Municipal Water Demand Modeling for Logan City, Utah Using Water Evaluation and Planning (WEAP)

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Abstract

Urban areas are continuously changing with time in demographic and economic development context. Water resources manager needs planning and management tools to come up with decisions for managing water resources to meet demand of present as well as future. Logan city in Cache County, Utah is facing high population growth rate which exceeds the population projection. To meet increasing water demand, modelling of available water resources is required to determine the system ability to meet those demand. The aim of the project is to model municipal water demand of Logan city meanwhile facing competition from other stakeholders. To do this, performance metrics were developed, structural and non-structural management alternatives were proposed then these alternatives were evaluated in WEAP. Based on the results, it is recommended to build a new reservoir to meet the increasing water demand in Logan city.

1 Introduction

Water resources planning and management is a challenge for an urban area which is rapidly growing. Utah is the second driest state in US, creates an additional challenge for water managers to meet the water demand of the stakeholders in the region. The inadequate water supply can result in conflicts over water rights and pose a serious threat to health and safety. Water managers and planners need structural and non-structural management alternatives to make decisions for effective management of available water resources.

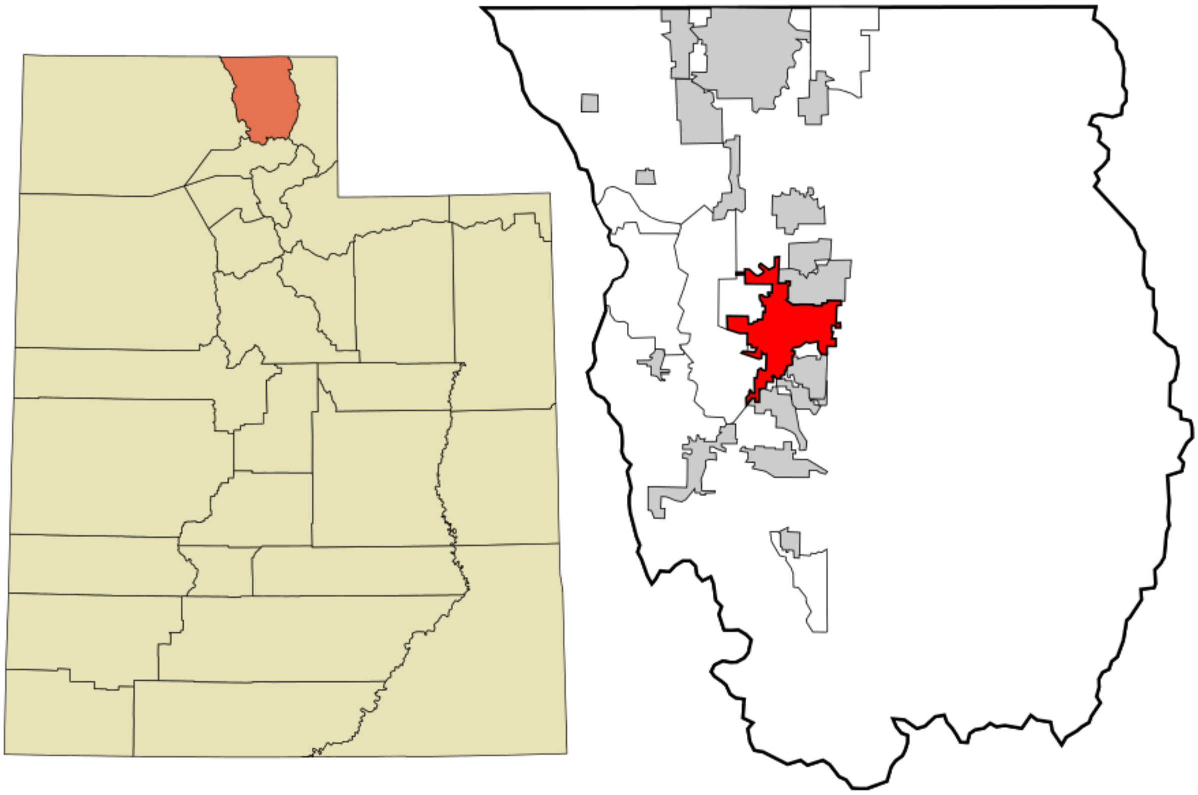
Logan City implemented water conservation plans and projects to meet the increasing water demand. In 1997 a water distribution master plan was generated (CH2MHILL 1997), then in 2007 culinary water system master plan was developed as an update on water supply system status, and maps out prioritized improvements to ensure that the City can meet an acceptable level of service in the future (Veatch 2007). During the same time frame four water conservation plans have been proposed for saving water resources (Department 2015).

