Case Study of Emery County Real-time Monitoring and Control System Implementation

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Executive Summary

The overall purpose of this project is to engage stakeholders in Emery County (including water managers and producers) and to understand, document, and evaluate the drivers, methods, costs, benefits and lessons learned from implementation of a network of flow measurement structures with transparent, Real-Time Monitoring and Control System (RTMCS).

Background

In 1992, Emery Water Conservancy District (District) began the installation of a real-time monitoring system in its agricultural service area. The system was initially designed to protect their water rights by monitoring flows at 19 sites throughout their service area. The District soon discovered that the real-time information could also be used for operational purposes and began to expand the system. They also began to install remote control systems on their major water control structures. By 2002, the District's real-time monitoring and control system (RTMCS) had grown to 80 sites and had posted their real-time information on the District's website: www.ewcd.org. Today, the Emery RTMCS has over 200 real-time sites, and over 50 of those sites have automated controls. Every major control structure is fully automated. To pay for the system, the District received several grants from the Federal government, and Emery County enacted an *ad valorem* tax.

Key Findings

Costs. The cost for a simple monitoring station is between $3,000 to $5,000. For a control site, costs range above $7,000, depending on the complexity of the installation.

Benefits-Cost. Using an ex post analysis and CPI for cost adjustments, the Net Present Value (NPV) is $1.47 million. The Internal Rate of Return (IRR) is 6.13% and the Benefit-Cost (B-C) ratio is 1.18. Even under the most conservative assumptions, the agricultural benefits of RTMCS are positive by all three measures. The salinity benefit of $6.3 million (attributable to RTMCS) is not

included in the B-C ratio. Using an ex ante analysis, based on declining equipment cost, the NPV is $4.75 million with a 32. 38% internal rate of return. In this analysis, the B-C ratio measure went up to 1.93.
Other Benefits. In addition, stakeholders perceive the benefits of improved crop production (because of the lengthened irrigation season of up to a month) and increased transparency. Benefits to the environment include reduced salt loading to the Colorado River, plus reductions in fertilizer, herbicide, and pesticide loads to the water system.

Recommendations for RTMCS Adoption

Challenges. Any area considering an RTMCS will likely need to overcome possible concerns, which include: an evolving system, the challenge of finding and keeping trained personnel, possible system malfunction, and system security. In the past, the Bureau of Reclamation has provided technical backup for the RTMCSs in the State. That help will continue to diminish.
Pre-requisites. Any area considering an RTMCS should: ensure they have the financial means and personnel to install and maintain the system; get buy-in from the water users; consider a basinwide system; seek federal and state grants where available; and use standardized equipment and software for ease of installation and maintenance.
Statewide Action. The State of Utah Divisions of Water Resources and Water Rights should consider: enlarging their real-time support staff; providing grants to encourage RTMCS; developing operational and water rights models to interface with the real-time information; and installing a state-wide, real-time website.

Conclusions

RTMCS:

1. Are a cost effective and environmentally sound way to improve agricultural irrigation delivery systems
2. Are an excellent water conservation tools for the canal companies, districts, and associations throughout the State
3. Provide transparency, which is important for improving trust between all water users.

Extended Abstract

The overall purpose of this project is to identify and engage water managers, producers and other stakeholders in Emery County to understand, document, and evaluate the drivers, methods, costs, benefits and lessons learned from implementation of a network of flow measurement structures, and transparent Real-Time Monitoring and Control System (RTMCS).

In 1992, Emery Water Conservancy District (District) began the installation of a real-time monitoring system in its agricultural service area. The system was initially designed to protect their water rights by monitoring flows at 19 sites throughout their service area. The District soon discovered that the real-time information could also be used for operational purposes and almost immediately began to expand the system. They also began to install remote controls on their major water control structures. By 2002, the District's real-time monitoring and control system (RTMCS) had grown to 80 sites. It also began to post real-time information on the District website: www.ewcd.org. Today, the Emery RTMCS has over 200 real-time sites, with over 50 sites having automated control. Every major control structure is fully automated. To pay for the system, the District received several grants from the Federal government, and Emery County enacted an *ad valorem* tax.

Key Findings

Benefit-Cost Analysis (BCA) is undertaken for evaluating the economics of RTMCS. When BCA is done prior to undertaking a project, it is called ex ante BCA. Less often, but in special circumstances (such as in the case of Emery County), in order to analyze RTMCS, BCA is undertaken ex post or after the project, to learn lessons so that the project approach may be applied to other counties and in order to get better results.

The three quantifiable benefits are 1) additional water delivered to take-outs at the farm; 2) reduced conveyance efficiency losses and salt loading; and 3) reduced

(autonomous) annual irrigation diversions from creeks to the canal systems during the analysis period. Benefits relating to the additional water delivery attributable to RTMCS is the only component that is used for the benefit-cost analysis (BCA).

Benefits-Costs

Three separate benefit-cost measures are developed. The first is the net present value (NPV) measure which is the present discounted value of benefits minus costs. The second measure is the internal rate of return (IRR). IRR seeks that particular rate of return that makes the discounted net benefit stream equal to zero. The third measure developed for this study involves the ratio of the present value of benefits to the present value of costs called benefit-cost ratio or B-C ratio. These three measures were computed for two scenarios.

- Scenario 1A: ex post BCA using CPI for cost adjustments. NPV (2017) $1,474,083; IRR 6.13%; B-C ratio 1.18
- Scenario 1B: ex post BCA using CPI for cost adjustments without diversion reduction for reducing salinity impacts. NPV (2017) $2,875,614; IRR 8.77%; B-C ratio 1.34
- Scenario 2: ex ante CBA using electrical index for costs adjustments. NPV (2017) $4,746,255; IRR 32.38%; B-C ratio 1.93

Under scenario 1, two ex post analyses were done. For the first, labeled Scenario 1A, the ex post analysis indicates that the NPV is $1.47 million. The internal rate of return is 6.13% and the B/C ratio is 1.18. Even under the most conservative assumptions, the overall agricultural benefits of RTMCS are positive by all three measures. The salinity benefits of $6.3 million attributable to RTMCS are not included in BCA, as explained earlier. Since the salinity benefits were not included, it will be interesting to do a BCA by hypothetically increasing the diversions for agriculture by the amount of water that was left in the stream for downstream salinity benefits. Such analysis will provide a better BCA for Utah counties that are not part of the Colorado River drainage system. This analysis is labeled as Scenario 1B. Under this scenario, the net present value almost doubled. The internal rate of return increased by more than 2.5% and the benefit-cost ratio went up to 1.34. This is a better measure to use as ex post analysis data for a county similar to Emery, but not part of the Upper Colorado River drainage area.

Under scenario 2, the ex-ante BCA based on declining equipment cost, the NPV is $4.75 million with a 32. 38% internal rate of return. The B-C ratio measure went up to 1.93. This is clearly an improvement in all three BCA measures, which is what one could expect if RTMCS is instituted in other Utah counties in a more realistic ex ante cost situation.

In summary, RTMCS is an investment in improving conveyance efficiency (CE) in an irrigation system through information technology. It differs from other forms of CE enhancing measures, such as structural or operational means. RTCMS requires human decision-making skills to effectively improve CE as opposed to other measures. RTCMS can increase CE from about 20 % to 50%, depending on the initial CE. If the initial CE is 40%, a 30% increase means the CE will increase to 52%. Limited empirical evidence suggests that systems with lower initial CE appear to have greater potential to improve CE than those with high initial CE.

Other Benefits

Stakeholders perceive other benefits, including improved crop production (lengthened irrigation season by up to a month) and increased transparency. Benefits to the environment include reduced salt loading to the Colorado River, plus reductions in fertilizer, herbicide, and pesticide loads to the hydrologic system.

Recommendations for RTMCS Adoption

Challenges. Any area considering an RTMCS will likely need to overcome possible concerns, which include: 1. Constantly evolving real-time system; 2. The challenge of finding and keeping trained personnel; 3. Possible system malfunction; and 4. System security. Reclamation in the past has provided technical backup for the RTMCSs in the State. That continued role is in doubt.

Pre-requisites. Any area considering an RTMCS should: 1. Insure they have the financial means and personnel to install and maintain the system; 2. Get buy-in from the water users; 3. Consider a basin-wide system; 4. Seek Federal and State grants where available; and 5. Use standardized equipment and software for ease of installation and maintenance.

Statewide Action. The State of Utah Divisions of Water Resources and Water Rights should consider: 1. Enlarging their real-time support staff; 2. Providing grants to encourage RTMCSs; 3. Developing operational and water rights models to interface with the real-time information; and 4. Installing a state wide real-time website.

Conclusions

RTMCS:

1. Are cost effective and environmentally sound way of improving agricultural irrigation delivery systems; 2. Are excellent water conservation tools for the canal companies, districts, and associations throughout the State; and 3. Provide transparency which is important for improving trust between all water users.

<u>Introduction</u>

The overall purpose of this project is to "identify and engage water managers, producers, and other stakeholders in Emery County to understand, document, and evaluate the drivers, methods, costs, benefits, and lessons learned from implementation of a network of flow measurement structures and transparent, real-time monitoring."

This report is organized into chapters addressing specific tasks outlined by the Utah Division of Water Resources (Resources):

Chapter One provides a profile of Emery County agriculture—including an inventory of agricultural land use. Data are provided for irrigated land and agricultural crop and livestock output. A discussion of the size distribution of farms is also provided. The data reveal several important issues related to irrigated agriculture and establish the need for Real-time Monitoring and Control Systems (RTMCS).

Chapter Two deals with the economics of the RTMCS involving a network of flow measurement structures and sensing devices, gate actuators and other control devices, webcams, and network interface with broadcasting capabilities. This chapter provides an overall conceptual economic framework for the quantification of water-related costs and benefits of RTMCS.

Chapter Three presents data pertaining to irrigation in Emery County where RTMCS has been in operation for over two decades. Challenges with respect to the availability and quality of data related to irrigation are discussed. Specific methodology based on *ex post* analysis is developed to elicit potential increase in water deliveries based on relationships between conveyance efficiency changes, water deliveries, and reduction in diversions. Estimates derived from this analysis provide the basis for estimating agricultural benefits.

Chapter Four provides an overview of the cost component of RTMCS. These are derived based on the annual budget of the Emery County Water Conservancy District (District).

Chapter Five provides calculations on the impacts of RTMCS on salt loading and potential downstream water quality benefits. The impacts and benefits are calculated using secondary data obtained from various Reclamation and Natural Resources Conservation Service (NRCS), Environmental Impact Statements (EIS), and other publications.

Chapter Six presents the results from the qualitative interviews conducted with the various stakeholders in Emery County. A grounded theory methodology is used to analyze the perceived benefits and costs benefits of the RTMCS. The benefits identified primarily relate to increased efficiency and enhanced transparency. Stakeholders generally perceive the costs as minimal or as an acceptable tradeoff.

Chapter Seven provides a roadmap for replicating Emery's success in other areas of the State. The roadmap includes a set of considerations for other basins, and a set of recommendations for the state of Utah.

Chapter Eight summarizes the results of the analyses of the Emery RTMCS.

Chapter 1

Overview of Emery County

Emery County occupies about 4,500 square miles and is located in central Utah. It was created in 1880 by the Utah Territorial Legislature. At that time, it included the area known today as Carbon County—one of the several adjacent counties to Emery County. Major communities within the county include Castle Dale, Huntington, Ferron, and Orangeville. In 2017, the county population was estimated at around 10,000.

Major Irrigation Water Resources

The Green River flows along the eastern edge of the county. The San Rafael River is a tributary of the Green River. The San Rafael River is formed by Cottonwood Creek, Huntington Creek, and Ferron Creek. All three start in the mountainous area of the northwestern part of the county, then flow through the agricultural areas of the central part of the county known as Castle Dale Valley. The three creeks merge to become the San Rafael River, which flows through the desert landscape of eastern part of the county before joining the Green River. Muddy Creek is another source of irrigation water that drains into the Dirty Devil River, which joins the green River.

Several irrigation canals were constructed between 1880 and 1890, including Huntington, Emery, and Cleveland canals. Over time, additional canals were built and small storage reservoirs constructed, which brought more land into cultivation. Reservoirs also supplied water for coal-fired electric plants owned by Utah Power and Light Company (PacifiCorp).

The Emery County Project (ECP) was authorized as a participating project in the Colorado River Storage Project by the Act of April 11, 1956. The Bureau of Reclamation completed planning on the water development project in February 1962. Construction of the project began in 1963 and was completed in 1966. Joe's Valley Dam and Reservoir, Huntington North Dam and Reservoir, Swasey Diversion Dam, and Cottonwood Creek-Huntington (CC-H) Canal are the project's major features.

The ECP is administered by the District (headquartered in Castle Dale, Utah) and has 3 full-time employees, plus seasonal help. Even though the District is a water wholesaler, it is committed to helping all water users in western Emery County better manage their water supply.

Photograph 1. Swasey Diversion Structure with the CC-H Canal on the left. This structure is now fully automated.

Millsite Reservoir (funded by the Utah Board of Water Resources) was completed in 1971 as part of the Ferron Watershed Project, under the authority of the Watershed Protection Act. This project was designed by NRCS and included upgrading water quality, sediment and flood retention, irrigation distribution, and rangeland stabilization of the Ferron Creek drainage.

Agricultural Profile

The crop agriculture in Emery County is focused on feed for its livestock industry. Alfalfa and other hay mixtures, corn silage, and small grains constitute the predominant irrigated crops. The livestock is primarily beef cattle and sheep. The agricultural land use trend from 1992 to 2017 is shown in Table 1 and is based on the U.S. Census of Agriculture.

Photograph 2. Agriculture fields in Emery County. Note salinity on adjacent lands.

Table 1: Irrigated Land trends in Emery County

Year	2017	2012	2007	2002	1997	1992
Irrigated Farms	439	478	465	397	413	383
Land in Irrigated Farms in Acres	128,580	147,098	194,467		149,202	187,138
Irrigated Land in Acres	32,848	51,743	41,823	33,099	41,198	31,669
Harvested Crop Land in Acres	21,300	24,301	19,040	16,210	20,539	18,415
Pasture and other land in Acres	11,458	27,442	22,783	16,889	20,360	13,254

The number of irrigated farms has been increasing from 1992 to 2012, and then shows a downward trend for 2017. Harvested crop lands have remained fairly steady (perhaps a small upward trend) during 1992-2017. Much of the variations are likely due to fluctuations in water availability in those census years. Irrigated pasture and other lands have increased substantially from 1992, except for declines in the years 2002 and 2017.

Available crop yield data from the annual survey the National Agricultural Statistical Service (NASS) for Emery County for the period 1992-2017 is shown in Table 2. Some of the data, for the years 2012 and 2017 when NASS data were missing, were replaced with available data from the U.S. Census of Agriculture. The trends do not show a clear pattern of change over the 26-year period chosen for this analysis.

Table 2: Crop yield trends in Emery County 1992-2017

Year	Alf. Hay	All Hay	Hay excl.alf	Oats	Corn	Corn Silage	
	ton/ac	ton/ac	ton/ac	bu/ac	bu/ac	ton/ac	
2017	3.25	3.15	2.10			18.60	
2016	3.35						
2015	3.30						
2014	3.45						
2013	3.00						
2012	3.05		2.40	65.76	124.29	20.50	
2011	3.25						
2010	3.20						
2009	3.15						
2008	3.40	3.19	2.20	57.00			
2007	2.90	2.80	1.90	100.00	169.00	17.00	
2006	3.30	3.10	2.30	78.00	169.00	18.00	
2005	3.50	3.30	2.50	68.00	168.00	18.00	
2004	3.40	3.20	2.00	72.00	132.00	16.00	
2003	3.50	3.30	2.30		150.00	17.00	
2002	3.10	3.00	2.00	67.00	170.00	21.00	
2001	3.40	3.30	2.30	70.00	140.00	16.00	
2000	3.50	3.40	2.40	66.00	132.00	18.00	
1999	3.70	3.60	2.80	76.00	140.00	22.00	
1998	3.80	3.60	2.60	79.00	140.00	17.00	
1997	3.70	3.50	2.60	66.00	151.00	18.00	
1996	3.10	3.00	2.20	70.00	145.00	16.00	
1995	3.30	3.10	1.80	65.00	101.00	15.00	
1994	3.30	3.10	2.10	70.00	137.00	16.00	
1993	3.60	3.40	2.10	68.00	129.00	12.00	
1992	3.02	2.88	2.00	64.00	133.30	11.80	

Table 3 shows the distribution of farm size in Emery County based on the U.S. Census of Agriculture data. The number of farms increased from 383 in 1992 to 478 in 2012. However, in 2017 the total number of farms decreased to 439. Farms 10-49 acres have increased consistently every census period from 88 to

165. Large farms over 2000 acres have declined from 23 to 9. Continued decline in farm sizes may mean more small farms, thus increasing the number of water right holders, resulting in more diverse water delivery requirements over time, both in terms of timing of demand for irrigation water and delivery points. This increases the complexity of operating an irrigation system and places a larger burden on canal company water managers and other employees.

Table 3: Farm Size Distribution in Emery County

Farm Size in Acres	2017	2012	2007	2002	1997	1992
1 to 9	43	56	34	24	19	10
10 to 49	165	153	150	118	109	88
50 to 69	36	51	36	32	26	22
70 to 99	34	38	50	31	33	33
100 to 139	28	28	25	34	33	21
140 to 179	22	31	26	29	31	31
180 to 219	8	7	10	19	28	28
220 to 259	12	9	9	17	9	17
260 to 499	35	38	36	30	44	56
500 to 999	22	37	48	28	47	35
1000 to 1999	25	21	25	21	21	19
2000 and more	9	9	16	14	13	23
Total Number of Farms	**439**	**478**	**465**	**397**	**413**	**383**

Table 4 shows the distribution of irrigated acres for different farm sizes over time, as obtained from the U.S. Census of Agriculture. Irrigated acres do tend to fluctuate from year to year based on water availability, fallowing decisions, and other cropping changes for profitability reasons. Noteworthy, however, is the increase in irrigated acreages associated with smaller size farms of 1-9 acres (except for 2017) and 10-49 acres. Although these smaller farm sizes have a very small fraction of the irrigated land, the cost of administering the irrigation water delivery is likely to increase.

Table 4: Irrigated Acres by farm size in Emery County

Farm Size in Acres	2017	2012	2007	2002	1997	1992
1 to 9	190	222	143	102	73	48
10 to 49	2508	2437	2058	1825	2066	1411
50 to 69	971	1481	1252	1140	1037	678
70 to 99	1270	1578	1825	1226	1523	1220
100 to 139	1972	1967	1633	1804	2248	1134
140 to 179	1676	2366	1941	1917	2392	1663
180 to 219	954	703	1015	1491	2352	2129
220 to 259	1248	782	1241	1432	1205	1824
260 to 499	5626	5278	4617	3704	6471	6117
500 to 999	5432	6730	8014	6048	9738	5702
1000 to 1999	4929	5844	7514	4772	5448	3394
2000 and more	6072	22355	10570	7638	6645	6349
Total Irrigated Acres	**32848**	**51543**	**41823**	**33099**	**41198**	**31669**

The trends exhibited by the data in both Table 2 and Table 3 show the importance of the changing structure of administrative costs associated with delivering water to meet water demands coming from ever-increasing customer base with smaller farm sizes, smaller water rights, and possibly more diverse farming operations.

