiliency for BRMBR and Logan City), or slight increase in reliability, resiliency and decrease in vulnerability (+4.8% resiliency improvement, 640 Ac-feet vulnerability decrease for BRCC). The negative effects on the BRMBR and Logan City demand sites are negligible, and hence can be said that the reservoir release policies do not affect them. The reservoir release policies do not disturb the other existing sites, and increase the hydropower production, at the same time decreasing the unmet water demand. Hence, the recommendations are justified.

Reference

Bear River Commission - Home Page. (2016). *Bearrivercommission.org*, <http://bearrivercommission.org/> (April 13, 2016).

Bear River Settlement Agreement Explanatory Statement. 28 AUG 2002. <http://www.lowimpacthydro.org/assets/files/Bear%20River%20ID/Bear_River_Settlement_Agreement_Explanatory_Statement.pdf>

Francis turbine. (2016, March 3). In Wikipedia, The Free Encyclopedia. Retrieved 02:43, April 10, 2016, from https://en.wikipedia.org/w/index.php?title=Francis_turbine&oldid=708143911

Huber-Lee, A., Swartz, C., Sieber, J., Goldstein, J., Purkey, D., Young, C., Soderstrom, E., Henderson, J., and Raucher, R. (2005). “Decision Support System for Sustainable Water Supply Planning.” AWWA Research Foundation, Denver, CO.

Johnson, W.K. (1994). "Accounting for Water Supply and Demand: An Application of Computer Program Weap to the Upper Chattahoochee River Basin, Georgia." Training Document No. 34, Hydrologic Engineering Center, US Army Corps of Engineers, Davis, CA

Levite, H., Sally, H., and Cour, J. (2003). "Testing Water Demand Management Scenarios in a Water-Stressed Basin in South Africa: Application of the Weap Model." *Physics and Chemistry of the Earth*, 28, 779–786.

PacifiCorp. (2016). Bear River Project. <http://www.pacificorp.com/es/hydro/hl/br.html?> (April 3, 2016).

Purkey, D. R., Joyce, B., Vicuna, S., Hanemann, M. W., Dale, L. L., Yates, D., and Dracup, J. A. (2008). "Robust Analysis of Future Climate Change Impacts on Water for Agriculture and Other Sectors: A Case Study in the Sacramento Valley." *Climatic Change*, 87 (Suppl 1), S109–S122.

Raskin, P., Hansen, E., Zhu, Z., and Stavisky, D. (1992). "Simulation of Water Supply and Demand in the Aral Sea Region." Water International, 17, 55-67.

Rosenberg, D. (2016). CEE-6490-River Basin Planning/Spring-2016. GitHub Repository, <https://github.com/CEE-6490-RiverBasinPlanning/Spring-2016/tree/master/CombinedWEAPArea>

Rosenberg, D. (2016). Water Evaluation and Planning (WEAP) Lab Exercise Lower Bear River,Utah.

Stockholm Environmental Institute (SEI) (2007). WEAP Water Evaluation and Planning System User Guide for Version 3.2; (www.weap21.org).

Utah Division of Water Resources (UDWR) (2011). "Genres model for the Lower Bear River." Salt Lake City, Utah.

Appendix A. WEAP Demand Sites

Demand Site Name	Annual Water Demand (Ac-feet)	Return Flow fraction	Priority	Monthly Variation in Demand (Acre-feet)											
				October	November	December	January	February	March	April	May	June	July	August	September
Bear River Canal Company	242,444	0	2	16691	4576	1561	1277	787	289	2544	34448	45953	50966	47807	35537
Bird Refuge	425,760	0	3	42150	3406	-	-	4258	60884	59181	61309	46834	50240	43002	54497
South Cache Existing	-	1	5	**	**	**	**	**	**	**	**	**	**	**	**
New Cache County	53,667	**	8	6332	1869	1869	1869	1869	1869	6332	6332	6332	6332	6332	6332
Logan	6,333	**	8	863	58	58	58	58	58	863	863	863	863	863	863
Weber Basin	-	1	20	**	**	**	**	**	**	**	**	**	**	**	**

** Varies monthly and yearly

- Inapplicable

Appendix B. Streamflow Data in the WEAP Model for Major Bear River Tributaries Assigned as Headflow

