The Economics of Irrigation in Colorado's Lower Arkansas River Valley

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This report was constructed with the helpful insights and recommendations of the Arkansas River Management Committee (ARMAC), a group of LARV stakeholders including agricultural producers, water managers, and policymakers (see the website for detailed information at www.coloradoarmac.org). This dedicated group was assembled to assist, inform, and guide CSU researchers whose projects focus on improving water quality, conserving water, and ensuring the future of irrigated agriculture in the LARV.

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> *"There was a learning curve of about three years to operate a sprinkler to obtain outcomes. Throw the book away or advice of the sprinkler salesman. Apply as much water as possible without getting sprinkler stuck. On water short ditches this allows root formation. When you apply small amounts the roots do not follow water and it is hard to get rid of weeds and grasses because they are healthier than crop plants and spray does not work as well. Also on grain I will only plant corn 1 year and back to alfalfa. This has allowed me to cut down on fertilizer and with drought on and off my yields have stayed high with much lower inputs. "*
>
> *Don McBee*

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Executive Summary
Irrigation Management Decisions in the LARV

Like all businesses, farms have to innovate to stay relevant. In the Lower Arkansas River Valley (LARV), that means that farmers have to keep up with the latest technologies for managing water, especially as other users press their claims for the region's very limited water resources. The most popular technology that many are considering involves increasing irrigation application efficiency, primarily by switching from furrow irrigation to sprinklers, but also including drip irrigation systems, laser leveling and surge irrigation to name just a few examples. Besides the potential to help farmers by increasing crop yields, research shows that these systems could also reduce contamination of the Arkansas River with salinity and selenium (Se); improve soil quality; and perhaps even conserve water (Burkhalter and Gates 2006; Morway and Gates 2012; Morway et al., 2013; Bailey et al., 2015).

The first thing that farmers have to think about when considering whether to install or change an irrigation system is what type of system they want to build and whether it is going to make them more money. From an economic perspective, this means that farmers need to know what a system costs to own and operate, as well as what it returns. Traditionally, that means what it costs to buy, build and maintain a system, plus how much it costs to pump and apply water. However, in the LARV there are several additional considerations, call them "economic adjustments," that can affect benefits or costs. These adjustments are there because the way a farmer manages water also affects other water users. Therefore, there are many rules in place that are designed to assure that other water users' interests are considered and protected. Many of these adjustments are complicated to understand and apply, which likely holds many farmers back from making changes to their own irrigation systems. This executive summary provides a simplified overview of the irrigation management decision by way of a realistic example. Since just about everything we consider can vary greatly from one field, farm, or farmer to the next, we provide a detailed discussion about each of these costs in our detailed report (www.coloradoarmac.org). Consider this summary as a kind of road map, where detailed information can be found in the full report. Of course, not everything that a farmer might care about can be summed up conveniently as a cost. Everyone that we talked to that has installed sprinklers, for example, has been happy with their decision and found that their new system offered surprises. Talking to someone that has made the change you are considering might reveal hidden benefits like convenience, or costs like potential for increased salinity, that should be considered.

A detailed budget is provided below in Table A. The types of costs are listed on the left side and the systems compared are listed on the top. Only three of the systems we look at in the main report are presented in this overview. Furrow is included because it is the predominant system in the LARV and the least efficient. We then examine two options to increase irrigation efficiency. The first does not trigger any regulations or requirements for off-farm approval. For this example, we chose laser leveling with gated pipe. This increases irrigation efficiency from approximately 65% to about 75%. The second is a center-pivot sprinkler system, which does trigger the need for approval by the State. While it improves efficiency a bit more than the non-triggering example we use, it requires approval in order to assure that return flows are maintained in compliance with Colorado's interstate river compact with Kansas; and that can cost a lot of money. We assume that someone considering a triggering option would apply through a Rule 10, which allows farmers to apply as a group at much lower cost than applying individually and with the potential advantage of reducing replacement water requirements. The Lower Arkansas Valley Water Conservancy District (LAVWCD) currently is assisting member-farmers with these plans for an administrative fee of $300.

Ownership and Operating Costs

Farmers and other individuals that measure costs typically stop when they have calculated their on-farm ownership and operating costs. Ownership costs are those required to pay off the investment of a system over time. Operating costs include how much it takes to irrigate a field on an annual basis. As shown below, based on operating costs alone, the best estimate in our example of three systems favors sprinklers at $75/acre per year. However, when ownership costs are added, furrow irrigation has the lowest cost at $136/acre per year compared to nearly $181/acre for sprinklers and over $200/acre for laser leveling with gated pipe. Much more has to be considered in the LARV in order to account for impacts on other stakeholders. We review several economic adjustments, with our lowest, highest, and best estimates for our example in the LARV below. More are discussed in the main report. After adding in the effect of economic adjustments, sprinklers, at $175/acre, have the lowest cost in our example. This example shows how important it is to consider how economic adjustments will affect each individual farm before changing irrigation systems.

Economic Adjustments

Crop yield (See Chapter 7) – The yield may be different between the three systems. Focusing on the "best" columns, studies we found showed that sprinkler systems had about a $115/acre per year advantage compared to furrow irrigation due to more uniform water coverage, reduced salinity and other variables. That advantage decreased to $38/acre per year over the laser-leveled system. If we think about the yield advantage of sprinklers as an opportunity cost when using another system (a cost in lost yield potential), the furrow system's cost increases from $136 to, $251/acre per year, which is about 40% higher than the cost of the sprinkler system (about $75/acre more). In addition, a local farmer tells us that his alfalfa quality improved "dramatically" under sprinklers, which is another way to increase revenue.

Rule 10 (See Chapter 5) - The sprinkler system requires a Colorado Division of Water Resources (CDWR) Rule 10 plan (or equivalent) and the purchase of replacement water. In our example, the Rule 10 cost is $2.50/acre for the sprinkler system ($300/120 acres). We assume for the sake of this example that the Rule 10 plan determines that $20 per year must be spent on replacement water, which cuts the advantage of sprinklers over furrow irrigation from about $75/acre to about $72/acre. Rule 10 planning can cut the transactions cost of adopting sprinkler systems dramatically compared to going it alone to get approvals.

Cost sharing (See Chapter 7) - Sprinklers are also eligible for cost sharing. Using the maximum amount that a farm could expect in 2016, the sprinkler gains another $36 through these cost savings.

***Acreage Adjustment (See Chapter 7)* -** Sprinklers might require changes in field shape or size in order to accommodate the system. These changes result in economic adjustments from previous system. We estimate that a change in acreage could result in a $15 cost per acre irrigated by the sprinkler based on losing about 8 acres of irrigated area. On the opposite side of the coin, some farms may have some room to increase acreage from their current use to the historical high recognized in the Kansas v. Colorado litigation (1985), which may help accommodate a new system. This option likely does not require State Engineer or Water Court approval but we urge extreme caution before increasing acreage.

***Total Costs (See Chapter 10)* -** In the end, with all of our assumptions, we estimate that sprinklers are the least costly system at $175 compared to $251 for furrow and $289 for laser leveling with gated pipe.

Table A: Low, high and best "guess" cost estimates for traditional furrow, laser leveling with gated pipe, and sprinkler systems in the LARV, Colorado.

	Furrow			**Laser Leveling w/ Gated Pipe**			**Sprinkler (Electric)**		
	Low	High	Best	Low	High	Best	Low	High	Best
Operating									
Field Prep	$92	$98	$92	$92	$98	$92	$35	$44	$35
Pumping	NA	NA	NA	$-	$-	$-	$22	$38	$21
Labor	$20	$34	$39	$20	$34	$26	$15	$34	$19
Subtotal			$131			$118			$75
Ownership									
Pumping plant			NA			$-			$10
Equipment/ Practice	$4	$6	$5	$75	$112	$93	$63	$95	$79
Pipe			NA	$13	$19	$16	$5	$8	$9
Pond			NA			$-			$7
Subtotal			$5			$109			$106
Total			$136			$227			$180
Adjustments (+/-)									
Yield	$85	$182	$115	$-	$103	$38			NA
Rule 10			NA			$-	$3	$3	$3
Replacement water			NA			$-	NA	$38	$20
Cost Sharing			NA	-$21	-$23	-$23	-$34	-$35	-$36
Acreage			NA			$-	-$10	$25	$15
Subtotal			$115			$15			$2
Total			**$251**			$242			**$182**

Detailed Report

1.0 Competition for Water in the Lower Arkansas River Valley

The old adage regarding water in the Western U.S. is worth repeating, "Whiskey is for drinking; Water is for fighting." In the Arkansas Basin, this adage continues to ring true. Perpetual growth in the Basin increasingly strains water supplies and intensifies rivalry between states, regions, and users. The competition for water is a direct result of the fully or perhaps over allocation of water during most years. This, combined with highly variable weather conditions, creates a fair amount of uncertainty for water users, especially farmers with junior rights. More detailed information about water competition is summarized below.

1.1 Colorado and Kansas

One significant driver of competition for water in the LARV is an old and lingering dispute between the states of Kansas and Colorado. The expansion of irrigated agriculture in the late 19th century[1] caused downstream users in Kansas to claim damages from the decreased flows in the Arkansas River into Kansas. Continuous litigation between the two states eventually resulted in the Arkansas River Compact (Compact) in 1949, which will be explored in depth later in this report. The Compact resulted in a 60% and 40% split of the flows of the Arkansas River and Purgatoire River into John Martin Reservoir to Colorado and Kansas, respectively, and established that "stateline flow" must be maintained in usable quantity and availability.

While the Compact was able to quell some of the dispute, Kansas later filed suit in court against Colorado over depletions in excess of the Arkansas River Compact and was awarded damages by the U.S. Supreme Court. Lawsuits and subsequent policy changes have had a regional impact on how water is used in the LARV.

1.2 Rural and Urban

Population shifts and trends add to the narrative of the water struggle in the LARV. Demand for water in growing urban areas such as Pueblo, Colorado Springs, and the Denver Metro area add pressure to an already constrained system. Trends in the LARV's population show that growth is primarily in Pueblo County, with the remaining, mostly rural counties having experienced either large swings in population or consistent losses. These trends have significant long-term impacts on water use in the LARV as pressure to move water out of agriculture continues to mount.

1.3 Upper vs. Lower

Unfortunately, in recent years the entire Arkansas River Basin has generally seen a divergence in water values between many upstream and downstream residents. The Upper Arkansas River Basin, typically encompassing the headwaters regions of Fremont, Lake, Chaffee, Custer, and Park counties, is experiencing rapid population growth, which has sometimes come at the expense of local agricultural lands. At the same time, the LARV is seeing a slight net migration out of the area. With changes in demographics come changes in the perceptions of how new residents view water. Although a strict prior appropriation system is in place, changing demographics may sway public opinion about water uses,

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[1] Citizen's Guide to Interstate Compacts (2010)

transfers, and policy measures. It will be important that new residents to the Arkansas Basin learn about current *and* historical uses of Arkansas River Basin water and, when/if conflicts arise, work with longtime residents to find agreeable solutions.

1.4 Measures of Efficiency

When water is scarce, common sense points to making what water supplies we have stretch further and insuring that adverse effects of excess water diversion are minimized. Throughout this report, comparisons of different irrigation systems and scenarios are analyzed based on their relative efficiency in using water intended for crop production. In particular, we are interested in two measures of efficiency: 1) conveyance efficiency, and 2) irrigation application efficiency.

For the purpose of this report, conveyance efficiency (E_c) is used to measure on-farm water losses that occur between the diversions from main canal to the field application, and is given by

$$E_c(\%) = \left[\frac{Volume\ of\ water\ reaching\ the\ fields}{Volume\ of\ water\ diverted\ from\ canal}\right] \text{x } 100.$$

Only on-farm conveyance efficiency is considered here, as that is the part that in a farmer's control. Losses generally are attributed to non-consumptive uses such as seepage, and non-beneficial consumptive uses through evaporation and phreatophyte transpiration[2]. It is important to differentiate between these two losses. Non-consumptive uses indicate water that does not leave the system but is potentially available for other consumptive uses in the system at some later time. Non-beneficial consumptive losses, such as those to phreatophytes, are removed from the system and represent water that cannot be used again within the system.

Irrigation application efficiency (E_i) measures the percentage of water applied that is beneficially used by crops and is given by

$$E_i = \left[\frac{Volume\ of\ water\ beneficially\ used}{Volume\ of\ water\ applied}\right] \text{x } 100$$

Beneficial uses include consumptive plant uptake and soil evaporation, and non-consumptive salt leaching, and other input-related (fertilizer, pesticide, herbicides, etc.) water requirements. Water losses in this phase generally occur due to excess soil evaporation, field surface run-off, and deep percolation below the crop root zone. Often deep percolation volume exceeds that required for salt leaching. Field run-off and deep percolation losses are considered to be non-consumptive losses, in that the water is stored or transported within the system for potential down gradient uses.