Using data collected and previous work done, this project models municipal water use in Logan city. The objectives for this projects are to determine water supply system performance and providing management options to improve water supply system performance. The work was carried out following steps of rational planning of water resources system comprising of steps; problem statement, data collection, selection of performance metrics, defining management alternative, evaluating alternatives using modeling program and lastly providing recommendations based on performance of these alternatives (Lund 2008).

This report provides background of Logan city which is the stakeholder we selected for the research project and institutional analysis. After this description of water inventory and rights for Logan city is provided. Then report focuses on performance metrics, management alternatives and modeling of these alternatives in WEAP (Institute 2016). Comparison of other stakeholder's performance metrics and how it affects the performance of our stakeholder is provided. Finally the recommendations for management of water resources in Logan city is provided.

1.1 Background

Logan City was founded in 1859 and is located in Cache County, Utah. According to the United States Census Bureau, the city has a total area of 18.5 square miles (48.0 km^2), of which 18.0 square miles (46.5 km^2) is land and 0.58 square miles (1.5 km^2), or 3.16%, is water. Logan has a humid continental climate with very warm though usually dry summers and cold winters with moderate snowfall. Precipitation tends to be heaviest in the spring months (Wikipedia 2016).



Source: Logan City Wikipedia Page

Figure 1. Location of Logan City colored red in Cache County, Utah

1.2 Problem Statement

The city of Logan is experiencing growth that consistently exceeds population projections (Department 2015). Moreover, the city is the commercial and institutional hub of a growing metropolitan area with many outlying residential communities and also home to Utah State University. Logan city is composed of multiple water supply systems, most of which exceed current demand (Department 2015). However, the future population will result in that these will be nearly at or have already exceeded their supply capacity which triggers the need to explore different management alternatives in order to meet the projected future demands.

2 Scope of Work

The scope of work for this project is within Logan city boundary as shown in Figure 1. The project will account for municipal demand for stakeholder. Agricultural water demands are not considered in the scope of this project.

3 Water Inventory and Rights

Logan City water demand is satisfied through the water that is available from springs and wells. The primary sources of water for the city of Logan are Dewitt Springs, four wells out which are located near Utah State University campus, the third is located near the center town, and the forth is at the south side of the town. The city also have a well on north side to supply irrigation water to canal companies in exchange for additional water diversion at Dewitt Springs.

3.1 Water Rights

Total water rights available for municipal use in the city of Logan permitted from the State of Utah the owner of the water is 83 cubic feet per second (cfs) as per Division of Water Rights, 56cfs as per Division of Drinking Water, while total available water during a peak demand season is 79 cfs as per Division of Water Rights, 56 cfs as per Division of Drinking Water (Department 2015). The difference in values of water availability is due the reason that Division of Drinking Water only considers the lowest of water from a spring during any given year as the available water. The city approved water rights are provided in appendix.

4 Institutional Analysis

Municipal and Industrial demand in Logan is supplied through three public and industrial water suppliers from springs and wells. The table below provides information of these water supplier institutes (Rights 2016).

Table 1. Water supply institutions and population served

Institution	Primary Use	Type	Area	Population Served (2015)
Goosner Food Inc.	Industrial	Industrial	Logan	470[1]
Logan Municipal Water System	Water supplier	Public	Logan	52,510
Utah State University	Water supplier	Public	Logan	9,000

[1]This is the number of employees in 2015 working with Goosner Food Incorporation

5 Methods

5.1 Performance Metrics

The performance of water supply system can measured using various criteria (Hashimoto 1982). Following are the performance metrics selected to measure and evaluate the proposed management alternatives. The performance metrics of this project are:

i. Reliability, resiliency and vulnerability (RRV) of water supply system
ii. Unmet demand

The explanation of performance metrics are stated below;

Reliability: The reliability of any time series can be defined as the number of data in a satisfactory state divided by the total number of data in the time series.

$$Reliability = \frac{Number\ of\ satisfactory\ observations}{Total\ observations} \tag{1}$$

Resiliency: Resilience can be expressed as the probability that if a system is in an unsatisfactory state, the next state will be satisfactory. It is the probability of having a satisfactory value in time period t +1, given an unsatisfactory value in any time period.

$$\textit{Resiliency} = \frac{\text{Number of tmes a satisfactory value follows an unsatisfactory value}}{Number\ of\ times\ an\ unsatisfactory\ value\ occured} \quad (2)$$