The farm economy produces income from marketable sales of crops and livestock products. Field crops produced are partly consumed internally for feeding livestock within the county. Table 5 shows the cash receipts from crop and livestock products for Emery County obtained from the U.S. Census of Agriculture. The crop sector is getting larger relative to the livestock sector. Crop receipts were 14% of livestock receipts in 1992. However, in 2017, they constituted almost 50% of livestock receipts. Feed prices have risen much faster over time relative to livestock product prices, thus increasing demand for water for irrigated feed crops and irrigated pasture grounds.

Table 5: Cash Receipts in $1,000 for Crop and Livestock Products for Emery County

Year	2017	2012	2007	2002	1997	1992
Livestock/products	10,471	8,983	9,126	9,957	8,885	7,050
Crops	4,883	5,092	2,197	1,495	2,028	1,118
Total	**15,354**	**14,075**	**11,323**	**11,452**	**10,913**	**8,168**

There are other interesting socioeconomic and demographic factors that can play a role in bringing about changes in the structure of irrigated agriculture. While there are no time-series data for Emery County in the Census of Agriculture, national and state trends can be used to draw conclusions. For example, there has been an increas in the number of producers who supplement their income by engaging in off-farm employment. Table 6 shows the days worked in off-farm operations by producers in Emery County. From the data, it is clear that the majority of the Emery County producers rely on off-farm operations as a means of supplementing their income. From the table it is also evident that the majority of producers work more than half-time in off-farm operations. Employment in off-farm operations has been enerally increasing throughout the country to offset the loss of farm income as a result of decreasing farm size and increasing variability in farm income. This indicates that more services may be required from the irrigation managers.

Table 6: Days worked in off-farm operations by producers in Emery County, 2017

Days worked off operation	Number of producers
0 days	284
1-49 days	54
50 -99 days	46
100 - 199 days	109
Greater than 199 days	371

Looking at the age distribution of the producers from Table 7, there are about 396 producers below age 55 and 468 producers above age 55 (the average age of a producer in Emery County). The general trend in the country is that the average age of farm operators is generally increasing. As population grows in a community, suburban growth occurs as farm lands are subdivided to meet housing needs. This creates smaller and some hobby-oriented farms owned by a younger population who have part-time off-farm employment.

Table 7: Age distribution of producers in Emery County, 2017

Age	Number of producers
LE 25	9
25-34	93
35-44	160
45-54	134
55-64	209
65-74	171
GE 75	88

This factor explains the changes in size distribution of farms and the consequent increase in administering the irrigation delivery system.

Irrigation Practices and Methods

Since irrigation began in the Castle Dale Valley, water was diverted from the major creeks (Ferron, Cottonwood, Huntington and Muddy Creeks) into a network of earthen canals and transported for delivery to irrigated lands. Flood irrigation is the most common means of getting water to the crops. Appropriated water rights exceed water available for irrigation in most years. In most years, irrigated harvested crop land is between 20,000 to 30,000 acres. In those years, when water available for diversion is above average, more pasture lands are irrigated. In the 1990s, substantial changes started to occur.

There were two major issues with the traditional irrigation practices at that time:

Irrigation Efficiency Issues. Conveyance efficiency (CE) (which is defined as the ratio of the quantity of water delivered (WD) to the irrigated fields of the farm to the quantity of water diverted (QD) into the canals) was typically low, in the range 40%-60% (Benefits of the Salinity Control Program in the Upper Colorado River Basin, p12, 2016). This meant keeping diversion as high as possible to deliver the appropriated water, or as close to it as possible. Flood irrigation as a means of distributing water on-farm also has had typically a low application efficiency, defined as the ratio of the amount of water beneficially used by the crops to the water applied—estimated at 50 to 55% (Price-San Rafael Unit, Utah, Planning Report final EIS IV-31, 1993). Increasing efficiency would allow delivery of greater proportion of the appropriated water rights in most years, and hence, the possibility of increasing agricultural output. This may happen in three ways: 1) more water available for irrigation at every point in time, 2) the ability to deliver water closer to the desired time irrigation is needed, and 3) the possibility of being able to deliver water at the tail end of the irrigation season.

Salt Loading Issues. Lower irrigation efficiency means a greater percentage of water is lost both during conveyance and in application on-farm. These losses mean, for any given diversion, that a greater amount of seepage from the canal system and a greater amount of return flows from deep percolation occur. Thus, these losses leach greater amounts of salt from the soil, and this highly saline water joins the river system, ultimately draining into the Colorado River with a greater salt loading. Conversely, any reduction in diversion likely will reduce salt loading from the Emery County drainage basin. Diversions can be reduced in many ways, including: retiring irrigated lands; reducing winter and early spring diversions; increasing conveyance and/or on-farm application efficiencies; and other such means. Each of the above measures has both costs—costs associated with implementing various infrastructure alternatives—and benefits—benefits from agricultural output increases, as well as downstream damage avoided from changes in salt loading. Reclamation and NRCS have implemented, pursuant to the 1993 final EIS, many measures outlined above in Emery County as part of the 1974 Colorado River Salinity Control Program (CRSCP).

However, reductions in diversions achieved through such infrastructure improvements can adversely affect the wetland ecosystem created by return flows and the associated benefits. Selecting resource protection plans consistent with cost effectiveness has been the primary goal of the salinity control program.

The infrastructure implemented over the last three decades under such a plan has resulted in three major areas.

- Improved surface irrigation systems which include water measuring devices, water control structures, and automated water control valves as part of the RTMCS.
- Replacement of open channel conveyance system for canals and laterals by pressurized pipe system.
- Through cost share programs, installation of sprinkler systems by which on-farm application efficiencies were increased. This is facilitated by the installation of pressurized pipe systems.

The focus of this study is the quantification of water-related benefits and costs of real-time monitoring and water quantification program (RTMCS), which is the first infrastructure investments mentioned above. In addition, socio-economic impacts and benefits of the program, as well as the environmental benefits from reduced salinity loading, will be part of the analysis.

Summary

In this chapter, the data presented suggest the following: 1) the number of farms are increasing; 2) average farm size is declining; and 3) farms between 1 to 50 acres show significant growth over time. Increasing population in a community and the consequent subdividing of farms adjacent to the community often creates smaller, hobby type farms owned by younger part-time producers who still rely on timely delivery of irrigation water. The value of water has increased not only from population growth around rural communities, but also due to exogenous factors such as increases in livestock feed costs, which in turn will increase demand for water for production of irrigated field crops. These trends suggest that there are more irrigation customers and a likely increase in the complexity of serving the demands of these customers. Small-size farms are likely to have more variety and diversity in crops produced, requiring more frequent demands on their irrigation water, which again raises the administrative costs of an irrigation system.

RTMCS provides a transparent mechanism to administer an ever-increasingly complex irrigation system, where all irrigation customers and providers have access to the same real-time information. In the next chapter, the economics of RTMCS will be discussed, and a methodology will be developed to estimate some of the benefits of RTMCS.

Chapter 2

Overview of RTMCS

The purpose of this chapter is to "evaluate the drivers, methods, costs and benefits from implementation of a network of flow measurement structures and transparent, real-time monitoring."

What is a real-time monitoring and control system (RTMCS)? Typically it involves a network of flow measurement structures and other sensing devices, gate actuators and other control devices, and webcams, all with Internet display capabilities.

What does RTMCS do? The sensors collect and broadcast information such as stream discharge rates, depth of water in open channels, and velocity of discharge, and broadcast them at multiple points on the stream, which information is then fed into a website, so that anyone has access to it. Water managers and others can see how the water is being transported through the network of diversions, canals and ditches, and laterals, and also monitor water storage levels in ponds and reservoirs.

How can RTMCS help manage an irrigation network? A RTMCS can direct water flows more precisely to delivery points avoiding the need to visually inspect and manually adjust releases at various take-outs. With automated gate controls, they can maintain necessary head and flow rates precisely to deliver water to meet water demands and respond rapidly to any changing conditions such as rain or flash flooding. RTMCS takes out the guesswork and eliminates the need to drive long distances to visually inspect and manually control releases. Furthermore, breakdowns in water flow due to trash, debris, algae, moss, leaves, and branches can be easily and quickly detected and fixed. With RTMCS, less water needs to be diverted from the supply source to meet a specified water demand at the farm take-outs, if the information provided by the RTMCS is used efficiently.

Thus real-time monitoring and water quantification and the associated automation of controls can be viewed as one of the means to increase conveyance efficiency in the supply of irrigation water. System-wide conveyance efficiency (CE), as previously defined, is the ratio of the amount of water delivered to farms (WD) to the total amount of water diverted (QD) at the source. In the case of water conveyance and delivery by open earthen canals and laterals, there is potential to increase the conveyance efficiency with real-time monitoring programs. How much increase is achieved depends on the extent of the network of flow measurement and the automation of irrigation structures, which in turn relates to the investment and operating and labor costs, including IT personnel hired to maintain the system. Also, the increase depends on how frequently the information is monitored by the water manager and how effectively decision-making is done using the information from RTMCS.

<u>Are there other ways of increasing CE?</u> As opposed to the informational technology (IT) means of increasing CE through RTMCS, there are various other structural and operational means of increasing CE in open channels. These include, but are not limited to, such measures as: 1) lining of canals with clay, plastic materials, or concrete; 2) reducing or eliminating vegetation along canal banks; 3) removing leaves, tree branches, debris and other accumulated trash on a regular basis; 4) fixing eroded ditch banks and leakage from the conveyance system; and 5) treating algae with appropriate chemicals. While all these measures are practiced in operating most irrigation systems, the increase in conveyance efficiencies achieved through these means are directly related to how much labor and operational costs are incurred.

<u>What is unique about RTMCS?</u> There is a major difference between the structural and operational means discussed above and the informational means of increasing CE through the RTMCS. The latter provides **information** for **potentially** increasing CE, but the actual increase will depend on managerial decisions with respect to **frequency of monitoring** various sites, **decision-making with respect to the logistics** of the delivery system working in conjunction with automated controls, **learning by doing,** and **acquiring operational experience** and **continuous learning**. It is the combination of IT with human management skills and experience that increases CE. Therefore, the extent of increase in CE will depend on the skill set and the time put in to make decisions by the water manager.

Another important distinction is that structural and operational measures, once implemented, take effect immediately in improving CE. However the informational measure through RTMCS takes time since the water managers need to learn to gather and compile the information, understand the data, react to the data in a timely manner, and learn to make decisions by trial and error. Since most irrigation systems are unique in some ways, even though there are certain commonalities, educational efforts alone may not be sufficient. Learning on the job is important and that could take some years for operational proficiency to get the most effective increase in CE.

Budgets and labor factors are also important in getting the most out of RTMCS. Water managers may need to increase their IT personnel, and salaries for IT personnel may be higher than the canal company employees. Obsolescence of equipment will be frequent because of rapid change in technology, and flexibility in budget to accommodate these changes will be important.

However, conveyance efficiencies can be increased substantially when water is supplied through closed pipe systems as in much of Emery county delivery system in recent years (Ferron, Huntington and Cottonwood irrigation systems). Still, real-time monitoring systems are synergistic with the pressurized pipe system in being able to increase water deliveries, in terms of timing and reducing waste due to breakdowns.

History of RTMCS

During a period of drought that began in the early 1990s, the lack of accurate information about the water supply and distribution systems (i.e., being able to compare where water is with where it should be) resulted in frustrations and inefficiencies in the management of water. A responsive measurement and control system was needed to improve water management.

With funding provided by a drought-program grant from Reclamation in 1993, the District designed and installed the first step in a comprehensive hydrologic data collection system. The system was originally designed to improve hydrologic records, but RTMCS also improved the responsiveness of the county's water delivery systems. Data from the field sites were telemetered back to the District's office by line-of-sight radio using a VHF frequency. The field monitoring sites fell into three general categories: San Rafael River and its tributaries; canals (largely at diversions); and springs critical to M&I water supply. In total, 17 water gauging sites were upgraded to real-time monitoring.

This initial effort was expanded as part of the Emery County Water Management Study. To fund the ever expanding system, the county raised its ad valorem tax.

By 2002, the District had a monitoring and control system covering western Emery County that included 77 field sites (see Appendix A for a description of the 2002 RTMCS).

The basic components for a real-time flow monitoring site (in 2002) included: 1) a remote terminal unit (RTU); 2) a water-level sensor; 3) a VHF telemetry radio and antenna; 4) a radio modem; 5) a solar-energy system; and 6) enclosures. It required as little as 4 hours to install, assuming there was a stilling well in place.

Today, the District has an extensive real-time monitoring and control system. It includes over 200 monitoring sites, 50 control sites, weather stations, and webcams. The District's real-time data is collected hourly and displayed on its website at www.ewcd.org. District staff and other water managers have found the system and website to be invaluable in managing their water systems.

The system also includes an early warning system on Joe's Valley Dam and three fully-automated cloud-seeding units. All these various components have similar equipment to facilitate operation, maintenance, and repairs (OM&R). For a further description to these add-ons see Appendix B.

One reason the RTMCS has been successful is because it has evolved in an orderly fashion. It started out with data monitoring, then moved to remote control (moving gates remotely), and finally to automated gates (setting the flow remotely). The latter is designed to maintain a constant flow in a canal. With the addition of the pressure pipe systems, the automation was reconfigured to keep the water levels in regulating ponds within a specific range.

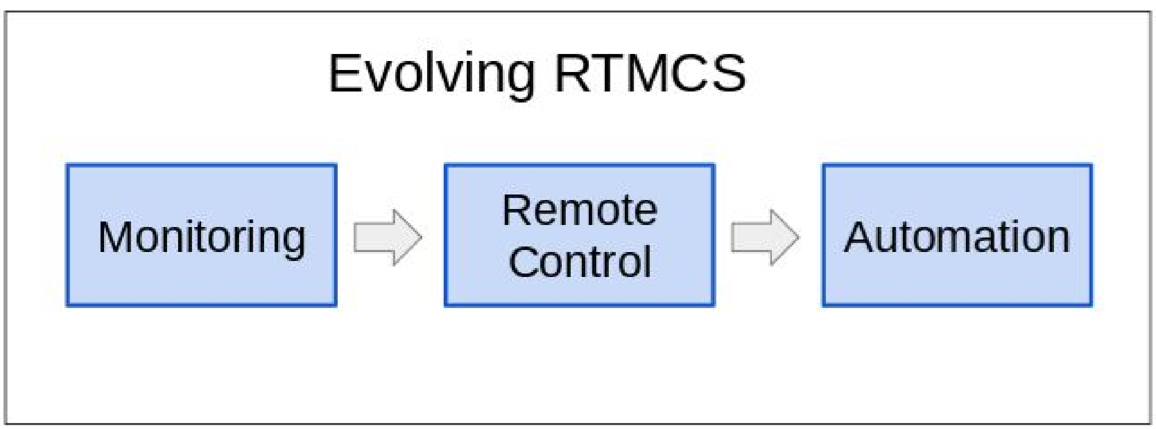


Figure 1. District's progression from monitoring to gate automation

The nature of the automation/Internet/decision-support technological intervention needs discussion. Reclamation and State water projects in the past have typically had definite beginnings and ends. For example, the agency constructed a dam and then turned it over to the water users to repay and operate. In the case of automation/Internet/decision-support technologies, there is a continually-evolving product. The technologies get more sophisticated and less costly with each passing day. And as the technologies get more complex, so do the needs of the water users.

With real-time technologies, we are describing an ongoing process more than we are a specific product. Having an automation/Internet/decision-support system that is continually evolving has not always been easy on the District. It is not uncommon for them to express frustration with new "improvements." Comments like: "But I just got used to the last one" are not uncommon. Ways to mitigate the impact of a continually-changing product need to be carefully addressed, particularly as the rate of technological change continues to increase.

RTMCS Website

The District Manager, Jay, checks the RTMCS multiple times during the day. When he gets up in the morning, when he arrives at work, before he goes home, and before he goes to bed — he sits down at his computer, and logs onto: www.ewcd.org. The website provides him (and all Emery County residents) with hourly updates on weather conditions, the status of the county's water supply, and general environmental conditions in the watershed and the District's service area. From the convenience of his desktop, Jay can check the depth of the snow-pack in the mountains, the quantity of water stored in Joe's Valley, Huntington North, and Millsite Reservoirs, and the flows at the various points on Huntington, Cottonwood, Ferron, and Muddy Creeks. With a click of the mouse, he surveys real-time environmental conditions throughout western Emery County. Information on the website is never more than one hour old.

Jay has been surprised by the wide range of interest in the District's website and the increasing usage. For example, during the high water season, kayakers are a frequent user of the website. They check Cottonwood Creek below Joe's Valley Dam to see if there is adequate flow for kayaking down Straight Canyon.

The District's website includes five major real-time data collection categories: reservoirs, rivers, canals, springs, and weather. By clicking on a selection from the navigation bar, the user is taken to a page where specific measurement locations in the given category can be selected. For example, one web page presents the user with a schematic diagram of the reservoirs in Emery County. The relative size of the teacup indicates the storage capacity of the reservoir. In addition to the teacup diagram, a table showing the reservoir elevations is included on the page. Since data transmission between the field site and the base station is not always perfect, each measurement is color coded to indicate how old it is. Green indicates that the data is current; red indicates a measurement that is over 24 hours old.

RTMCS and Water Conservation

It is important to note that RTMCS is an important component of the District's Water Management and Conservation Plan. Goals of the plan include:

- Maintaining and Upgrading RTMCS Software and Hardware;
- Assisting Shareholder Flow Measurement Improvement Activities; and
- Fine-tuning RTMCS to More Fully Integrate with Private Systems.

Real-time data collection and Internet display are also an important component of the Governor's State Water Plan, which encourages active improvements to "the science and technology of water management," including:

- Improving the quality of water data collected; and
- Making water data more accessible to the public as a way to educate and inform.

The Emery RTMCS fits in well with both the District and State conservation efforts.

RTMCS Costs and Expenditures

Costs for Monitoring Equipment. The costs for a simple real-time monitoring site is shown below:

Table 8. Costs for datalogger, communication, and other equipment for a field site (this Table does include the cost for a sensor or sensors)

STATION	Quantity	Cost	Total
CR206	1	$725	$725
Solar Panel (50 W with Pole mount)	1	$180	$180
Battery (gel)	1	$ 55	$ 55
Coax (20 feet)	1	$ 30	$ 30
Antenna (900Mhz - 2.5 Ghz) directional	1	$ 70	$ 70
Pigtail for CR206	1	$ 30	$ 30
Lightning Arrestor	1	$ 25	$ 25
Fiberglass Box	1	$130	$130
Pole (20 foot) with guidelines and concrete	1	$120	$120
Sunsaver-6 regulator	1	$ 60	$ 60
Shipping	1	$ 75	$ 75
Total			**$1,500**

These costs assume the canal site has an existing flume and stilling well. A float and pulley float sensor system costs approximately $500. Thus the total cost for a simple site would be approximately $2,000/site. It is recommended that for planning purposes a cost of $3,000/site be used, because there are frequently unexpected costs associated with an individual site. The cost for a pipeline monitoring site would be $1,500, plus the cost of the flow meter.

Photograph 3. Monitoring station on the inlet structure to Huntington North Reservoir.

With the above configuration, a repeater site is needed for each 25 monitoring sites. The cost for a repeater is shown below.