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[2] Phreatophytes are plants that rely on groundwater within the reach of their roots to survive (Robinson, 1958). These plants are commonly found along the banks of irrigation ditches and streams, and in areas where excess soil moisture is available.

All cost modeling for this report will focus on on-farm system efficiency which will be calculated as the product of conveyance and application efficiencies, or $E_s = E_c * E_i$. For cost modeling, this measure will take a constant value. However, it is more likely that this measure takes a range of values depending on many factors such as field characteristics and management decisions.

2.0 Water Quantity and Water Quality in the LARV

Many issues are shared collectively between the upper and lower portions of the Arkansas River Watershed. There are two main water issues that unite or divide these two basins: water quantity and water quality. Both upper and lower basin water users typically face issues associated with the magnitude and variability of flow rates, especially in years of water scarcity. Water quantity issues related to droughts and floods have negative consequences for users along the entire length of the river. Moreover, as discussed more fully below, water is lost throughout the basin due to excess consumptive use brought about by inefficient irrigation.

Conversely, water quality historically has been more region-specific. Water quality issues come in the form of naturally-occurring compounds such as salt, selenium (Se), and uranium (Ur) or by way of human introduction such as nutrients and pathogens. Much of the elevated levels of naturally-occurring compounds are attributed to human related activities such as irrigated agriculture and wastewater from urban areas and livestock operations. While not the only contributors to water quality concerns, these are understood to be significant contributors. Curbing the impact of these contributors could provide noteworthy improvement to Arkansas River water quality.

One issue of increasing concern is the presence of high levels of Se in the waters of the LARV. High levels of Se are the result of evaporative concentration, subsurface irrigation return flows mixing with applied fertilizers, and the presence of Se-bearing rock formations. The presence of groundwater return flows and nitrate (NO3-) from fertilizer is understood to accelerate the dissolution and transport of Se from the region's shallow marine shale into the groundwater and eventually back to the river. The United States Geological Survey (USGS) classified the Arkansas River basin as a Se-contaminated region, identifying irrigation as the primary contributor to pollution (Seiler et al., 1999). Gates et al. (2009, 2016) provided a more detailed analysis of dissolved Se concentrations in the LARV and identified significant variability in spatial and temporal distribution of Se concentration by segmenting the LARV into two study regions, an upstream and downstream region[3]. These studies examined LARV dissolved Se levels for comparison against the Colorado Department of Public Health and Environment (CDPHE) and U.S. Environmental Protection Agency's (EPA) chronic criterion for aquatic habitat protection of 4.6 micrograms/liter (μg/L) in streams and the standard for livestock watering of 50 μg/L in groundwater. The studies found that while both sites exceeded the stream criterion, upstream measures[4] were significantly less than those downstream, being about 13.5 μg/L and 15.2 μg/L respectively. Groundwater concentrations also exceed the standard, averaging 64.2 μg/L and 58.7 μg/L in the upstream and downstream regions, respectively.

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[3] The upstream region is defined as the stretch of Arkansas River from Pueblo, CO to the John Martin Reservoir, while the downstream region extends from John Martin to the CO-KS Stateline.

[4] The stream chronic criterion and the field measures of Se, Ur, and N in streams are 85th percentile values.

More recently, high concentrations of Ur in the LARV have caught the attention of water managers. Concentrations in the Arkansas River and the groundwater substantially exceed the chronic standard of 30 μg/L (Gates et al 2016). Values average 15.1 μg/L in the upstream region and 56.5 μg/L in the downstream region. Average groundwater concentrations are 111 μg/L and 165 μg/L in the upstream and downstream regions, respectively.

In 2012, CDPHE issued Regulation 85 to address the growing concern over nutrient pollution of Colorado's waterways, which can lead to the proliferation of algae blooms and affect human health. The regulation sets up interim standards for the concentration of N and phosphorus (P). The standard for inorganic N in all forms is 2 milligrams/liter (mg/L). Data from the upstream and downstream regions of the LARV indicate that NO3-N alone exceeds the interim standard for total N (NO3- + NO2− +NH4+) at several stream locations. Measures of NO3- nitrogen concentration are 7.7 mg/L and 6.4 mg/L in the groundwater of the upstream and downstream study regions. Though these concentrations are below the chronic drinking water standard of 10 mg/L, they have been shown to cause chemical reactions that contribute to increased Se concentrations (Bailey et al., 2012, 2014).

Salinity, or the total concentration of dissolved inorganic ions in water or soil, is a major concern in irrigated regions around the world. This mainly is because high salt concentrations inhibit the ability of crops to take water from the soil, thereby causing yields to decline. Like Se, salts build up in irrigated soils due to evaporative concentration and the dissolving of salt compounds out of geologic formations. Soil salinity levels in more than 40% of the study regions in the LARV exceed threshold tolerances for crops, with the regional average of crop yield reduction from salinity and waterlogging estimated to range from 6 to 17% (Morway and Gates, 2012). Average salinity concentration of the water table aquifer is approximately 2,700 to 3,000 mg/L, and annual salt loading to the Arkansas River from groundwater return flows is about 715 lb per irrigated acre, per mile along the river (Gates et al., 2016). In the 1990s, 68% of surveyed producers stated that high salinity levels are a significant concern (Frasier et al., 1999). A survey completed this year by Hoag et al. (2016) confirms that this concern remains.

Canal seepage and deep percolation from excess irrigation have caused shallow groundwater levels to rise in the LARV. These water tables near the ground surface not only contribute to the upward flow of water and salt under irrigated fields but also under adjacent fallow and naturally-vegetated fields. It has been estimated that high water levels result in a significant amount of evaporation from the soil on fallow and naturally-vegetated fields, amounting to excessive non-beneficial consumptive use (Niemann et al., 2011, Morway et al., 2013).

Over the last few years, studies using data and computer models reveal that best-management practices (BMPs) such as canal sealing, reduced irrigation application, reduced N fertilizer loading, and land fallowing could significantly lower salt, Se, and NO3- + NO2− +NH4+ concentrations in the LARV. They also could increase crop yield and potentially lower non-beneficial consumptive use (Burkhalter and Gates, 2006; Morway et al 2013; Bailey et al., 2015). Sound economic data on alternative irrigation practices, like that provided in this report, are essential to determining if widespread adoption of these BMPs is feasible and practical.

3.0 Institutions Governing the Irrigation Landscape

Like much of the western United States, complex institutional structures have an important effect on water ownership and use in the LARV. Institutional structures complicate decision making for farmers and ranchers who often operate with multiple objectives. A brief introduction into these structures follows.

3.1 Doctrine of Prior Appropriation

Colorado surface water and tributary groundwater is allocated through the Doctrine of Prior Appropriation. This legal framework, authorized by the Colorado Constitution, guarantees a water right holder access to river conditions and an associated water quantity that existed at the time of adjudication, so long as water is put to a designated beneficial use.[5] This last piece is critical and will be explored in coming sections. In simple terms, this doctrine is often referred to as "First in time, first in right."

The Colorado Constitution describes prior appropriation in Article XVI, Section 5 and 6 and requires water routinely be put to a beneficial use or else a water right could be subject to abandonment in part, or in whole. The state of Colorado specifies that, to lose one's water right, not only must a water right be unused for a length of time (typically 10 years or more), but there also must be *intent* to abandon that right. Thus, a prolonged period of non-use does automatically result in abandonment.

Nevertheless, many irrigators insist on continuing to divert their maximum allowable amount under the assumption that a reduction in the *diversion* could be deemed abandonment and would impact the security and value of their right. In fact, the total amount diverted does not constitute the value of the asset, as the only water that can be transferred, or sold, is the historical consumptive use and not water losses (via canal seepage, deep percolation, runoff, etc.).

Recently, a CSU Colorado Water Institute (CWI) workgroup, which included State Engineer Dick Wolfe, authored a FAQ report aimed at debunking common misbeliefs about "use it or lose it" (Waskom et al., 2016). The report clarifies that "use it or lose it" is not meant to deter water conservation practices or efficiency improvements. There is emphasis on the importance of diverting only the necessary amount of water required to fulfill the decreed beneficial use of a water right. Excess diversions can even be deemed as wasteful, which can result in the need to increase the return flow requirement for a grower. It is critical that growers maintain accurate diversion and use measurements and that they carefully document any efficiency improvements to avoid future discrepancies and to ensure the value of their water rights.

3.2 Arkansas River Compact

Ratified December 14, 1948, the bilateral compact between the states of Colorado and Kansas acts as the primary governance mechanism for the waters of the Arkansas River. The Compact's objectives as defined in Article I are to:

> A. Settle existing disputes and removes causes of future controversy between the states of Colorado and Kansas, between citizens of one and citizens of the other state, concerning the waters of the Arkansas River and

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[5] Citizen's Guide to Colorado Water Law (2004)

> their control, conservation and utilization for irrigation and other beneficial purposes.
>
> B. Equitably divide and apportion between the states of Colorado and Kansas the waters of the Arkansas River and their utilization as well as the benefits arising from the construction, operation and maintenance by the United States of John Martin Reservoir Project for water conservation purposes. [6]

Article IV-D of the Compact further protects future beneficial development in the LARV provided said development does not "…materially deplet[e] in usable quantity or availability," the waters of the Arkansas River.[7] This essentially means that developments on or along the Arkansas River cannot impact the "Stateline flow" of water from Colorado into Kansas. Such developments include certain changes in conveyance efficiency and irrigation application efficiency. The compact also creates an interstate agency, which is tasked with administering the Compact through rule creation, review, and enforcement, including investigating any allegations of compact violation. This administration is comprised of three governor appointed state representatives from both Colorado and Kansas, of who are required to be residents and water rights holders of identified counties/ water districts. It is also required that one Colorado member be the director of the Colorado Water

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[6] Arkansas River Compact (1949), C.R.S. Secs. 37-69-101 to 37-69-106

[7] The Arkansas River Compact defines the "waters of the Arkansas River" as "…waters originating in the natural drainage basin of the Arkansas River, including its tributaries, upstream from the state line, and excluding waters brought into the Arkansas river basin from other river basins."

Conservation Board (CWCB) and one Kansas member is the chief officer in charge of water rights administration. The administration is bound in by-laws to meet annually where it receives reports from its Operations, Engineering, and Administrative and Legal standing committees.

3.3 Irrigation Improvement Rules

Colorado State Engineer Dick Wolfe filed the *Compact Rules Governing the Improvement to Surface Water Irrigation Systems in the Arkansas River Basin in Colorado* (Rules) in 2009 as a means of regulating surface water irrigation improvements to ensure compliance with the Arkansas River Compact. The Rules, which took effect on January 1, 2011, apply to surface water irrigation users [8] and practices in the Arkansas River Drainage Basin. These rules specifically address Article IV-D of the Compact to protect against the material depletion of Arkansas River water downstream.

3.3.1 Rule 8: Application for Irrigation Improvement

Rule 8 describes the process for applying for the Division Engineer's approval to make an improvement to an irrigation system. Applications require a detailed description of the current surface water irrigation system and the improvement being made. However, Rule 8 also allows for the optional submittal of

> "…any relevant information, including a report from [a] licensed professional engineer [and] information pertinent to the leaching requirement [and] information from the manufacturer, distributor, installer describing the improvement['s] effect on consumptive use of water or historical seepage losses and return flows."

Recognizing the potentially high cost of acquiring such information for a single farmer, the Rules added a provision for multiple growers to act as a single party in filing an application to improve an irrigation system known as rule 10.

3.3.2 Rule 10: Compact Compliance Plans

The Compact Compliance Plans, Rule 10 provides an opportunity for growers in the LARV to apply for a surface water system improvement as a collaborative group and replace reduced irrigation return flows with water other than the "subject water right."

Joint-application submittal, through a ditch company, augmentation association, or conservancy group provides benefits to regional growers by reducing the cost of irrigation improvement impact analysis, and the administrative burden for both growers and engineers by consolidating multiple irrigation improvement applications.

While increased consumptive use is, in most cases, not allowed, enrollment in a Rule 10 plan mitigates the legal risk of increasing consumptive use, so long as the plan has sufficient return flow volumes. This creates an additional benefit for some growers taking part in a Rule 10 plan. By allowing the use of water from all farms to maintain historical return flows in a collective fashion, a grower can replace flows depleted by his particular efficiency improvements with water from other members in the plan and/or with non-native flows from outside the basin. Growers who return excess water to the river after an improvement

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[8] The Rules apply to surface water irrigators who irrigate over on acre of land.

provide a public good to growers who return less by allowing them to offset deficits, with accretions. This will be further explained and discussed in later sections.