Vulnerability: Vulnerability is a measure of the extent of the differences between the threshold value and the unsatisfactory time series values.

$$\text{Vulnerability} = \frac{Sum\ of\ positive\ values\ of\ (XT - Xt)}{Number\ of\ times\ unsatifactory\ value\ occured} \quad (3)$$

Where,

X_T = Performance indicator

X_t = Threshold value

Unmet Demand: Inability of the water supply system to meet the stakeholder demand

5.2 Management Alternatives

One non-structural and one non-structural management alternatives were proposed, that will be modelled in WEAP and compared against base scenario. The management alternatives are;

i. **Structural Alternative:** Construction of Above Cutler Reservoir
ii. **Non-structural Alternative:** Reduction of water demand by 25% as per UDWR recommendations

5.3 Performance Metrics of Other Stakeholders

Each group chose and defined performance metrics for their stakeholder to measure success of their management alternatives. The data of each performance metrics from other stakeholders was provided in form excel sheet exported from WEAP model. The performance metrics selected by other stakeholders are described below.

Bear River Canal Company (BRCC): Performance metrics selected by Bear River Canal Company were reliability, resiliency and vulnerability and unmet demand. The values of the performance metrics were provided in Excel sheet for copy and pasting data.

Pacific Corp: Performance metrics selected by Pacific Corp for three reservoirs Soda, Onieda and Grace are hydropower generated from three reservoirs in megawatt-hours (MW-hr) and total umet demand at the demand sites in acre-ft (AF).

Bear River Migratory Bird Refugee (BRMBR): The BRMBR group used performance metrics of reliability, resiliency and vulnerability formulated from (Loucks et. al. 2005) and they created monthly weighted bird use specifically for their project. The results from their WEAP modelling were provided in excel format for total unmet demand.

6 Model Development

6.1 Existing Model

The WEAP model for this project was provided by Dr. David Rosenberg in class CEE-6490-2016. The model has 11 demand sites, 4 active reservoirs and 5 inactive and 1 is under considering named as “Above Cutler Reservoir” with proposed location on Bear River. The WEAP model allocates water among demand sites depending on the priority assigned to it which were provided in class as part of ILO-5 (Rosenberg, 2016) and is included in Table 8 in appendix.

6.2 Model Modification and Schematic

In the model the only modification we made was splitting the demand site of the entire Cache County into two sites Logan and other counties without Logan, the layout is represented in schematics below.