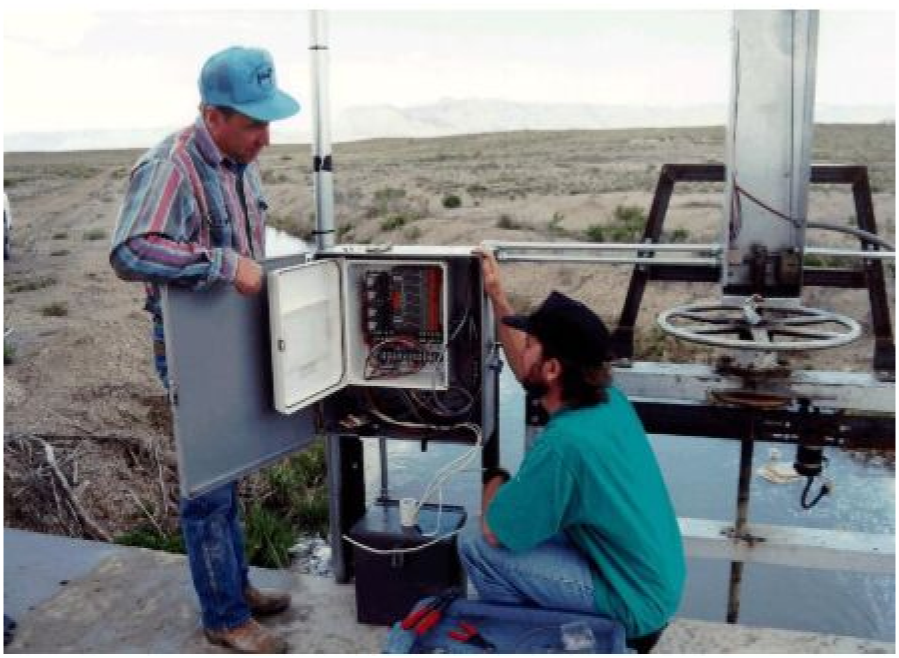
Table 9. Costs for a repeater site

Repeater	Quantity	Cost	Total
401A-Datalogger	1	$465	$465
Solar Panel (50 W with Pole mount)	1	$180	$180
Battery (gel)	1	$ 55	$ 55
Coax (30 feet)	1	$ 50	$ 50
Antenna (900Mhz - 2.5 Ghz) omni	1	$145	$145
Pigtail for 401A	1	$ 30	$ 30
Lightning Arrestor	1	$ 23	$ 23
Fiberglass Box	1	$ 50	$ 50
Rohn 30' 25G Free Standing Tower Kit	1	$840	$840
Sunsaver-6 regulator	1	$ 60	$ 60
Shipping	1	$ 75	$ 75
Total			**$1,973**

Costs for monitoring and repeating sites are exclusive of labor, but that is frequently something that can be contributed by the water user.

Costs for a Control Site. Equipment costs for a control site varies widely depending on the type of installation. A single slide gate (without an existing gate actuator) can cost as little as $5,000 (for equipment) to automate. More complex configurations can cost considerably more. For example, at Joe's Valley Dam, because of adjacent mountains, satellite communication was required. Labor costs are additional. It is important to note that most control sites can be solar powered.

Researchers at Utah State University (USU) demonstrated that a low-cost gate actuator can be manufactured and installed by the water users. The USU gate design was refined by Reclamation technicians (see Appendix C). This is the design that was widely used in Emery County (and along the Sevier and Duchesne Rivers). It has proven to be very reliable and easily repaired. The moving components are easily replaced.



Photograph 4. Reclamation staff working with District manager on a solar-powered gate control system.

District Expenditures on RTMCS

Equipment Expenditures. Figure 2 plots the District's annual expenditures for real-time equipment from 1992-2017. The high expenditures from 1995-2004 are explained by federal grants. Since 2004, the District has expended, on average, $73,250/year. This number is high because the real-time system:

- Was originally installed on open-ditch irrigation delivery systems that were largely converted to pressure pipe systems requiring different configurations of equipment.
- Underwent conversion of communications from VHF radios to spread-spectrum radios and cell service.
- Is continually expanding. Current expansion involves installing real-time communications on the individual connections to the pipeline systems, first in Castledale area and eventually moving to the Huntington area. There are currently over 200 individual connections (out of 600) that are connected to the real-time system.

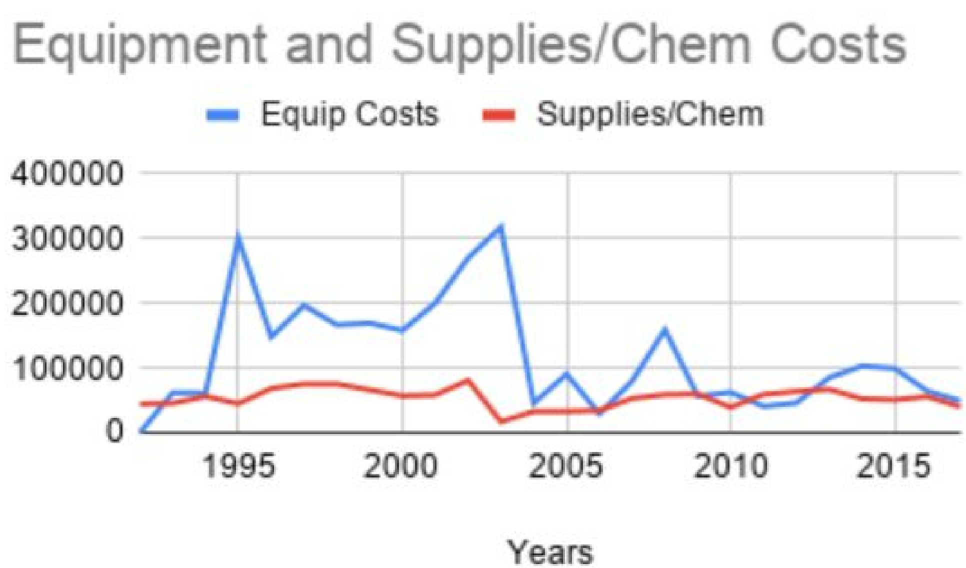


Figure 2. District's annual expenditures on Equipment and Chemical Supplies.

Notably, we were unable to separate out the replacement equipment costs from the expansion expenditures. But the replacement costs have not been high. The manager indicates that vandalism has not been a significant problem. The District has had an occasional solar panel destroyed by shooters. The voltage controllers and batteries have required occasional replacement.

Personnel Costs. A decade ago, the District hired an assistant manager who spends half-time on the real-time monitoring and control system. The manager spends approximately 10 percent of his time on RTMCS issues. The District's seasonal help also works on installation and maintenance of the system. These costs are included as part of the cost component in the benefit-cost calculations.

Measures Implemented to Increase Conveyance Efficiency in Emery County as part of the Colorado River Salinity Control Program

Regardless of mechanisms to increase conveyance efficiency, an increase in CE provides water managers greater ability to deliver more water to users when they need it, up to the amount they are entitled to based on their appropriated water rights. When greater amounts of water are delivered at the appropriate time, there are three possible ways production and yield can increase: 1) by delivering more water to farms during years of "lower than normal" or even years of "normal" snow pack (since only about 20% of the time there is enough water to deliver the full appropriated water in Emery County because of low irrigation efficiency during mid 90s and prior years); 2) by matching water deliveries with the irrigation needs in terms of timing; and 3) by increasing late season deliveries.

In addition, other possible benefits of RTMCS may include: 1) reduced "transactions costs" in terms of information being readily available to users due to increased transparency of the system operation; 2) quicker response time to breakdown of delivery system; and 3) improvement in stream water quality since return flows are reduced.

Reduction in salt loading is a significant factor in Emery County, since it is part of the Upper Colorado basin. Any increase in CE that reduces water diversions for agriculture could potentially reduce salt loading from surface run-offs and deep percolation. Such reduction in turn reduces salt concentrations of the Colorado River and thus could confer social benefits to downstream users by reducing salinity damages to both agriculture and non-agricultural water users. The USBR as part of the Colorado River salinity reduction program has funded installation of pressurized pipes to deliver water for much of the irrigated land in Emery County starting in the mid- to late-1990s (water supplied by canals and laterals from Ferron, Huntington and Cottonwood Creeks). Emery County Water Conservancy District has modestly invested in RTMCS in the Muddy Creek basin (Emery and Moore canals).

Increases in on-farm application efficiency is also a factor in the possible reduction of surface run-off and deep percolation, while increasing yields due in part to more uniform application. Since water deliveries for a major portion of Emery County are made through pressurized pipes, NRCS, through its cost-sharing program, has helped farmers in Emery County install sprinkler systems on their farms. This accounts for the large proportion of the irrigated crop land in the County being sprinkler irrigated, with generally higher on-farm efficiency relative to flood irrigation in most other counties.

Investments in 1) real-time water monitoring, 2) pressurized pipe system delivery, and 3) sprinkler systems have been made to the county's irrigation infrastructure in multiple overlapping stages in Emery County over a nearly twenty-year period. These changes all contribute to the overall irrigation efficiency improvement (in terms of both conveyance and on-farm efficiencies).

To analyze the effects of real-time water measurement network on the conveyance efficiency requires isolating its singular effect from installation of pressurized pipe systems and sprinkler systems. Once this effect is isolated, the relationship between the extent of conveyance efficiency increase from real-time measurement, and the capital expenditures and annual operations cost pertaining only to the real-time measurement network, must be established. The higher the investment in monitoring systems and associated operational costs (with more monitoring stations in the network having an impact on larger acreage), the greater the expected increase in conveyance efficiency. This is the first part of the required analysis.

Benefits of RTMCS

The second part of the analysis requires establishing potential increase in water deliveries to the farm associated with the increase in conveyance efficiency over time. The available water for diversion from rivers and streams depends on snowpack and thus vary from year to year. In Emery County, even in the so called *normal or average year*, i.e., a year in which flows are at the 30 year average value, stream flows are not adequate to meet all the appropriated water for irrigation. Only about 20% of the time is there sufficient water supply to fully meet the appropriated water rights. However, when available water for diversion falls *below- normal,* improvements in conveyance efficiency allows more water to be delivered than otherwise—even if it falls short of appropriated water rights. The analysis further requires determining the monetary values of agricultural output associated with additional water deliveries. Because of increased water deliveries, users may plant more crop acreage, also increasing the yields due in part to more favorable timing of irrigation, resulting in greater output as compared to a situation with lower conveyance efficiencies. Also, water deliveries may be increased in late season, allowing another cutting of hay. Monetary benefits will be calculated for each year from 1992-2017 using marginal values of water calculated from cash rents/lease values.

The major component of benefits may come from the impact of reduced diversions, if any, resulting from real-time monitoring infrastructure, in addition to other water conveyance infrastructure (pressurized pipes and sprinklers, largely) on salt loading. If diversions are reduced, the extent to which salt loading impacts the Colorado River will also be reduced, averting economic damage to downstream users. Again, separating the impact of RWQP from other improvements is the challenging part of the analysis.

Benefit-Cost Calculations

The final phase is the benefit-cost analysis. Agricultural benefits for Emery County and the downstream salinity benefits associated with increase in conveyance efficiency will be calculated for each year of the analysis from 1992 to 2017. Installation of a pressurized pipe system began in 1997 for the Ferron Creek agricultural basin. For Huntington, the project started around 2007, and for Cottonwood, installation began closer to 2011. Project completion took 3-7 years for each of those basins. Most sprinkler systems came into being after the installation of the pressurized pipe systems. For the Muddy Creek basin, a small investment was made only for RTMCS.

The annual benefits resulting from CE will be calculated for each basin from 1992 to up to the time pressurized pipe system was installed. In this way, the effect of RTMCS can be separated from increases in efficiency achieved through pipe system and sprinklers. The benefits will then be compared to the annualized capital cost plus the annual operational cost to derive the net annual benefit stream associated with real-time monitoring and the measurement system implemented in Emery County. Thus, a “net benefit” measure as well as benefit-cost ratios can be calculated and used as guidelines for implementing this system in other counties, with appropriate modifications allowing for cropping patterns and the economic values, length of open channel canal systems, and statistical distribution of snow packs or diversion water availability.

In the next chapter, a discussion of the specific methodology used for calculating the benefits is provided. The data availability and the assumptions made for the analysis are discussed. Then, specific numerical results are obtained using a statistical model to derive changes in conveyance efficiency. From these results, annual value of benefits will be calculated both for Emery County agriculture, as well as the downstream benefits from reduced salt loading.

Chapter 3

Data availability and Assumptions

There are two important pieces of information that are required to get preliminary benefit estimates:

1. Systematic changes in agricultural diversions from the stream; and
2. Changes in conveyance efficiency.

An increase in agricultural diversions means increased potential for salt loading from the conveyance system losses through both surface run-off and deep percolation impacting the salinity of the Colorado River. Conversely, any reduction in diversions will reduce the potential for salt loading.

The importance of estimating changes in conveyance efficiency (CE) cannot be overemphasized in terms of the benefit analysis. Since CE is the ratio of irrigation water delivery (WD) to total irrigation diversions (QD) from the water source, if data were available on WD and QD over time, it would be possible to estimate CE. Once a time-series of CE is estimated, it is then possible to statistically explore what factors and to what extent these factors affect CE. In particular, it is important to know how interventional factors such as RTMCS, pressurizeed pipe system installation and other strategies to improve conveyance systems affect CE of the irrigation service area. If the effect of RTMCS on changes in CE can be estimated separately, then the benefits of increased water availability at the farm as well as the benefits fromthe reduction in salt loading can also be estimated.

Unfortunately, data on WD were not available for any of the canals that might have potential to benefit from RTMCS. In fact, even time-series diversion data for Ferron and Muddy creeks were not available, except for the last three years. Data sets for diversions were available for only Huntington and Cottonwood Creeks. Given the absence of required water delivery data to estimate changes in conveyance efficiency, a back door approach is used.

Every year, based on forecasted streamflow information from NRCS, the irrigation manager makes allocation decisions before the growing season begins. For example, if it is a dry year with an expectation of water available to meet only 60% of appropriated water rights, the manager announces his decision. Individual farmers then adjust their crop choice, which fields to irrigate, irrigation timing and number of irrigations, and the quantity of water based on expected water delivery over the season for that year. As the reduced allocation of water is delivered to farmers over the irrigation season through the conveyance system based on their demand, the manager keeps track of total diversions from the stream. Sometimes, there are mid-season corrections to the initial allocation, based on changing water supply conditions. When the announced final allocations are met or the season ends, whichever is earlier, the manager shuts off the diversions.

It turned out that the manager diverted systematically less water per year from the creeks to the farmers while still meeting the declared water allocation to the farms during the 1992-2017 period. This is evidenced by time-series data on primary shares of water diversions from both Cottonwood and Huntington Creeks.

Diversion data for Cottonwood and Huntington were analyzed to see if a statistically-justifiable trend exists. If it does, it will be used to do the benefit analysis. Furthermore, this trend could also be used for Ferron Creek since a full set of diversion data are not available.

Statistical Methodology

The District uses NRCS streamflow forecast (SF) to make diversion (QD) decisions and adjust diversions later in the season, if conditions deviate from forecasts. Therefore, it is clear that Cottonwood and Huntington diversions are assumed to be a function of NRCS streamflow forecasts for April-July issued in May. **Diversions are expected to be greater with higher forecasted flows.** Any mathematical representation of the relationship between QD and SF should reflect this. Furthermore, **with larger streamflow, diversions will likely increase at a decreasing rate** due to water right restrictions and limited capacities of canals and ditches and laterals. In addition, it is important to examine if QD has a time trend component. Notwithstanding the annual diversion to flow relationship, **is there a time trend in CE caused by exogenous factors** such as RTMCS or pressurized pipe system installation? All three propositions above are statistically testable. In order to test these, the following functional relationship is proposed for estimation and testing.

$QD = A^*e^{B^*t} (SF)^{C}$ .... (1)

Where: e = base of the natural logarithm and QD and SF are in acre-feet(AF)

A, B and C = parameters to be estimated.

t = time in year going from t=1 for year 1992 to t=26 for year 2017.

If A>0 implies a positive relationship between QD and SF. IF B is not equal to 0, implies a time trend in CE. The value of B multiplied by 100 is the rate of annual percent change per year in diversions after accounting for diversion changes in intra-year flows. Finally, if C is between 0 and 1, it means that QD increases at a decreasing rate with respect to SF. The coefficient, C, represents the percentage increase in QD if the forecasted streamflow increased by one percent. Taking logarithm on both sides,

$Ln (QD) = Ln (A) + B^*t + C^*Ln (SF)$... (2)

Where: Ln = natural logarithm.

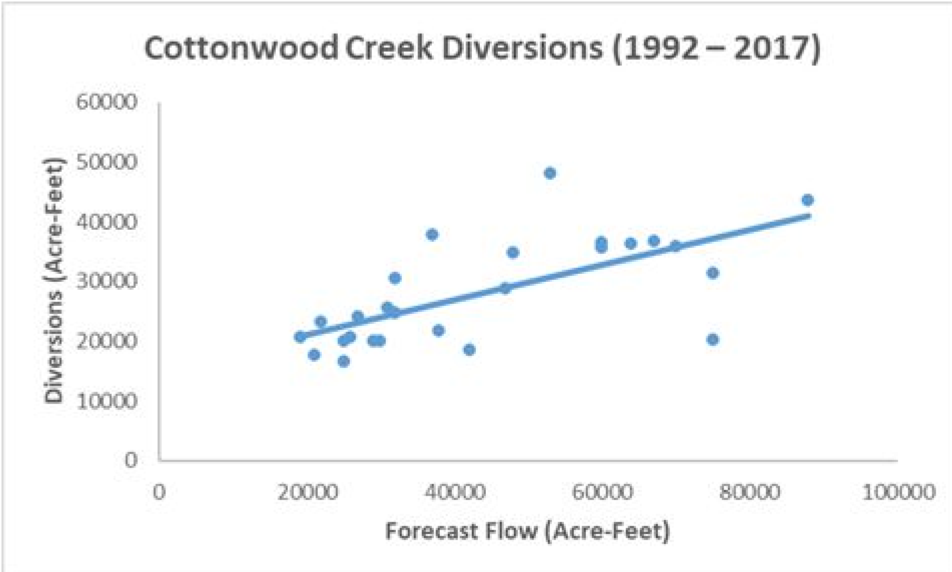
For estimation purposes, QD represents only primary water that are diversions from the creek referred to as “A shares”. Federal project water from storage called “B shares” are additional water not related to forecast flows. Regression results for Cottonwood and Huntington Creeks for A shares are shown in Table 10 below and depicted in Figures 3 and 4:

Table 10. Regression results for the individual for individual creeks

	LN(A)	B	C	R Squared	F(2, 23) Value
Cottonwood Creek Regression Analysis Results					
Parameter Estimates	5.629	-0.0146	0.4497	0.62	18.98
t Values	(6.021)	(-2.82)	(5.153)		
Huntington Creek Regression Analysis Results					
Parameter Estimates	5.441	-0.0152	0.509	0.54	13.75
t Values	(4.717)	(-2.12)	(4.614)		

The two regression results above indicate that the variations in diversions are explained 62% and 54% by the independent variables as indicated by their respective R^2 values (also known as goodness of fit). The F (2, 23) values of 18.98 and 13.75 indicate that all three parameters are significantly different from zero at 5% level. The t-values corresponding to each of the three estimates for each of the two equations are also significant at the 5% level.