Major Tributaries	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Sum**
Bear River	49268	51138	49475	47538	41191	57888	66876	71658	68096	68455	64359	51385	687327
Blacksmith Fork	3176	2880	2838	2728	2346	2910	3260	2392	2256	3931	3685	3274	35677
Little Bear River	1683	1674	1689	1830	1864	3785	6885	10395	6267	2628	1863	1609	42173
Malad River	2899	4159	4567	5902	6249	10842	7677	5818	2934	1744	1692	1749	56232
Weber surplus	63	52	120	172	164	387	785	1349	610	9	0	2	3712

The units are (Acre-feet)

Appendix C. Parameters for Reference Scenarios in WEAP for the Three PacifiCorp Reservoirs

Reservoir Name	Storage Capacity (Ac-feet)	Initial Storage (Ac-feet)	Volume-Elevation relation	ET	Top of Inactive	Top of Buffer	Top of Conservation	Buffer Coefficient	Priority
Soda	16300	0	Present	Present	Default	Default	Default	Default	10
Grace	320	0	Present	Present	Default	Default	Default	Default	10
Oneida	10880	0	Present	Present	Default	Default	Default	Default	10

Appendix D. Elevation-Storage Relationship in the Three Reservoirs

i) Soda

Volume [AF]	Elevation [feet]
0	5641
654	5651
1598	5661
2870	5671
4428	5681
6272	5690
8572	5700
12161	5710
16300	5720

ii) Grace

Volume [AF]	Elevation [feet]
0	4921
13	4931
31	4941
56	4951
87	4961
123	4970
168	4980
239	4990
320	5000

iii) Oneida

Volume [AF]	Elevation [feet]
0	4833
436.5	4839.25
1066.7	4845.5
1915.4	4851.75
2955.9	4858
4186.3	4864.25
5722	4870.5
8117.2	4876.75
10880	4883

Appendix E. Evapotranspiration Rate for the Three Reservoirs

	Month	Evaporation Rate (feet)
10	October	0.05
11	November	0
12	December	0
1	January	0
2	February	0
3	March	0.02
4	April	0.13
5	May	0.22
6	June	0.36
7	July	0.43
8	August	0.39
9	September	0.2
	Total	**1.79**

