ECONOMIC ANALYSIS

of

Groundwater Curtailment

in

Colorado's Republican River Basin





COLORADO STATE UNIVERSITY

AGRICULTURAL AND
RESOURCE ECONOMICS

COLORADO
WATER CENTER
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Rebecca Hill
Extension Professor, Office of Engagement and Extension, Colorado State University

Dale T. Manning
Associate Professor, Baker School of Public Policy and Agricultural and Resource Economics, University of Tennessee; Faculty Partner, Dept. of Agricultural and Resource Economics, Colorado State University

Jordan Suter
Professor, Dept. of Agricultural and Resource Economics, Colorado State University

Innocent Vomitadyo
PhD Candidate, Dept. of Agricultural and Resource Economics, Colorado State University

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Contents

Executive Summary

Colorado's Republican River Basin is a key agricultural region reliant on groundwater irrigation. Livestock and crop production, including irrigated production, are critical to the local economy, representing over 25% of total revenue and almost 20% of employment in the region. Groundwater use in the Basin is influenced by the Republican River Compact, an agreement between Colorado, Nebraska, and Kansas. To remain in compliance with the Compact, Colorado has agreed to remove 25,000 acres of irrigated land from production in a part of the Republican Basin known as the South Fork Focus Zone by 2030. Failure to achieve the 25,000 acre requirement could result in the curtailment of all groundwater use in the Basin, which would have significant economic repercussions. Without irrigation from groundwater sources, agricultural production in the Basin would transition primarily to lower-value dryland crops and grazing, reducing revenue for agricultural producers and generating cascading effects on input suppliers, local businesses, and regional economies.

Using data from the IMPLAN modeling tool, Colorado's Decision Support Systems, crop-enterprise budgets, and the USDA's Cropland Data Layer, this study evaluates the primary and secondary economic impacts of groundwater curtailment on the eight counties in Colorado's Republican River Basin, as well as the spillover economic impacts on adjacent regions in Colorado, Kansas, and Nebraska. The analysis

Failure to meet Republican River Compact requirements could result in the curtailment of all groundwater use in the Basin.

CURTAILMENT SCENARIOS

Each of the four scenarios provides a description for how the 526,431 acres that are currently irrigated by groundwater could be impacted by curtailment.

ONE

All groundwater-irrigated land in the Study Area converted to grazing.

TWO

Conversion of irrigated acres to dryland crop production and grazing based on the current land use share of non-irrigated acres in the Study Area.

THREE

A predictive model of land conversion based on outcomes and characteristics of land enrolled in EQIP in the Basin.

FOUR

The land use changes from Scenario 3 with the addition of a 50% reduction in demand for non-grazing livestock sectors as a result of livestock operations leaving the area.

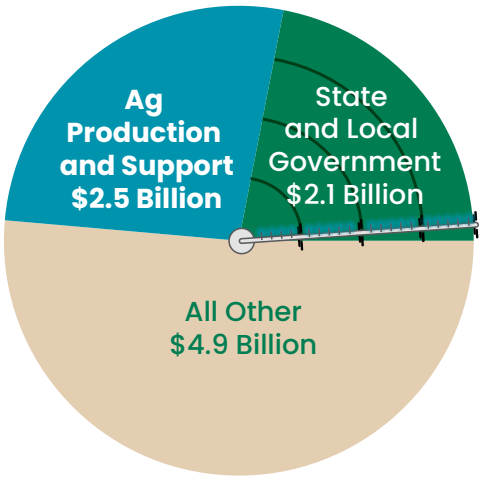
The analysis finds that groundwater curtailment could reduce revenue in the study region by as much as $1.5 billion annually.

estimates changes in revenue and employment related to alternative land-use scenarios ranging from complete conversion to non-irrigated pasture to a mix of dryland crop production and grazing. The scenarios highlight significant economic adjustments across the agricultural sector, and the findings provide stakeholders with insights into potential economic outcomes if groundwater curtailment were to occur.