From the results, it is clear that the relationship between QD and SF is positive and that for any given year, a one percent increase in forecasted streamflow results in 0.45 % increase in diversion for Cottonwood Creek and 0.51% increase in Huntington Creek diversions of primary A share water, confirming that diversions increase at a decreasing rate with forecasted flows. The most interesting result is that the estimate of the coefficient B is negative and different from zero at 5% level of significance. The estimates indicate a 1.46% reduction per year for Cottonwood irrigation system diversions, and a 1.52% per year reduction per year for Huntington irrigation system. These numbers require further explanation.



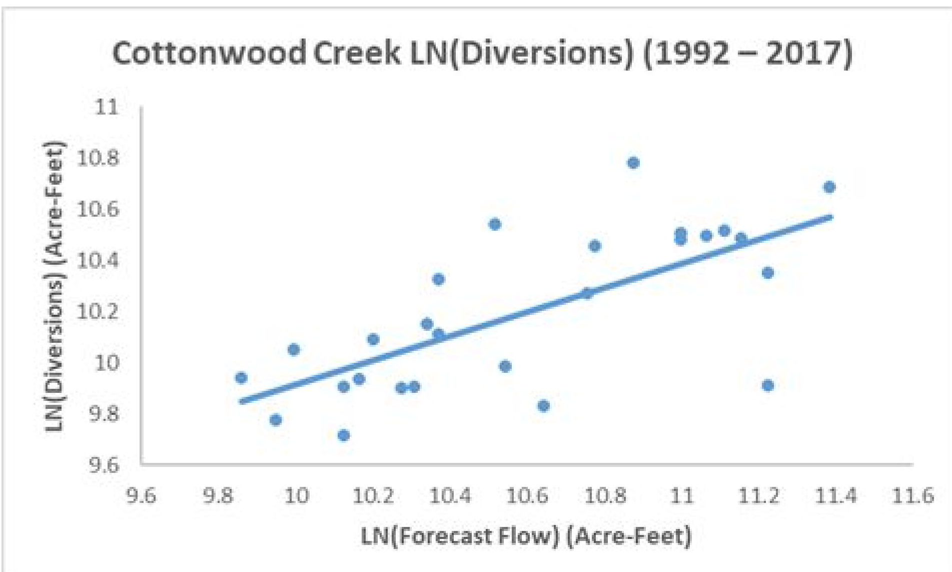
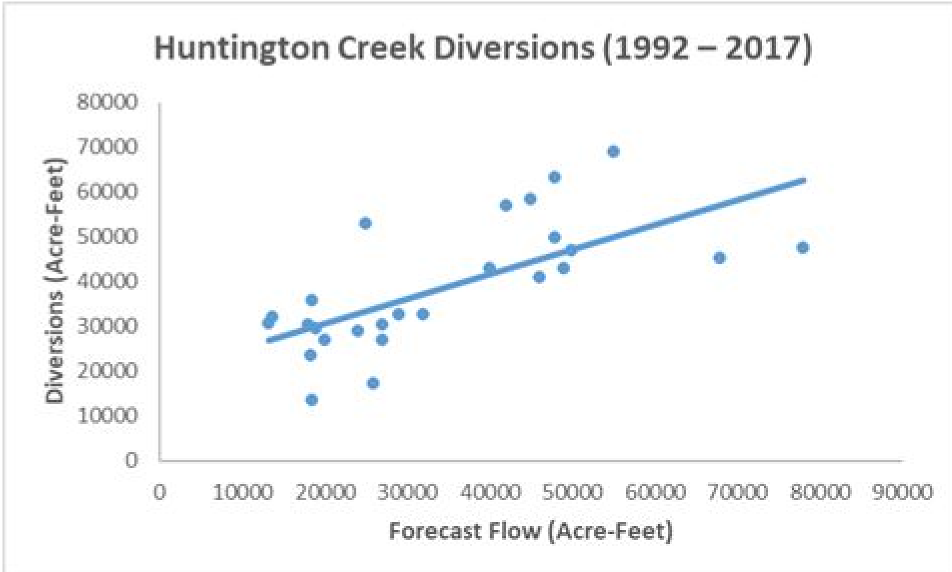


Figure 3. Cottonwood Creek Diversions as a Function of Forecast Flow



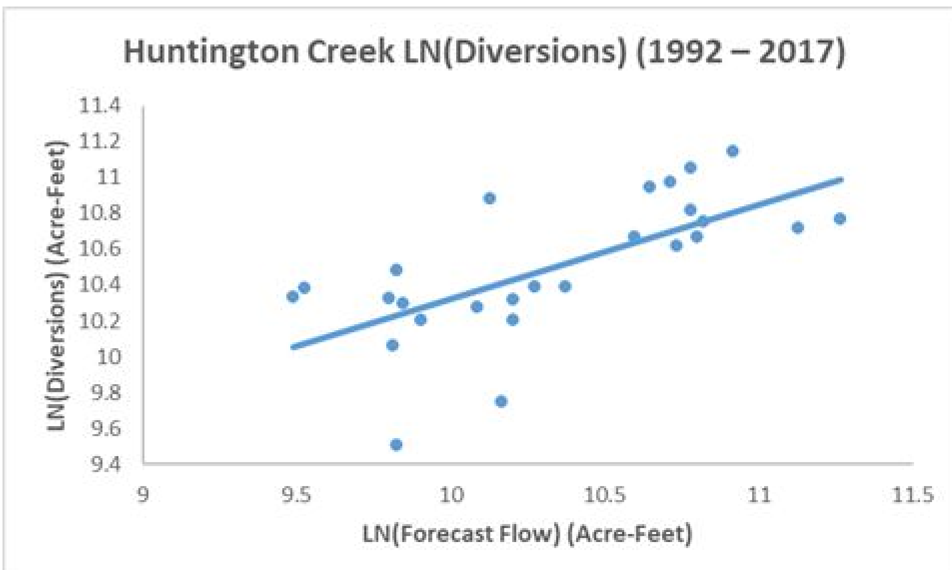


Figure 4. Huntington Creek Diversions as a Function of Forecast Flow

From 1992-2017, the average diversions for agriculture from Cottonwood and Huntington creeks exhibit a systematic downward trend. The regression analysis, after adjusting for annual variations in diversions as they relate to fluctuating stream flows, finds that there is an autonomous decrease in the diversion of about 1.5% per year from each of the two creeks. First, it should be noted that this decrease is only for primary shares and does not take into account the project water. Second, it should also be noted that project water or B shares constitute additional diversions of 14% of the primary water diversion for the Cottonwood system and 41% for the Huntington system. Since total diversions is the sum of A shares and B shares, the total reduction in diversions should account for project water. Thus, the 1.5% estimate thus needs to be adjusted downward by 14% for the Cottonwood system and 41% for the Huntington system. As a result, for the Cottonwood system, the adjusted diversion trend is 1.32 % less per year, and for the Huntington system, it is 1.11% less per year. These are adjustments based on averages for the analysis period of 1992-2017. Finally, it should be noted that at least part or all of this systematic downward trend in diversions may be attributable **to operational and informational** conveyance efficiency improvement measures including RWQP, as well as **structural measures** of installation of pressurized pipe system and any other off-farm efficiency measures.

Based on the assumptions made earlier, these reductions in diversions translate to 1.32% growth rate per year for the conveyance efficiency CE of the Cottonwood system, and 1.11% growth rate of conveyance efficiency CE for the Huntington system. Over the 26 year analysis period, this implies 34.3% increase in the Cottonwood system and 28.9% for the Huntington system. As an example, if the baseline conveyance efficiency CEs in 1991 for Cottonwood and Huntington systems are assumed to be 50%, the CE would have increased to 67% (1.343 times 50%) in 2017 for the Cottonwood system and 64% (1.289 times 50%) for the Huntington system.

A suggestion made by the District's manager was to analyze three ditches in the Cottonwood system. These three ditches have had only RTMCS without pressurized pipe system or sprinklers on-farm. This means the results in terms of CE, changes, if any, will capture the effect of only RTMCS on CE. The three ditches—Peacock, Johnson, and Swasey—are all part of the Cottonwood Creek basin (see Figure 5).

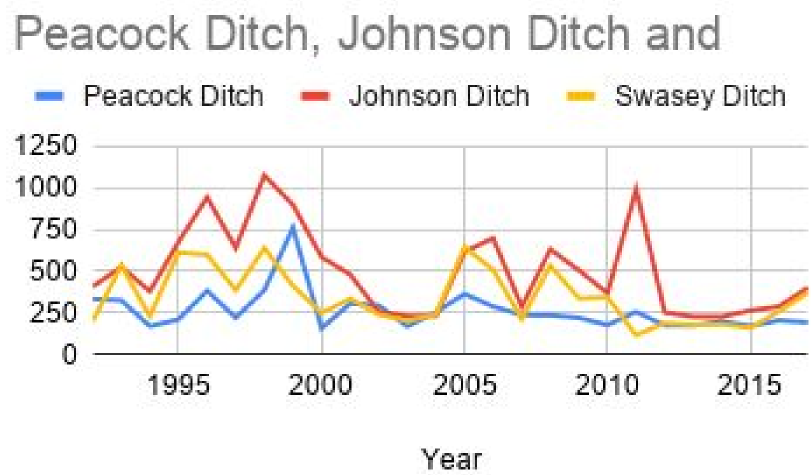


Figure 5. Annual AF diverted into 3 small Cottonwood canals

The same regression models were used for the analyses of the three ditches as for the Cottonwood Creek and Huntington Creek analyses above. Also, a regression analysis was done using the combined data for all three ditches. Results for the three ditches separately and the combined model results are shown below. Again, as before, the resulting estimates of the three parameters Ln (A), B, are all individually significant at the 5% level for each of the 4 models based on t-values, with the exception of one estimate (corresponding to the estimate of C for Peacock ditch). All three coefficients of each of the 4 models are significantly different from zero at the 5% level as indicated by the F statistic. The goodness of fit R^2 varies from .26 to .66, with Peacock ditch model having the lowest explanatory power.

The results are consistent with those a priori hypotheses that diversions are positively related to forecasted stream flows, and diversions increase with stream flows at decreasing rates since estimates of C are all between 0 and 1. Furthermore, the estimates of B, the rate of autonomous decrease in diversions per year, are all negative and vary between 1.97% for Peacock ditch to 2.49% for Johnson ditch. While these rates are higher than the 1.5% rate obtained for Cottonwood Creek and Huntington Creek systems, these higher rates are expected because of these small ditch systems having a low baseline conveyance efficiency. If the baseline CE is assumed to be 30% in 1991, a 2.49% annual rate of decline in diversion rate over a 26 year period would equate to a 65% increase in CE, which would indicate that CE will go from 30% to 50% in 2017.

Table 11. Regression results for non-pipeline distribution systems

	Ln(A)	**B**	**C**	**R Squared**	**F(2, 23) Value**
Peacock Ditch	5.072	-0.0197	0.191	0.26	3.95
t-Values	9.129	-2.325	1.329		
Johnson Ditch	3.753	-0.0249	0.7278	0.61	18.42
t-Values	6.663	-2.890	5.008		
Swasey Ditch	3.920	-0.0232	0.575	0.46	9.61
t-Values	6.051	-2.346	3.441		
All combined	5.088	-0.0226	0.5835	0.66	22.47
t-Values	12.000	-3.487	5.334		

The results of these smaller ditches not only provide a confirmation of the results for the larger systems of Cottonwood and Huntington creeks, but also give an indication of the effect of RTMCS alone on CE, separated from the effects of pressurized pipe systems.

Several alternative model specifications as well as several variants of the model presented here were tested. For example, linear models instead of logarithmic models were also specified and tested. Some linear models did have good statistical results, but the results were not subject to easy interpretation. Existence of time trends in the coefficient C were tested and rejected. Similarly, using dummy variable techniques, changes in diversion trends relative to the construction of pressurized pipe systems, were also tested for both creeks and rejected. The simple model chosen seems to provide the best statistical model with easily interpretable results. However, the model results should not be used in extrapolative results beyond the period of analysis.

In summary, from the extensive statistical analyses, it is clear that starting in 1992, there is a systematic (autonomous) decrease in water diversions for irrigation from the Cottonwood and Huntington systems. It will be presumed that such was the case for Ferron Creek, although diversion records were not available. The annual percentage reductions in diversions must have been offset by at least an equal percentage increases in conveyance efficiencies, since water deliveries seemed to have been met in accordance with the water allocations declared by the manager each of years from 1992-2017, based on NRCS streamflow forecasts. Also, it is possible to infer that these increases in CE must have been due to operational and informational measures including RTMCS. The actual increase in CE will depend on the baseline CE in 1991, and the changes in CE over time will be influenced by the structural measures implemented during the analysis period.

Estimating Conveyance Efficiencies

1. The estimated autonomous trend in water diversions provides an indirect or back door approach for benefit estimation, as explained below. Here is a summary of information that will be used in the proposed approach. Statistical results indicate around 1.32% decrease in irrigation diversions per year over the 26 year period of analysis from 1992-2017 for Cottonwood and Huntington Creek basins. This translates to 34% and 29% increase in conveyance efficiency percentage from the base level of CE in 1991 over 26 years. (Reduction in diversions is indicative of only one component of conveyance efficiency changes as explained below.)
2. CE estimate from previous studies indicate a range of 40% to 60%.
3. The manager estimates the conveyance efficiency of the irrigation systems recently after completion of pipe system installation is around 85%. This is partly because some segments of open channels still exist even though much of the Ferron, Cottonwood, and Huntington have closed pipe systems.
4. Anecdotal information from users indicates increased late season water deliveries. The manager indicates that during a low snowpack year, he is able to meet the full appropriated amounts.

If initial CE was 40% in 1991 and final CE was 85% in 2017, the percentage increase in CE would be 112.5%. Similarly, if the initial CE were 50% and 60%, respectively, and the final CE in 2017 was 85%, the corresponding percentage increases in CE would be 70% and 41.7%.

A 1.32% annual reduction in diversions for Cottonwood Creek over a 26-year period amounts to 34.3% based on adjusted reduction in diversions estimated by the regression models. Therefore, the water delivery increases corresponding to initial CE of 40%, 50%, and 60% can be estimated to be 78.2%, 35.7%, and 7.4%, respectively, over the 26-year period for the Cottonwood Creek system. Irrigation water delivery increases for the Huntington Creek system corresponding to baseline CE of 40%, 50%, and 60% will be 83.6%, 41.1%, and 12.8%, respectively, over the 26-year period.

Some additional assumptions were made to utilize the available data. These are explained below:

1. Diversion data for Ferron were estimated based on the average of the two available years of data for 2016 and 2017. Diversion, as a percent of the average of Ferron Creek USGS data, for those two years was calculated. The same percent was then applied to USGS gauging station annual data to construct the time-series from 1992-2017.
2. It is further assumed that the trend in CE is the same as that of Huntington Creek, since they have both RWQP and both canal systems have a pressurized pipe system. Differences in the installation period will be accounted for.
3. Muddy Creek will not be included since the RTMCS investments are relatively minor and there is no time-series data available.

For the purpose of this cost- benefit analysis, the initial CE in 1991 will be assumed to be 50%, the mid-point of the range 40%-60%. Water diversions are assumed to decrease 1.34% per year for the Cottonwood Creek system and 1.11% for the Huntington Creek system. For Ferron, the same percent decrease as Huntington Creek system of 1.11% will be used, since it will give the most conservative benefit estimate. Projected increase in water deliveries due to CE improvement for Cottonwood Creek system will be 35.7% and for the Huntington Creek and Ferron Creek systems, it will be 41.1%.

Chapter 4

Overview of Economic Benefits

This chapter presents numerical results of benefit-cost analysis of RTMCS. For the benefit part, the following three major quantifiable areas are identified:

1. Reduced agricultural diversions from streams imply smaller salt loading from surface leaching and deep percolation, thus reducing salinity damages to the lower Colorado Basin.
2. Increased conveyance efficiency (CE) means less conveyance losses which again leads to reduced salt loading.
3. Increased CE means a greater proportion of the diverted water can be delivered to the farm, thus, increasing the quantity of water supply, increasing the security of water supply (more often water deliveries closer to the appropriated amount), and improving the timing of water delivery for irrigation.

In addition, there are a number of benefits that are not quantified in this study. These include the following:

1. RTMCS reduces the administrative costs of sequencing water deliveries to meet demands both spatially and on timing, monitoring take-outs, billing issues, if any, as well as addressing customer complaints and requests. This is especially important as the customer base keeps increasing and farm sizes are shrinking.
2. When high flows occur, RTMCS is of value in dissipating flood waters, preventing open channel systems and other valuable diversion structures from being washed out, as well as protecting private properties.
3. Efficiency increases in both conveyance and on-farm systems could enhance or adversely affect the ecosystems depending on how water is managed.
4. The water manager's need to drive around to survey conditions on the systems they operate is reduced. They can now make gate and flow changes remotely.
5. According to the District manager, it reduces the need for herbicide applications on his major canal (CC-H). Historically, they have spent

between $20,000 and $40,000 on herbicides. If it turns out that this number is cut in half, it could be a significant benefit.

The CE improvements provide another important value. In extreme drought years, there is the option of diverting water that would have been otherwise left in the stream for the mitigation of salinity impacts during normal years. This is particularly true for counties that drain into the upper Colorado basin. The possibility of having the option for additional diversion during extreme drought and the resulting benefits are not captured by this analysis based on averages. A probabilistic model will be needed to calculate such benefits.

The importance of constructing a time-series for conveyance efficiency cannot be overemphasized in order to explore the benefits of RTMCS. However, as indicated earlier, separating out the effects of various CE-enhancing measures during the analysis period of 1992-2017 is extremely difficult and a challenging problem. Many factors contribute to the difficulties, including:

1. measures undertaken are overlapping between years
2. some measures have lagged effects, most notably RTMCS
3. routine operational measures undertaken by the irrigation management may have varied from year to year
4. data on dates of initiation of structural measures, completion of such measures, and the extent of annul completion are not readily available
5. expenditures allocable to the measures undertaken are also not individually trackable
6. various measures are often undertaken by different parties—District, canal companies, Reclamation, and NRCS.

However, once a reasonable method to estimate CE is identified, the time-series can be developed for each of the three agricultural basins—Ferron, Cottonwood and Huntington.

Constructing the Conveyance Efficiency Time-Series

If time-series data on water deliveries to farm take-outs or laterals were available along with canal diversion data, a time series for CE could have been developed. The process would be data intensive. There would always be measurement issues, but overall a better set of data could have been developed. The data on water deliveries were not available from the district data set. Even though the water orders by users were recorded, the manager said the order data is destroyed as soon as the orders are filled. Even though RTMCS generates flow data at different points in the canal system, records of these data were not kept and were not available.

In the absence of water delivery data, the following step-by-step process is adopted for this study. While the CE series were constructed based on reasonable assumptions using every available piece of data (some based on manager's statements and anecdotes), the conveyance efficiency figures estimated nevertheless provide a reasonable first approximation. The logic used in constructing these series helps establish upper and lower bounds for CE.