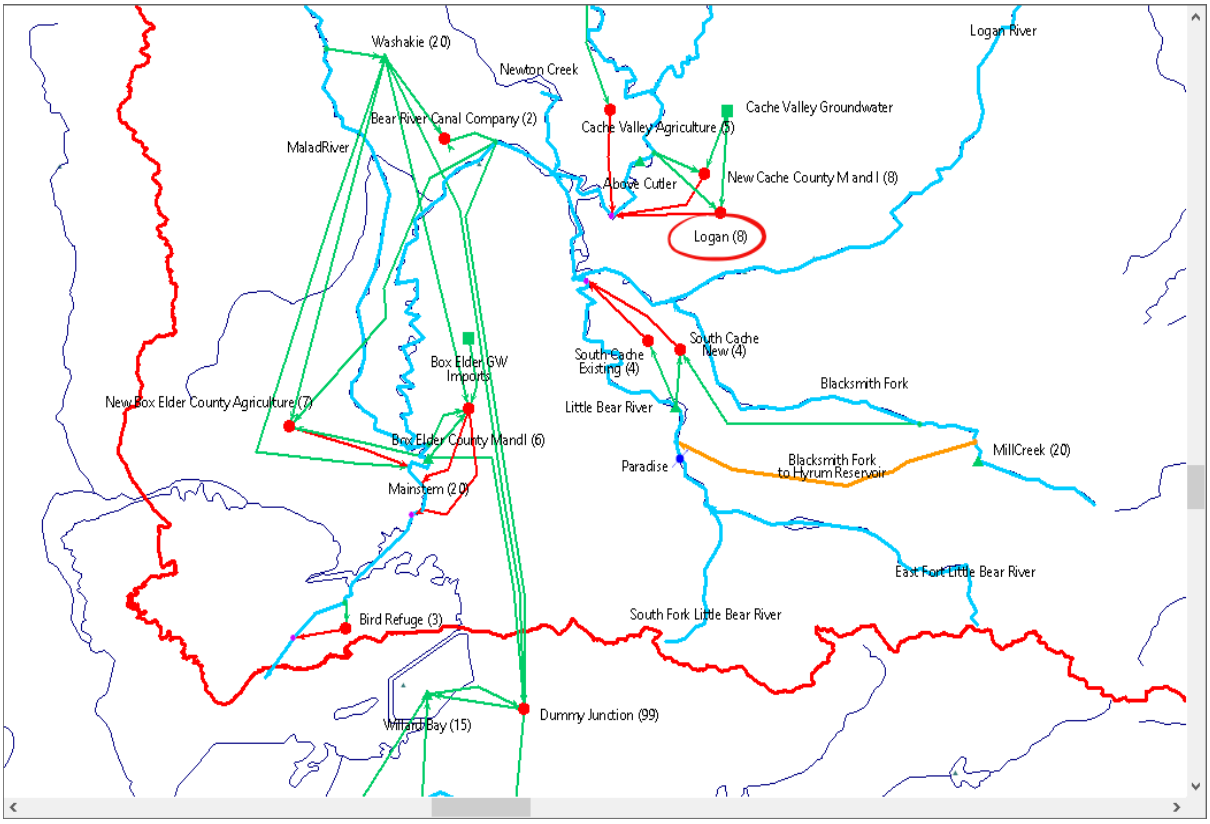


Figure 2. Schematic view of Logan model in WEAP

The approach used to calculate the monthly demand for Logan:

Cache Valley annual demand= 60,000 acre-ft. (AF) "Utah Division of Water Resources (UDWR) (2011)."

The 60,000 AF annual demand is distributed monthly as the following;

Table 2. Monthly water demand calculations

Season	Percentage
Winter (November to March)	3.2% of annual demand
Summer (April to September)	12% of annual demand
Total	(7*12%)+(5*3.2%) = 100%

Monthly water demand for the entire Cache Valley was entered in WEAP;

- Summer demand equals to 12% * 60,000= 7,195 AF
- Winter demand is 3.2% * 60,000= 1,927 AF.

Considering the same year of 2011, the annual water demand for Logan was 12,000 AF.

Distributing the annual demand over the 12 months;

- Winter seasons demand will be 3.2% * 12,000= 384 AF
- Summer demand is 12% * 12,000= 1,440 AF.

These monthly water demand for the entire Cache Valley except Logan (Annual = 48,000 AF, summer= 5755 AF, and winter= 1543 AF) were added again in WEAP model. The average monthly demand and consumption developed in WEAP model are given in below figures.