The analysis finds that groundwater curtailment could reduce annual revenue in the study region by between $656 million and $1.5 billion depending on land use changes and impacts to feedlots. This reflects a 6.9% to 16.1% reduction in the value of economic output. The decrease in economic output is associated with a decrease in employment of between 2,591 and 5,263 jobs, representing a 6.9% to 13.9% decrease in employment. The decreases in revenue and employment are concentrated in Yuma and Kit Carson counties, which lie fully within the Republican Basin. The economic declines are associated with significant reductions in household income and state/local government revenue and lead to diminished economic outcomes in Colorado counties that lie outside of the Republican Basin and in bordering counties in Kansas and Nebraska.

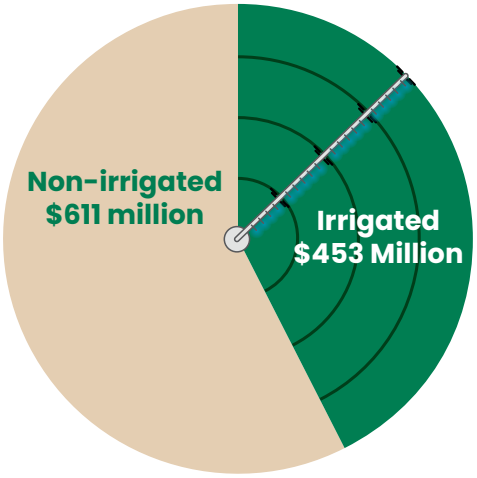
Achieving compliance with the 2030 land retirement requirement will avoid the negative economic consequences of basin-wide groundwater curtailment. This report underscores the cost of basin-wide curtailment on the State of Colorado and neighboring areas in Kansas and Nebraska. The findings can also inform policymakers and stakeholders about the economic implications of alternative land use scenarios.