First, the diversion data series indicated a **systematic** downward trend. This systematic downward trend is assumed to be the result of RTMCS. There were no other major events to alter the conveyance efficiency during the period of analysis except for routine maintenance. Thus, the cumulative annual percent reduction (1.11%/yr for Huntington and Ferron and 1.32/yr for Cottonwood) in diversions can be assumed to be the **minimum** estimate of increase in CE due to RTMCS from 1992-2017 (Series A). Why is this so? Since CE= WD/QD, the total derivative of CE d(CE)= (1/QD)d(WD)-(WD/QD**2)d(QD). Dividing both sides by CE, we get d(CE)/CE = (d(WD)/WD)- (d(QD)/QD (since CE is WD/QD). This means percent change in CE equals percent change in water delivered minus percent change in water diverted. If the percent change in water delivered is greater than or equal to zero, it means the percent change in conveyance efficiency is greater than or equal to negative of percent change in water diverted. This implies, if the users were satisfied with the water deliveries during the period when there was a systematic downward trend in diversion took place, it means RTMCS helped offset the reduction in water diversion by CE increase. Again, CE increase is due to information technology rather than the traditional structural measures most engineers are used to in these discussions.Other factors such as routine measures undertaken by the management could have increased CE by more than this percent rate.

Second, it is assumed that the baseline CE in 1991 is assumed to be 50% (midpoint of the range 40% to 60% as suggested in previous Reclamation studies for all three creek systems. There was no other valid measured data that could be found to get a more accurate number. Since pressurized pipe systems have been mostly completed for all three systems, the current CE is around 85% based on information from the District manager. That is a 35% increase over 26 years or a uniform rate of 1.346% per year (Series B). This assumes that there are CE improving measures pursued systematically and uniformly every year prior to and during construction of various segments of the pressurized pipe system. While this may be an arbitrary assumption, in the absence of detailed information on construction schedules of various segments of the conveyance system and lacking water flow measurement data at various points in the canal system, there appears to be no better alternative to this assumption. Series A and Series B serve as the lower and upper bound numbers for the CE. It should be noted that, a priori, there is no reason to expect which of these two series will be the lower and upper bound. The CE values in the series depend on initial CE, final CE, and the rate of reduction estimated in annual diversions.

Series C is constructed using the larger number of series A and series B for every year. This is because anecdotal information by users suggests that with RTMCS, additional water was available even with the diversion reductions, implying higher CE values than Series A values (which only just offsets reduced diversions). Also, it was understood that construction of pressurized pipe system in all three basins proceeded in various segments thus partially increasing CE values by unknown amounts. While it is conceivable to use some weighted values of series, it was decided to use the larger of Series A and Series B to create Series C. In this way, the terminal values of CE will be consistent with the pressurized pipe system efficiencies suggested by the district manager. Thus, Series C is to be regarded as the preliminary estimate of CE. Two other series were constructed from Series C. Series C is modified by changing the value of individual CE values to 85% at the completion of the pipe system for each creek and for all subsequent years (in year 2002 for Ferron, in 2013 for Huntington and 2017 for the Cottonwood system). This is Series D, the final estimated CE values, for all years. To examine the effect of RTMCS only, another series is constructed by replacing all individual CE values by the CE value a year before the completion of the pipe system for all subsequent years up to 2017(Series E). Given the resources, and the time frame and size of this study, combined with absence of detailed water delivery data at the farm or take out points for laterals, lack of dates of construction schedules of pipelines, and annual changes in resulting CE values as a result for the three canal system, the assumptions made to arrive at Series D and E are reasonable enough to estimate benefits of RTMCS.

Time-series diversion data for each creek is multiplied by Series D to get estimated water deliveries with RTMCS and pipe system in place. If diversions are multiplied by Series E, estimated water deliveries by year can be obtained with only RTMCS. Water deliveries without any CE enhancing measures will be 50% of diversions. Thus, increases in water supply with both RTMCS and the pressurized pipe system, as well as with the RTMCS alone, can also be estimated for each creek system.

Based on additional water supply estimates with and without pipe system conveyance, estimates of the value of water can be derived. Census of Agriculture estimates a cash rent value of $33/acre in 2017. Lease contracts will have to be often agreed upon early in the season with considerable uncertainty in water
availability. If the full 4 AF/ac becomes available, which is seldom the case, the rent is $8.25/ AF. In the past, only a small percent of the time is full water available. There is also considerable variation in the quality of the ground leased. The cash rent has been up to $50 in some previous years, according to the census. The District manager found rentals ranging from $10 to $30/AF. The average productivity of water in Emery County, based on harvested irrigated cropland, is about $53 in 2017. Of course, the marginal value of water will be less. Based on all these data, it was decided that $16.50/acft may reflect a marginal value under current conditions.

Table 12: Average annual impacts of RTMCS and pressure pipe delivery system

	Additional Water Delivery		Salt Loading	
	Pipe System	Only RTMCS	Pipe System	Only RTMCS
Ferron (units)	5,029 AF	2,381 AF	9,180 tons	4,346 tons
Ferron ($ value)	$82,984	$39,294	$1,973,713	$934,587
Huntington	9937 AF	9273 AF	18,138 tons	16,926 tons
Huntington	$294,675	$163,959	$3,899,644	$3,639,091
Cottonwood	5504 AF	5504 AF	10,046 tons	10,046 tons
Cottonwood	$90,813	$90,813	$2,159,905	$2,159,905

Ferron water supply increased by 5,029 AF/yr on average with both RTMCS and pressure pipe system from 1992- 2017. The average estimated benefit is

$82,984/yr for the 26 year period. If there were no pressure pipe system, the economic benefit from RTMCS alone would have been $39/yr on average corresponding to 2,381 AF of increased water supply. The same interpretations follow for Huntington and Cottonwood systems. Since Cottonwood pipe system construction is not fully complete, the full impact of the pressure pipe system will begin only after 2017. This is why the impact numbers are the same as that of "only RTMCS."

Because of the increase in conveyance efficiency, water that would have been lost in the conveyance system is now available for increased delivery at the farm. If the on-farm efficiency is assumed to be 50%, the other 50% of delivered water however would be lost as surface run-off or deep percolation and increase salinity loading. In other words, only 50 % of the additional water delivered confers salinity benefits. The estimate Reclamation uses for salt loading is 3.6506 tons/AF and the marginal downstream (Lower Basin) benefits, again using Reclamation estimate of $215/ton, the salinity damage costs averted are calculated. From the table above, Ferron reduces salt loading by 9180 tons/yr on average averting downstream cost of $1.97 million/yr with a pipe system operated with RTMCS. If there were no pressure pipe system, RTMCS alone would have reduced salt loading by 4,346 tons/yr, averting downstream damage of $0.93 million per year. Similar interpretation applies for Huntington and Cottonwood systems.
For the three systems combined, which captures Emery County as a whole, the water supply increases by 20,470 AF with the pipe system operated with RWQP conferring $468,472/yr of agricultural benefits. With only RWQP without the pipe system, water supply increases by 17,158 AF showing agricultural benefits of $294,066/yr.

As for salinity benefits from efficiency improvement, with pipe system operated by RTMCS, 37,364 tons of salt loading will be reduced for all 3 creek system resulting in $8 million in avoided damage costs, but expected to increase for the next few years. With only RTMCS, the salinity reduction will be 31,318 tons yielding a corresponding benefit of $6.73 million annually. These are average annual figures over the 26 years from 1992-2017.

There are a few points worth noting. First, benefits from pressurized pipe system will likely grow for some time since Huntington was only recently completed and the full effect on the Cottonwood system from pressurized pipe has not taken place. The second point is RTMCS is complementary to the operation of a pressure pipe system and they are not competitive. The third point is that the additional delivery of water from increases in CE will vary from year to year depending on stream water availability and hence the agricultural benefits and the salinity benefits. The full year-to-year agricultural benefits and salinity benefits are in the appendix. Finally, it is important to note that the study has only evaluated ***ex post*** benefits. There will be a steam of continuing future benefits that are not captured by this study.

Salinity Benefits from Reduced Agricultural Diversions

As discussed earlier, diversions for irrigation decreased by 1.32% per year from Cottonwood Creek and 1.11% per year from Huntington Creek. The Huntington figure was used for Ferron Creek since time-series data on diversion was not readily available. Over the 26 year period of analysis, these reductions amount to 34% and 29% respectively. Reduction in agricultural diversion means less salt loading from surface leaching and deep percolation. Reduced salt loading is estimated using 3.6506 tons/AF decrease in diversions, a figure used by Reclamation. At $215/ ton estimate of downstream damage averted, the economic impacts run into several million dollars. The table below shows the salt loading reductions and the consequent monetary benefits for each of the three agricultural basins.

Table 13: Decreased salt loading and damage costs averted from reduced diversions

	Average Tons/Year In Million	**Average $/Year In Million**		**Total Tons 1992-2017 In Million**	**Total $ 1992 - 2017 In Million**
Ferron	14.1	$3.03		365.8	$78.68
Huntington	25.7	$5.52		667.2	$143.39
Cottonwood	36.5	$7.86		950.0	$204.26
Total	**76.3**	**$16.40**		**1983.0**	**$426.32**

The average annual diversions from all three creeks—Ferron, Huntington and Cottonwood—is about 108,000 AF over the period 1992-2017. The diversion would have been 20% more, had it not been for the conveyance efficiency enhancement measures of RTMCS, installation of pressurized pipe system, and other routine management efforts.

The table above shows the reduced salt loading effects from each individual creek and the corresponding economic value generated. Downstream benefits to the Lower Colorado River Basin from reduced salt loading of 1983 tons amounts to $426 million over the 26-year period.

While it is difficult to separate the effect of RTMCS statistically, an indirect approach would be to calculate the number of years each creek system had only RTMCS without the benefit of the pipe system and weight these years by the quantity of water diversions. Ferron had 5 years (1992-1997), Huntington had 16 years (1992-2008), and Cottonwood had 20 years (1992-2012). The years correspond to the midpoint of the pipe system construction period. If these are weighted by diversions the weights are 0.2, 0.3 and 0.5 respectively. Thus, about 15.75 years out of 26 years of the analysis period, the conveyance efficiency increases are attributable to RTMCS and other routine measures. Thus, a reasonable rationale is to attribute a minimum of 60% of salinity benefits to RTMCS and 40% to the structural measures. If on-farm efficiency measures are included, the proportion may tilt more heavily towards structural measures and less towards RTMCS. In the most conservative case, it is still reasonable to attribute a minimum of 50% of benefits to RTMCS.

In summary, three aspects of economic benefits of RTMCS are quantified. These include:

1. Increased delivery of water to farms and the average economic value.
2. Reduction in conveyance losses due to efficiency increase and the resultant impact on salt loading and the downstream benefits.
3. Reduction in agricultural diversions from the streams and the salinity impacts and corresponding benefits.

Chapter 5

Economic Costs of Real-Time Monitoring and Control System (RTMCS)

The cost components were divided into three categories: equipment, labor, and chemical.

Equipment costs and quality have undergone substantial changes since the inception of RTMCS in Emery County. Cost of equipment has gone down almost 50%, while the quality of components has improved. Also, since Emery and Sevier started this pioneering effort in Utah, extensive amounts of time and labor were involved in designing, installing, and using this technology. The fact that technology was rapidly changing made this effort difficult and hence more costly than in present conditions.

Data on equipment costs were obtained from the ECWD annual budgets. These data were in current budget year dollars, which need adjustment (based on consumer price index CPI and electronic equipment cost index), as will be explained later for the benefit-cost analysis. All newly purchased equipment, cost of any replacement equipment and all electrical components for automated gate operations, and other controls were included. An important issue is that some of the increase in equipment cost was due to the conversion of the conveyance system from an open channel to a closed pipe system. This was an additional cost incurred for RTMCS.

Labor cost involved a half-time IT technician and about 10% of the manager's time. Labor costs also include field personnel. However as RTMCS expanded, it is assumed that the field personnel time allocation to physically attend to the conveyance system needs were reduced and instead used in attending to needs of maintaining RTMCS components and parts. Labor cost in current dollars is assumed to have been $40,000 in 1992, and increased over time at 2.25% per year
to $60,000 in 2017. This is the best estimate based on discussions with the manager.

Chemical costs were compiled from the budget to treat moss/algae to improve flow of water in the open channel system. There was a possibility that the costs may have changed over time as a result of conveyance efficiency improvement efforts including the conversion to a closed pipe system. No discernable statistical trend was noticed upon cursory statistical analysis. Therefore, this component was not included in the analysis. It is the manager's view that expenses on chemicals have been trending lower recently and may show up as statistically significant savings in a few years.

Benefit- Cost Analysis (BCA)

Most of the time BCA is undertaken for evaluating the economics of a proposed project. The goal of BCA is to select the best alternative from an economic efficiency point of view from among several competing project alternatives. In other words, BCA is often undertaken in an attempt to achieve the best possible resource allocation given various constraints. This type of an approach, to project evaluation, is called ex ante BCA. The BCA is done prior to undertaking a project.

Less often, but in special circumstances such as in the case of Emery County's analysis of RTMCS, BCA is undertaken ex post or after the project to learn lessons so that such a project approach may be applied to other counties and to get better
results. Because of the pioneering efforts of the project with no planning for resource allocation and without the explicit goal of economic efficiency, ex post BCAs tend to show how future projects of the same type can be made more efficient by improving the project economics.

The most important point to understand with respect to the ex post BCA is that it is based on one (and only one) actual realization of the random processes associated with snow packs and the resultant stream flows. If this study were to be repeated for a different 26 year realization of stream flows, the results would have been different. A more detailed simulation approach will be required to study possible realizations of the random stream flows and evaluate benefits and costs using a probabilistic approach. Given that there is one observable realization of stream flows and diversions and water delivery demands, the BCA is applied to this data set and conclusions are drawn for guidance purposes.

Discussion of Benefit-Cost Measures Used in the Ex Post BCA

As explained earlier, in this study, only three types of benefits are estimated and quantified pertaining to RTMCS, while several other benefits are mentioned descriptively. The three quantifiable benefits are 1) additional water delivered to take-outs at the farm level or laterals or made available in closed pipes; 2) reduced
conveyance efficiency losses and benefits of reduced salt loading attributable to RTMCS—to the extent the analysis could separate RTMCS from pipe system conveyance; and 3) reduced (autonomous) annual irrigation diversions from creeks to the canal systems during the analysis period.

The first benefit relating to the additional water delivery attributable to RTMCS is the only component that will be used for the BCA. There are two reasons for considering only this component. First, the second and third components of benefits are partly due to Reclamation and NRCS project efforts, even though some of the benefits may be separately attributable to RTMCS and quantified earlier. The second reason is that the salinity benefits may not be relevant or not as important for many Utah counties as it is for Emery County and a few others.

The cost components have been already discussed and a time series has been constructed just like the benefit measure from 1992 to 2017. Three separate benefit-cost measures are developed.

First is the NPV measure. Since benefits and costs are estimated at different points in time, net benefits are calculated for each year by subtracting estimated benefits from costs for each year. A discount rate of 2.75% (based on Federal Register guidelines applicable for water resource projects issued in 2016) is used to compute the NPV. Since this is an ex post evaluation, instead of discounting future values, future value of net benefit figures are calculated to the present (2016-2018 base level). Obviously, if the NPV is positive, the project provides positive benefits and the larger the NPV, the higher the economic gains from the project.

The second measure is the IRR which seeks the particular rate of return that makes the discounted net benefit stream equal to zero. It can be thought of as similar to a rate of return for any investment that identifies a break-even point. Project alternatives are selected based on the ranking of IRR.

Finally, the third measure developed for this study involves the ratio of the present value of benefits to the present value of costs called benefit-cost ratio or B-C ratio. The larger the value B-C, the greater its desirability over other alternatives. The value of B-C greater than 1 indicates economic gains from undertaking the project. The larger the B-C ratio, the greater the economic gains.

These three measures were computed for two scenarios. The first scenario is the ex post BCA. It is ex post in the sense, the equipment costs are actual dollars spent in specified years from the annual budget of the District. For example, the value of $100 spent on equipment in 1993 dollars is worth $170 in today's dollars. The fact that the real price of equipment has declined by 50% does not have any relevance to the way the costs are evaluated. However, in the second scenario, one could assume that the same specific benefit data series represents a future set of realization and the future costs of equipment is declining from 100% from the beginning year to 50% in the ending year. Thus using the cost data adjusted by Electronic Equipment Price Index instead of the Consumer Price Index CPI can be regarded in some sense as an ex ante BCA results. The comparison of BCA analyses using the two scenarios are instructive as demonstrated below:

- Scenario 1A: ex post BCA, using CPI for cost adjustments.
  NPV (2017) $1,474,83; IRR 6.13%; B-C ratio 1.18
  Scenario 1B: ex post BCA, using CPI for cost adjustments without diversion reduction for reducing salinity impacts.
  NPV(2017) $2,875,614; IRR 8.77%; B-C ratio 1.34
- Scenario 2: ex ante CBA, using electrical index for costs adjustments.
  NPV(2017) $4,746,255; IRR 32.38%; B-C ratio 1.93

Under scenario 1, there were two ex post analyses undertaken. In the first one, labeled as Scenario 1A, the ex post indicates that the NPV is $1.47 million. The internal rate of return is 6.13% and the B-C ratio is 1.18. Even under the most conservative assumptions, the agricultural benefits of RTMCS is overall positive by all three measures. The salinity benefits of $6.3 million attributable to RTMCS is not included in BCA as explained earlier. Since the salinity benefits were not included, it will be interesting to do a BCA by hypothetically increasing the diversions for agriculture by the amount of water that was left in the stream for downstream salinity benefits. Such analysis will provide a better BCA for Utah counties that are not part of the Colorado River drainage system. This analysis is labeled as Scenario 1B. Under this scenario, the net present value almost doubled. The internal rate of return increased by more than 2.5% and the benefit-cost ratio went up to 1.34. This is a better measure to use as ex post analysis data for a county similar to Emery, but not part of the Upper Colorado River drainage area.

Under scenario 2, the ex ante BCA based on declining equipment cost, the NPV is $4.75 million with a 32. 38% internal rate of return. The B-C ratio measure went up to 1.93. This is clearly an improvement in all three BCA measures indicating what one could expect if RTMCS is instituted in other Utah counties in a more realistic ex ante cost situation.

In summary, RTMCS is an investment in improving conveyance efficiency (CE) in an irrigation system through information technology. It differs from other forms of CE enhancing measures such as structural or operational means. RTCMS requires human decision-making skills to effectively improve CE as opposed to other measures. RTCMS can increase CE from about 20 % to 50% depending on the initial CE. If the initial CE is 40%, a 30% increase means the CE will increase to 52%. The limited empirical evidence suggests that systems with lower initial CE appear to have greater potential to improve CE than those with high initial CE.

RTCMS is a low cost means of increasing CE relative to structural alternatives. It is particularly beneficial for irrigation systems with 1) a large customer base where the farm size is decreasing; 2) a large number of diversion points; 3) a great distance between diversion points; 4) open earthen canal systems; and 5) a highly variable water supply from streams. Increase in CE not only increases water deliveries in an average year, but also helps increase water deliveries during dry years, creating a more reliable irrigation water. Depending on the irrigation system, late season water deliveries can also be increased.

The BCA indicates positive economic gains from all three measures. The ex ante BCA measures are considerably more impressive than the ex post BCA measures suggesting great potential for RTMCS in other Utah counties. Careful selection and prioritization through BCA will be key to identifying potential counties for investments in RTMCS.