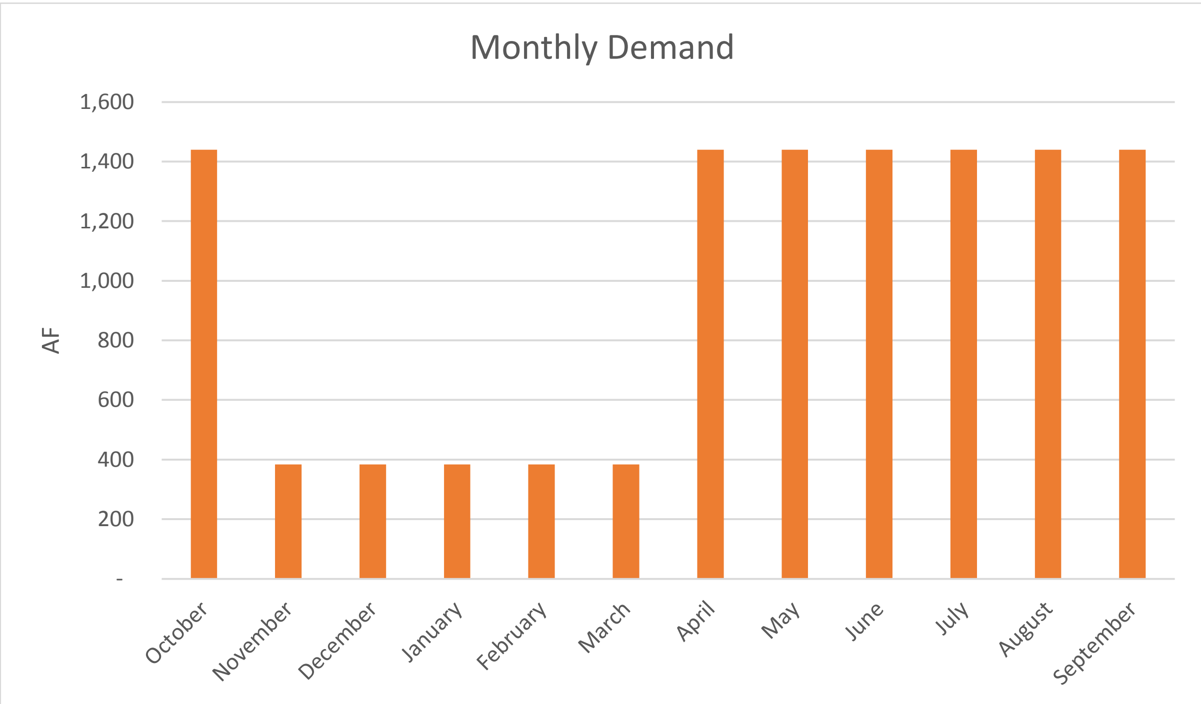


Figure 3. Average monthly supply chart

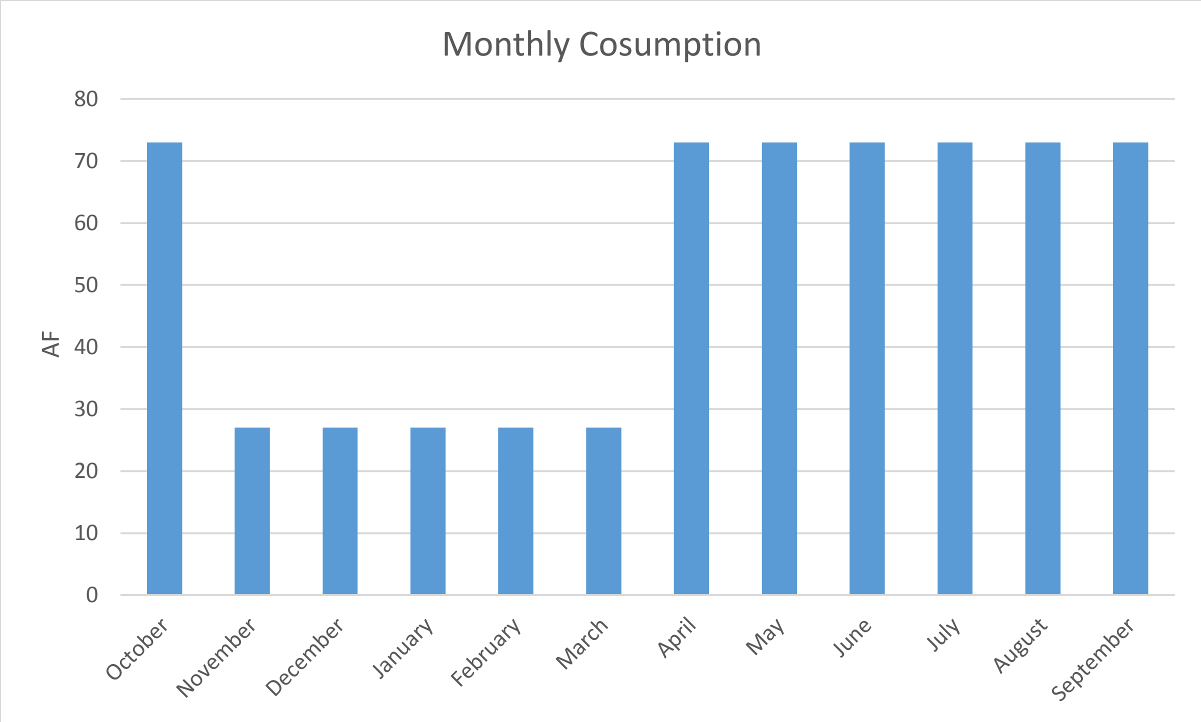


Figure 4. Average monthly demand chart

6.3 Scenarios Definition

The above mentioned management alternatives where examined and combined to show potential system improvement for each municipality and the following scenarios were developed

- **Reference Scenario**

This scenario represents the existing demand and supply conditions using existing WEAP model provided.

- **Reduce Demand Scenario**

In this scenario assumption is made that the water suppliers and users will implement water conservation strategies which will reduce municipal demand by 25% by 2050 (Resources 2004). In WEAP model the existing monthly demand of Logan was reduced by 25% in data input.

- **Above Cutler Reservoir**

Above Cutler Reservoir is proposed to be built on Bear River just above existing Cutler reservoir in Cache County. The Above Cutler reservoir could also supply water to Cache Valley users (Rosenberg, 2016).