Annual Revenue in the Study Area by Sector, 2022



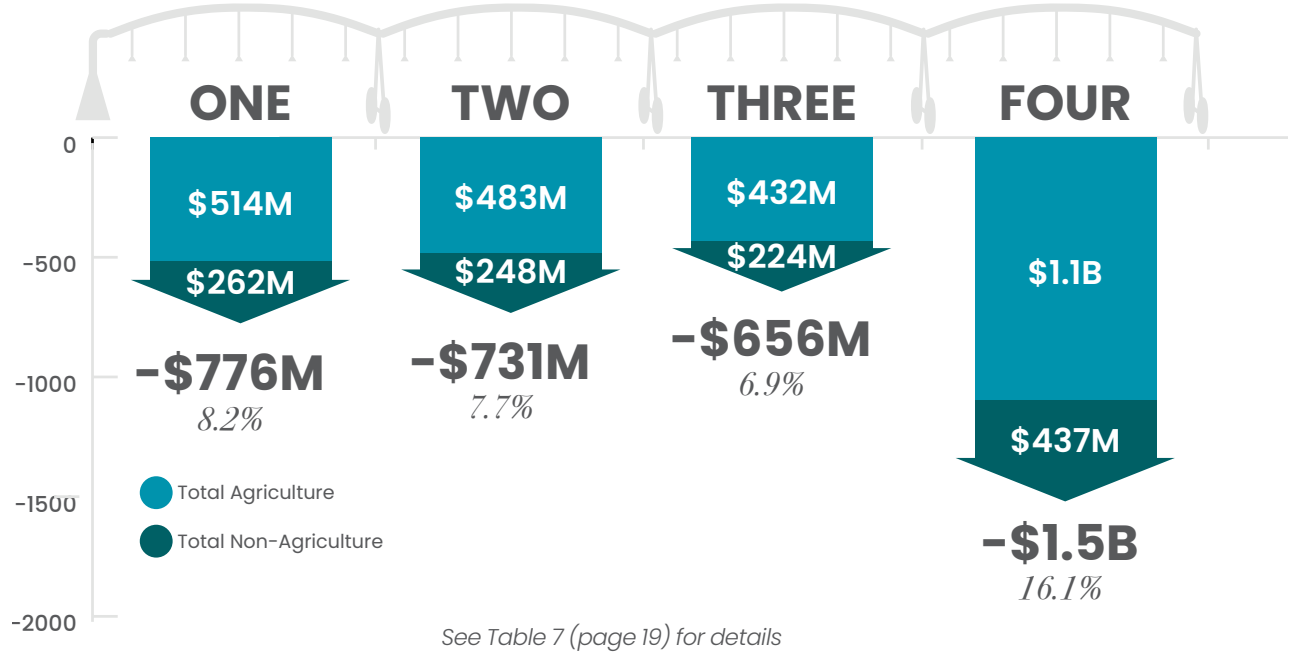
See Table 1 (page 6) for details

Annual Ag Revenue in the Study Area, 2022



See Table 5 (page 17) for details

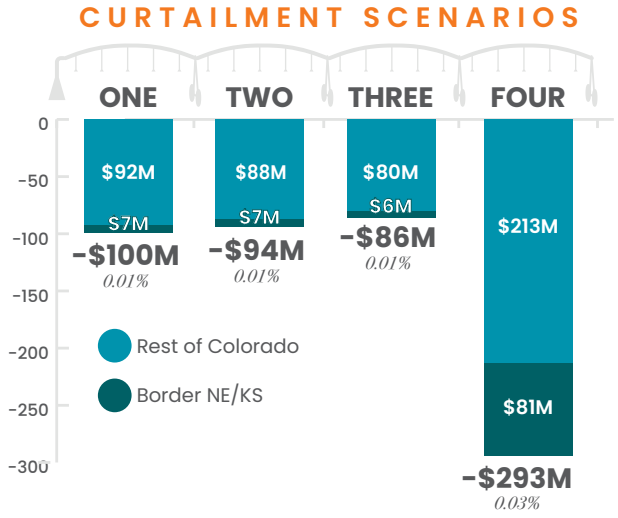
Changes in Annual Revenue in the Eight-County Study Area



See Table 7 (page 19) for details

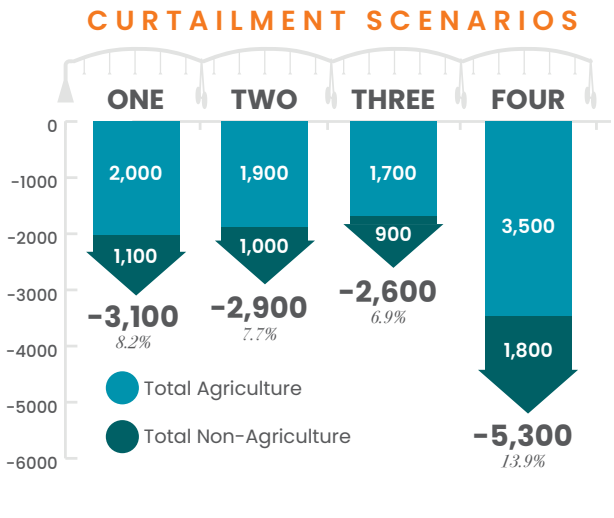
Achieving compliance with the land retirement requirement would avoid the negative economic consequences of basin-wide groundwater curtailment.

Annual Revenue Impacts in other Colorado Counties and Adjacent States



See Table 12 (page 26) for details

Changes in Employment in the Eight County Study Area



See Table 8 (page 20) for details

Introduction

Colorado's Republican River Basin is a highly productive agricultural region in the Northeastern portion of the state. The Basin originates east of Colorado's Front Range and therefore does not receive surface water flows from mountain snowmelt. Irrigated agriculture contributes significantly to economic activity in the region, with nearly all the irrigation water sourced from groundwater. The groundwater for irrigation is pumped from more than 3,000 large-capacity irrigation wells distributed across the region, as illustrated in Figure 1.

Significant economic linkages exist between agriculture and other sectors of the economy, meaning that irrigated agricultural production has a large impact on the region's entire economy. As directed by House Bill 23-1220, this report describes analysis of the potential economic impact associated with the curtailment of groundwater use from all large-capacity irrigation wells in Colorado's Republican River Basin (hereafter referred to interchangeably as "the Basin"). In particular, the report highlights the economy-wide impacts of groundwater curtailment within the eight counties that comprise the Basin (orange-colored counties in Figure 1), within the rest of the State of Colorado (tan-colored counties in Figure 1), and the counties in the states of Nebraska and Kansas that border Colorado's Republican River Basin (the blue-colored counties in Figure 1).