Appendix F. Effects of Recommended Reservoir Release Policies Other Demand Sites

i. BRMBR

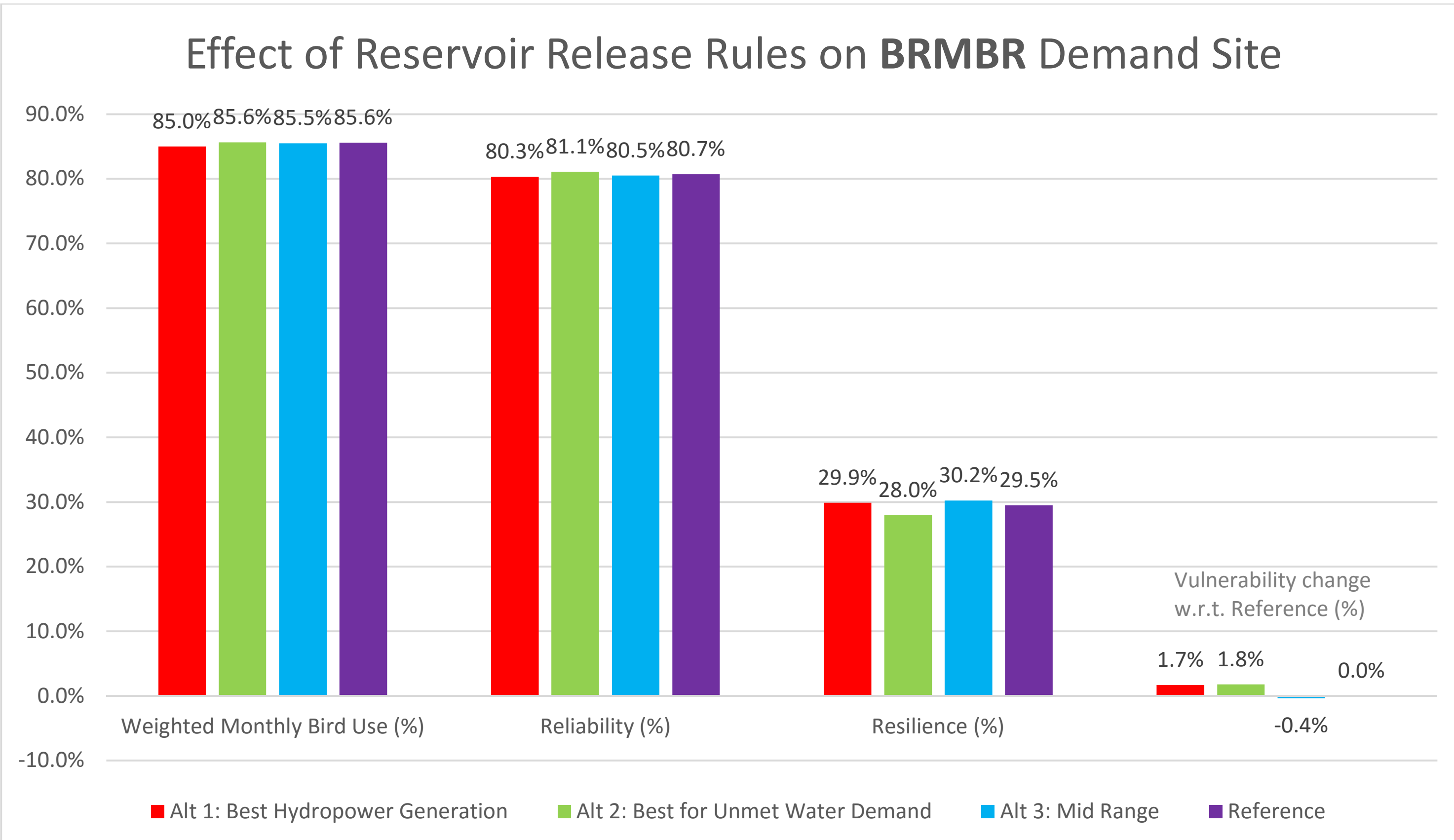

Figure 15. The bar diagram showing performance metrics for BRMBR for the four scenarios to demonstrate the effect of Reservoir Release Rules on BRMBR Demand Site

ii. BRCC

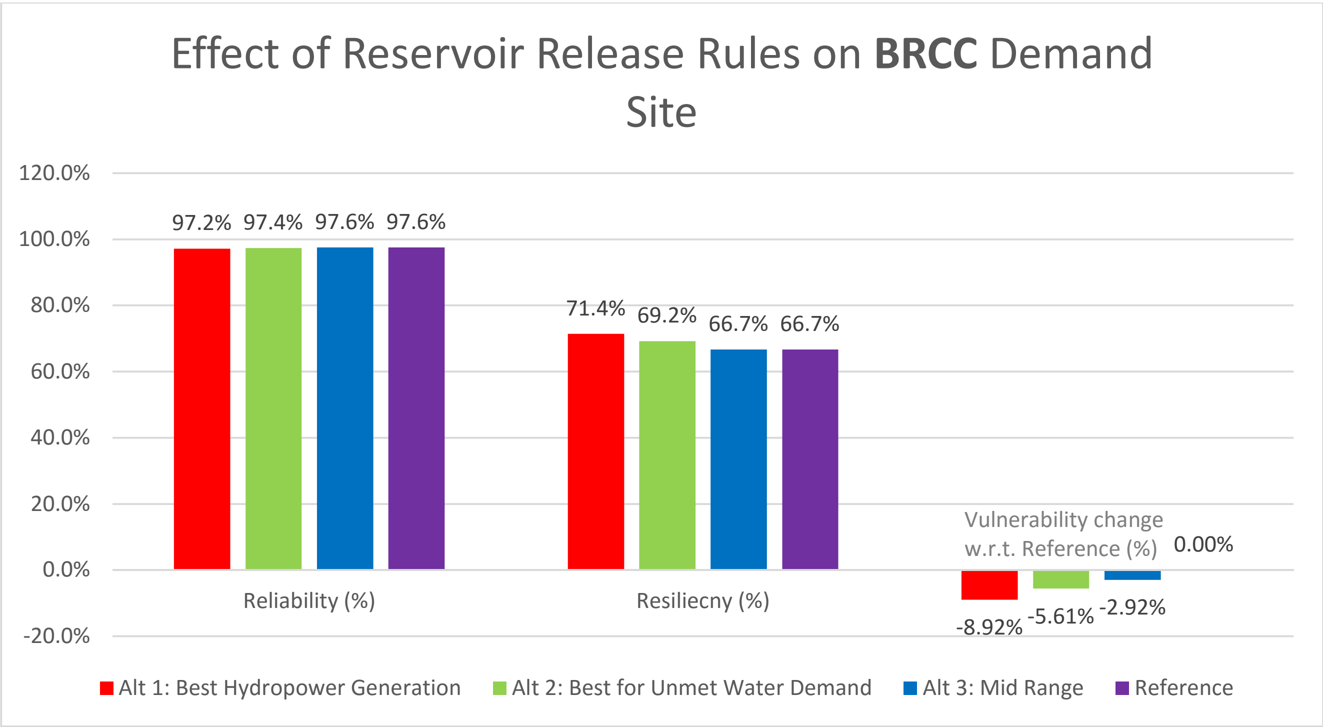

Figure 16. The bar diagram showing performance metrics for BRCC for the four scenarios to demonstrate the effect of Reservoir Release Rules on BRCC Demand Site