For modelling purpose, the Above Cutler Reservoir was added between the New Cache County M&I diversion and New Cache County M&I. The values for evaporation losses and surface area volume relationship were obtained from course assignment 04, provided by Dr. David Rosenberg. The maximum storage capacity of reservoir is 51,342 ac-ft except for months of April, May and June in which 15,000 ac-ft. of storage is reserved for spring runoff. The buffer coefficient is set at 1 for reservoir operations.

- **Reduced Demand and Above Cutler Scenario**

This uses the assumption of reduced demand and construction of Above Cutler reservoir and modelling was done to determine the performance of water supply system and compared against reference scenario.

7 Results

For the City of Logan WEAP was used to simulate the different scenarios, after that results were exported to excel for analysis. The following two tables summarize Logan city performance metrics under different scenarios.

Table 3. Reliability, resiliency and vulnerability (RRV) evaluation

Scenario/Indicator	Reliability (%)	Resiliency (%)	Vulnerability (AF)
Reference	82.72	22.35	1393.59
Reduced Demand	82.72	22.35	1071.46
Above Cutler	87.6	23.23	1360.78
Above Cutler and Reduced Demand	88.01	27.12	1064.32

Table 4. Reliability, resiliency and vulnerability evaluation

relative to reference scenario

Scenario/Indicator	Reliability (%)	Resiliency (%)	Vulnerability (%)
Reduced Demand	00.00	00.00	23.12
Above Cutler	5.9	17.34	2.35
Above Cutler and Reduced Demand	6.39	21.32	23.63

For graphical visualization the following two charts illustrate the RRV performance metrics