The Republican River Compact, originally agreed to in 1943 by the states of Colorado, Nebraska, and Kansas, governs flows of the North and South Forks of the Republican River, as well as the Arikaree River. All three rivers join to form the main stem of the Republican River in Nebraska. While initially focused on surface water, the compact has significant implications for groundwater users in Colorado. The Republican River Basin overlies a portion of the Ogallala (High Plains) aquifer and is hydrologically connected to the surface water sources, meaning that groundwater pumping can reduce river flows and impact compact obligations. The expansion of groundwater pumping across the region in the post-World War II period has led to a reduction in surface water flows. In 1998, Kansas filed suit against Nebraska and Colorado in the U.S. Supreme Court, claiming that excessive groundwater pumping was causing the states to be out of compliance with the compact (Popelka 2004).

In 2000, a Supreme Court-appointed Special Master determined that groundwater pumping could be considered a contributor to compact violations (SCOTUS 2000). In response to the ruling of the Special Master and subsequent penalties, Colorado established the Republican River Water Conservation District (RRWCD) in 2004. The RRWCD oversaw the construction and operation of a "compliance pipeline" along the North Fork of the Republican River and the retirement of irrigated land and associated groundwater wells throughout the Basin. The RRWCD also administered a fee (originally $14.50 per acre) on all irrigated land in the Basin to generate the funds required to support the pipeline and irrigated land retirement efforts. Compact compliance also required Colorado to drain Bonny Reservoir along the South Fork of the Republican River to cut down on evaporative losses (MacIlroy and Holm 2021).

In 2016, Kansas and Nebraska agreed to credit the water delivered as part of the compliance pipeline on the North Fork, but further required the retirement of an additional 25,000 acres of irrigated land by 2030 in the South Fork of the Republican River watershed, known as the South Fork Focus Zone (MacIlroy and Holm 2021). Since 2016, 17,991 acres of irrigated agricultural land have been retired in this region (as of December 2025). If the required 25,000 irrigated acres are not retired by the December 31, 2029 deadline, then Colorado's State Engineer has threatened to curtail groundwater use from all large-capacity irrigation

