Performance Evaluation of the Bear River Canal Company (BRCC) to meet the irrigation demand of Box Elder County.

Names: Muhammad Rezaul Haider, Sal Bir Limbu

Instructor: Dr. David Rosenberg
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Abstract: Currently Bear River Canal Company (BRCC) is facing some problems like loss of irrigation water through seepage, shortage of supply in peak periods, and inefficient irrigation method which are responsible for reduced crop yield in Box Elder County, Utah, USA. In order to minimize the current problems, some structural and non-structural measures have been suggested. This report will evaluate performance matrices like Reliability, Resiliency, and vulnerability (RRV) under different management scenarios like do nothing condition, with implementation of structural and non-structural measures. Water Evaluation and Planning (WEAP) model will be developed for the Bear River watershed to simulate water deliveries under historical flow conditions and existing infrastructure. The major findings to-date, the performance criteria and some management alternatives have been reported, and the future work have been summarized.

Keywords: Crop yield, Reliability, Resiliency, and vulnerability (RRV), Water Evaluation and Planning (WEAP) model.

1. Introduction:

According to United States Department of Agriculture (USDA 2015), Agriculture is a major user of ground and surface water in the United States, accounting for approximately 80 percent of the Nation's consumptive water use and over 90 percent in many Western States.

Currently BRCC is facing some problems like loss of irrigation water through seepage, shortage of supply in peak periods, and inefficient irrigation method which are responsible for reduced crop yield in Box Elder County, Utah, USA. In order to minimize the current problems, some structural and non-structural measures have been suggested. This report will evaluate performance matrices like Reliability, Resiliency, and vulnerability (RRV) under different management scenarios like do nothing condition, with implementation of structural and non-structural measures.

Water Evaluation and Planning (WEAP) model (Stockholm Environment Institute, 2012) will be developed for the Bear River watershed to simulate water deliveries under historical flow conditions and existing infrastructure. The major findings to-date, the performance criteria and some management alternatives have been reported, and the future work have been summarized.

This report first provides the background information, the current problems and the stakeholder's objectives. Then the project motivation and objectives have been presented. After that, it introduces the institutional analysis, the performance criteria and some management alternatives. Finally, the major findings to-date and future work have been summarized.

2. Background:

Box Elder County is located in the northwest corner of Utah and is bordered by the states of Idaho and Nevada. The eastern part of the county is where the majority of the population is located and where the bulk of the irrigated farmland lies. About 60 percent of the irrigation water available in Box Elder County is from the Bear River Canal System (Holmgren et al., 2012).

Box Elder County lies in one of the primary agricultural production regions in the state. The majority of the irrigated and dry land farming is done in the eastern half of the county. Irrigated land consists mostly of soft white wheat, silage and grain corn, alfalfa, barley and onions. These acres vary over time with the number of acres of corn increased in recent years primarily due to better prices and yields. Acres of barley, oats and onions have notably decreased.

The Bear River covers an area of about 7,600 square miles in Utah, Idaho and Wyoming. The most senior (highest priority) water rights holder in the Bear River basin is the Bear River Canal Company (BRCC) which is located in Box Elder County downstream of the Cutler Reservoir (Figure 1). Two irrigation canals (Bear River East and West Canals) divert irrigation water from the east and west sides of Cutler Dam.