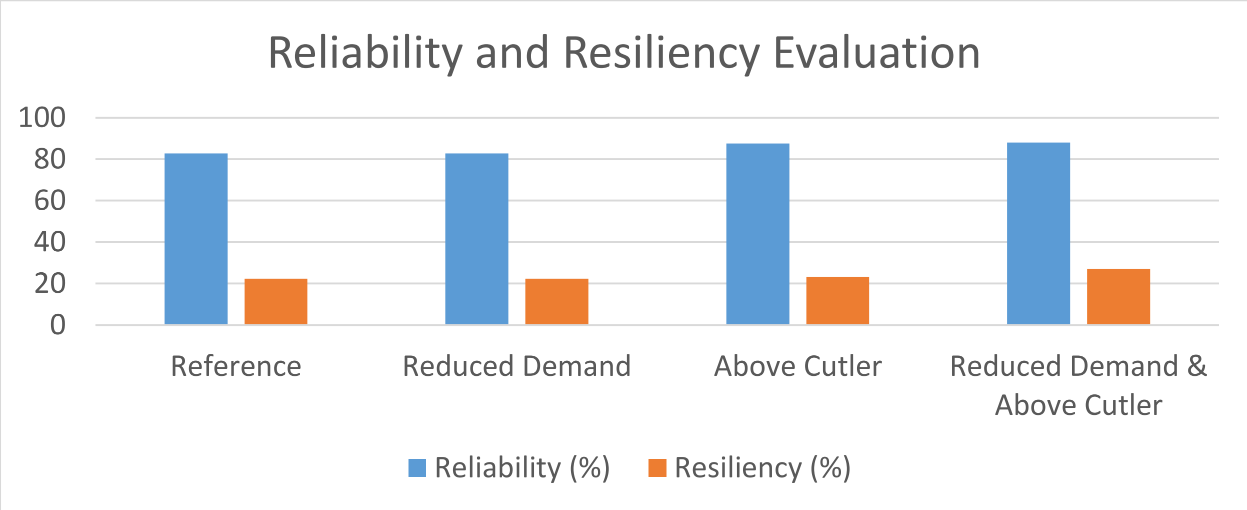


Figure 5. Reliability and resilience results for four scenarios

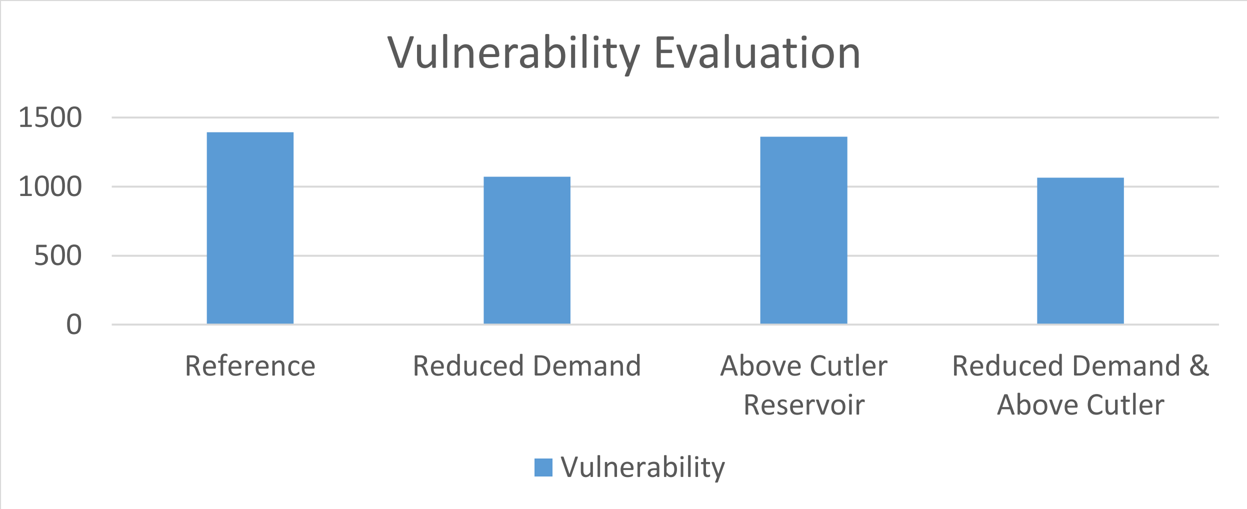


Figure 6. Vulnerability results for four scenarios

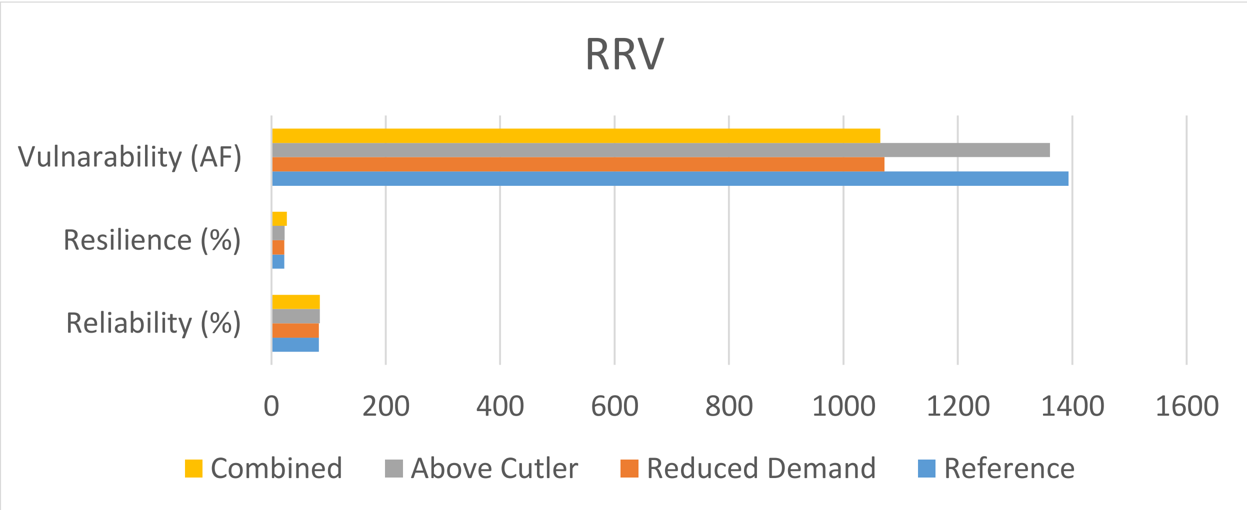


Figure 7. Performance of each metrics selected for Logan city

As we can see from the results reducing demand scenario did not improve either the reliability or the resilience of the system. However, this scenario has improved the vulnerability of the system comparing to the reference scenario -the vulnerability of the system improved by 23% relative to base scenario-.

On the other hand, building and operation the above cutler will improve both the reliability and the resilience of the system holding the same vulnerability of the system comparing to reference scenario.

Hence, combining the two alternatives together supposed to improve the reliability, resilience, and vulnerability of the system and that what we tried to achieve in the final scenario by operating the above cutler reservoir while reducing water demand.

Calculations were also made for unmet demand criteria, the following table summarizes the average monthly unmet demand for different months considering different scenarios.