3.4 Mutual Ditch Companies

Mutual ditch (canal) companies, or ditch companies, play a critical role in the management of water in Colorado. Ditch companies are private entities, owned by shareholders, who manage water structures, water rights, and water conveyance (Jones and Cech, 2009). Ditch companies generally have a set of by-laws by which they operate, and are governed by a shareholder-elected board of directors. Because ditch companies act as the holders of water rights, seniority is generally assessed at the canal level.

The volumetric worth of a share in a ditch company varies from canal to canal, but generally represents a proportional amount of available water in a given year. Each canal employs a “ditch rider” to control head gates and conduct canal maintenance. The ditch rider is responsible for ensuring that each grower accurately and consistently receives his/her shares of water.

3.5 Lateral Ditch Companies

Lateral ditch companies play a very similar role to mutual ditch companies; managing conveyance structures, and operating conveyance of water along lateral canals that divert flow from main canals. The two differ in that lateral ditch companies own no water rights. The sole propose of lateral ditch companies is to transport water from a main canal head gate to a farm. Often farms that are not adjacently located near a main canal own shares in a lateral ditch company. Shares in a lateral ditch company allow for the conveyance of water through the lateral onto a farm. Lateral ditch companies perform the same canal maintenance and operation activities as mutual ditch companies.

4.0 Irrigation Methods

The methods that farms in the LARV use to irrigate are varied and nuanced. For the purpose of this report, we focus our attention on those systems that have been identified as best management practices (BMPs) for improving water quality, boosting productivity, and conserving water. In describing the common technologies, we will assume that irrigation water is sourced from the Arkansas River, and that an individual irrigator receives water deliveries through a mutual ditch company.

Irrigation methods will be identified as “triggering” and “non-triggering” with regard to the *Irrigation Improvement Rules*. We define a triggering option as one requiring a Rule 10 plan, whereas a non-triggering option can be applied without a Rule 10 plan. That is, farmers can make non-triggering irrigation efficiency improvements on their farm without special permissions or permits, but all triggering options must be approved. This becomes important when analyzing the costs of adopting various BMPs. Triggering options do not require Rule 8 compliance if Rule 10 is used. The high costs of an individual Rule 8 plan make it an uncommon occurrence in the LARV, and impractical for most growers.

Irrigation practices occur at two levels – on-farm and off-farm. This distinction is important because some of the BMPs are inherently on-farm practices, controlled primarily by the proprietor of a farm (i.e. altered irrigation technology or management). Other decisions, such as main-canal sealing, are made at the canal level, by farmer shareholders and the board of directors. These decisions are more complicated because they involve heavy organization and often require approval from shareholders.

On-farm improvements are assumed to occur on fields utilizing furrow (also referred to as flood) irrigation. According to the CDWR, an estimated 80% of fields in the LARV utilized furrow irrigation in 2014. Figure 1 shows how total irrigation acreage and the percentage of different irrigation systems have changed since 2004.

Water in these systems typically is delivered from the lateral canal to a field ditch, then to the field, via siphon tubes. Furrow lengths are highly dependent on field characteristics and vary significantly across farms. Common lengths generally range between ⅛ mile (660 ft) and ½ mile (2,640 ft.). Furrowing is the most common form of surface irrigation and, coupled with earthen on-farm ditches, serves as the baseline irrigation method for this study. It is expected that the baseline irrigation method delivers on farm system efficiencies (E_s) between 35% and 70%.

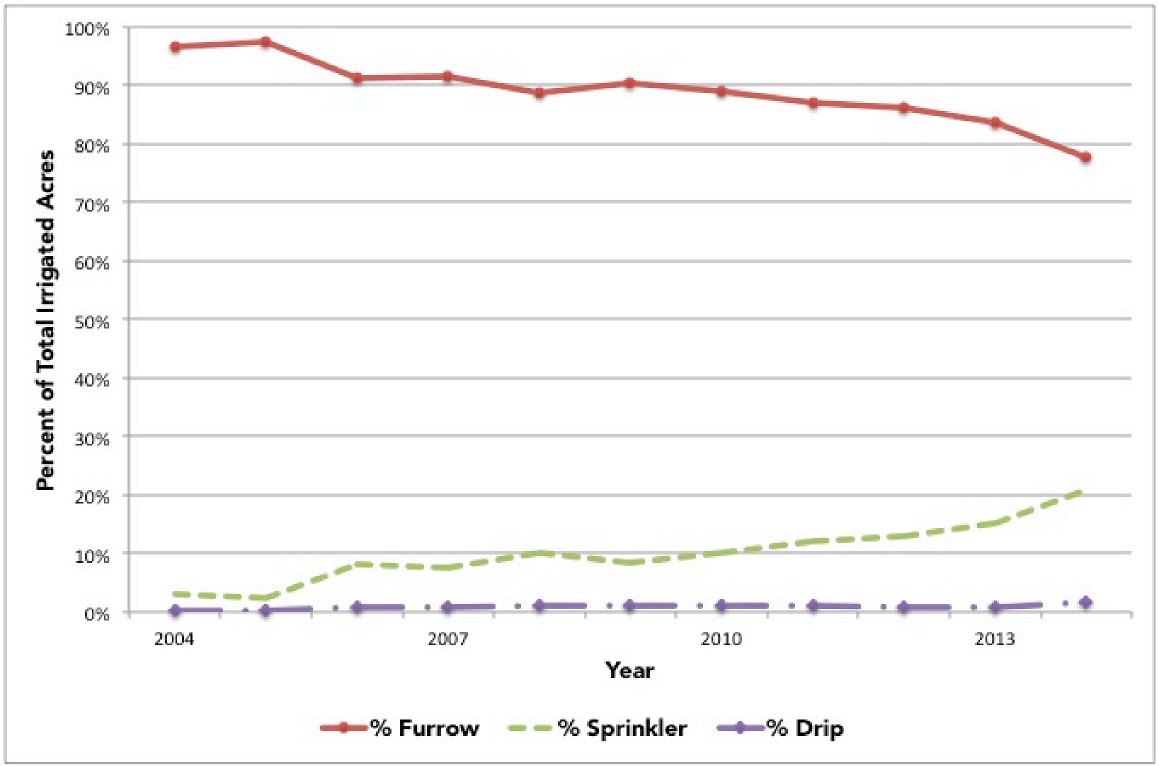

Figure 1: Total irrigated acreage percentages of furrow, sprinkler, and drip irrigation in the Lower Arkansas River Basin, 2004-2014. Source: Hydrological-Institutional (H-I) Model, Colorado Division of Water Resources.

4.1 Surface Water Conveyance

Prior to application in a field, water must be conveyed from the river to the application site. There are generally three diversions that take place: (a) from the river into a main canal where it is again diverted either, (b) directly to a farm, or (c) into a lateral canal, where it transported to numerous farms. The main canal and off-farm lateral canals make up the off-farm portion of conveyance. On-farm ditches are used for moving water within the same farm, generally between fields.

The conveyance process means that not all water that is diverted makes it to the crop being grown. When analyzing on-farm irrigation decisions, conveyance efficiency also must be considered.

Conveyance systems, both on- and off-farm, generally are constructed in one of three methods, where efficiencies are given by E_c:

- Earthen channel (E_c = 70-85%)
- Concrete channel (E_c = 90-95%)
- Pipeline (E_c = 99-100%)

The most basic form of water transportation is by earthen canals. Earthen canals are trenches dug into the ground and constitute the least efficient method of conveying water to a farm. It is estimated that between 15-30% of water flowing through earthen canals is lost to evaporation, seepage, and non-beneficial consumption by phreatophytes (Martin and Gates, 2014; Byelich et al., 2013; Brouwer et al., 1989). Most off-farm systems transport water using earthen canals. The performance of earthen canals can be significantly improved through the use of sealants, minimizing seepage losses in an often cost-effective way (Susfalk et al., 2008).

Concrete ditches represent a significant upgrade from earthen ditches and are estimated to lose only between 5-10% of water to seepage. Due to their relatively high cost, these are more common in smaller on-farm channels than in main or lateral canals. The last option for on-farm conveyance is pipeline. Pipelines are estimated to be 99-100% efficient, but carry the highest investment cost.

4.2 Non-triggering Improvement Options

There are several improvements to existing irrigation systems in the LARV that do not require State Engineer approval. These practices generate benefits to individual growers, ditch companies, and to the region, without changing historical return flow patterns or consumptive use.

4.2.1 On-Farm Non-Triggering Improvements

On-farm improvements provide numerous benefits, not only on-farm and but also off-farm. These can increase the distribution uniformity of applied water to better meet evapotranspiration requirements of crops, potentially increasing yields. Lowering the water table and decreasing dissolved salt, trace elements, and excess nutrient levels are benefits that accrue to the basin as a whole.

On-farm improvements that do not require State Engineer approval include:

- Gated pipe installation
- Laser-leveling of fields
- On-farm ditch lining, sealing, and compaction
- Irrigation measurement and scheduling
- Fertilizer management

A gated-pipe system typically consists of a PVC, polyethylene, or aluminum pipe that is laid out along the head-end of a furrowed field. Irrigation water is supplied into the pipe via on-farm ditch, and flows through small gated outlets into furrows. Gates can be fixed or adjustable, providing a grower with flexibility in the amount of water that flows onto a field. Gated-pipe systems offer opportunities to leverage other irrigation technologies such as surge valves, which can be used to adjust the flow rate into the furrow to achieve more uniform infiltration along the furrow. Coupling surge valves with gated pipe, irrigators are able to increase the uniformity of irrigation water application and to reduce the over-application that commonly occurs along the upper end of the field and leads to excess deep percolation. It is also common for irrigators to forego surge valves and to simply time flows through the gated pipe, so as to mimic surge irrigation. Gated pipe systems are expected to deliver system efficiencies (E_s) in a similar range as the baseline scenario, although in general we expect to see values on the upper end of the 35% -70% range.

Laser leveling is a field management practice that involves precision grading the land to ensure more uniform irrigation flows and to reduce soil erosion. While often applied to surface irrigated fields, sprinkler irrigated fields also can substantially benefit from this practice. Leveling allows water to flow at closer to optimal rates across the field's surface, contributing to greater uniformity and control of infiltration and to less soil erosion. For this report, laser leveled fields are assumed to be irrigated with furrows and gated pipe. This practice provides a significant improvement to the performance of these surface irrigation technologies, and increases the range of E_s to 50%-75%.

Concrete lining of on-farm ditches is a practice that significantly reduces the amount of water lost during conveyance. This practice involves lining the bottom of an existing ditch with a 2.5-inch thick concrete. This practice is assessed in this report for a ¼ mile (1,320 ft) field ditch.

Sealants and compaction are less costly non-triggering alternatives that can be used to control seepage losses in on-farm ditches but require seasonal implementation. Sealants, like polyacrylamide, can be sprayed as an emulsion onto the perimeter of a dry ditch or can be dispersed in granular form onto flowing water in the ditch. Compaction is accomplished using heavy machinery. Burt et al. (2010) conducted field studies on canal compaction and found that sites with compaction of bottom and sides resulted in an 85% reduction in seepage rates. Seepage rate of compacted earthen canals is found to be comparable to that for concrete ditches, and often costs significantly less.

4.2.2 Off-farm Non-Triggering Improvements

The list of off-farm improvement options that are not subject to State Engineer approval include:

- Eradication of phreatophytes along a canal or ditch
- Dredging canals and laterals
- Compaction of canals

4.3 Triggering Improvement Options

Triggering practices are changes to irrigation systems that require approval from the State Engineer in the form of a Rule 10 plan.[9] Rule 10 plans ensure compliance with the Arkansas River Compact by accounting for changes to return flows (time and place) using computer modeling. Modeling return flows provides growers with an estimate of the volume of replacement water owed to the river. Because a Rule 10 plan spans various canals and farms, return flow changes can be in the form of deficits or accretions. A significant advantage of a Rule 10 plan is that accretions can be counted as credits to the river, and can be used to off-set deficits from other farms in the plan.

4.3.1 On-Farm Triggering Improvements

On-farm practices subject to State Engineer approval through a Rule 10 plan include the following:

- Head stabilization ponds
- Irrigation system improvements (center-pivot sprinkler or drip)

Head stabilization ponds commonly are constructed prior to making the transition from a gravity fed system to a pressurized system. Water is then pumped from the head stabilization pond to the sprinkler where it is applied to the field. Arkansas River water is often laden with suspended sediments that can clog pumps and nozzles of pressurized irrigation systems. Stabilization ponds allow suspended particles (silt, sand, etc.) to settle prior to pumping, lengthening the life of pumps and minimizing labor efforts to clear nozzles. By providing a modest volume of storage capacity they also serve to dampen any differences between the canal inflow rate and the sprinkler-pumping rate. Moreover, Colorado water administration policy allows for water to be detained in storage for no longer than 72 hours without storage rights (Simpson and Wolfe, 2016), which is often sufficient time for farmers to complete an irrigation set.