Environmental and Ecosystem Issues

For those counties where salt loading is a concern, increases in CE through RTMCS reduce losses of diverted water, and reduce diversion from the stream thus minimizing salt loading creating substantially larger secondary benefits. Ecosystems impacts resulting from RTMCS depend on how the additional, more secure water deliveries are distributed between farm irrigation or enhancing ecosystem services. It is more of a distribution and management issue.

Chapter 6

Qualitative Methods

There are two primary purposes of the qualitative portion of the study. The first was to obtain a historical narrative about the circumstances leading to the development of the real-time quantification system in Emery County. The second was to understand the range of impacts of the real-time water quantification system, as perceived by District's stakeholders.

Stakeholder Framework

We use the Freeman, Harrison & Wicks (2007)[1] framework to identify the population of relevant stakeholders for this case analysis. Stakeholders are "the groups that can affect or be affected by the achievement of a business's core purpose" (p.68). Freeman, et al. (2007) categorize stakeholders into two groups: primary stakeholders and secondary stakeholders. Primary stakeholders have a direct interest in the focal organization, while secondary stakeholders have an indirect interest in the focal organization. In general, primary stakeholders include financiers, suppliers, employees, customers, and communities. Secondary stakeholders may include the media, special interest groups, consumer advocate groups, competitors, and government.

Context

The District, like other water conservancy districts in the state, is a political subdivision of the State of Utah and operates as a water wholesale business in a designated geographic area. The purpose of all water conservancy districts is described in Utah Code 17B-2a-1002.

In order to develop a set of relevant stakeholders to interview, we identified all primary stakeholders. First, we enumerated the set of stakeholder groups identified by Freeman, et al. (2007). We then evaluated this list for idiosyncrasies related to our context and determined that, because of the unique role of the District as a political subdivision central to agriculture, two additional stakeholder groups merited consideration as primary stakeholders: the Utah state government and the Utah State University Extension, representing the state's Land Grant University. Where necessary, we then identified the specific

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[1] Freeman, R. E., Harrison, J. S., & Wicks, A. C. (2007). *Managing for Stakeholders: Survival, Reputation, and Success*. New Haven: Yale University Press.

corresponding organizations within each stakeholder group in this context. Our rationale for selecting each organization is included in the table below, labeled "District Stakeholders."

Interviews

The interview process began with the development of a semi-structured, open-ended interview guide, which is included as Appendix D. We used theoretical sampling based on the stakeholder analysis above to identify the population of relevant stakeholders targeted for an interview. We identified at least one, and up to four, informants from each organization identified and conducted interviews with each of these individuals. Overall, in addition to multiple interviews conducted with Jay Humphrey, the District manager, we interviewed sixteen informants representing all six of the primary stakeholder groups.

Table 14. District stakeholders

Stakeholder Group	Corresponding Organization(s)	Informants	Rationale
Focal Organization	Emery Water Conservancy District	Jay Humphrey	Identified as the case study subject.
Financiers	EWCD Board	Lee McElpring Roger Barton	EWCD is funded (other than water sales) through ad valorem tax revenue and through federal grants. The EWCD Board represents these varied interests.
Suppliers	(1) Rural Water Technology Alliance (2) Bureau of Reclamation, Provo Area	(1) Sydne Jacques (2) Arlen Hilton	The primary input is water, which is obtained naturally and by the State's authority. Inputs in the real time monitoring system are RWTA and the U.S. Bureau of Reclamation, which co-developed the software system.
Employees	[Individuals]	Diane Bott	EWCD has a small number of current and former employees. Jay Humphrey is the EWCD Manager.
Customers	(1) Cottonwood Creek Consolidated (2) PacifiCorp Power Co. (3) Ferron Canal Co. (4) Muddy Creek Irrigation Co. (5) Huntington/Cleveland Irrigation (6) General water users (farmers)	(1) Craig Johansen (2) Cody Allred (3) Gordon Bennett (4) Morris Sorenson (5) Allen Staker (6) Rod Magnuson	Cottonwood Creek is the primary water retailer in Emery County. Pacificorp is also a large water consumer.

Government	DNR Division of Water Rights	Brett Leamaster Marc Stilson Jared Manning Susan Odekirk	The Division of Water Rights is the state agency tasked with overseeing water resources.
Special Interest Groups	USU Emery Extension	Dennis Worwood	As the local office of the state's Land Grant Institution, USU Emery Extension provided valuable training support for EWCD.

Analysis

We use the grounded theory development[2] approach to analyzing interview data. This analysis approach proceeds in stages. In the first stage, an initial interview guide is developed and implemented with a single informant (in this case, the District manager). The guide is improved and then used in an open-ended way to seek information about the topics of interest. Over time, the interviewer asks increasingly detailed questions, as more information comes to light. After interviews are completed, they are transcribed. Within each transcription, researchers coded the text, searching for responses (specific portions of text) relevant to the different buckets of information sought. For this portion of the analysis, we identified two main buckets: 1) benefits and 2) costs of the system, as perceived by stakeholders.

After this initial coding is completed, each bucket of responses is examined for similarities with other responses, and then aggregated by similarity into first-order categories. These categories are then aggregated into second-order themes. This categorization and aggregation analysis is presented in the tables below. The second-order themes that result from this analysis constitute the findings of the qualitative data analysis.

[2] Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory*. Chicago: Aidine.

Table 15. Perceived Benefits of the RTMCS

<u>Informant Responses</u> [Anonymous Source ID]	**<u>First Order Categories</u>**	**<u>Second Order Themes</u>**
"Now, it's an open book, and everybody knows where the water's going and how much water everybody's getting."[15] "And this has given us the tools to really know how much we can use, how much we have used, which we're entitled to use, whatever the downside, how much we're not entitled to use…"[28b] "It's transparent, it lets people know what's going on."[33] "I think transparency is a big one. They've got natural flow rights and they've got source water and they want to know when they're using what and how that's being calculated."[33] "So after a while, none of them worried about us displaying their data. Because they got to see what everyone else was doing."[35] "And it was a very positive effect on all the water users, whether it was federal government or a lowly little farmer that only had 15 acre-feet of water, but he could show that he had not used all his water. Or if they said, "Your water's gone," then he could look at the records and say, "Yeah, you're right.""[36] "...because they have the water that can be transferred from here to there to everywhere, and they know how much and when because of the telemetry system. I think the county benefits along that same line, because they know where their water..."[36] "Yes, and it gives you a visual on the different water-right holders and it lets you know if you're treating them fair or whatever."[39] "It gives you a better outlook on it, or a better visual. I don't know what the right word is. Observation. It's like, you observe it a lot more effective."[39]	Information availability	Transparency

“I think, it's made it be more honest, if you know what I mean, because they know if they can see it somebody else can see it, and they don't want to be called dishonest but if somebody see it then it's not as easy for it to be honest.”[39] “Most people feel like there may be secrets being held and so forth. They can look on the website, it's no lies there. We're all on the same boat, we're all doing the same thing, and everything is great. Not a lot of people use it, but those who do can already see a benefit.”[39c] “that brought the trust back to the people. It takes out the human error and a machine doesn't lie.”[31] “...they liked the transparency. In fact, when there is a problem, they usually call us before we find it. So Otherwise we have is there two or three people out looking for problems? We have a whole Valley and when there's a problem we get a call.”[31] “We have add every month and see what the individuals using and correlate with them. Some of them have their own graph on their own computers where they know exactly when they turn it on and off.”[29] “I think they also have better information available to them for planning and for managing their own operations, knowing how much water they require, how much water they use for a certain yield. “[34] “It optimizes the ability to manage your water effectively, efficiently. You can see a problem. Now, obviously we don't stay glued to the website, but we check it periodically during the day, and you can see a problem pretty darn quick compared to what we used to have.”[39]		
“Record keeping.”[28a] “...to be able to demonstrate that it was fairly distributed and distributed in accordance with their shares on the water rights.”[34] “...any opportunity for economic development. Most of those opportunities are ... many of those opportunities will need water. And so a county would have to be able to accurately say what water is available, when it's available,	Record availability	Transparency

how much does it cost, what are the avenues for you to acquire water? And I think that Emery County has all of that information readily available.” [34] “Well I think its a lot more precise. I think it's a lot more efficient, a lot more transparent. I think it is... The more accurately accounted for ... It's accounted for in a lot more detail. “[34] “So, obviously, having good measurements and accurate measurements, and as real time as you can measurements, is great. It just helps us in our regulatory ability to maintain a system of order and priority in the distribution of water.”[32] “...how to deliver the water more efficient and keep track of the water that was delivered and make sure every shareholder got their share and to have a record of it.”[38] “I know in the last 10 years as the state has set about trying to work on their conservation program [inaudible 00:10:30] and that sort of thing, having some base data for how much water has been used,”[34]		
“I think we've come a long ways in the battles. It's quieted down overall so.”[28a] “...by getting everything out there transparent, it cut down on a lot of fighting because people could see exactly what was going on. And where they might have assumed something was improper going on, now they could see exactly what was going on.”[32] “When we started moving it to the canal and monitoring that, it saved so much fighting, and so much water. We knew where it was coming from, where it was going and who had it. And anybody that was on the system could get online and see where the water was and who had it, and it saved a lot of fights, a lot of contention.”[36] “Get this information out to our end users. That was a big deal and transparency. So saved a lot of problems. Stop the fighting among the water users, because you had records to prove this is what you got.”[31]	Conflict Resolution	Transparency

"...ditch riders who used to spend literally hours to drive to the gate to change the gate... when we got to the point where they could remotely control the gate from wherever they were at, I remember when that happened, and that, again, that was just life changing to them." [15] "If this wasn't here, I'd spend six, seven hours just trying to get to every turnout or diversion to see what's going on. I can get up in the morning, flip the computer on and I can figure out if I can have another cup of coffee or two, or if I've got to panic."[28a] "And then we've got the ability now he can adjust two of my reservoirs on top of the mountain. If I don't have enough water, it's gonna take me two hours to get up there and turn out so we can turn me down or up. It saves water. It's more efficient. A thousand times over than the old."[28a] "So the efficiency for me not to have to run up there every couple hours, I can pull it up on my phone and look at to see the water going, and if the ponds are running over and how to cut it back."[29] "It saves time and travel costs. And decisions are able to be made much more quickly. Rather than maybe on a weekly basis, it could be done on more of a daily basis."[33] "those who manage the reservoir. I talked about that, how it makes the accounting on that a lot easier as well. And it lessens the time that it takes to do it."[33] "we used to have a River Commissioner and a deputy that manually went around and read plumbs and other measurement devices, recorded how much water was being diverted and then took orders from people or how much water they would like and then, in many cases, operated the gates to distribute them that water. And now we don't have a system on Cottonwood Creek anymore. That's by and large done automatically now"[34] "the users don't have to go out to the site to change it. So it saves them time. When they do change it, it changes when they ask for the change. So it uses water better. But it also will control, keep the amount of water they want there as the river level changes. "[35]	Time Savings	Efficiency

“But probably the biggest change was just the amount of time it requires personnel, water managers and water people to be in the field or traveling many miles to various sites to observe flows and such things.”[37] “They used to take me six hours a day to read just the federal canal diversion before the project order to us six hours a day. Now I can do it six times and Hey, we're going to read them any time I want, but this is my daily routine. “[31]		
“We've got people who haven't got a lot of shares, they've gone out and rented them, found a... increased their ability to water. “[26] “Well, the season's the same, but we got water for longer time...We got guys... [redacted] got four crops this year.”[26] “So I think that was the biggest thing is in making water last all summer instead of just until August 15th. But it used to be, now we're watering clear until the first of November.”[29] “I don't think people realized that it would help their farms produce more. I don't think they really realize that.”[29] “So he's increased in two areas, so he's making more money.”[29] “...the other thing that happened was the water didn't get wasted either on the farm or in the delivery system. And so they had water into the fall where they might have run out of water at the end of July, now they had water until mid, late September, which meant now I can plant fall grain if I want.”[30] “The other thing it did was it brought in some other crop options. The furrow systems really aren't set up very well to water pasture because again, you're wasting so much water. You're putting so much water below the roots.”[30] “have been able to use the water more efficiently, meaning each individual has had more water available to them than they would have otherwise had with the less efficient management and distribution.”[34]	Production	Efficiency

“Yeah. From what I've heard it's, there are savings of maybe up to 25 percent.’[35] “I think all the water owners have been affected in a good way because they can use their water more efficiently.”[38] “Yes, it's helped to conserve a lot of water, yes.”[38] “I think that landowners are producing more per acre than they thought they was getting.”[38] “Well, there's an increased crop growth, of course, which is good.”[39b] “Yeah, we've been able to do that. We were usually out of water in the --. In fact, well, all these communities kind of still wanting to go hunting Cleveland to --. They were all out of water basically in September, and now we're going into the end of November, end of October. Our irrigation water-right goes from April 1st to November 1st, so we've been able to stretch that water through the full season.”[39c] “They're the last ones to get into this Salinity Program. As people see it, to them it's an efficiency, it's a water savings benefit. It's not so much labor-savings unless you have a pivot, but it's, they can see that the crops grow better, you get more yield per acre, and the federal government that participates, they see it as reducing the assaults that tow down the Colorado River to our water users downstream, and so on”[39c] “...the main goal is water conservation, trying to stretch our water supply further instead of being out of water in August and September, but try to go a little longer. That, as far as locally, that's the benefit and that has been accomplished.”[39c] “...automated the canal system to where we'd say they tell the canal that wanted to serve a flow and it would make automatically keep that flow in the canal. That was a big deal. Has saved a lot of water.”[31]		

"That's where today all this information you can get so that people can learn their water rights, learn to take care of the water."[28b] "Just how efficient it is. It's too good to be true for me."[28a] "[The farmers get] what they're entitled to."[28a] "For instance, the total budget in 2012 was $30,000, and that cost was borne by the water users for a river commissioner, a full time river commissioner. So that would be a cost that they've been able to eliminate, because now instead of having a full time river commissioner, they've got enough automation that we can see it in real time and produce a report."[32] "So, yeah, having that kind of real time automation definitely can help mitigate flood events."[32] "being able to distribute the water more exactly, more precisely,"[34] "But it does help with flood control, so maybe that."[35] "I'd say everybody from the top manager down to the end user has benefited from it. Because that's the manager's job, to get them the water they want when they need it, and know where it's at."[35] "The biggest benefit is water savings efficiency, I guess."[35] "being able to make decisions and manage our water supplies remotely on a real time basis."[37] "That has been accomplished, and as far as the government's side, they're seeing a reduction in the salinity."[39c] "The other thing about this system is non-accountable water is very low. All the water is accounted for, and before it was being derived about 25% it was being lost."[31] "I think this is ready to go to the next generation."[28a]	Management	Efficiency

"Which normally means that it's going well, because I tend to get pulled into systems because I'm in charge of the whole state. And I've got three distribution engineers underneath me who manage the different systems, and commissioners throughout the state. And they work and do that pretty independently. But as there are problems and things like that, that's where I tend to get pulled in. And so, I have not been pulled in on Emery County stuff. So that, like I said, is usually a good sign."[33] "Selling the idea to the board and the county was a whole 'nother story in itself. But I think that because of the background work that Jay did... All of the board and most of the county commissioners were involved with farming, they knew we had to protect our rights."[36] "The one good thing with it all is that we didn't have to deal with government regulations as much as we had, and that's kind of hard to explain as far as the requirements of the Bureau of Reclamation. That helped us a lot in dealing with the regulations that we had to do."[36]	Independence	Externalities
"...the beauty that our communities look so much prettier now as, where they're so much greener. To benefit everybody, just as they drive through their communities look beautiful, "[39c] "In Ferron, we've tied into the city's secondary system to give them a more stable source of water,"[39c] "98% of the people really enjoyed it and it wasn't just the AG Users. There was the County governments and the state governments. They could look at different sites and see how the weather was or what the rainfall was and some the recreation has like to know if there was opportunities to kayak the stream or to go fishing or, even just what the temperature was around her as before."[31]	Externalities	Externalities

Table 16. Perceived Costs of the Real-time Quantification System

Informant Responses [Anonymous Source ID]	**First Order Categories**	**Second Order Themes**
"And we're willing to accept that tax so that they could have the benefits." [15]	Tradeoff Acceptance	Acceptance

“It’s a benefit, but if you're making that much more hay and can increase your herd, you're paying for it and then you're going to make, it's going to take still a long time.’[29] “But even with those costs, it's been a huge benefit to them.”[30]		
“We haven't had any major complaints about metering our water.” [26] “We presented this whole concept right up front, back in... I don't know when it was.. ‘9 or ‘10. And we had a stockholder vote, and there were I think three stockholders out of the 400 and some odd, that voted no.”[26] “I don't think we had anybody that was too uptight about [doubling their cost]...I don't know how happy they were. They were willing.” [26]	Minimal opposition	Acceptance
“There was still matching that had to be done there, and then of course there's been the maintenance since.”[30] “There's been some cost you have, but there's always -- that the credit can break for. They also need to be repaired.”[39c]	Maintenance	Financial burden
“Yeah. You need to put out the expenses first, before you receive the benefits. I think that's a bit of a challenge.”[35] “Well, they end up with at least 25% of the total cost.”[39c]	Upfront	Financial burden
“...is other people feel like they're now not getting their fair share. I think what was happening was they were toward the end of the canal and they were actually picking up waste water before.”[30] “Unless, they want to steal something else. Most of them are grateful that they can see what they're getting and they plan their weekly activity or whatever.”[31]	Precision	Precision

Findings

<u>Benefits.</u> It is striking to note the significant difference in volume of benefit-related responses relative to cost-related responses. Despite our efforts to seek feedback on both benefits and costs, stakeholders overwhelmingly articulated benefits, rather than costs, of the system. In terms of frequency of comments, benefits-related comments outnumbered cost-related comments by a six to one margin. This simple observation is representative of the patterns we observe in the responses; generally speaking, stakeholders view the system as very beneficial and have difficulty articulating significant costs of the system.

Stakeholders perceive three different sets of benefits from the real-time system: efficiency, transparency, and externalities. The first, which we label efficiency, largely confirms the hypothesis that stakeholders perceive a noticeable decrease in time-draining activities, an increase in production, and overall improved water management. One informant described the time savings this way: "...ditch riders who used to spend literally hours to drive to the gate to change the gate... when we got to the point where they could remotely control the gate from wherever they were at, I remember when that happened, and that, again, that was just life changing to them." Efficiency is also observed in the overall management of the water. One informant put it simply: "[The farmers get] what they're entitled to." The results of this efficiency are, perhaps, the most startling. We repeatedly heard stakeholders claim large increases in their production. "So I think that was the biggest thing is in making water last all summer instead of just until August 15th. But it used to be, now we're watering clear until the first of November." This extended season appears to have significant effects for farmers: "Well, the season's the same, but we got water for a longer time...We got guys... [redacted] got four crops this year."

In addition to efficiency, stakeholders value the transparency afforded by the system. In particular, we heard through three separate mechanisms emerge. The first is immediately-available information. One informant told us that, "[n]ow, it's an open book, and everybody knows where the water's going and how much water everybody's getting." The second is the accessibility of accurate records. One informant told us that the system allowed them, "...to be able to demonstrate that it [the water] was fairly distributed and distributed in accordance with their shares on the water rights." Finally, these benefits appear to result in reduced conflict. As one informant told us, "...by getting everything out there transparent, it cut down on a lot of fighting because people could see exactly what was going on."

