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Assessing the feasibility of using produced water for irrigation in Colorado

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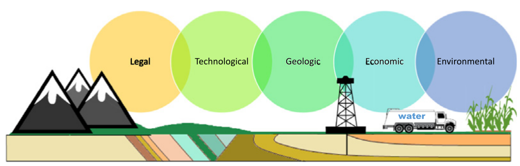
HIGHLIGHTS

- We identify six counties in Colorado where reuse of produced water for agriculture is most feasible.
- Produced water can make a substantial volumetric impact on irrigation demand in the identified counties.
- Treating produced water to agricultural standards is economically feasible when compared to the cost of disposal in commercial injection wells.

GRAPHICAL ABSTRACT



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ABSTRACT

The Colorado Water Plan estimates as much as 0.8 million irrigated acres may dry up statewide from agricultural to municipal and industrial transfers. To help mitigate this loss, new sources of water are being explored in Colorado. One such source may be produced water. Oil and gas production in 2016 alone produced over 300 million barrels of produced water. Currently, the most common method of disposal of produced water is deep well injection, which is costly and has been shown to cause induced seismicity. Treating this water to agricultural standards eliminates the need to dispose of this water and provides a new source of water. This research explores which counties in Colorado may be best suited to reusing produced water for agriculture based on a combined index of need, quality of produced water, and quantity of produced water. The volumetric impact of using produced water for agricultural needs is determined for the top six counties. Irrigation demand is obtained using evapotranspiration estimates from a range of methods, including remote sensing products and ground-based observations. The economic feasibility of treating produced water to irrigation standards is also determined using an integrated decision selection tool (iDST). We find that produced water can make a substantial volumetric impact on irrigation demand in some counties. Results from the iDST indicate that while costs of treating produced water are higher than the cost of injection into private disposal wells, the costs are much less than disposal into commercial wells. The results of this research may aid in the transition between viewing produced water as a waste product and using it as a tool to help secure water for the arid west.

1. Introduction

Agricultural production in the arid western United States has long been constrained by water resources. Global climate change will exacerbate this problem because higher temperatures will accelerate crop growth but reduce maturity time, and therefore yields (Islam et al., 2012). Population growth puts additional pressure on water resources. Colorado in particular has been experiencing rapid population growth—by 2050, Colorado's population is estimated to double (CWCB, 2015). To meet water demand, municipalities in Colorado are buying agricultural water rights in a process known as “buy and dry” (Mclane and Dingess, 2014). As a result, an estimated 0.8 million acres (3237 km^2) of irrigated land may dry up by 2050. According to the

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Colorado Water Plan, there may be a supply gap of up to 500,000 acre-feet (0.6 billion m^3) of water in Colorado by 2050 (CWCB, 2015). The Colorado Water Plan gathered estimates from roundtables, which consist of stakeholders from the major basins in Colorado, to determine how much the gap could be closed through conservation strategies and new reservoir projects (SWSI, 2010). The roundtables estimated that conservation strategies could reduce the projected supply gap but would not be enough to close it (CWCB, 2015). Additionally, large-scale reservoir projects and trans-basin diversions are frequently politically and economically untenable. Therefore, Colorado is under pressure to find new or alternative sources of water to fill this projected gap.

In recent years, some western states have begun viewing produced water, a byproduct of oil and gas production, as a viable new source of water (Clark and Veil, 2009). In 2016 alone, oil and gas wells in Colorado produced over 47 million m^3 (300 million barrels) of produced water (COGCC Data, 2018)—commonly a very contaminated waste stream. The primary method of managing/handling produced water in most states, including Colorado, has been injection into Class II disposal wells (Clark and Veil, 2009). This process is costly (McCurdy, 2011) and has been shown to induce seismic activity (Chang and Segall, 2016; Ellsworth, 2013; Guglielmi et al., 2015). Across the nation, the combination of increasing regulatory pressure and limited access to disposal wells has encouraged states to begin the transition to reusing produced water. In Colorado, approximately a third of produced water is being reused for enhanced recovery purposes for oil and gas production (Clark and Veil, 2009). Even after reuse for enhanced recovery, some wells may generate more produced water than is needed for this purpose. In this scenario (e.g., reduced exploration and fracking), new uses of treated produced water may be needed.

Consuming 83% of total water resources, agriculture is Colorado's main consumptive user of water (CWCB, 2015) and therefore is a likely end-use of produced water. The reuse of produced water for irrigation is not a new concept. Several states, including California, Montana, and Wyoming have started seeing the advantages of this beneficial use. Beneficial use is defined by the Colorado Regulatory Statutes as "the use of that amount of water that is reasonable and appropriate under reasonably efficient practices to accomplish without waste the purpose for which the appropriation is lawfully made" (C.R.S. § 37-92-107). Other examples of beneficial use include dust suppression, livestock watering, and municipal use.