Unlined-ponds also serve as a source of return flows for Rule 10 accounting. Seepage of water from head stabilization ponds for sprinklers sometimes can generate accretions to

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[9] Approval can also come through an individual farm's Rule 8 plan. However, due to the high costs of arranging a Rule 8 plan, we have ruled out this situation as a practical approach for most farmers.

the river, or amounts greater than historical return flows from previously surface-irrigated fields, and provide an opportunity for some growers to avoid purchasing replacement water.

Growth of sprinkler irrigation systems in the LARV is undeniable. Sprinklers, which were uncommon in the LARV in 2004, currently account for an estimated 20% of irrigated acreage in the LARV. In particular, sprinklers fed from surface water are currently driving growth of sprinkler-irrigated acreage, possibly impacted some by the implementation of the *Irrigation Improvement Rules*. Figure 2 shows the growth in sprinkler acreage by water source.

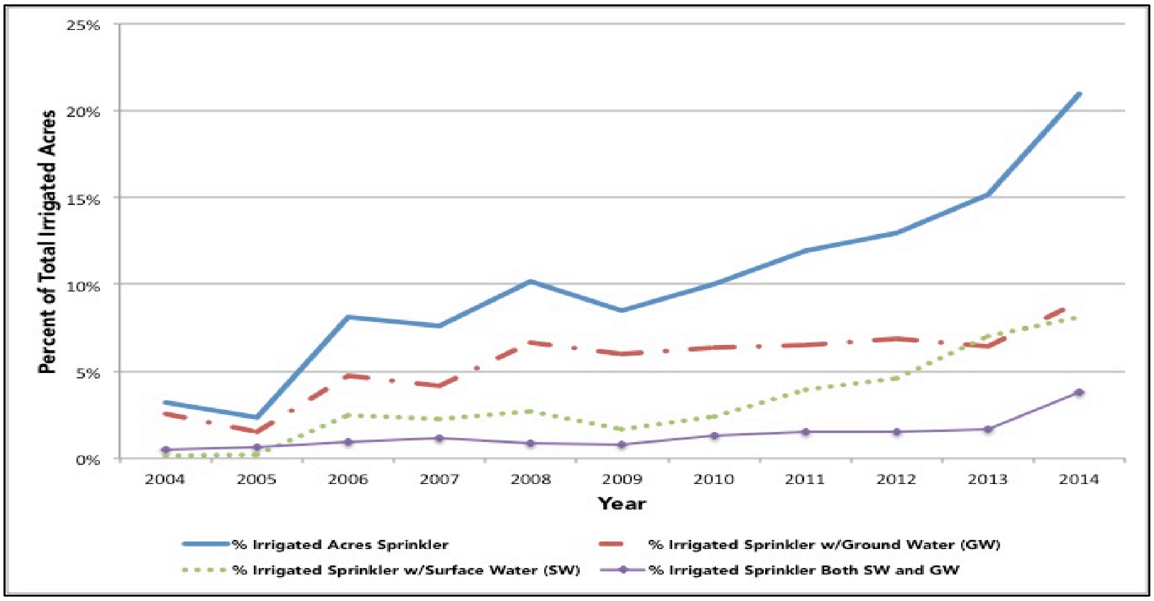

Figure 2: Sprinkler irrigated acres by water source in the Lower Arkansas River Valley, 2004-2014. Source: Hydrological-Institutional (H-I) Model, Colorado Division of Water Resources.

The most common area covered by a sprinkler is a quarter section (2,460 ft x 2,460 ft), which irrigates a 120-160 acres depending on the use of corner attachments. This report addresses two variations of low-pressure center pivot systems which are commonly used.

Mid-elevation spray application (MESA) systems deliver water through drop tubes situated between five and ten feet above the ground. MESA irrigation is well suited for tall crops like corn and sorghum, and applies water above the crop canopy. Application uniformity is marginally impacted by height, although more evaporation and wind drift losses occur with higher positioned sprinklers, and system efficiencies are expected to range between 70% and 90%.

Low Elevation Spray Application (LESA) systems deliver irrigation water through similar drop tubes as MESA, except water is delivered much closer to the ground. LESA irrigation systems generally deliver water between 12-18 inches from the ground, minimizing losses to wind drift (United States Department of Agriculture, n.d.). Decreasing losses improves the expected range of system efficiency to between 75% and 95%.

This report will also investigate center pivot installation on a 40-acre (1,320 ft. x 1,320 ft.), resulting in a roughly 30 acre irrigated area. LARV growers identified this scenario as a realistic option for those with limited field space. Under this scenario, both MESA and LESA application methods will be analyzed.

Based on conversations with local growers, the primary benefits of installing sprinklers includes reduced labor costs; reduced fieldwork (utilization of minimal/no-till practices); increased application uniformity; and potential increases in yields. By filing a Rule 10 plan, growers can improve their irrigation system and have an accurate estimate as to the amount of replacement water they need to purchase. As previously highlighted, replacement water costs can be zero if the net change across the plan is negative.

Drip irrigation represents another Rule 10 plan triggering irrigation improvement. Drip irrigation systems deliver lower water volumes in a slow and continuous manner, keeping soil moisture and plant uptake levels more consistent (Lamont Jr. et al., 2012). These low-pressure systems can be installed above or below the surface, and deliver water through thin tubes or drip tape. These systems offer the highest range of efficiencies, estimated between 85% and 98%. However, drip irrigation is best suited for high value specialty crops and generally requires a steady, reliable water source. This may limit its application and expansion potential in the LARV.

4.3.2 Off-Farm Triggering Improvements

Off-farm practices that are subject to State Engineer approval through a Rule 10 plan include the following:

- Lining or sealing the main canal or off-farm lateral canal
- Pipeline installation replacing earthen off-farm laterals

These practices, discussed in previous sections, have been found to alter the historical pattern of return flows (time and place), potentially creating a situation where Stateline flow is altered. Thus, they require measures to be taken to offset these impacts.

5.0 Investment Costs

Investment costs of individual on-farm irrigation systems are the “up front” charges that are incurred before a system can be used. These were derived through careful consideration of the following issues:

- Conveyance or access to water
- Fees/costs for permissions (Rule 10 plan)
- Equipment investment and annual ownership costs
- Water storage and pumping costs

Table 1 summarizes the assumptions about characteristics of alternative irrigation systems that were made for calculating investment costs. These assumptions are not comprehensive and it is recognized that not all farms will operate under these conditions. However, these assumptions are consistent with various other economic analyses and generally reflect the nature of the systems investigated.

Table 1 - Assumptions about the characteristics of alternative irrigation systems made in calculating investment costs.

Practice	Operating Pressure (PSI)	Conveyance Efficiency (%)[b]	Application Efficiency (%)	System Efficiency (%)	Acres Irrigated	Useful Life (Years)
Non-Triggering						
Furrow (Earthen Ditches)	*GF*[a]	80%	60%	48%	60	5
Furrow (Compacted Earthen Ditches)	*GF*	93%	60%	56%	60	5
Furrow (Concrete Ditches)	*GF*	95%	65%	62%	60	25
Gated Pipe	*GF*	100%	65%	65%	60	15
Gated Pipe (Surge Valve)	*GF*	100%	70%	70%	60	15
Laser-Leveling (Furrow & Concrete Ditches)	*GF*	95%	75%	71%	60	15
Laser-Leveling (Gated Pipe)	*GF*	100%	75%	75%	60	15
Triggering						
Center Pivot (MESA)	20	95%	85%	81%	120	20-25
Center Pivot (LESA)	20	95%	90%	86%	120	20-25
SDI	15	100%	95%	95%	60	15

a – Gravity fed system
b – On-farm losses only.

5.1 Conveyance Costs

Costs associated with surface water conveyance generally take the form of ditch company assessments. Shareholders pay these fees to cover administrative costs, ditch rider services, and canal rehabilitation and maintenance. These costs vary from canal to canal, but represent a real economic cost that an irrigator will pay each year. However, this report focuses on the on-farm decisions a grower can choose, and assessments do not change between irrigation systems, and therefore assessments are not included in cost comparisons.

5.2 Rule 10 Costs

Replacement water plans are required for all irrigation practices that are recognized by the Colorado Division of Water Resources (CDWR) to increase consumptive use or alter historic return flow patterns. The required engineering reports, showing spatial and temporal distribution of altered return flows and sources of replacement water, often are cost prohibitive for a single farmer. However, Rule 10 provides relief for these high costs by allowing multiple growers to submit a single plan for replacement to off-set any change in historic return flows.

The LAVWCD further simplifies this process by operating a Rule 10 plan for growers in their district, including all five counties in the LARV. LAVWCD requires that a farmer be a member, which costs $500/year, and charges a $300 administrative fee to develop and file a plan for farmers; the plan includes engineering analysis, replacement water sourcing, and return flow accounting. This significantly lowers the transaction costs of participating in a replacement water plan. If your farm exists in one of the five counties served by the LAVWCD (Bent, Crowley, Otero, Prowers, Pueblo), you are eligible to take part in this Rule 10 plan.

5.3 Annual Ownership Costs

Improving an irrigation system requires an investment in equipment and/or installation services. The gross investment costs, initial cost of system installation, presented in Table 2 include necessary equipment, and installation materials and labor for several types of systems irrigating an assumed land area. Gross investment costs were taken from the USDA Natural Resources Conservation Service report (2016), *EQIP Regional Payment Scenario Details - State of Colorado*. NRCS estimates are of particular interest due to their expansive cost sharing programs for projects such as irrigation efficiency improvements.

Annual ownership costs represent a fixed production cost, meaning they occur each year with or without crop production, and take into consideration initial cost of equipment (gross investment cost), depreciation, taxes, insurance, and housing costs (TIH), and repairs and maintenance costs. Annual ownership costs are presented on a per acre basis and are calculated as the sum of depreciation (d), interest (i), TIH (h), and repairs and maintenance (r) divided by the number of acres, where:

$$d = \frac{(gross\ investment - salvage\ value)}{useful\ life}, \text{ where salvage value is estimated as 20\% of the present value gross investment}$$

$$i = interest\ rate * \left(\frac{gross\ investment - salvage\ value}{2}\right)$$

$$h = 0.005 * \left(\frac{gross\ investment - salvage\ value}{2}\right)$$

$$r = .02 * gross\ investment$$

Table 2 - Investment costs for various irrigation management options. Source: USDA Natural Resource Conservation Service cost schedule

Practice	**Acres Irrigated**	**Gross Investment Cost ($)**	**Gross Investment/Acre**
Non-Triggering			
Siphon Tubes	60	$2,712	$45
Gated Pipe	60	$6,242	$104
Surge Controller	60	$2,290	$38
Laser-leveling	60	$112,821	$1,880
Farm Ditch Compaction	60	$1,292	$22
Farm Ditch Concrete Lining	60	$20,156	$336
Triggering			
Head Stabilization Pond	30/120[a]	$9,500	$79/317
Center Pivot (MESA & LESA)	120	$98,144	$818
Center Pivot (MESA & LESA)	30	$52,296	$1,743
SDI	60	$116,735	$1,946
Diesel Pumping Plant	30/120	$21,600	$720/$180
Electric Pumping Plant	30/120	$12,215	$407/$102
PVC Pipeline	30/120	$14,404/$28,809	$480/$240

a - 30/120 designates costs of installing equipment on 30 or 120-acre field, respectively. Costs of these options are presented similarly.

Table 3 shows annual ownership costs for five identified irrigation systems and their components. Component estimates such as head stabilization ponds and pumping stations only apply to sprinkler and drip systems, and are discussed in further detail below.

Table 3 – Annual ownership costs of irrigation systems.