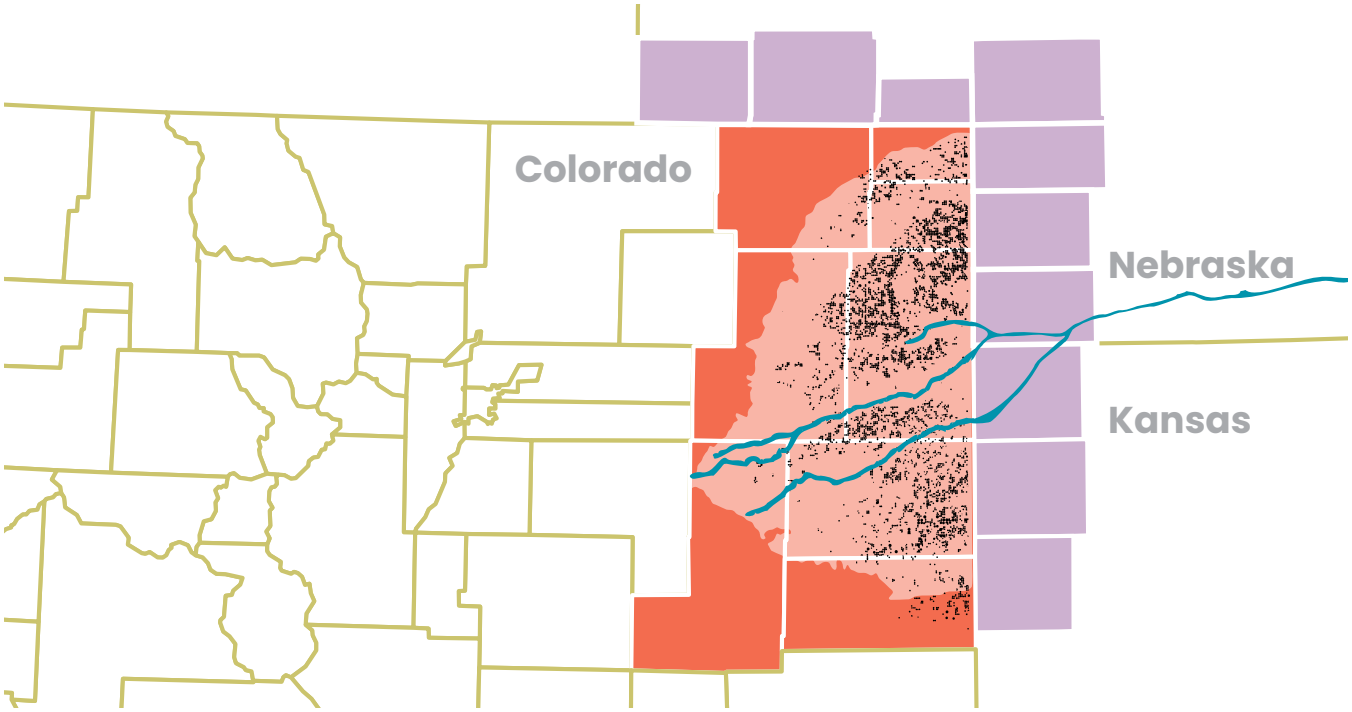


Figure 1: *Light orange area indicates the Republican River Water Conservation District boundary. The orange counties represent the study area. The purple counties are neighboring counties in Nebraska and Kansas. The Black dots indicate irrigation wells located in the Colorado portion of the District. The blue lines represent the south and north forks of the Republican River, and the Arikaree River.*

wells in Colorado's portion of the Republican River Basin. Chris Arend, spokesperson for the state engineer's office, confirmed "the state engineer would likely be faced with curtailing all wells across the Basin to address Colorado being out of compliance" (KUNC 2022).

To provide additional background for the analysis described in this report, the next section discusses current crop production and economic activities in the Basin. This is followed by a section that describes the two primary irrigated land retirement programs that are actively enrolling acreage in the study area, and the rationale for the analysis that we carry out.

The 2016 Republican River agreement requires the retirement of 25,000 acres of irrigated land in Colorado's South Fork Focus Zone by 2030.

Background

The Republican River Basin in Colorado covers nearly 7,000 square miles and is made up of all or parts of eight counties (Phillips and Yuma fall entirely within the Basin in addition to portions of Cheyenne, Kit Carson, Lincoln, Logan, Sedgwick, and Washington). In this analysis, we study the economic impacts of groundwater curtailment within the Basin on outcomes in the entirety of these eight counties. The eight counties have a land area of 14,474 square miles (9.26 million acres) and a population of 56,312 people (as of 2023). Figure 1 illustrates the eight Colorado counties in the Republican Basin, as well as the counties in Nebraska and Kansas that border the Basin.

Agriculture is a key economic activity in the eight-county study area, with crop production and animal production using almost 95% of the total land area. Table 1 provides a depiction of economic activity, measured as the dollar value of revenue and employment by sector, aggregated over the eight counties. Together, animal production and crop production account for more than 26% of the total revenue for the region, surpassing other top sectors such as manufacturing (7.5%) and real estate (6.7%). Agriculture is also an important source of employment in the region, with animal and crop production directly responsible for approximately 20% of all employment.