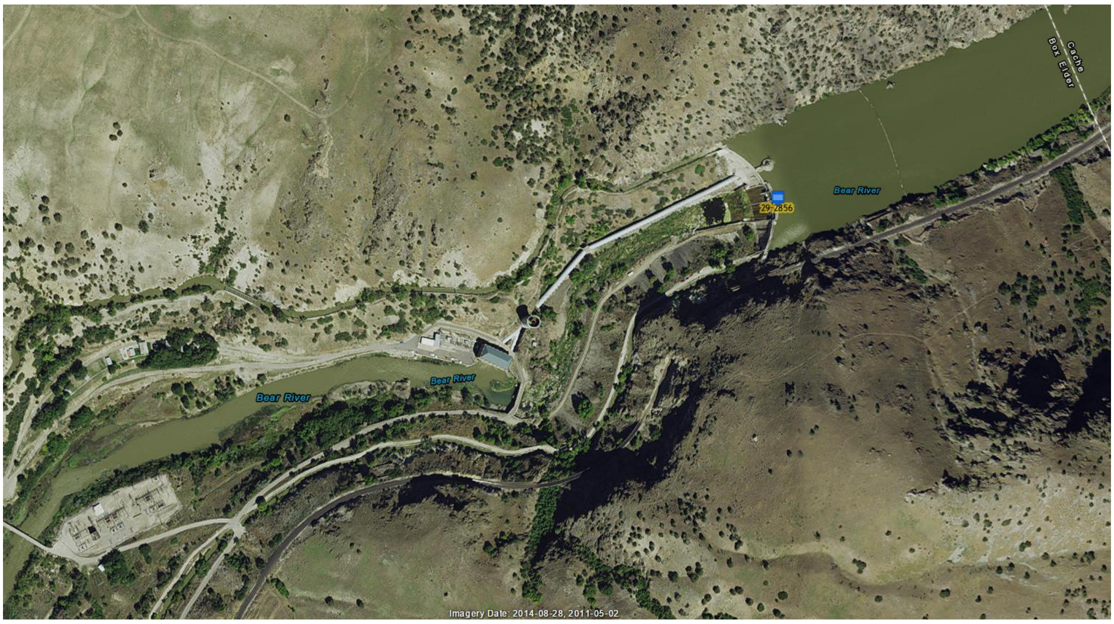

Fig 1: Map showing diversion from Cutler Dam.

Efficient irrigation systems and water management practices can help maintain farm profitability in an era of increasingly limited and more costly water supplies (USDA 2015). In view of less efficiency of BRCC irrigation system and deficit supply of water in times of peak demand it is worthy of investigation into the reasons behind such problems and formulate remedial measures to increase the reliability of BRCC service.

3. Stakeholder’s type(s) of water uses:

BRCC diverts water from Bear River upstream of the Cutler Dam through two canals (Bear River East and West Canals) and supplies irrigation water to Box Elder County.

4. Current problem(s):

BRCC currently faces some problems as stated below:

(i) Significant amount of water is lost from the distribution system because of seepage.
(ii) Irrigation water is applied to the fields by flooding method which results in huge loss of irrigation water.
(iii) At the times of high irrigation water demand (late April / early May, last two weeks of June, and the first two weeks of July), there is shortage of supply to meet the irrigation demands which reduces crop yield.
(iv) Currently the distribution gates are operated manually which results in more labor cost.

5. Stakeholder objectives:

BRCC has some objectives to mitigate the current problems as stated below:

(i) Minimizing losses of irrigation water from canal system.
(ii) Maximizing irrigation efficiency.
(iii) Managing the peak demand.

6. Motivation and Objectives:

Given that BRCC faces shortage of supply to meet the irrigation demands in peak season, it is worth to determine the performance of the Bear River system to meet the irrigation water demand of BRCC. Thus, this project has two objectives: first is to determine the RRV of the BRCC to meet the irrigation water demand; second is to provide management alternatives to fulfill the stakeholder’s objectives and then to determine how much the performance of the BRCC improves with the implementation of the management alternatives.

7. Results of Institutional Analysis:

We performed Institutional analysis for Irrigation in Box Elder County to assess the capacity and role of different organizations and stakeholders. Major stake holders and their role in Irrigation management of Box Elder are presented in Table 1.

Table 1: Major Stakeholders and their role in Irrigation of Box Elder.

Stakeholders	**Role in Irrigation management of Box Elder**
Bear River Commission	To remove the causes of present and future controversy over the distribution and use of the waters of the Bear River; to provide for efficient use of water for multiple purposes; to permit additional development of the water resources of Bear River; and to accomplish an equitable apportionment of the waters of the Bear River among the compacting States.
Bear River Canal Company	BRCC negotiates with other water users on the Bear River as to using the best management practices to conserve water from Bear Lake primarily, and administer water through the canal system.
Ditch Companies	To divert water from the canal system, make assessments for maintenance and negotiate "trading" water from one neighbor to another.
Utah State University (USU)	Researches aiming to increase irrigation efficiencies, estimation of water demand, optimization of water resources.
Utah Division of Water Rights	Administration of the appropriation and distribution of the State water resources, and maintaining public record for information pertaining to water rights.

SWOT analysis is a structured planning method used to evaluate the Strengths, Weakness, Opportunities and Threats involved in a project (SWOT). In our project SWOT analysis is performed for BRCC to identify the external and internal factors that are favorable and unfavorable to provide irrigation service the results of which are as follows:

Strengths: 1) Maintenance of canal network as per requirement, 2) Negotiation with other stakeholders, 3) Communication with users.