Finally, stakeholders noted some benefits of the system related to external, non-stakeholders. First, the system created a sense of independence for stakeholders. There was a sense among stakeholders that without accurate records, their water rights would be eroded over time. One informant told us that, "[a]ll of the board and most of the county commissioners were involved with farming, they knew we had to protect our rights." Second, the system created a set of positive externalities for non-farmers. For example, one informant told us that, "[t]hey could look at different sites and see how the weather was or what the rainfall was and some [of] the recreation has, like to know if there was opportunities to kayak the stream or to go fishing or, even just what the temperature was around here." We conducted a brief survey to web users of the system, and this perspective was confirmed by these users. One respondent said, "[the website provides] easy access and I can check most of my fishing areas with the camera or just the weather info." Another told us that, "[r]eservoir cameras when updated every 15 minutes are perfect for fishermen and water sports recreational information!"

<u>Costs.</u> On the cost side, stakeholders' mentioned three sets of costs: acceptable tradeoffs, a financial burden, and the downside of transparency, which is precise measurement. The most common response to queries about the cost seemed to be a general acceptance of the tradeoff being made. Even acknowledging the tax burden, one informant told us that, "[a]nd we're willing to accept that tax so that they could have the benefits." Perhaps as a result of stakeholders' willingness to make this tradeoff, we collected multiple statements that there was minimal opposition to the system. One informant recalled a very small percentage of individuals opposed to the system: "We presented this whole concept right up front, back in... I don't know when it was.. '9 or '10. And we had a stockholder vote, and there were I think three stockholders out of the 400 and some odd, that voted no." The effort to be transparent, complete the Truth in Taxation process, and involve shareholders appears to have allowed stakeholders to support the system.

Where stakeholders did perceive a financial burden, they noted both the startup costs, as well as the ongoing maintenance costs. One unexpected cost that was mentioned multiple times was the dark side of transparency: a small set of individuals who perhaps previously benefited unduly from more than their fair share of water perceived a loss to the water they received. "...Other people feel like they're now not getting their fair share. I think what was happening was they were toward the end of the canal and they were actually picking up waste water before."

Summary

We conducted interviews with the major stakeholders in Emery County to obtain their perceptions of the costs and benefits of the real-time water quantification system. Using a grounded theory development methodology to interpret the interview responses, we found the following:

1. By a six to one margin, stakeholders mentioned benefits far more frequently than costs of the system.
2. Stakeholders' perceived benefits fall into three categories:
    a. Efficiency, including time savings, increased production (growing season), and improved water management.
    b. Transparency, including the availability of both current and recorded data and their effects on reducing conflict among stakeholders.
    c. Externalities, including an increased sense of independence from external stakeholders as well as unintended positive externalities for others groups (such as recreationists).
3. Stakeholders' perceived costs are nuanced. Though they recognize both the startup and ongoing maintenance costs of the system, many noted their willingness to make this tradeoff for the perceived benefits or noted that few people opposed the system. The one unexpected cost was born by individuals who previously "were actually picking up waste water before," and therefore, saw a reduction in water as the waste water was eliminated.

Chapter 7

Considerations for water users

Other River Basins that are considering initiating a real-time system should:

1. Determine what resources they can commit to the project, both dollars and manpower.
2. Whenever possible, think basin-wide system. Do a site survey and plan for the basin wide system. Prioritize the projects and add as much as you can at a time.
3. Make sure to budget money for maintenance costs.
4. Get local leadership buy in. To get this buy-in, a demonstration site is useful.
5. Search out financial resources (grants and loans) to supplement their own resources.
6. Hire or identify an existing individual to take “ownership”of the system. No system will survive without someone who believes in it and relies on it.
7. Take a field trip to Emery and take advantage of the lessons learned.
8. Hire contract workers that have knowledge of water projects.

Recommendations for the State of Utah

With Reclamation’s future support ramping down, the State should consider:

1. A state-wide real-time monitoring system, with website.
2. Expanding its technology support staff that is assisting with real-time monitoring and control systems.
3. Grants and loans to support real-time systems.
4. Developing water rights and river operations models (algorithms) that can be tied to the real-time monitoring and control systems.

Chapter 8

Lessons learned from the Emery Real-time Monitoring and Control System

1. Even though the system was initially designed forprotecting water rights and improving water records, it has been an invaluable operational tool. With the water saved, farmers have been able to extend their irrigation season thus their crop yield. The real-time system coupled with the pressurized pipeline system and on-farm improvements have allowed irrigators to take water as they need it.
2. The real-time system is valuable in all water supply conditions including: drought, normal, and flooding. It helps mitigate the conditions on either extreme of the water supply.
3. Because the backup support was important to the system's success, Reclamation provided the technical expertise that allowed the District's system to evolve at the same time as the real-time technologies evolve. As technology has advanced, so have the District's potential uses of the system.
4. Having a strong local commitment from both the District's Board and Manager has been critical to the system's success.
5. Training provided first by Reclamation and more recently by RWTA has been important. Once each year, typically in February, the water users have been invited to a 2-day training course in Provo. Hands-on sessions are provided to assist water users in operating, maintaining, and expanding their systems.
6. There are numerous secondary uses for the real-time data and images. They include irrigators interested in weather conditions, parents concerned about how to dress their children, highway department watching weather conditions, etc.
7. The transparency provided by the District's real-time website (www.ewcd.org) has developed trust and encouraged cooperation between water user groups, including: irrigators, mine operators, state regulators, wildlife enthusiasts, managers, fishermen and boaters interested in river flows, and reservation elevations, etc.

8. Real-time monitoring and control is changing job descriptions. Employees who have typically been gate-turners and data recorders are evolving into computer and communication technicians.
9. The District's system is migrating from a canal gate-control system to a pond-regulating system. This evolution has occurred smoothly indicating the flexibility of the system.

This study assumed that any saved water from increasing conveyance efficiency could be delivered to farms enabling producers to increase crop output. This assumption is reasonable for this study area since the irrigation service areas are parallel and downstream impacts on water rights are minimal, if any. Also, given that this area does not get the appropriated water rights 80 percent of the time, any additional water saving can be used for the benefit of the irrigators without exceeding appropriated water rights most of the time. However, in other areas of the state, the situation could be very different. If water saved by increasing conveyance efficiency is delivered to farms as additional water, it will likely have a negative impact on users downstream. Thus this study did not look at methods to determine potential impacts to other water rights in such cases. This could be an important issue in other areas and RTMCS could be a valuable tool in such areas to quantify impacts.

There are 3 other similar--but smaller--real-time, river-basin systems in the state of Utah: Sevier, Duchesne, and Bear. There is also a small system in the Scipio Basin, and parts of systems on the San Pitch and Beaver Rivers. Only Duchesne has a strong Federal presence, although there are two small Federal projects on the San Pitch. This is important because Reclamation has an O&M budget for Federal projects, but no base-level funding for non-Federal projects. Thus, Reclamation assistance may be problematic.

When it comes to financial resources, only the Emery District has taxing authority. The other systems have mainly relied on local water user support. It has been demonstrated in Sevier and Duchesne that local water managers can do much of the installation and maintenance work themselves.

APPENDIX A

A MULTI-PURPOSE BASIN-WIDE MONITORING SYSTEM: EMERY WATER CONSERVANCY DISTRICT EXPERIENCE

Jay Mark Humphrey
Roger D. Hansen
Arlen Hilton
Bret Berger

ABSTRACT

Over the last 11 years the Emery Water Conservancy District (District) has developed an integrated county-wide water monitoring and control system for the San Rafael River Basin, a tributary of the Colorado-Green River system. Key modules of the Emery real-time water management system include: (a) a comprehensive water supply and water quality monitoring system (initially designed to protect water rights, but increasingly being used for water management); (b) automatic remote control on three key water control structures; (c) a real-time weather monitoring system that feeds information to the National Weather Service; (d) a developing irrigation advisory system based on evapotranspiration (ET); and (e) an early warning system on Joes Valley Dam and Reservoir. A critical component of the District(s system is its link to the world-wide web at www.ewcd.org. The ExacTraq real-time water management software facilitates data distribution and encourages trust among the various water user groups.

The Emery County real-time monitoring system is a cooperative effort of the District, Bureau of Reclamation (Reclamation), StoneFly Technology (StoneFly), and Utah State University, and the Rural Water Technology Alliance. Possible future partners include the Museum of the San Rafael (in Castle Dale), Mesonet (a real-time weather site sponsored by the University of Utah), National Weather Service, Bureau of Land Management, Forest Service, Utah State Parks, and Natural Resource Conservation Service.

EMERY COUNTY PROJECT

The Emery County Project was authorized as a participating project in the Colorado River Storage Project by the Act of April 11, 1956. The Bureau of Reclamation completed planning on the water development project in February 1962. Construction of the project began in 1963 and was completed in 1966. The project has helped stabilize the county(s population by providing a reliable water supply to both agriculture and industry.
The Emery County Project is administered by the District, which was organized as a state agency on April 4, 1961, to operate and maintain project facilities and to repay the U.S. Treasury for the reimbursable costs of the project. The District is headquartered in Castle Dale, Utah, and has two full-time employees, plus seasonal help to assist with irrigation-season operation and maintenance. Despite the fact that the District is strictly a water wholesaler, it is committed to helping all water users in western Emery County better manage their water supply.

HISTORY AND DESCRIPTION OF DISTRICT'S MONITORING SYSTEM

In 1993, with funding provided by a drought-program grant from Reclamation, the District designed and installed the first step in a comprehensive hydrologic data collection system. This system was designed to improve the responsiveness of the county(s water delivery systems. Data from the field sites was telemetered back to the District(s office by line-of-sight radio using a VHF frequency. The field monitoring sites fell into three general categories: the San Rafael River and its tributaries, canals (largely at the diversions), and springs that are critical to the county(s Municipal and Industrial (M&I) water supply. In this initial effort, 17 water monitoring sites were upgraded to real-time. To facilitate communications, 2 repeaters were included in the initial system.

The initial effort was expanded in subsequent years. The District now has a monitoring system covering western Emery County that includes 80 field sites (see Table 1), 5 repeaters, and a base station. The system also includes an early warning system on the project(s major water storage facility (Joes Valley Reservoir. All these sites have similar equipment to facilitate operation, maintenance and repairs (OM&R). In 1994, to pay for the real-time environmental monitoring system, the county raised its *ad valorem* tax.

Table 1
Real-Time Monitoring Sites
Identified by Type and Drainage (2002)

	San Rafael River				
Type of Site	Huntington Creek	Cottonwood Creek	Ferron Creek	Muddy Creek	Total
River/Reservoir	8	8	3	2	21
Canal	12	10	3	0	25
Spring	8	10	3	6	27
Weather	1	4	2	0	7
Total	29	32	11	8	80

The Emery County monitoring system has proved to be very successful. According to the Utah State Water Plan, “The District’s installation of real-time monitoring...has helped to make the water supply much more efficient. This could be critical, especially during the inevitable dry years. There will also be savings in the cost of water management.”

APPENDIX B

Emery Real-Time Systems Related to Its RTMCS

There are three related real-time projects that have transpired in Emery County. Where possible they use the same equipment as the Real-time Monitoring and Control System.

Early Warning System. An early warning system for Joe's Valley Dam and Reservoir was installed to negate the need to make expensive structural changes to the dam. This system includes 2 weather stations--one at the dam and the other in the watershed at Grassy Flats--and monitoring equipment on the reservoir. Communications is by GOES.

Micro-hydro on Joe's Valley Dam. Since there was no commercial power available at the dam, consideration was given to running power lines, but it was cost-prohibitive due to the distances involved. Historically, needed power was supplied by a propane-fueled 16 kw generator. The generator was manually started when needed; a hand-operated hydraulic pump provided backup capability to operate the gates if the generator was inoperable.

After considering other options, it was decided to install a small micro-hydroelectric (or micro-hydro) facility at the dam. The micro-hydro system had the sole purpose of supplying power at the dam; this negated the need for a FERC permit. The Emery County Project required 10 cfs in-stream-flow release from the dam. This makes water available for power generation year round. The primary goal was to install a system capable of powering the hydraulic motor used to operate gates on the dam. Other uses of the power include operating the ventilation and lighting systems, and powering the RTUs (including communications) at the dam.

With the Joe's Valley micro-hydro system, peak demands are supplied by batteries with a hydropower DC alternator running continuously to charge the batteries. The alternator produces 750 to 1,400 watts on a 24-VDC system. The system consists of a small turbine coupled to a DC alternator, a bank of deep-cycle batteries, a charge controller and diversion load to waste power if the batteries are fully charged, a sine-wave inverter to convert power to AC, and a transformer. The system is inexpensive and simple, with the primary cost in the batteries and inverter. The estimated cost for the Joe's Valley Dam was $8,700, exclusive of the costs for the supply line, drain line, and concrete building. The system is plumbed for three turbine/alternators, but only two are currently installed.

<u>Cloud seeding</u>. In 2004 and 2005, Reclamation was contracted to head the State's cloud seeding research program. They tested releasing liquid propane into the atmosphere from mountains locations. The research was carried out on the east side of the Wasatch Plateau. The principal beneficiary of the improvements in snowfall was Emery County on the western side. The District inherited the cloud seeding sites and kept the system operational, adding 2 additional sites, for a total of 5. Now Sanpete County is also participating.

The research project experimented with using propane liquid as a seeding agent. The scientist in charge of Utah's project, Arlin Super, a retired professor of meteorology with 30 years of experience in cloud seeding, said the propane method appeared to increase snowfall by at least 7 percent. And propane seeding (from ground generators rather than aircraft) is far less expensive than dry ice or silver iodide seeding.

Appendix C

Do-It-Yourself (DIY) Solar-Powered Gate Actuator

After studying a low-cost AC installation made by Utah State University researchers and the water users in the Delta, Utah, area, a prototype solar-powered gate actuator was fine-tuned by Bureau of Reclamation, Provo Area Office. The first model was installed in 1994 on three slide gates on an irrigation diversion structure in central Utah (see Photograph 1). The unit proved highly successful. The basic cost for equipment (in 2000) was $1,400 per gate and requires approximately 4 man-days to install.

The DIY actuator is raised and lowered by a fractional horsepower 12-VDC gear motor attached to the handwheel by a chain and sprocket. A gate position sensor and limit switches are attached to the gate stem. The gate controller (datalogger) can be shared with the adjacent flow monitoring site. The unit is solar powered, typically using a small solar panel (30+ watts) and a deep-cycle battery. The DIY actuator has been installed on both frame and pedestal gate supports. These solar-powered gate actuators have been successfully installed at over 100 sites throughout the Intermountain West. Experience has shown that the DIY actuators are very durable, and the parts are easy to replace.

For more information: Contact Reclamation, Provo Area Office.

Photograph 1. Do-It-Yourself gate actuators on the slide gates of the Richfield Canal diversion structure.

APPENDIX D

Interview Guide

INTERVIEW GOALS

1. Understand the benefits and costs of implementing a real-time water quantification program.
2. Evaluate what made the project feasible for successful implementation.
3. Evaluate the impacts on water management and productivity for stakeholders in Emery County.

BACKGROUND INFORMATION

1. What is your name? What is your current role in [name organization]?
2. What has been your role in the development [or use] of the system [perhaps use different language, such as real-time water quantification system]?
3. How did you first become involved with the system?

BENEFITS, COSTS AND IMPACTS

4. Before the system was implemented, how was water managed?
5. When the system was first being developed, what other solutions existed?
    a. How did you decide to develop a software over those other solutions? [This question may need to be adapted depending on the participant interviewed.]
6. What were the primary reasons for developing the system (or, said differently, what was the system trying to solve)?
    a. In what ways has the system accomplished those goals?
    b. In what ways has the system not accomplished those goals?
    c. What unexpected benefits have arisen from the system?
7. Which groups or individuals have been most affected by implementing the system?
    a. In what ways have they been affected?
    b. [If focus above was on benefits] What costs have stakeholders in Emery County borne due to implementing the system?
    c. Who else has borne costs associated with the system? What are those costs?

d. [If focus above was on costs] In what ways have water users in Emery County benefited from implementing the system?
e. Who else has benefitted from the system?
f. What are those benefits?

8. How has the system changed water management in Emery County?

FEASIBILITY & IMPLEMENTATION

9. What allowed the system to be implemented successfully?
10. What challenges were faced in implementing the system?
    a. How were those challenges overcome?
    b. What could have been done differently to avoid or prevent those challenges?
    c. What challenges remain in implementing the system?
    d. Why do they remain?
11. If another basin wanted to implement a similar system, what recommendations would you make? What should they avoid?