Practice	Acres Irrigated	Annual Ownership Costs	Annual Ownership Costs/acre
Non-Triggering			
Siphon Tubes	60	$285	$5
Gated Pipe	60	$620	$10
PVC Pipeline (500 ft.)	60	$339	$6
Surge Controller	60	$227	$4
Laser-leveling	60	$5163	$86
Farm Ditch Compaction	60	$701	$12
Farm Ditch Concrete Lining	60	$1662	$28
Triggering			
Head Stabilization Pond	30/120[a]	$879	$29/$7
Center Pivot (MESA & LESA)	120	$8,429	$70
Center Pivot (MESA & LESA)	30	$4,991	$150
SDI	60	$1,946	$200
Diesel Pumping Plant	30/120	$2,720	$91/$23
Electric Pumping Plant	30/120	$1213	$40/$10
PVC Pipeline (900/1,800 ft.)	30/120	$527/$824	$18/$9
[a]– 30/120 designates costs of installing equipment on 30 or 120-acre field, respectively			

5.3.1 Furrow Costs

As previously identified, the baseline irrigating practice for this report is furrow irrigation. Equipment costs for this practice are limited, the primary costs are siphon tubes used to deliver water to the furrows, and the formation of ditches for conveyance to the field. A 60-acre field (1,320 ft. X 2,000 ft.) with 40-inch furrow spacing requires 33 furrows. The cost of 50 siphon tubes[10] is estimated at $572, with a useful life of 15 years. Earthen ditches are estimated to cost $1.18 per foot for a 2 ft. deep, by 2 ft. wide ditch. Given the field measurements, we assume an irrigated area of 1,320 ft. x 2000 ft., and 500 ft. of conveyance, with a total gross investment cost of $2,712. These combined gross investment costs result in an annual ownership cost of $5 per acre.

The efficiency of furrow irrigation can be improved by minimizing the conveyance losses associated with transporting water from the main canal turnout to the field. We present two solutions for doing so: 1) compaction of earthen ditches, and 2) concrete lining of ditches.

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[10] Siphon tubes are assumed to be 1¼ "diameter and 72" length, double-bend aluminum tubes.

Compaction of farm ditches is assumed to reduce seepage losses by 70% in comparison to un-compacted earthen ditches, although estimates as high as 90% have been recorded (Burt et al., 2010). It is estimated to cost $0.71 per ft. to compact 1,820 ft. of ditch. Compaction is estimated to have a useful life of two years and annual ownership costs of $12 per acre. Permission from CDWR is not required for on-farm improvements like this.

Concrete-lining of farm ditches further increases the efficiency of transporting water on the farm. This practice involves installation of a semi-permanent concrete lining into an existing earthen ditch. Installation and materials over 1,820 ft. is estimated to cost $20,156, with a useful life of 25 years. The annual ownership cost of concrete-lined laterals is $28 per acre.

5.3.2 Gated Pipe Costs

Gated pipe is generally installed where furrow irrigation exists as a means of improving the distribution of irrigation water across the field. Costs for installing gated pipe depends on furrow spacing and field dimensions. Costs were calculated assuming 1,320 linear feet of PVC gated pipe, with 40-inch gate spacing, and 500 ft. of conveyance pipeline. Assuming a 15-year useful life, total annual ownership costs are estimated at $16 per acre. The addition of a surge controller to this system is estimated to increase per acre costs by $3.79 bringing the total cost of a gate pipe system with surge controller to $20 per acre.

5.3.3 Laser leveling Costs

Laser leveling cost estimates are very dependent on individual characteristics of a field including size, slope, and soil type. For a 60-acre field, we assumed 39,000 cubic yards of material are removed or relocated. The cost to move this amount of soil is estimated at $84,630. We assume once a field is initially leveled, it is only necessary to maintain the level annually with regular field practices. Therefore, we assume a 60-year useful life of this practice. Also, because this practice is used in conjunction with an irrigation application system, costs are presented for two scenarios. The total annual ownership costs assuming the baseline furrow scenario are estimated at $86 per acre. When laser leveling is applied to a gated pipe-equipped field, costs increase to $99 per acre.

5.3.4 Center-Pivot Sprinkler Costs

Analyzing the costs of installing a center pivot sprinkler system requires a determination of the footprint that the system will have on a field or the size of the new area irrigated. This decision can have a significant impact on the total cost of adopting a system if augmentation water is required with new acreage. For example, in this report we identified three possible footprint options that farmers could potentially face: 1) a square field that fits a full circle, 2) a half circle on a rectangular field, and 3) two quarter circles on opposite sides of a single field. For the calculations in this report, we focus on option 1, where a center pivot sprinkler is used to irrigate a 120-acre field, and operates in a full circle.

In the first option, the sprinkler is run in a full circle, leaving the four corners un-irrigated by the sprinkler. Furrow irrigation can be, and is often, maintained on the corners. In the second case, half of a center pivot is applied along the longest side of a field, which results in about 60% fewer irrigated acres than the full circle scenario depending on field shape. Finally, when two sprinklers are installed for optimum coverage, even on an odd shaped field, the system can compare to the coverage in option 1, but with a substantial increase in costs. Some farmers in the LARV told us that the investment was worth it when considering that the time to cover each side of the irrigation circles was faster with two sprinklers.

Suspended sediment particles in Arkansas River water prevent most growers from pumping water directly though sprinklers. To account for this, many growers install head-stabilization ponds that allow particles to settle out of the water. Estimating pond costs are complicated because costs are highly dependent on pond size, whether the excavation services and equipment are leased or owned, and whether excavated soil is disposed of on-site or transported away. For this report, we will assume excavation is a contracted service, and that the cost of a 2-acre-foot pond is $9,500. The annual ownership cost, assuming a useful life of 20 years, is estimated at $7 per acre of irrigated land.

A 10-inch, class 80 PVC pipeline typically is required to convey water from the head stabilization pond to the center-pivot irrigation system. This pipeline is assumed to be 1,800 linear feet, which costs $9 per acre of irrigated land annually. It is assumed that this pipeline has a usable life of 25 years and is sufficient to meet flows of up to 1,200 gallons/minute.

Finally, a low-pressure center-pivot sprinkle irrigation system, irrigating 120 acres is estimated to cost between $90,000 and $115,000. For this report, we assumed a gross investment cost for a 1,300-foot, center pivot sprinkler system to be $98,000. Installing a poly-pipe lined center-pivot system (primarily used with highly corrosive water sources) increases the initial investment to about $111,000. These costs are consistent with NRCS estimates used to determine cost sharing values, a topic discussed later in the report. We also estimate the gross investment cost of $52,300 for a 650-foot center pivot, irrigating 30 acres.

The gross investment cost includes the pivot point, pad, controls, pipe, towers, sprinklers, and installation. Although the initial investment of a poly-pipe system is greater, the extra useful life makes the annual ownership costs only marginally different. The total annual ownership cost for a 120-acre, full circle (option one described above) center-pivot sprinkler system, assuming a 20-year useful life, is about $6,921, resulting in annual ownership cost of $70 per acre. It is assumed that despite the how the sprinkler is installed, the field’s corners remain irrigated with surface methods. Accounting for the cost of the head-stabilization pond, PVC pipeline, and corner irrigation, the total estimated annual ownership cost is $106 per acre of irrigated land. When a full circle sprinkler is applied to 30-acre field, costs increase on a per acre basis for pond, pipeline, and sprinkler increase to $237 per acre of irrigated land. Figure 3 shows how annual ownership costs change with irrigated area, where as expected, costs decrease as the irrigated area increases.

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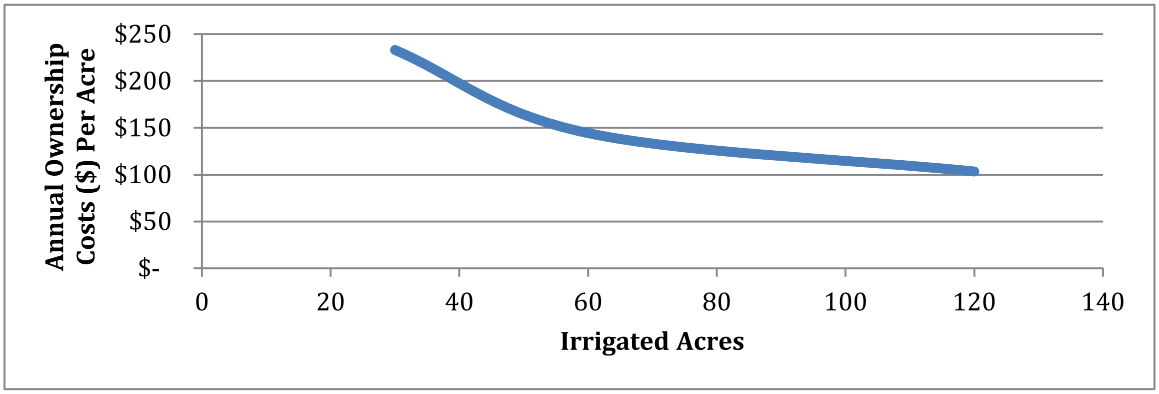

Figure 3: Annual ownership costs/per acre for various size center pivot sprinkler systems. Source: Author's calculations.

5.3.5 Sub-Surface Drip Irrigation Costs

Sub-surface drip irrigation (SDI) is uncommon in the LARV, accounting for less than 5% of the irrigated acreage. SDI requires a constant water source, which limits its feasibility to growers with high priority surface water rights or to groundwater users. However, there may exist instances when SDI is viable option for other growers. The ARMAC has identified operations growing high value vegetables and fruits as the primary users of drip irrigation, due to the increased marketability of the produce. The cost of an SDI system is significantly higher than that for other systems investigated and is estimated in the $120,000 range. This assumes the system is installed on a 60-acre field, with drip tape or drip line, installed in 40-inch rows, plowed 10-14 inches below the surface. The comprehensive system as described by NRCS includes all necessary components such as filter station, flow meter, drip tape, supply and flushing manifolds, and various control valves (USDA Natural Resources Conservation Service, 2016). The annualized ownership costs installing a SDI system on a 60-acre field are $200 per acre. Due to the water supply requirement of SDI, expansion of these systems in the LARV is relatively limited.

6.0 Pumping Costs

Irrigation pumping costs are considered in two parts: fixed equipment costs and variable costs. These costs are considered in this report only in application to pressurized systems (MESA, LESA, and SDI) and are highly variable depending on a wide range of factors. Typically, furrow irrigation systems using surface water are gravity fed. Fixed equipment costs are calculated as described above using a total annual ownership cost per acre. Variable costs are compared across energy sources and water volumes.

6.1 Fixed Equipment Costs

The cost of a pumping well is dependent on two key factors; energy source and size. The two primary sources of energy in the LARV are diesel fuel and electricity. The investment and operating associated with these types of pumps vary significantly. For this report, we are assuming a 50 HP pumping plant. This assumption is based on NRCS requirements for cost sharing programs. The pumping plant is assumed to consist of the pump, pump power unit, concrete slab, and installation.

A 50 HP, internal combustion engine is estimated to cost $21,600, with a useful life of 10 years. Installing this pump to serve a 126-acre center-pivot system results in an annual per acre cost of $23 over the life of the pumping plant. A 50 HP electric pumping plant is estimated to cost $12,215, with a useful life of 15 years. Installation of this pumping plant is expected to cost $10 per acre annually.

6.2 Variable Pumping Costs

Variable pumping costs are determined based on energy source, energy use, and irrigation water requirement and will vary significantly across farms. In calculating pumping costs, we need to introduce cropping scenarios that have varying irrigation water requirements. We analyze three pumping scenarios for crops with a High (alfalfa), Intermediate (corn), and Low (melon) water requirement. Typical pumping requirement calculations are conducted based on the amount of energy needed to bring water from an aquifer, to the delivery point at a required pressure. This report is focused on users who pump from a surface reservoir into a pressurized irrigation system.

The equation used to calculate the energy required in kilowatt-hours (Kwh) to apply one acre-inch is presented below:

$$ER = \frac{((H+F+P)*W)}{(E_p*2{,}655{,}220)}, \text{ where}$$

H = Vertical distance water is pumped (from surface of pond to discharge height)
F = Friction losses calculated using the Hazen-Williams equation
P = Pressurization of the systems equal to the systems operating pressure * 2 .00
W = Weight of water (226,602.22 lbs. /acre inch)

E_p = Pumping plant efficiency (engine efficiency rating * pump efficiency rating)

The result of the preceding equation is then multiplied by a crop water requirement to determine the total annual energy required to produce a given crop. Crop water requirements (acre-inch) are based on annual net water requirements as calculated by Colorado State University Extension (Schneekloth and Andales, 2009). Annual net water requirement (NWR) is the amount of water required by a crop necessary to maximize yield on one acre. The net irrigation requirement (NIR) is equal to the NWR, minus the average precipitation. Dividing the NIR by the system efficiency (as previously identified), expressed as a fraction, provides the gross irrigation requirement (GIR), or the amount of applied water that is required to meet NWR, given application losses. It was assumed that deep percolation losses are large enough to provide adequate leaching of salts from the soil profile. For sprinklers, however, this may not be true and additional GIR may be needed for leaching. Table 4 shows the GIR for three commonly grown crops with varying water requirements. Commonly grown crops in the LARV include alfalfa, corn, and melons.

Table 4 – Estimated GIR amounts for three commonly-grown crops in the LARV.