Weakness: 1) High summer demands. 2) Seepage losses. 3) Less efficient method of irrigation. 4) High labor cost.

Opportunities: 1) Collaborations with organizations such as USU and other government departments.

Threats: 1) Natural disaster to water infrastructures. 2) Climate change.

8. Available data on stakeholder water demands in the basin:

8.1 Water Rights:

The total water right of BRCC for both canals is 900 cfs. The most senior right of BRCC is 29-2856 which accounts for 333 cfs (Utah Division of Water Rights, 2016). There are several other water rights of BRCC namely 29-2857, 29-2858, and 29-3321 etc.

8.2 Command Area for different crops:

BRCC supplies irrigation water for 66000 acres of agricultural land through a network of canals 120 miles in length in Box Elder. The command areas under different crops are stated in Table 2:

Table 2: Command areas under different crops.

Sl. No.	Crop	Command Area (acre)	Percent of Total
1	Wheat	19800	30%
2	Barley	1980	3%
3	Alfalfa	19800	30%
4	Corn of all types	16500	25%
5	Pasture	3960	6%
6	Onion	1980	3%
7	Mint	660	1%
8	Other	1320	2%
	Total:	66000	100%

8.3 Planting date for different crops:

Crop period for different crops are stated in Table 3. It is obvious that in the month of May the demand of water rises to the peak which leaves some crops in stress.

Table 3: Crop period for different crops.

Sl. no	Types of crops	Crop period
1	Wheat	Early May to early July
2	Corns of all types	Early July to early September
3	Pasture	Throughout the irrigation season
4	Onion	Late May to Late August

8.4 Irrigation Scheduling:

Information on Irrigation scheduling in the field is stated in Table 4. The crop water requirement depends on rainfall intensity, soil condition, root zone depth of crops and other climatic factors. Generally, wheat, corns, onion, and pasture require more frequent irrigation.

Table 4: Irrigation scheduling of different crops.

Sl. No.	Crop	Frequency of Irrigation
1	Wheat	Once in 2-3 weeks*
2	Alfalfa	Once in 4-5 weeks
3	Corn of all types	Once in every 1-2 weeks*
4	Pasture	Once in 2-3 weeks*
5	Onion	Once in a week

*Depends on Rainfall intensity and water requirement of other crops, and water availability.

8.5 Canal infrastructure data:

More than 90% of the canal is unlined. Canal infrastructures vary widely as the canal near the head of the system is 20 feet wide at the bottom and 35 to 40 feet at the top. The water depths vary from 3 to 5 feet. At the canal ends the canals are 4 feet wide at the bottom and 6 feet wide at the top and have only a depth of 2 feet. BRCC maintains over 120 miles of canals in the system.

9. Methodology:

9.1 Estimation of Evapotranspiration (ET_c):

The FAO Penman-Monteith equation (Allen et al., 1998) is used for estimating reference crop evapotranspiration:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma(\frac{900}{T + 273})u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \dots\dots\dots\dots\dots\dots\dots\dots (i)$$

Where,

ET_o reference evapotranspiration [mm day^{-1}],
R_n net radiation at the crop surface [MJ m^{-2} day^{-1}],
G soil heat flux density [MJ m^{-2} day^{-1}],
T mean daily air temperature at 2 m height [°C],
u_2 wind speed at 2 m height [m/s],

e_s saturation vapour pressure [kPa],
ea actual vapour pressure [kPa],
e_s-e_a saturation vapour pressure deficit [kPa],
Δ slope of vapour pressure curve [kPa /°C],
γ psychrometric constant [kPa/°C].

The details of the parameters can be found at Allen et al, 1998.

The evapotranspiration for each crop is found by multiplying the reference crop evapotranspiration by the respective crop co-efficient, K_c:

$$ET_c = ET_0 * K_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Where

ET_c is the evapotranspiration of a crop [mm day-1],
K_c is the crop co-efficient.

Due to differences in evapotranspiration during the various growth stages, the K_c for a given crop will vary over the growing period. The growing period can be divided into four distinct growth stages: initial, crop development, mid-season and late season (Allen et al, 1998).

9.2 Net Irrigation Requirements (NIR):

Net irrigation requirements (NIR) will be calculated as follows:

$$NIR = ET_c - P_{eff} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (iii)$$

where

NIR is the Net irrigation requirement
P_{eff} is effective precipitation.