APPENDIX E: ESTIMATED CONVEYANCE EFFICIENCIES

Ferron Creek Conveyance Efficiency Estimates used in this study

Year	CE in 1991	Series A	Series B	Series C	Series D	Series E
1992	50.0	50.6	51.3	51.3	51.3	51.3
1993	50.0	51.1	52.7	52.7	52.7	52.7
1994	50.0	51.7	54.0	54.0	54.0	54.0
1995	50.0	52.2	55.4	55.4	55.4	55.4
1996	50.0	52.8	56.7	56.7	56.7	56.7
1997	50.0	53.3	58.1	58.1	58.1	58.1
1998	50.0	53.9	59.4	59.4	59.4	59.4
1999	50.0	54.4	60.8	60.8	60.8	60.8
2000	50.0	55.0	62.1	62.1	62.1	62.1
2001	50.0	55.5	63.5	63.5	63.5	63.5
2002	50.0	56.1	64.8	64.8	85.0	63.5
2003	50.0	56.6	66.2	66.2	85.0	63.5
2004	50.0	57.2	67.5	67.5	85.0	63.5
2005	50.0	57.7	68.8	68.8	85.0	63.5
2006	50.0	58.3	70.2	70.2	85.0	63.5
2007	50.0	58.8	71.5	71.5	85.0	63.5
2008	50.0	59.4	72.9	72.9	85.0	63.5
2009	50.0	59.9	74.2	74.2	85.0	63.5
2010	50.0	60.5	75.6	75.6	85.0	63.5
2011	50.0	61.0	76.9	76.9	85.0	63.5
2012	50.0	61.6	78.3	78.3	85.0	63.5

2013	50.0	62.1	79.6	79.6	85.0	63.5
2014	50.0	62.7	81.0	81.0	85.0	63.5
2015	50.0	63.2	82.3	82.3	85.0	63.5
2016	50.0	63.8	83.7	83.7	85.0	63.5
2017	50.0	64.3	85.0	85.0	85.0	63.5

Huntington Conveyance Efficiency Estimates used in this study

Year	CE in 1991	Series A	Series B	Series C	Series D	Series E
1992	50.0	50.6	51.3	51.3	51.3	51.3
1993	50.0	51.1	52.7	52.7	52.7	52.7
1994	50.0	51.7	54.0	54.0	54.0	54.0
1995	50.0	52.2	55.4	55.4	55.4	55.4
1996	50.0	52.8	56.7	56.7	56.7	56.7
1997	50.0	53.3	58.1	58.1	58.1	58.1
1998	50.0	53.9	59.4	59.4	59.4	59.4
1999	50.0	54.4	60.8	60.8	60.8	60.8
2000	50.0	55.0	62.1	62.1	62.1	62.1
2001	50.0	55.5	63.5	63.5	63.5	63.5
2002	50.0	56.1	64.8	64.8	64.8	64.8
2003	50.0	56.6	66.2	66.2	66.2	66.2
2004	50.0	57.2	67.5	67.5	67.5	67.5
2005	50.0	57.7	68.8	68.8	68.8	68.8
2006	50.0	58.3	70.2	70.2	70.2	70.2
2007	50.0	58.8	71.5	71.5	71.5	71.5

2008	50.0	59.4	72.9	72.9	72.9	72.9
2009	50.0	59.9	74.2	74.2	74.2	74.2
2010	50.0	60.5	75.6	75.6	75.6	75.6
2011	50.0	61.0	76.9	76.9	76.9	76.9
2012	50.0	61.6	78.3	78.3	78.3	78.3
2013	50.0	62.1	79.6	79.6	85.0	78.3
2014	50.0	62.7	81.0	81.0	85.0	78.3
2015	50.0	63.2	82.3	82.3	85.0	78.3
2016	50.0	63.8	83.7	83.7	85.0	78.3
2017	50.0	64.3	85.0	85.0	85.0	78.3

Cottonwood Conveyance Efficiency estimates used in this study

Year	CE in 1991	Series A	Series B	Series C	Series D	Series E
1992	50.0	50.7	51.3	51.3	51.3	51.3
1993	50.0	51.3	52.7	52.7	52.7	52.7
1994	50.0	52.0	54.0	54.0	54.0	54.0
1995	50.0	52.6	55.4	55.4	55.4	55.4
1996	50.0	53.3	56.7	56.7	56.7	56.7
1997	50.0	54.0	58.1	58.1	58.1	58.1
1998	50.0	54.6	59.4	59.4	59.4	59.4
1999	50.0	55.3	60.8	60.8	60.8	60.8
2000	50.0	55.9	62.1	62.1	62.1	62.1
2001	50.0	56.6	63.5	63.5	63.5	63.5
2002	50.0	57.3	64.8	64.8	64.8	64.8

2003	50.0	57.9	66.2	66.2	66.2	66.2
2004	50.0	58.6	67.5	67.5	67.5	67.5
2005	50.0	59.2	68.8	68.8	68.8	68.8
2006	50.0	59.9	70.2	70.2	70.2	70.2
2007	50.0	60.6	71.5	71.5	71.5	71.5
2008	50.0	61.2	72.9	72.9	72.9	72.9
2009	50.0	61.9	74.2	74.2	74.2	74.2
2010	50.0	62.5	75.6	75.6	75.6	75.6
2011	50.0	63.2	76.9	76.9	76.9	76.9
2012	50.0	63.9	78.3	78.3	78.3	78.3
2013	50.0	64.5	79.6	79.6	79.6	79.6
2014	50.0	65.2	81.0	81.0	81.0	81.0
2015	50.0	65.8	82.3	82.3	82.3	82.3
2016	50.0	66.5	83.7	83.7	83.7	83.7
2017	50.0	67.2	85.0	85.0	85.0	85.0

APPENDIX F: Abbreviations

Abbreviations

AE = Application Efficiency
AF = Acre-foot or acre-feet
B-C = Benefit-Cost
B/C=Benefit Cost Ratio
BCA = Benefit cost analysis
CE = Conveyance efficiency (WD/QD)
CE(%) = CE*100
CPI = Consumer Price Index
District = Emery Water Conservancy District
ECP = Emery Country Project
EIS = Environmental impact statement
IRR = Internal rate of return
IT = Information technology
NPV = Net present value
NRCS = Natural Resources Conservation Service
QD = Water diverted into the canal
Reclamation = Bureau of Reclamation
RTMCS = real-time monitoring and control system
RWTA = Rural Water Technology Alliance
SF = Streamflow forecast
WD = Water delivered to the farm

APPENDIX G: RMTCS USERS ANNUAL TRAINING ROUND TABLE DISCUSSION

On February 4, 2020 a group of about 30 RTMCS users attended an annual training at the Bureau of Reclamation in Provo, UT. We thought it would be interesting to get their responses to some of the questions being asked in the Emery Study. These are the notes from that discussion. We felt like their responses would be valuable to you and so we have included them in the final report of the Retroactive Emery Study.

WHAT MADE INSTALLING A REAL-TIME MONITORING AND CONTROL SYSTEM (RTMCS) FEASIBLE?

WHY DO IT?

1- We saw what someone else was doing and toured their sites.

2- We didn't have records to protect our water rights.

3- "Watching your neighbor" - everyone always thinks the other person is getting more than their share.

4- To be compliant with water decrees and fulfill responsibilities to report to the state.

5- The transparency removed distrust.

6- Automation created efficiency.

7- Improved operational efficiency. Water managers could do so much more in a lot less time.

8- Water Savings. Removed the guess work from measuring and tracking.

9- We could justify decisions because there was quantifiable data to back them.

10- Time savings.

11- “Keeps the Bishops honest”

12- Improves confidence

13- Reduces uncertainty for design/operations

14- Less O&M money needed

15- Transparency/self policing

WHEN YOU CHOSE THIS SOLUTION, WHAT OTHER SOLUTIONS WERE AVAILABLE?

1- When this began there were not many solutions available that weren’t cost prohibitive and meant for larger operations. The Bureau of Reclamation saw a need and pioneered the systems you see in place today. They have grown and evolved over the years. Cost of parts has decreased, ingenuity has increased, awareness has increased and the advantages of having a RTMCS is widely known.

2- Cost was a driver and a barrier

3- Knowing where to look was a barrier. As mentioned before this was being pioneered and there were not many examples readily available to draw from. Being able to look at a system that was in place and working, even in the beginning stages was an advantage.

4- Having the districts come together helped to create an information and technology co-op of sorts. Kind of a clearinghouse.

5- RTMCS were a benefit to many more beyond water users.

6- Versatility was important. These systems were built with the ability to use cost effective components that could be adapted to suit the needs of the system.

7- The technology, just like the physical components needs to be maintained and updated. This keeps the systems current and in good working order.

8- The real-time data is useful for record keeping, but also for warnings on systems where a breach or unexpected water event occurs. There is adequate warning time to mitigate damage.

WHAT MADE IT FEASIBLE TO BEGIN A REAL-TIME MONITORING AND CONTROL SYSTEM?

1- There was a need. We needed to protect our water rights, we needed to have defensible data, and we need a better way to manage the water.

2- Seed money was a big factor in making it feasible. Initially the costs were high and the outcome was unsure. Financial assistance was a big factor in the beginning. Money built into the project for installation and for operation and maintenance creates value and longevity.

3- There was someone who was willing to “take ownership” of the project.

4- 3 Keys: Who could help? – Finding the correct person for the job, finding out the options available/accurate applicable information, who will pay for it?

5- Trial and error are a part of the process.

6- Technology and providers are constantly changing and evolving, which makes implementation more feasible.

7- We needed to understand the tradeoffs.

8- Trust was a motivating factor, seeing is believing.

9- Initially cost was a barrier so learning about ROI/Value is a key.

WHAT CAN WE DO IN PLANNING FOR THE FUTURE?

1- Teach problem solving. This generation is too used to asking "Google" and has not had enough experience problem solving. It needs to be taught in a hands on setting.

2- Problem: There are too few people with knowledge of the water, training and expertise in water systems and technology. There are too few people to train them. It would be wise to begin some sort of classroom and field training program. Perhaps partner with a University. Not many people know that water management is an option or even think about it unless they have grown up with someone who is responsible for water.

3- We need to find a way to reach out to the next generation. They are technologically savvy but lack the water experience, or they have water experience but lack other important skills. Again, awareness and training is key.

4- Water is valuable! We need to communicate the value of water and water professionals. We will only be able to retain a workforce in the next generation if there value placed on water which will translate into a higher salary attracting more people to the profession. Value = Salary/Benefits.

5- It would be advisable for the State to explore the advantages of a hands on training program.

WHAT ARE THE SOCIOECONOMIC BENEFITS?

1- Used by sportsmen and recreation, which brings in commerce.

2- Increases yield and conserves water.

3- Time management and efficient.

4- Transparency creates trust.

5- Frequent data

6- Advanced warning and remote automation/operation minimizes damage

7- Reduces 99% of water conflicts because of frequent and readily available data.

WHAT WOULD YOU TELL OTHERS WHO ARE CONSIDERING INSTALLING A RTMCS?

1- Don't wait!

2- Get educated. Look at other systems already in place. Evaluate your needs with a professional who has experience in water projects.

3- Find the right contact/mentor to help you through the process. Learn from their lessons and make better choices for your system.

4- Seeing is believing. Take a field trip and visit a working system.

5- You need to see the value in the "New Way" compared to the "Old Way". Generations of hard work optimized for the future, benefitting generations to come.

6- Have a strategy to overcome initial risks/fear to try something new. Good information is key.

WHAT CAN THE STATE DO?

1- Create a funding source to get the ball rolling and create an interest

2- Open up funding access to existing infrastructure.

3- Anyone given funding should have to have "skin in the game". Cost share should be involved in any financial funding incentives.

4- Keep ag in mind when creating new programs.

5- Provide a champion people can trust.

APPENDIX H: MONTHLY EMAIL UPDATES

PROJECT UPDATE

Case Study of Emery County Agricultural Water Quantification System
18 September, 2019

Dear Task Force:

We are pleased to report that the Study is now well underway and appears to be on schedule. To date, we have accomplished the following:

1) *Stakeholder Identification*. Through interviews (described below), we have identified the set of key stakeholders to interview, including: the Emery Water Conservancy District, the U.S. Bureau of Reclamation, the Rural Water Technology Alliance, and the Utah Division of Water Rights.

2) *Data Collection*.
    a) We have so far compiled available agricultural data relevant to our project - irrigated land, crop yields, size distribution of irrigated farms, agricultural output etc. for Emery county over time. We now have enough materials to get a good profile of irrigated agriculture and to perhaps estimate the relationship between water and value of agricultural output.
    b) We have conducted interviews with informants from the Emery Water Conservancy District, the U.S. Bureau of Reclamation, and the Rural Water Technology Alliance.

3) *Data Analysis*.
    a) We have constructed a hypothetical example of cost/benefit analysis of changes in irrigation conveyance efficiency in order to illustrate the type of water resources data we need. These data include total water diversions and total deliveries to irrigated lands for different years, in addition to estimated stream flows with associated probabilities and reservoir drawdown.
    b) We have begun our grounded theory-based analysis of the interview data and note some interesting trends emerging. In particular, the perceived benefits of the system are quite diverse, and range from a significantly extended season to reduced conflict among water users.

Sincerely,

Amy Green, President
Rural Water Technology Alliance

PROJECT UPDATE

Case Study of Emery County Agricultural Water Quantification System

23 October, 2019

Dear Task Force:

The study appears to be on schedule. Below you will find the project progress.

Developed Stakeholder Identification Framework and continue to hold interviews.

We have begun a comprehensive history of the Emery WCD real-time monitoring and control history.

Gathered background information from the Emery WCD and Bureau of Reclamation.

Gathered time-series data for the years 1992-2018 on Emery County irrigation diversions, District finances, San Rafael River salt loads, etc. Performed preliminary analysis on data.

Agricultural Sector of Emery County

The following data collected helps establish agricultural profile of Emery County and estimate benefits (of agricultural sector) from installation of real-time measurement infrastructure and associated automation that occurred over the last 25 years.

Specifically, the following time-series data were collected in order to complete the required tasks.

Cash receipts from Crops and livestock /and products were collected from three different sources: U.S. Agricultural Census (every 5 years), National Agricultural Statistical Service (NASS) (annual data estimated from sample survey) and the Bureau of Economic Analysis (BEA) (annual data). There are inconsistencies in these data sources. Correspondence with Mr. John Hilton from Utah NASS office has been helpful in identifying some of the reasons for these inconsistencies and provided some missing data. The reason for collecting this data is to estimate the monetary benefits of irrigation water in Emery County.

Land Use data collected from census helps establish irrigated and non-irrigated lands, irrigated cropland and pastureland in the county. The purpose is to estimate the agricultural output generated from irrigated agricultural lands.

Size distribution of Farms and irrigated acres by farm size compiled from census allow inferences on social impacts in terms of part-time and full-time agricultural operations in the county.

Price received index compiled from Annual Agricultural Statistics allows converting nominal agricultural output measures to real or constant dollars by taking out inflationary factors.

<u>Water Resources Data and Analysis</u>

Forecast data on water diversions from the major creeks into the various irrigation canals have been compiled. Irrigation diversions in Emery county, by and large, are determined based on the Natural Resources Conservation Service (NRCS) forecasts of April through July flows published in May update and often adjusted slightly in the middle of irrigation season. Probabilty distribution of annual irrigation water availability will be constructed from the NRCS data.

Irrigation diversion data collected for the canals will be used for two main purposes. The first is to estimate changes in conveyance efficiency improvements over time due to installation of real-time measurement. Conveyance efficiency increases contribute to agricultural benefits during below normal flow years by being able to deliver relatively more to the farms. Moreover, irrigation timing and late season deliveries could further contribute to agricultural benefits. The second purpose is to evaluate changes in salt loading as a result of real-time measurement systems along with installation of pressurized pipe system in much of the county.

Diversion data for open channel ditches with real-time measurement system and **diversion data for canals that have pressurized pipes** in addition to real-time measurement are separately collected. This will help distinguish between conveyance efficiency changes resulting from real-time systems from those that are due to pipe conveyance.

Regression analysis is used to evaluate diversion changes over time for the open channel ditches. Preliminary results indicate a downward trend in diversions adjusted for variations in annual flows over time. Results are not conclusive at this time of this progress report.

Water Rights and water used on-farm have been collected, but not analyzed yet. These data will be used to partly estimate conveyance efficiency changes.

Cost data from Emery County Water Conservancy that have been collected and it will be used to calculate the annual equipment investment costs adjusted by price index for electronic equipment and adjusted by appropriate depreciation to get real annual costs.

It would be nice to have the river commissioner report for Ferron Creek and Muddy Creek. Can the water rights department help?

Sincerely,

Amy Green, President

Rural Water Technology Alliance

PROJECT UPDATE

Case Study of Emery County Agricultural Water Quantification System

16 November, 2019

Dear Task Force:

I regret that I was not able to join the meeting by phone on Friday because of technical issues. Paul Monroe was able to bridge me in for part of the meeting, but I did not hear any of the discussion on our project. The Emery study has been very interesting as it develops, but not as much to report as the USU study until we have reached our findings when the study is completed. We will have the first draft to you by December 1, 2019 as scheduled in our contract. I was hoping for any feed back you may have on the direction of the study, methods, etc. as we have had no feedback on previous required monthly updates and our time is getting short to complete the project. Below you will find the project progress.

<u>Progress Report for November 15, 2019</u>

1. Analysis on Diversions:

The Real- time Water Quantification Program (RWQP) affects four creeks in Emery County: Cottonwood, Huntington, Ferron and Muddy. Irrigation diversions from these four creeks into various distributing canals and ditches typically fluctuate from year to year. These fluctuations are often the result of annual variations in stream (creek) flows and thus the availability of water for irrigation as determined by the structure of water rights. For the analysis period selected for this study, i.e., 1992-2017, water allocations for irrigation from these four creeks are assumed to be based on NRCS's May forecast of stream flows for months of April-July as this is the best available information in the beginning of the irrigation season. Frequently allocations are adjusted slightly mid-season based on changes from the forecasted values.

2. Data Issues

Diversions for irrigation are expected to have a positive relationship to forecasted stream flows. Full set of time-series diversion data were available for Cottonwood and Huntington creeks. They both have primary diversions (A shares) from the creeks as well as additional water diverted from reservoir storage (B shares). At this time, complete data set for diversions is not available for Ferron and Muddy creeks. However, both forecasted NRCS data as well as creek flow data are available for the 26 year period from USGS gauging stations. Diversion data are available only for the last 3 years for these two creeks. Based on available data thus far, the statistical relationships between diversions and forecasted stream flows are estimated using regression analysis for Cottonwood and Huntington

Creeks. For Ferron and Muddy, they are estimated as a deterministic relationship.

For Cottonwood, Huntington and Ferron, in addition to RWQP, many miles of pressurized pipes replacing open channel earthen main canals and laterals have been installed over the years. This has been a complicating factor in that it is difficult to isolate the effect of RWQP from those of the pressurized pipe conveyance system. This problem is being currently addressed as the analyses progress.

3. Statistical Analyses

It is hypothesized that the real-time measurement system causes an autonomous decrease in primary diversions over time even after accounting for fluctuations in stream flows. This hypothesis is tested for both Cottonwood and Huntington systems. This hypothesis could not be rejected for both systems. The statistical result indicates about 1.5% annual (surprisingly equal) autonomous decrease in primary diversions (A shares) in both areas indicating an increase in conveyance efficiency from 60% in 1992 to 83% in 2017.

In order to isolate the effects of pressurized pipe system from that of RWQP, a statistical analysis of diversion records for three ditches (Peacock, Johnson and Swasey) was under taken since these three ditches off of Cottonwood creek had only RWQP and no pressurized pipe system. These are small ditches with extremely low conveyance efficiency to start with.

However, these three showed about a 2% autonomous decrease in diversion rates annually even after accounting for fluctuations in forecasted stream flows for Cottonwood confirming the beneficial effect of RWQP.

These statistical results further reinforce that RWQP works in improving conveyance efficiency with or without pressurized pipe system.

4. Preliminary Results

Preliminary results seem to indicate that for all the 4 major creeks (Cottonwood, Huntington, Ferron and Muddy), the annual benefits may be around 1 to 2 Million dollars to agriculture from both RWQP and the pipe system. <u>These results are strictly preliminary and are subject to revision and the benefits do include those efficiency gains from pressure pipe system.</u>

Using the statistical results in terms of autonomous changes in diversions, preliminary calculations are made to evaluate the effects on salt loading. Using USBR estimate of 3.6 tons/ AF and at $55/ton damage cost, the effect of reduction in irrigation diversions are calculated over time for

Cottonwood and Huntington systems. **<u>Preliminary results indicate that for Cottonwood and Huntington, about 80,000 tons of salt loading reduction is estimated in year 2017 with benefits of around 40 million dollars annually. Again, this is a preliminary estimate subject to revision and isolating the effects of RWQP from that of pipe system is a considerable challenge.</u>**

Most of the cost component of RWQP are available from Emery County conservancy District data and River Commissioner reports. The benefit cost calculations are being conducted at this time.

<u>Preliminary Socioeconomic research</u>

Initially the district was looking to protect themselves from trans basin diversions from the mines, but soon realized there would be significant operational benefits.

The real-time monitoring website provided transparency, and made the data available to a wider range of users: oaters, fisherman, UDOT, mothers needing weather conditions, hunters, etc.

The district has invented new ways to use the system: for example, reduce the need for algaecides.

Emery started out with 19 sites in 1992. In 2002 EWCD had 80 plus sites. Now they have over 200, and if you count the individual irrigation connections, the district has over 400 plus.

To date no one has questioned the expenditure on the system. It has become a valuable tool basin wide. During the water season the district manager checks the entire system from his computer before he goes to work, before he goes home and before he goes to bed. Alarms and warnings built into the system, alert him of potential problems 24/7, providing extended active management.

Sincerely,

Amy Green, President

Rural Water Technology Alliance