	Acres Served	System Efficiency	High GIR[1] (Alfalfa) (Acre Inch)	Intermediate GIR (Corn) (Acre Inch)	Low GIR (Melons) (Acre Inch)
Non-Triggering					
Furrow	60	48%	59.29	36.09	11.50
Furrow (Compacted Earthen Ditches)	60	56%	51.14	31.13	9.92
Furrow (Concrete Ditches)	60	62%	46.09	28.06	8.94
Gated Pipe	60	65%	43.78	26.65	8.49
Gated Pipe (Surge Valve)	60	70%	40.66	24.75	7.89
Laser-Leveling (Furrow & Concrete Ditches)	60	71%	39.94	24.32	7.75
Laser-Leveling (Gated Pipe)	60	80%	35.58	21.66	6.90
Triggering					
Center Pivot (MESA)	120	85%	33.48	20.38	6.49
Center Pivot (LESA)	120	90%	31.62	19.25	6.13
SDI	60	95%	29.96	18.24	5.81
1 - GIR assumes an average effective rainfall of 9.95 inches in the LARV					

It should be evident from Table 4 that as system efficiency increases, the GIR approaches the NIR, meaning good yields can be obtained with smaller application amounts, assuming that salt leaching is adequate. Again, pumping costs are assumed to only exist with pressurized irrigation systems (sprinkler and drip). Table 5 below illustrates estimated pumping costs per acre inch of water applied for three commonly grown crops in the LARV (alfalfa, corn, melons), while also providing estimates for both electric and diesel-powered pumping plants. Pumping costs are presented as a dollar per acre estimate. This estimate is based on the calculated energy requirement to pump the seasonal GIR of a crop. Assuming water is applied over eight irrigation events, the calculated cost is then divided by the number of acres for the assumed field size. These costs represent a portion of the variable costs associated with crop production and are primarily dependent on crop, field size, precipitation, and energy source/cost.

Table 5 - Pumping cost per acre.

Electric[1]	High GIR (Alfalfa) ($/ac)	Intermediate GIR (Corn) ($/ac)	Low GIR (Melons) ($/ac)
Medium Elevation Spray Application (MESA) Center Pivot	$29.02	$24.56	$19.83
Low-Elevation Spray Application (LESA) Center Pivot	$23.73	$21.34	$18.81
SDI	$46.91	$42.35	$37.51
1 – Pumping costs assume electricity cost structure of Southeast Colorado Power Association			
Diesel[2]			
Medium Elevation Spray Application (MESA) Center Pivot	$32.53	$19.80	$6.31
Low-Elevation Spray Application (LESA) Center Pivot	$17.45	$10.62	$3.38
SDI	$33.30	$20.27	$6.46
2 – Pumping costs assume diesel fuel cost of $2/gallon			

7.0 Economic Adjustments

Most Extension publications about the costs of irrigation stop here, with the presentation of ownership and operating costs of each irrigation system. However, as already mentioned, farmers in the LARV have to consider how any on-farm decision might affect other water users, including Kansas, and whether it could be costly to reconcile any potential negative impacts to those water users. These additional irrigation costs or returns are discussed below.

7.1 Replacement Water Costs

Replacement water costs are those borne by an irrigator who has changed the efficiency of his/her irrigation system, thereby altering the historic timing and location of return flows to the river. These changes are offset through the purchase and release of additional water to the river.

Providing an estimate of the depletion of return flow to the river by an average farmer in the LARV is difficult; the return flow impact and efficiency change can have substantially different results from farm to farm depending on weather, soil type, crop selection, and current irrigating methods. For the purpose of this report, we provide deficit estimates by canal, based on data from the 2015 and 2016 LAVWCD Rule Ten Plan approvals for the Ft. Lyon Canal and other canal plans. Cost estimates are based on a LAVWCD member purchasing their projected deficit from LAVWCD. LAVWCD members pay a $300 annual administrative fee to participate in a Rule 10 plan, and can then purchase replacement water from LAVWCD. LAVWCD procures water primarily from the Fryingpan-Arkansas Project water stored in Pueblo reservoir and Lake Meredith. Replacement water prices vary from year-to-year depending on supply (mostly from precipitation and snow pack) and demand (Number of Rule 10 participants crop water needs). This report assumes a per acre-foot charge of $100 based on 2016 prices.

Table 6 - Return flow impacts by canal in the Lower Arkansas River Basin, 2015-2016.

2015					
Canal	**Mean Acres Under Improvement**	**Median Acres Under Improvement**	**Average Annual Depletion[a] (AF-ft)**	**Cost[b]**	**Cost/Acre**
Amity	157	154	23	$2,300	$14.65
Catlin	81	104	-9	-	-
Ft. Lyon	156	121	19	$1,900	$12.18
Rocky Ford Highline	102	116	39	$3,900	$38.24
Holbrook	92	70	15	$1,500	$16.30

2016					
Canal	**Mean Acres Under Improvement**	**Median Acres Under Improvement**	**Average Annual Depletion[1] (AF-ft)**	**Cost[-2]**	**Cost/Acre**
Amity	157	154	-3	-	-
Catlin	130	77	-19	-	-
Ft. Lyon	155	121	-8	-	-
Rocky Ford Highline	103	118	33	$3,300	$32.04
Holbrook	95	89	-2	-	-

a - On a per farm basis; Negative values represent an accretion to the river system
b - Costs represent $100/acre foot for augmentation water to supplement a deficit

Table 6 shows the average per acre costs of replacement water under a Rule 10 plan. Notice the considerable difference in projected deficits between 2015 and 2016. In 2015, an average farmer on all canals except the Catlin would incur some level of replacement water costs. In 2016, all projected depletions aside from the Rocky Ford Highline canal are negative, suggesting accretions to the river. This is the case because of changes made to pond seepage calculations, in which daily limits on seepage were removed, and seepage rates increased from 0.167 acre foot/day to 0.35 acre foot/day. The impact of allowing the Rule 10 plan to account for these accretions is significant because the credit from accretions can be used to eliminate the need for any farmer to purchase additional water.

Many growers are able to use accretions from a Rule 10 plan to offset their depletions, and eliminate their replacement water costs. It is important to note that despite the positive value on the Rocky Ford Highline Canal, their participation in the LAVWCD Rule 10 plan currently allows them to use the accretions from other canals to further offset their deficits. This added flexibility is another benefit of the Rule 10 plans.

It is hoped that eventually a plan will be formulated to allow growers to collectively augment depleted flows by storing and releasing water from on-stream or off-stream reservoirs. This would allow the water quality benefits gained from reduced irrigation deep percolation to not be canceled out by the creation of seepage from on-farm ponds.

7.2 Cost Sharing Programs for Irrigation Improvements

The Natural Resources Conservation Service (NRCS) offers significant cost sharing programs for irrigation technologies through the Environmental Quality Incentives Program (EQIP). The EQIP programs provide federal cost sharing funds for almost every technology examined in this report on a first-come-first-serve basis. Table 7 provides cost sharing amounts for the technologies we have discussed. Three cost sharing rates are available to LARV growers; an east slope (ES) rate, historically underserved (HU) rate, and a special initiatives (SI) rate. These rates apply to a wide range of individuals and circumstances, causing great variety in the amount of cost sharing that any single grower may receive. Currently, three of the five LARV counties (Bent, Otero, and Prowers) qualify for the Se management initiative, significantly increasing the amount of cost sharing funds. It is important to consult with your local NRCS field office for more information on cost sharing rate structure and funding availability.[11]

Cost sharing programs significantly decrease the investment costs of adopting more efficient technologies; even cutting estimated annual ownership costs in half for some practices. The changes in annual ownership costs, assuming full cost sharing on all components, can be seen in Table 8.

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[11] There are five NRCS offices that serve LARV growers. A list of locations and contact information is available at:
http://www.nrcs.usda.gov/wps/portal/nrcs/detail/co/contact/local/?cid=nrcs144p2_063074

Table 7: USDA Natural Resource Conservation Service cost sharing information for various irrigation systems in the Lower Arkansas River Basin, 2016.

NRCS No.	**Practice**	**Max Cost Share by NRCS**	**Cost Share Amount (ES Rate)**	**Cost Share Amount (HU Rate)**	**Cost Share Amount (SI Rate)**
443	PVC Gated Pipe	N/a	$3,552	$4,980	$4,947
430	PVC Pipeline (500 ft.)	N/a	$2,925	$4,398	$4,099
443	Surge Valve	N/a	$1,166	$1,749	$1,633
464	Laser-leveling	$20,000	$20,000	$20,000	$20,000
428	Concrete Ditch Lining (On-farm)	N/a	$11,092	$16,120	$14,111
442	Center Pivot System	$30,000	$30,000	$30,000	$30,000
378	Head-Stabilization Pond	N/a[1]	$5,208	$7,595	$6,634
533	Pumping Plant (Diesel)	N/a	$11,881	$17,281	$15,121
533	Pumping Plant (Electric)	N/a	$7,741	$11,260	$9,852
430	PVC Pipeline (1800 ft.)	N/a	$7,722	$11,611	$10,822
442	Center Pivot System	$30,000	$30,000	$30,000	$30,000
378	Head-Stabilization Pond (Small)	N/a	$5,208	$7,595	$6,634
533	Pumping Plant (Diesel & Small)	N/a	$11,881	$17,281	$15,121
533	Pumping Plant (Electric& Small)	N/a	$7,741	$11,260	$9,852
430	PVC Pipeline (900 ft.)	N/a	$3,861	$5,805	$5,411
441	SDI (Subsurface Drip Irrigation)	$40,000	$40,000	$40,000	$40,000

[1] - N/a indicates the lack of cost sharing funds or a defined maximum sharing amount

Table 8: Annual ownership costs estimates with NRCS cost sharing.

Practice	Acres	Annual Ownership Cost/acre	Annual Ownership Costs/acre (East Slope Rate)	Annual Ownership Costs/acre (HU Rate)	Annual Ownership Costs /acre (Special Initiatives Rate)
Non-triggering					
Furrow (Baseline)	60	$5	$5	$5	$5
Furrow (Compacted Ditches)	60	$17	$17	$17	$17
Furrow (Concrete Ditches)	60	$33	$17	$14	$16
Gated Pipe	60	$17	$9	$6	$6
Gated Pipe (Surge Controller)	60	$20	$4	$7	$7
Laser-leveling (Furrow)	60	$89	$78	$78	$78
Laser-leveling (Gated Pipe)	60	$102	$81	$78	$79
Triggering					
Center-pivot (MESA & LESA, Diesel)	120	$118	$83	$72	$75
Center-pivot (MESA & LESA, Electric)	120	$106	$83	$69	$70
Small Center-pivot (MESA & LESA, Diesel)	30	$142	$110	$95	$100
Small Center-pivot (MESA & LESA, Electric)	30	$125	$97	$88	$91
SDI (Diesel)	60	$256	$178	$160	$157
SDI (Electric)	60	$243	$165	$154	$152

7.3 Labor and Fieldwork Savings

Thus far, costs have been the primary focus of this report. However, there also may exist significant cost *savings* for growers who adopt a new irrigation technology. For example, center-pivot irrigation systems create opportunities for growers to reduce the amount of labor required to irrigate. In discussions with LARV growers, labor savings were identified as one of the primary benefits of sprinklers. In quantifying these values, we make assumptions based on these conversations regarding number of irrigations, irrigation run time, and field size.

For this exercise, we will assume that a farm has 8 irrigation events, and employs 3 irrigators to irrigate a 60-acre field. Under furrow irrigation, each irrigator works 8 hours per 48-hour irrigation event, and annual labor costs are $2,363. Labor is utilized to transport and set siphon tubes and to clear trash from farm ditches and furrows. On a per acre basis, labor costs are estimated at $39.39/acre. Utilizing a center-pivot, a grower can operate the system alone, and can often manage the system remotely using a computer or smart phone. This reduces per acre labor costs by 52% to only $18.92/acre, while providing the aforementioned flexibility of managing the system remotely. Sub-surface drip (SDI) systems do not provide the same labor savings, and are estimated to increase labor cost due to the relatively skilled labor required to maintain the system. Labor costs are estimated at $28 per acre and calculated under the assumption that two skilled farm laborers are employed for $21.00/hour.

Another type of fieldwork savings accrues from the reduced need for land preparation when using a sprinkler system. Under furrow irrigation, fieldwork is assumed to consist of moldboard plowing, disking (2), leveling, and furrowing. Our cost estimates are based on conversations with LARV growers, *Custom Rates for Colorado Farms and Ranches in 2015* (Russell et al. 2015), and *2016 Custom Machine and Work Rate Estimates* (Stein, 2016). These estimates assume a fuel cost of $2.00/gallon. The per-acre costs of these operations are estimated at $92.00. Center-pivot irrigation systems reduce the amount of fieldwork required and provide significant savings to LARV growers. Removing moldboard plow operations, a disking pass, and furrowing operations decreases the cost by 62% to $35 per acre.