It is also important to note that other economic sectors in the region depend on agricultural production. Support activities specifically for agriculture make up 0.6% of local economic activity. Further, firms in the wholesale trade sector provide many of the inputs to agricultural

Table 1: *Revenue and employment by sector for the eight-county region containing the Republican River Basin, 2022*

Sector	Revenue (million $)	Percent of Total Revenue	Employment
State/local Government*	2,089.7	22.0	7,709
Animal Production	1,501.8	15.8	3,883
Crop Production	979.3	10.3	3,317
Manufacturing	707.4	7.5	1,008
Real Estate and Housing	640.2	6.7	2,447
Retail	530.7	5.6	4,663
Utilities and Waste Management	477.3	5.0	405
Mining, Construction, and Forestry	463.8	4.9	2,457
Wholesale Trade	410.1	4.3	1,166
Monetary Authorities and Banking	388.5	4.1	1,937
Non-Agricultural Support Services	385.9	4.1	3,159
Energy	294.9	3.1	263
Health Industry	220.6	2.3	2,068
Transport	190.9	2.0	762
Communications	101.0	1.1	649
Recreation	58.4	0.6	776
Support Activities for Agriculture	54.5	0.6	1,103
Total	9,495	100	37,772

Source: *2022 IMPLAN sector-level data*
** Includes government enterprises (e.g., public transportation) and expenditures on administration, education, health, and other services such as police and fire departments.*

Table 2: *Average agricultural land use in the eight-county study area (2020–2023)*

Agricultural land use	Non-Irrigated Acreage	Irrigated Acreage		
		Groundwater	Surface Water	Surface + Groundwater*
Alfalfa	27,103	39,184	19,602	14,174
Corn	640,275	426,571	22,400	27,109
Dry Beans	582	11,895	53	10
Fallow/Idle Cropland	1,004,774	4,406	471	463
Grassland/Pasture	4,632,787	1,935	376	262
Other Hay (Non Alfalfa)	20,652	1,256	2,896	1,612
Sorghum	207,005	12,455	455	628
Soybeans	351	3,747	50	139
Winter Wheat	1,166,759	51,959	866	1,156
Other Crops	373,743	32,160	3,472	3,591
Total	8,074,032	585,569	50,642	49,144

Source: *Authors' calculations from irrigated land data provided by the Colorado Decision Support Systems and the USDA's Cropland Data Layer.*

**Surface+groundwater means that the irrigated acres use water from both surface and groundwater sources.*

production (e.g., fertilizer and machinery). If the scale of agricultural production were to be reduced, then sectors that provide inputs to agricultural production would also see declines in revenue and employment.

The average annual distribution of agricultural land in the counties that comprise the study area is provided in Table 2. The outcomes described in the table include land within the Republican River Basin as well as land that falls outside of the Basin, but within the boundaries of Cheyenne, Kit Carson, Lincoln, Logan, Phillips, Sedgwick, Washington, and Yuma counties.

In total, less than ten percent of the agricultural land in the study area is irrigated, with grazing land (classified as grassland/pasture) accounting for the majority of the non-irrigated agricultural land. Most of the irrigated land in the study area uses groundwater sources, with only seven percent of the irrigated land area sourced exclusively from surface water. Table 2 reports 585,569 acres of groundwater-irrigated land in the study area. Of these, 526,431 acres fall inside the Republican River Basin and would potentially be subject to curtailment. Acreage irrigated with surface water is almost entirely located in the portions of the eight-county study area that lie outside of the Basin.

The agricultural land that is irrigated in the study area is primarily used to grow corn (69.5% of irrigated acreage), alfalfa (10.6%), and winter wheat (7.9%). Importantly, alfalfa and hay account for a higher percentage of acreage irrigated by surface water, with most of that acreage located outside of the Republican River Basin.

Groundwater Rights Retirement Programs

As part of the Republican River Compact agreements stemming from the original lawsuit filed in 1998, the RRWCD established programs to take irrigated agricultural land out of production, beginning in 2005. Known as the Environmental Quality Incentives Program (EQIP) and the Conservation Research Enhancement Program (CREP), the two largest groundwater rights retirement programs provide financial compensation for agricultural producers who voluntarily agree to take irrigated land out of production and permanently retire the associated groundwater rights.[1] The programs are

1 Since 2005, the Agricultural Water Enhancement Program, Ogallala Aquifer Initiative, RRWCD Acreage Management Program, and Well Purchase Permit Program have also been used to retire irrigated acreage in the study area.

funded by a combination of federal, state, and local support and are administered by the RRWCD. Both programs pay participating producers an up-front payment and then provide annual payments over a contract period. The contract period is typically 5 years for EQIP and 15 years for CREP. Producers participating in EQIP can engage in dryland crop production or grazing during and after the contract period. By comparison, participants in CREP must plant a conservation land cover during the 15-year contract period and can engage in dryland crop production or grazing only after the end of the 15-year contract. Under both programs, producers can use limited irrigation to establish non-irrigated vegetation in the years following enrollment.