Table 5. Average Monthly Unmet Demand

Scenarios	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**June.**	**Jul.**	**Aug.**	**Sep.**
Reference	451	0.0	0.0	0.0	0.0	0.0	0.0	35	315	578	724	786
Reduced Demand	338	0.0	0.0	0.0	0.0	0.0	0.0	26	245	457	562	593
Above Cutler	451	0.0	0.0	0.0	0.0	0.0	0.0	0.0	108	306	443	716
Combined	338	0.0	0.0	0.0	0.0	0.0	0.0	0.0	87	233	334	539

As noticed from the results the deficit only occurred in summer season.

The following table summarizes all the group's performance metrics under different scenarios.

Table 6. Performance of each metrics selected by each stakeholder in basin

Stakeholder	Performance metrics	Reference	Reduced Demand	Above Cutler	Combined
Logan	Reliability (%)	83	83	88	88
	Resilience (%)	22.35	22.35	23.23	27.12
	Vulnerability (AF)	1393.6	1071.46	1360.75	1064.3
BRMBR	Weighted water Use (%)	88.29	88.53	93	93
	Reliability (%)	84	85	89	90
	Resilience (%)	30	30	35	35
	Vulnerability (AF)	25326	25359	23682	23836
BRCC	Reliability (%)	85	85	90	90
	Resilience (%)	100	100	100	100
	Vulnerability (AF)	9871	9959	8351	8351
Pacific Crop	Hydro-power relative to reference (%)	-	-6%	161.5%	170%
	Unmet Demand relative to reference (%)	-	4%	47%	48%

Further calculations were made, since most of the stakeholders have RRV as they performance metrics, we considered a comprehensive system that includes the different stakeholders and then we calculated the average reliability, resilience, and vulnerability of the system. The following table summarizes the reliability, resiliency and vulnerability for all four scenarios we considered in WEAP modelling. It should be noted that Pacific Corp is not included in these results as their performance metrics was not reliability, resiliency and vulnerability.

Table 7. Reliability, resiliency and vulnerability of stakeholders for reference scenario and other alternatives

Stakeholder/Indicator	**Reliability (%)**				**Resiliency (%)**				**Vulnerability (AF)**			
Scenario	1	2	3	4	1	2	3	4	1	2	3	4
Logan	82.72	82.72	87.6	88	22.35	22.35	23.23	27.12	1393.59	1071.5	1360.8	1064
BRCC	85	85	90	90	100	100	100	100	9959	9959	8351	8351
BRMBR	84	85	89	90	30	30	35	35	25326	25359	23682	23836
Avg.	**84**	**86**	**89**	**89**	**51**	**51**	**52**	**54**	**12226**	**12130**	**11131**	**11084**

Where;

1 = Reference scenario

2 = Reduced Demand scenario

3 = Above Cutler Reservoir Scenario

4 = Combined (Reduced demand and Above Cutler Reservoir Scenario)

8 Conclusion and Recommendations

Based on the results obtained from different alternatives, the City of Logan and the other counties should start thinking of building and operating the Above Cutler Reservoir since this option will improve the system.

Although reducing demand will also improve the system, improvements based on this scenario was not that significant comparing to the reference.

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Appendices

Logan City Water Sources and Rights

City of Logan Water Rights for Municipal Use			
Location	Priority	Flow	Water Right Number
DeWitt Spring	1 May 1860	10 cfs	25-3506
DeWitt Spring[1] (Apr- Sep)	1 May 1900	4 cfs	25-5429
DeWitt Spring[2] (Oct-Mar)	17 March 1981	20 cfs	25-8258
Combined Right[3]	1961, 1963, 1978	49 cfs	A28759
DeWitt Spring (Apr-Sep)[4]	1865	10 cfs	Contract Exchange
DeWitt Spring (Apr-Sep)[4]	1865	10 cfs	E1844
Total Water Rights Available[5]		83 cfs (Division of Water Rights) 56 cfs (Division of Drinking Water)	
Total Available Water During Peak Demand Season		79 cfs (Division of Water Rights) 56 cfs (Division of Drinking Water)	

[1]This right is only operable when Logan River flow exceeds 270 cfs.
[2]Late priority means this right from the Logan River can only be exercised outside of irrigation season or when river flows exceed 480 cfs.
[3]This right allows a varying amount of water from each well to be used as long as it does not exceed 49 cfs and allows the water to be pumped from the four existing wells and two proposed wells.
[4]This is an exchange of irrigation rights with canal companies allowing Logan City to take additional water from DeWitt Springs.
[5]The Division of drinking water only considers the lowest flow of water from a spring during any given year as the available water.

Source: City of Logan Water Conservation Plan

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	Environment	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

Source: Table was provided by Dr. David Rosenberg in CEE-6490