7.4 Crop Yield Impacts

LARV growers stand to further benefit from irrigation technology investments due to the prospective increase in crop yields. Many of the technologies are recognized to increase yields by improving the distributional uniformity of applied water and increasing soil quality. Some technologies simply prevent yield losses that are commonly associated with inefficient furrow irrigation such as soil waterlogging and salinization. While LARV specific data on these impacts are not readily available, many examples can be found in academic literature and university extension publications. Finally, one local farmer tells us that his alfalfa quality improved “dramatically” under sprinklers, which is another way of increasing revenue.

Houk et al. (2004), investigated the impact of waterlogging and soil salinity on crop yield and identifies thresholds for water table depth across various crops in the LARV. Houk et al. (2004), employs an approach used by Christopher and TeKrony (1982), and Gates and Grismer (1989), which assume a multiplicative relationship between soil salinity and water logging resulting in a relative yield. It is found that as water tables become shallower than these thresholds, crop yield is significantly impacted. Based on previous studies reviewed by Houk et al. (2004), yield estimates at water table depth of 20 inches for alfalfa, corn, and squash (proxy for melons) crops are 75%, 65%, and 60% of relative crop yield,

respectively[12]. Houk et al. (2004) estimated that at the time of their study, waterlogging and salinity were directly related to an average economic cost of about $68 per acre. While 20 inches represents an extremely shallow water table, water table depths between 20 and 60 inches exist in the region. Morway et al. (2013) suggests that water table depth less than 80 inches (~2 meters) constitutes land that is threatened by water logging and estimates that about 23% of land across the LARV experiences water table depths of less than 80 inches. Continued irrigation on waterlogged soil further raises the water table, choking out oxygen, increasing salinity levels and non-beneficial consumptive use, and ultimately impacting crop yields. Morway et al. (2013), suggest that increasing the efficiency of applications could contribute to achieving lower, more sustainable water table levels.

Pang et al. (1997) identified a negative relationship between uneven irrigation and corn grain yield, while also finding a positive relationship between excessive and uneven irrigation and nitrogen (N) leaching. The evenness of applied irrigation water is measured using a Christiansen uniformity coefficient (CUC) (Heermann and Solomon, 2007). Pang et al. (1997), evaluated CUCs of 100, 95, and 75 and determined optimal applied irrigation values of 31.5, 35, and 47 inches of water respectively. Poor distribution of irrigation water creates areas of saturation and increases N leaching, while leaving other areas deprived of sufficient water. Pang et al. (1997), found with a CUC of 75 or less, corn grain yields are negatively affected by about 10% and N leaching increased by an estimated 10-15 Kg/ha.

The use of limited/no-till practices, as commonly adopted with sprinkler and drip irrigation systems, is recognized to have significant positive impacts on soil quality. Various studies (Ellis at al., 1985; Harman et al., 1985; Al-Kaisi et al., 2005; Turmel et al., 2015) identify the wide range of soil benefits associated with limited/no-till practices including increased soil moisture, nutrient availability, organic N levels, and soil structure. These soil benefits translate to direct economic benefits in the form of aforementioned fieldwork savings, and increased yields.

Quantifying the impact of yield changes resulting from irrigation improvements is a complicated task. Crops respond to changes in irrigation differently and there are many exogenous factors that also affect yields. Maximum yield estimates are assumed from various studies, and technologies with lower efficiencies are assumed to produce less than these maximum yields. Table 9 shows expected per acre yields changes and associated costs for corn under alternative irrigation practices. For this report, we record adverse yield impacts as costs. That is, the yield loss for each system, compared to a MESA, LESA or SDI systems, is a cost of using that system. For example, the cost of using siphon tubes in a furrow irrigation system is a reduction in yield from 220 bu/acre to 188 bu/acre, or about $115/acre, given crop prices in 2016.

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[12] Alfalfa - Rai, S.D., D.A. Miller, and C.N. Hittle (1971), Benz, L.C., E.J. Doering, and G.A. Reichman (1985)
Corn - Goins, T.J. Lunin, and H.L. Worley (1966)
Melon (Squash) - Williamson, R.E., and G.J. Kriz (1970)

Table 9: Yield impacts and profit losses compared of various irrigation systems when compared to high efficiency systems in the Lower Arkansas River Basin, 2016.

Practice	% of Max Yield	Per acre Yield	Per acre loss ($)
Non-Triggering			
Siphon Tubes	83%	188.03	$115.08
Siphon Tube Furrow (Compacted Earthen Ditches)	85%	191.30	$103.30
Siphon Tube Furrow (Concrete Ditches)	86%	192.98	$97.26
Gated Pipe	88%	196.43	$84.86
Gated pipe with Surge Controller	90%	200.00	$72.00
Laser-leveling (Siphon Tubes)	88%	196.43	$84.86
Laser Leveling (Gated Pipe)	95%	209.52	$37.71
Triggering			
MESA Center Pivot	100%	220.00	$-
LESA Center Pivot	100%	220.00	$-
SDI	100%	220.00	$-
Assumes corn price of $3.60/bushel and 220 bushels/acre max yield. Per acre loss is equal to reduction in yield from max, times corn price.			

7.5 Acreage Adjustments

As described in Section 5, installing a sprinkler requires a careful consideration of the new system's footprint. Depending on the size and shape of existing fields, installation of a sprinkler system may require the removal or addition of acreage. Decreed water rights allow for a specified amount of water to be consumptively used in a particular place. Therefore, changing one's irrigated acreage technically constitutes a change in application location, and is generally ill-advised. However, because the consumptive use amount is based on a historical average of acres, there may be situations where land can be expanded or contracted in small amounts, as long as the historical maximum is not exceeded. In some situations, water shortage or land-use changes may have resulted in irrigated acreage below a producer's historically irrigated acreage. Installing a sprinkler may allow a producer to recover those historically irrigated acres, so long as consumptive use remains unchanged. Such changes appear to occur in the 2016 Lower Arkansas Valley Water Conservancy District Rule 10 plan approval, which shows 41 of 62 farms (66%) in the plan had a change in irrigated acreage when switching to sprinklers.

Of the 41 farms with changes in acreage, 11 increased their irrigated acreage by an average of 8.5 acres, while 30 decreased their irrigated acreage by an average of 24.5 acres. Changes in acreage are assumed within historical irrigated acreage, and therefore should not result in consumptive use changes. We estimate the economic gain/loss based on the expected net returns from crop production on this land. In the case of corn produced under sprinklers, the expected net return per acre is about $120. In the case of adding acreage, on average we expect a gain of $9/acre over the entire irrigated area. In the case of the farmer who losses acreage, we expect a loss of $25/acre over the entire irrigated acreage. The expected economic impact of these adjustments is assumed to be a cost of $15 per acre when changing to sprinkler irrigation. Again, we emphasize that any change in irrigated acreage should be approached with caution. The Lower Arkansas Valley Water Conservancy District is a wonderful resource if you have questions regarding a change in acreage related to Rule 10.

8.0 Total Costs

Table 10 below shows the summation of costs for the scenarios described above. It excludes some practices that are deemed economically inferior, which means that they provide lesser returns at a higher cost. This leaves four on-farm improvements from furrow irrigation; gated pipe, gated pipe with laser leveling, sprinkler[13] with electric pumping plant, and sprinkler with diesel pumping plant.

It becomes evident that when properly accounting for economic adjustments, such as labor and fieldwork savings, yield impacts, and NRCS cost sharing programs, the real cost of on-farm adoption becomes much more competitive for higher efficiency irrigation systems. Uncertainty or unfamiliarity about these adjustments might explain why farmers have not been quick to adopt high efficiency systems. Often times, these costs do not show up directly in accounting budgets and can be overlooked. In addition, conditions on some farms could be very different than the "typical" assumptions used here.

In Table 10, we present our *Low, High, and Best* estimates of costs. Low and high designations are based on a review of previous budgets and reports, discussions with growers, and our own estimates. We define the best option as the most applicable to the current situation in the LARV. These estimates are not representative of every farm in the LARV, and should not be interpreted as a recommendation for all farms. They are, however, meant to show the considerations that LARV grower might want to consider when making irrigation system decisions.

Three costs stand out as primary drivers of our estimates. Fieldwork, labor, and crop yields. Field work and labor costs repeatedly have been identified as the main drivers of switching from furrow irrigation to sprinklers. When talking with farmers, there is a significant amount of value placed on the convenience of sprinklers over furrow irrigation. Being able to manage a sprinkler's operation "from a smartphone 24/7," and avoiding reliance on hired labor in a thinning labor market makes growers more independent and efficient. There are also soil health benefits that can translate into economic gains through increased yields. Increased soil moisture levels and organic matter, along with decreased soil temperatures (Harman et al., 1985; Ellis et al., 1985; Al-Kaisi et al., 2005) are associated with the reduced-till/no-till practices that often accompany sprinkler irrigation.

Yield impacts present a significant impact on the costs of irrigating. Yield gains for sprinklers are estimated to be as high as a 17% compared to basic furrow irrigation. These estimates are highly variable depending on field conditions, irrigation management, and various weather conditions. Sprinkler irrigation is economically superior as long as the yields are 7% or more than furrow irrigation.

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[13] MESA and LESA systems are combined into sprinkler in this exercise due to the trivial differences in system costs.

Table 10: Total costs of triggering and non-triggering irrigation systems in the Lower Arkansas River Basin, 2016.

Action	**Furrow**			**Gated Pipe**			**Laser Leveling w/ Gated Pipe**			**Sprinkler (Electric)**			**Sprinkler (Diesel)**		
	Low	High	Best	Low	High	Best	Low	High	Best	Low	High	Best	Low	High	Best
Operating															
Field Prep	$92	$98	$92	$92	$98	$92	$92	$98	$92	$35	$44	$35	$35	$44	$35
Pumping	$-	$-	$-	$-	$-	$-	$-	$-	$-	$22	$38	$21	$22	$38	$11
Labor	$20	$34	$39	$16	$34	$26	$20	$34	$26	$15	$34	$19	$15	$34	$19
Subtotal			$131			$118			$118			$75			$65
Ownership															
Pumping plant			$-			$-			$-			$10			$23
Equipment/Practice	$4	$6	$5	$9	$14	$11	$77	$116	$96	$63	$95	$79	$63	$95	$79
Pipe			$-	$4	$6	$5	$13	$20	$17	$8	$11	$9	$8	$11	$9
Pond			$-			$-			$-			$7			$7
Subtotal			$5			$17			$113			$106			$118
Total			$136			$135			$231			$180			$183
Adjustments (+/-)															
Yield	$85	$182	$115	$72	$103	$85	$-	$103	$38			$-			$-
Rule 10			$-			$-			$-	$3	$3	$3	$-	$3	$3
Replacement water			$-			$-			$-	$-	$38	$20	$-	$38	$20
Cost Sharing			$-	-$8	-$11	-$11	-$21	-$23	-$23	-$36	-$37	-$36	-$37	-$45	-$42
Acreage			$-			$-			$-	-$10	$25	$15	-$10	$25	$15
Subtotal			$115			$74			$14			$2			-$4
Total			$251			$209			$246			$182			$179

9.0 Alternative Transfer Methods

Alternative Transfer Methods (ATMs) are temporary water transfers that allow water to be leased, shared, and stored between agricultural producers, municipalities, and other uses. ATMs have been identified in the Colorado Water Plan (2016) as a vital tool to be used in reducing "buy and dry" of agricultural land. ATMs may be preferable to many compared to "buy and dry" for several reasons. ATMs allow for water to be transferred between uses without a change in water right. This helps to maintain water ownership and productivity in agricultural communities. However, like irrigation technologies, ATMs are not one size fits all. ATMs can vary in how long water is leased, who water is leased to, how much water is leased, and by many other factors.

In 2015, select growers along the Catlin Canal participated in a seasonal lease fallowing pilot study (Lower Arkansas Valley Water Conservancy District et al., 2015). During the 2015 growing season, 235 acres of land historically utilized to grow crops were fallowed, and the consumptively usable water was leased to the town of Fowler, city of Fountain, and the Security Water District. Participating growers delivered 409 acre-feet of water, and were paid $500 per acre-foot. The average return per acre of land fallowed was $1,031; the cost was estimated at $40/acre, producing a net return of $991/acre for lease fallowing. This compares to an estimated $126/acre return if that same water was used to produce corn or $724/acre return if alfalfa was produced, both using sprinkler irrigation. Lease fallowing arrangements will pay to lease at most 3 years in 10, or on 30 percent of the land under contract.