Effective precipitation is defined as 80% of recorded precipitation during the growing season (Hill et al., 2011).

9.3 Field Irrigation Requirements (FIR):

Field irrigation requirements (FIR) will be calculated as follows:

$$FIR = \frac{NIR}{E_a * E_c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iv)$$

where

FIR is the Field irrigation requirement
E_a is the application efficiency
E_c is the conveyance efficiency.

9.4 Crop water requirement:

By multiplying the FIR for each growth stage of each crop by the respective crop areas, the volume of water needed for that growth stage will be calculated.

9.5 Calculation of RRV matrices:

Monthly flow data for the two canals have been collected from Utah Division of Water Rights (2016) for a duration of 1989 to 2015 (see Table A1 and A2 in Appendix). RRV matrices will be calculated by comparing the monthly demand and the monthly historical deliveries. Details of calculation of RRV matrices can be found at Hashimoto et al. (1982).

10. Management alternatives:

In Utah, the average efficiency of surface irrigation in Utah is less than 50% as compared to the higher sprinkler efficiency values of more than 65% for well managed systems (Hill et al., 2001). In order to satisfy the objectives of BRCC the following management alternatives will be considered:

Structural option:

(i) In order to reduce the seepage losses lining is recommended for the canal system of BRCC.

(ii) In order to increase the efficiency of irrigation, water users are recommended to use more efficient management practices like installing sprinkler irrigation system instead of current flooding system on the farm.

Non-Structural option:

(i) In order to manage the peak water demand, crop rotation should be practiced so that peak demands for different crops will occur at different times.

11. Quantitative metric(s) to be used to evaluate the extent to which a management alternative meets the stakeholder's objective(s):

RRV metrics measure different aspects of a water resources system performance (Hashimoto et al., 1982). RRV metrics provide one of the most comprehensive approaches for analyzing the probability of success or failure of a system, the rate of recovery of a system from unsatisfactory states, as well as quantifying the expected consequence of being in unsatisfactory states for extended periods (Asefa et at., 2014).

RRV of the BRCC will be evaluated for three scenarios:

(i) Do nothing scenario: RRV of the BRCC will be determined based on water demand and supply.

(ii) Structural alternative: RRV of the BRCC will be determined based on water demand and available water given that the structural options are implemented.

(iii) Non-Structural alternative: RRV of the BRCC will be determined based on water demand and available water given that the non-structural options are implemented.

12. Major findings to date:

12.1 Command area:

As is said previously, BRCC administers water through a canal system of 120 miles in length to 66,000 acres. The command area (by percent) under different crops are wheat 30%, barley 3%, alfalfa 30%, corn of all types 25%, onions 3%, pastures 6% Mint 1%, other vegetable crops and lawns and gardens 2%.

12.2 Water demand and planting dates: Demand reaches its peak in early May and then levels out in the mid of May. Onions which are first irrigated in late May to late August and are irrigated every seven days for the remaining of the summer. In late June or early July corn receives its first irrigation along with continuing irrigation of wheat, alfalfa, pasture, onions and other incidental items such as Mint, lawns, gardens. Corn is irrigated once in one to two weeks until early September. Although pasture requires irrigation once in every two to three weeks throughout the irrigation season in general, sometimes its frequency of irrigation is lowered when other crops demand more water.

Demand for irrigation water lowers significantly in the month of September which drops again in October and in November.

12.3 Control of Headgate: BRCC controls water at the Headgate but do not dictate how the water is used beyond the Headgates. There are numerous “ditch companies” that divert water from the canal system. BRCC provides scheduling for all the shareholders. The “ditch companies” are responsible for negotiating “trading” water from one neighbor to another.

12.4 Shortage period:BRCC generally has a good supply of water but at high demand times such as late April/early May and again the last two weeks of June and the first two weeks of July the farmers are forced to sacrifice one crop to benefit another on their own farm.

13. Future steps:

In the future, several tasks to be finished are as follows: (i) Estimation of crop water requirements based on crop growth stage as well as on monthly basis for different crops; (ii) Suggestion of crop rotation to manage the peak demand, (iii) Recommendation on irrigation scheduling to have the best utilization of available water, (iv) Quantifying the amount of irrigation water saved through canal lining, (v) Quantifying the amount of irrigation water saved by implementing sprinkler irrigation method, (vi) Calculating the RRV of BRCC for three scenarios stated earlier, (vii) Make recommendation on optimum management option for BRCC.