iii. Logan City

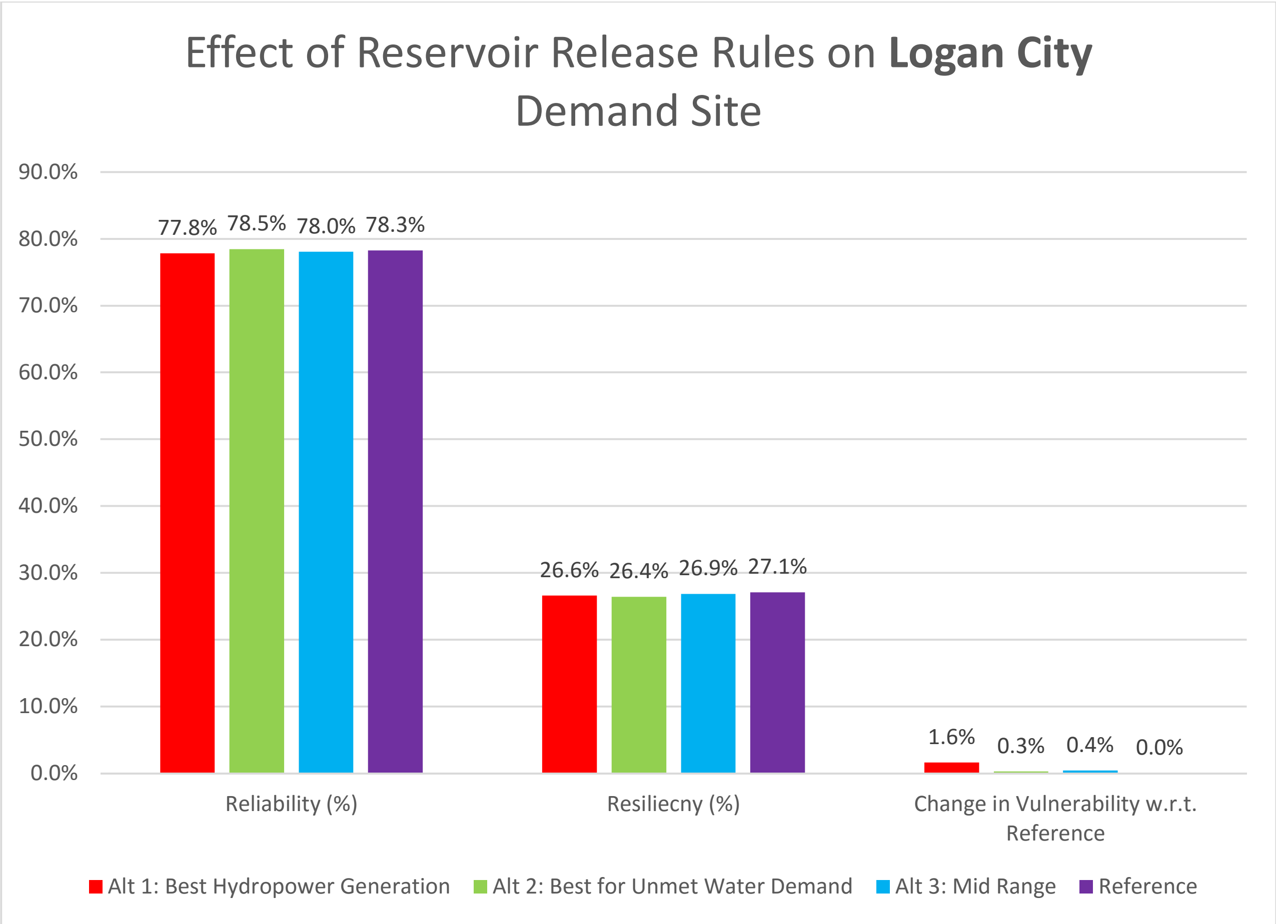

Figure 17. The bar diagram showing performance metrics for Logan City for the four scenarios to demonstrate the effect of Reservoir Release Rules