10.0 Conclusion

This report summarizes the considerations and management options for irrigators in Colorado's Lower Arkansas River Valley. We describe the institutional framework, management options, and provide cost estimates of adoption in order to better understand the mechanics and impacts of adopting proposed on-farm best management practices. It is the goal of this research to improve water quality outcomes and identify achievable options that ensure the existence of strong agricultural communities in southeastern Colorado. Working groups such as the ARMAC, and individual growers such as those who were of assistance for this report are vital to achieving the stated goals. Stakeholder involvement in discussions of best management practices, identification of shortcomings, and assistance in outreach vastly improve the quality and usefulness of our research. It is this mutually beneficial relationship that we hope to foster, as we continue on working toward the improvement, growth, and sustainability of agriculture in the Lower Arkansas River Valley.

References

Al-Kaisi, M. M., Yin, X., & Licht, M. A. (2005). Soil Carbon and Nitrogen Changes as Affected by Tillage System and Crop Biomass in a Corn–Soybean Rotation. *Applied Soil Ecology*, *30*(3), 174–191. http://doi.org/10.1016/j.apsoil.2005.02.014

Arkansas Basin Roundtable. (2015). *Arkansas Basin Roundtable Basin Implementation Plan*. Retrieved from http://www.arkansasbasin.com/uploads/2/7/1/8/27188421/ark_bip_plan_final_20150416.pdf

Bailey, R. T., Hunter, W. J., and Gates, T. K. (2012). The Influence of Nitrate on Selenium in Irrigated Agricultural Groundwater Systems. *Journal of Environmental Quality*, 41(3), 783 – 792.

Bailey, R. T., Gates, T. K., and Ahmadi, M. (2014). Simulating Reactive Transport of Selenium Coupled with Nitrogen in a Regional-Scale Irrigated Groundwater System. *Journal of Hydrology*, 515, 29 – 46.

Bailey, R. T., Romero, E. C., and Gates, T. K. (2015). Assessing Best Management Practices for Remediation of Selenium Loading in Groundwater to Streams in an Irrigated Region. *Journal of Hydrology*, 521, 341 - 359.

Benz, L. C., Doering, E. J., & Reichman, G. A. (1985). Alfalfa Yields and Evapotranspiration Response to Static Water Tables and Irrigation. *Transactions of the ASAE*, *28*(4), 1178–1185.

Brouwer, C., Prins, K., & Heibloem, M. (1989). Annex I: Irrigation Efficiencies. Retrieved February 21, 2016, from http://www.fao.org/docrep/t7202e/t7202e08.htm

Burkhalter, J. P., and Gates, T. K. (2006). Evaluating Regional Solutions to Salinization and Waterlogging in an Irrigated River Valley. *Journal of Irrigation and Drainage Engineering*, 132(1), 21 – 30.

Burt, C. M., Orvis, S., ASCE, M., & Alexander, N. (2010). Canal Seepage Reduction by Soil Compaction. *Journal of Irrigation and Drainage Engineering*, *136*(7), 479–485. http://doi.org/10.1061/ (ASCE)IR.1943-4774.0000205.

Byelich, B., Cook, J., & Rowley, C. (2013). *Small Acreage Irrigation Guide*. Colorado State University Extension. Retrieved from http://www.ext.colostate.edu/sam/sam-irr-guide.pdf.

Christopher, J. N., & TeKrony, R. G. (1982). Benefits Related to Water Table and Salinity Control (Drainage Planning). *Paper-American Society of Agricultural Engineers (Microfiche Collection) (USA)*.

Colorado Foundation for Water Education. (2010). *Citizen's Guide to Colorado's Interstate Compacts*. Retrieved from https://www.courts.state.co.us/userfiles/file/Court_Probation/19th_Judicial_District/Court_House_History/cfwe%20Compacts%20Guide%20text%20as%20published.pdf

Colorado Watershed Assembly - Colorado Water Facts. (n.d.). Retrieved March 17, 2016, from https://www.coloradowater.org/Colorado%20Water%20Facts/#AK

State of Colorado. Colorado Water Conservation Board (2016). Colorado's Water Plan. Retrieved from https://www.colorado.gov/pacific/cowaterplan/plan

Ellis, J. R., Lacewell, R. D., & Reneau, D. R. (1985). Estimated Economic Impact from Adoption of Water-Related Agricultural Technology. *Western Journal of Agricultural Economics*, 307–321.

Gates, T. K., Cody, B. M., Donnelly, J. P., Herting, A. W., Bailey, R. T., & Mueller Price, J. (2009). Assessing Selenium Contamination in the Irrigated Stream–Aquifer System of the Arkansas River, Colorado. *Journal of Environment Quality*, *38*(6), 23-44.

Gates, T. K., Garcia, L. A., Hemphill, R. A., Morway, E. D., and Elhaddad, A. (2012). "Irrigation practices, water consumption, & return flows in Colorado's Lower Arkansas River Valley: Field and model investigations." Colorado Water Institute Completion Report No. 221, Colorado Agricultural Experiment Station No. TR-12-10, Colorado State Univ., Fort Collins, Colo.

Gates, T. K., & Grismer, M. E. (1989). Irrigation and Drainage Strategies in Salinity-Affected Regions. *Journal of Irrigation and Drainage Engineering*, *115*(2), 255–284.

Gates, T. K., Steed, G. H., Niemann, J. D., and Labadie, J. W. (2016). "Data for Improved Water Management in Colorado's Arkansas River Basin: Hydrological and Water Quality Studies" Colorado Water Institute Special Report No. 24, Colorado State Univ., Fort Collins, Colo.

Goins, Lunin, T.J., and Worley, H.L. (1966)." Water Table Effects on Growth of Tomatoes, Snap Beans, and Sweet Corn." *Transactions of the American Society of Agricultural Engineers,* 9, 530-533.

Harman, W. L., Hardin, D. C., Wiese, A. F., Unger, P. W., & Musick, J. T. (1985). No-Till Technology: Impacts on Farm Income, Energy Use and Groundwater Depletion in the Plains. *Western Journal of Agricultural Economics*, 134–146.

Heermann, D. F., and Solomon, K. H. (2007). "Efficiency and Uniformity". Chap. 5 in Hoffman, G. J., Evans, R. G., Jensen, M. E., Martin, D. L., and Elliott, R. L. *Design and Operation of Farm Irrigation Systems*, Am. Soc. Agric. Biol. Eng., St. Joseph, MI.

Hoag, Dana. (Forthcoming). Irrigated Farmer Actions and Views About Managing Water for Pollution Prevention with Sustainably Returns. Web report: www.ColoradoARMAC.org

Hobbs Jr., G. (2004). *Citizens Guide to Colorado Water Law*. Colorado Foundation for Water Education. Retrieved fromhttp://www.colorado.edu/geography/class_homepages/geog_4501_s14/readings/CG-Law2004.pdf

Houk, E. E., Frasier, W. M., Schuck, E., & others. (2004). The Regional Effects of Waterlogging and Soil Salinization on a Rural County in the Arkansas River basin of Colorado. In *Western Agricultural Economics Association Meeting, Honolulu, HI*. Retrieved from http://ageconsearch.umn.edu/bitstream/36229/1/sp04ho02.pdf

Jones, P. A., & Cech T. (2009). Colorado Water Law for Non-Lawyers. Boulder, CO: University press of Colorado.

Lamont Jr., W., Orzolek, M., Harper, J., Kime, L., & Jarrett, A. R. (2012). *Drip Irrigation for Vegetable Production* (Agricultural Alternatives). College of Agricultural Sciences: Pennsylvania State University. Retrieved from http://extension.psu.edu/business/ag-alternatives/horticulture/horticultural-production-options/drip-irrigation-for-vegetable-production/extension_publication_file

Lower Arkansas Valley Water Conservancy District, Berg Hill Greenleaf Ruscitti LLP, & Martin and Wood Water Consultants, Inc. (2015). *2015 Annual Report: H.B. 13-1248 Catlin Canal Company Rotational Land Fallowing-Municipal Leasing Pilot Project*. Retrieved from http://dwrweblink.state.co.us/dwrweblink/ElectronicFile.aspx?docid=2860293&&dbid=0

Morway, E. D., and Gates, T. K. (2012). Regional Assessment of Soil Water Salinity Across an Intensively Irrigated River Valley. *Journal of Irrigation and Drainage Engineering*, 138(5), 393 – 405.

Morway, E. D., Gates, T. K., and Niswonger, R. G. (2013). Appraising Options to Reduce Shallow Groundwater Tables and Enhance Flow Conditions Over Regional Scales in an Irrigated Alluvial Aquifer System. *Journal of Hydrology*, 495, 216 - 237.

Niemann, J. D., Lehman, B. M., Gates, T. K., Hallberg, N. U., and Elhaddad, A. (2011). Impact of Shallow Groundwater on Evapotranspiration Losses from Uncultivated Land in an Irrigated River Valley. *Journal of Irrigation and Drainage Engineering*, 137(8), 501 – 512.

Hoag, D. L., Gates, T. K., and Smith, K. (2016). "A Survey of Irrigated Farmers Opinions and Actions Related to Selenium, Nitrogen, and Salinity in the Lower Arkansas River Basin, Colorado." (Forthcoming)

Pang, X. P., Letey, J., & Wu, L. (1997). Irrigation Quantity and Uniformity and Nitrogen Application Effects on Crop Yield and Nitrogen Leaching. *Soil Science Society of America Journal*, 61(1), 257–261.

Rai, S. D., Miller, D. A., & Hittle, C. N. (1971). Response of Alfalfa Varieties to Different Water Table Depths at Various Stages of Growth. *Agronomy Journal*, *63*(2), 331–332. https://doi.org/10.2134/agronj1971.00021962006300020040x

Robinson, T. (1958). *Phreatophytes* (Geological Survey Water-Supply Paper No. 1423). United States Geological Survey. Retrieved from http://pubs.usgs.gov/wsp/1423/report.pdf

Russell, J., Dalsted, N., Tranel, J. E., Young, R. B., and Seyler, J. (2015). *Custom Rates for Colorado Farms & Ranches in 2015*. Colorado State University Extension. Retrieved from http://www.coopext.colostate.edu/ABM/2015%20CustomRates.pdf

Schneekloth, J. P., & Andales, A. A. (2009). *Seasonal water needs and opportunities for limited irrigation for Colorado crops*. Colorado State University Extension. Retrieved from http://extension.colostate.edu/docs/pubs/crops/04718.pdf

Seiler, R. L., Skorupa, J. P., & Peltz, L. A. (1999). *Areas susceptible to irrigation-induced selenium contamination of water and biota in the western United States*. Carson City, Nev.: [Washington, D.C.]: U.S. Dept. of the Interior; U.S. G.P.O.

Simpson, H., & Wolfe, D. (2011). *General Administration Guidelines for Reservoirs* (pp. 26–27). Colorado Division of Water Resources. Retrieved from http://water.state.co.us/DWRIPub/Documents/Reservoir%20Administration%20Guidelines.pdf

Stein, D. (2016). *2016 Custom Machine and Work Rate Estimates* (Fact Sheet No. 16–1). Michigan State University. Retrieved from http://msue.anr.msu.edu/uploads/234/68202/FIRM_16-01_2016_final-2016_Custom_MachWork.pdf

Russell, J., Dalsted, N., Tranel, J. E., Young, R. B., & Seyler, J. (2015). *Custom Rates for Colorado Farms & Ranches in 2015*. Colorado State University Extension. Retrieved from http://www.coopext.colostate.edu/ABM/2015%20CustomRates.pdf

Turmel, M.-S., Speratti, A., Baudron, F., Verhulst, N., & Govaerts, B. (2015). Crop residue management and soil health: A systems analysis. *Agricultural Systems*, *134*, 6–16. http://doi.org/10.1016/j.agsy.2014.05.009

USDA Natural Resources Conservation Service. (2016). *EQIP Regional Payment Scenario Details - State of Colorado*.

United States Department of Agriculture. (n.d.). *Utilizing Center Pivot Sprinkler Irrigation Systems to Maximize Water Savings*. USDA Natural Resources Conservation Service. Retrieved from http://cotton.tamu.edu/Irrigation/NRCS%20Center%20Pivot%20Irrigation.pdf

Waskom, R., Rein, K., Wolfe, D., & Smith, M. (2016). *How Diversion and Beneficial Use of Water Affect the Value and Measure of a Water Right (Is "Use it or Lose It" an Absolute?)* (No. 25). Colorado Water Institute: Colorado State University. Retrieved from http://cwi.colostate.edu/publications/SR/25.pdf

Williamson, R. E., & Kriz, G. J. (1970). Response of agricultural crops to flooding, depth-of water table and soil gaseous composition. *Transactions of the ASAE*, *13*(2), 216–220.