In Colorado, the reuse of produced water for beneficial purposes is governed by the Colorado Regulatory Statutes (C.R.S. § 37-90-137(7)(a)). The beneficial uses specified in the statutes include road-spreading, enhanced recovery, drilling, well stimulation, well maintenance, pressure control, pump operations, dust control, pipeline and equipment testing, fire suppression, and discharge into state waters. Wellington, Colorado, has been reusing its produced water to augment shallow aquifers since 2008 (Stewart and Takichi, 2005). The city then extracts and uses this water for municipal use. Wellington faced multiple regulatory hurdles before putting produced water to beneficial use (Stewart and Takichi, 2005); however, legislation has recently been passed to accelerate the regulatory process for reuse of produced water (C.R.S. § 37-90-137(7)(c)) (Curtis, 2014). While irrigation using produced water has not yet occurred in Colorado, other states have been successfully using produced water for this purpose. Montana and Wyoming have begun to make use of their produced water originating in coalbed methane (CBM) formations in the Powder River Basin. The water that saturates these coal seams is a byproduct of CBM production and is generally much less saline than produced water from conventional hydrocarbon formations. The lower concentration of total dissolved solids substantially decreases the cost of treating this water. Approximately 13% of the CBM water in Wyoming and 26% of the CBM water in Montana were used for irrigation in 2009 (Clark and Veil, 2009).

In a 2005 report, Harvey et al. summarized the challenges of reusing CBM water in the Powder River Basin. The main barriers of reuse for agriculture are the salinity, sodicity, alkalinity, and specific ion toxicity of the produced water (Harvey and Brown, 2005). These challenges are the same as with irrigation with produced water but are magnified due to the overall lower quality of produced water. The salinity of produced water does not alter the physical soil properties but limits the plant's ability to uptake water. Salinity tolerances for various crops vary widely, though grains and grasses are among the most salt tolerant crops (FAO, 1985). Alternatively, the sodicity of the water directly impacts the permeability of the soil. The degree of change in permeability depends on the amount of clay in the soil. Negatively charged clay particles attract cations such as sodium, calcium, and magnesium in the water. When the proportion of sodium to calcium and magnesium (sodium adsorption ratio (SAR)) is high, clay particles repel each other and cause the clays to swell and degrade, reducing the permeability of the soil. Alkalinity at neutral pHs exists primarily as bicarbonate, which will precipitate available calcium and magnesium in the water, thus raising the SAR. Lastly, specific ion toxicity must be taken into consideration. High concentrations of sodium, chloride, and boron can be toxic to certain crops (Harvey and Brown, 2005), and therefore, the type of crop is an important consideration when using produced water for irrigation.

Examples of produced water reuse also occur outside of coalbed methane basins. Kern County in California has been reusing its produced water for agriculture for decades (Waldron, 2005). In 1994, Chevron (then Texaco) and the Cawelo Water District made a mutually beneficial deal to reuse produced water. Chevron treats its produced water with walnut shell filters and sells the water to the water district for agricultural use. Though this practice has been met with some recent public backlash (Cart, 2015), the food products (including citrus and nut crops) grown with this water have been distributed nationally for years (California Water Boards, 2016).

Although some studies have shown success in irrigating without treatment, the mostly unknown chemical composition of produced water impels the use of conventional treatment to mitigate health risks. Due to its chemical complexity, the task of treating produced water to agricultural standards may seem daunting; however, some studies have shown treatment to be technologically and economically feasible when comparing the cost of treatment to the cost of disposal in commercial wells (McCurdy, 2011). Costs of treating produced water to agricultural standards or potable standards may range from \$0.04/bbl (Xu et al., 2008) to \$3/bbl (Coday et al., 2015) (Table A.1 in the Supplementary material).

It is important to remember that the cost of treating produced water is highly dependent on the quality of the influent, the price of electricity, the capacity of the plant, the intended quality of the effluent, and the treatment train being used. Additionally, whether or not an author deems the treatment economically feasible depends on the cost of disposal by other methods, including deep well injection and the cost of transportation. In this study, treatment is considered economically feasible if the cost is lower than the cost of disposal.

Overall, other studies have assessed the technological and economic feasibility of treatment trains for treating produced water and have discussed the effect of irrigating with produced water. The current work builds on previous studies to determine the feasibility of reusing produced water for agriculture, specifically in Colorado (Harvey and Brown, 2005; Szép and Kohlheb, 2010; Xu et al., 2008). Colorado is relatively new to the frontier of reusing produced water, yet its arid climate and rapid population growth prompt the discovery of new sources of water. Thus a feasibility study of the reuse of produced water in Colorado may be especially beneficial to policymakers in the state. The current research explores the feasibility of reusing produced water in Colorado and determines the volumetric impact of produced water reuse on local irrigation demand. The economic feasibility of treating produced water to agricultural standards is also assessed using an integrated Decision Support Tool. Our goal is to provide policymakers with the relevant information needed to make informed decisions about the reuse of produced water in Colorado. Though this