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Appendix A:

Table A1: Historical flow data for West Canal of BRCC

YEAR	Monthly delivery (cfs)												Annual delivery (cfs)
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1989				1999	41343	43089	43053	41435	33913	22257	1809		228899
1990				11169	42742	38785	39441	39739	34483	21943			228301
1991				770	22405	38878	40858	36684	28651	21767			190013
1992				7585	41203	38489	31728	26463	16255	19059	5595		186377
1993					18768	38713	39435	37166	34282	10471	30		178865
1994				2305	43246	43591	37319	39523	30998	10816	5645		213441
1995				2525	26753	34397	42778	40564	34528	21743	2392		205680
1996				2325	39929	41722	41460	39362	32317	4653	8949		210718
1997					39671	39866	42555	37658	32001				191752
1998					29482	33832	44497	40980	37603	21332	9723	1609	219059
1999					25619	40752	45814	43359	33531	23693	11976		224743
2000					44828	45760	44475	42454	27319	14879	5685		225399
2001					43398	43027	41952	39771	17827	13067	5254		204298
2002					33015	42625	42853	36526	25396	9384	1801		191599
2003				454	40457	40752	37180	33493	27866	3933			184136
2004				17340	34247	30442	27189	27074	20824	8711			165828
2005					5455	34623	43948	40863	32755	2668			160312
2006					32606	42698	42732	42536	27874				188446
2007				10748	43020	42998	40562	37317	26005	12811	8934	3314	225709
2008	4068	3517	3108	5082	37422	41496	45572	42621	32463	12508	2083	0	229940
2009	0	30	184	87	26398	34508	44218	42413	33594	12375	0	0	193807
2010				1218	34768	38624	45483	43152	33112	16740	6540	0	219638
2011	0	0	0	0	8420	35153	45570	41000	37890	23338	6530	0	197901
2012	0	0	0	11881	41849	42107	41205	39765	31940	16935	9251	1494	236426
2013	0	0	0	0	39055	42476	43265	43265	27487	11371	4875	264	212059
2014	0	0	0	0	37652	43692	44128	40005	31954	14698	0	0	212128
2015				1422	37599	39237	43684	41429	30222	19666	8442	4875	226576

Table A2: Historical flow data for East Canal of BRCC

Year	Monthly delivery (cfs)												Annual delivery (cfs)
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1957					1473	7037	9757	9580	7041	2991	424		38304
1989					9019	9578	9711	9005	7014	4510	80		48917
1990				4306	8674	8382	8997	8678	6877	3786			49700
1991					5111	8700	9523	6944	4699	3382			38358
1992				2797	9802	9314	8095	6924	3221	3751	294		44198
1993					4393	8521	8951	7888	6700	3854	85		40393
1994				623	9461	7728	9211	9100	7537	1222	107		44989
1995					5266	7626	10479	9677	7954	3213	81		44297
1996				883	8329	9511	9836	10056	6942	4036			49593
1997				510	9336	9471	9757	8727	6817				44618
1998					6409	8596	9767	8908	7557	3566			44803
1999					5324	9580	9554	9937	7704	6444	1829		50372
2000					9199	10056	10655	10202	7394	3188	150		50844
2001					9185	9945	10399	9287	4659	2434			45909
2002					6801	9814	9923	8529	6464	1908			43440
2003					8648	9162	8715	8218	5794	1573			42109
2004				3241	7710	7700	6817	6889	5708	3043			41107
2005					879	8686	10848	9398	7285	496			37591
2006					8382	10108	9445	8955	6417				43307
2007				2055	10191	9935	9554	9255	4635	1087	0	0	46713
2008	0	0	0	280	9172	9707	11179	10415	6506	242	0	0	47500
2009	0	0	0	0	5242	8874	10455	9378	6171	478	0	0	40598
2010	0	0	0	760	8771	9529	9842	10219	7712	2610	0	0	49442
2011	0	0	0	0	3023	9066	10893	9618	8481	2491	0	0	43573
2012	0	0	0	1470	9788	10201	10003	9826	7146	2957	0	0	51392
2012										2957	0	0	2957
2013	0	0	0	0	8475	9961	10965	11096	6857	2432	0	0	49785
2014	0	0	0	0	8783	10356	10832	9053	7938	3677	0	0	50638
2015				534	8844	8753	10463	10518	8339	6327	833	300	54910