As part of the continuation of Republican River Compact negotiations, Colorado agreed in 2016 to take an additional 25,000 irrigated acres out of production in the South Fork of the Republican River watershed, an area referred to as the South Fork Focus Zone (SFFZ). The agreement calls for the 25,000-acre requirement to be met by December 31, 2029, with the threat of groundwater curtailment across the entire Basin in Colorado if that does not occur. Table 3 provides a year-by-year breakdown of irrigated acreage enrolled in the CREP and EQIP programs since 2005. Over that time frame, similar amounts of land have been enrolled in CREP relative to EQIP across the Basin, with most CREP enrollment happening in 2006. Within the SFFZ specifically, Table 3 shows that approximately 17,991 acres have participated in CREP or EQIP between 2016 and December 2025, with more than 70% of that land participating in EQIP. This suggests that there remains a considerable gap between the actual enrollment of irrigated acreage and the 25,000-acre requirement. Figure 2 illustrates the groundwater wells associated with the irrigated land that has been retired throughout the Basin in Colorado since 2005.

Rationale for Research

Potential curtailment of all groundwater pumping throughout Colorado's Republican River Basin represents a significant threat to the economic viability of agricultural production in the region. The elimination of groundwater irrigation in

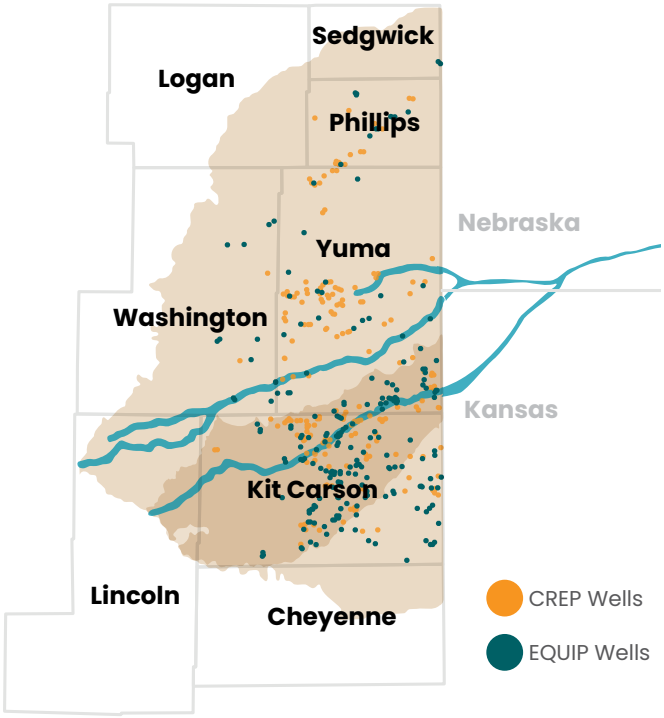


Figure 2: *Irrigated land participating in CREP and EQIP in the Republican River Water Conservation District. The dark brown colored area on the map is the South Fork Focus Zone (SFFZ).*

the region would involve a shift to lower-valued dryland crop production and grazing. This research explores the primary impact that shifting irrigated agricultural production to dryland crop production and grazing would have on agricultural producers, as well as the secondary impacts on businesses that supply inputs to agricultural production or benefit from the spending of agricultural producers and workers. In addition to evaluating economic impacts in terms of revenue generation, jobs, and government revenue in the Basin, the analysis also measures spillovers of economic impacts into other parts of the State of Colorado and into the counties in Kansas and Nebraska that border the Colorado portion of the Basin. The objective of this research is to highlight the magnitude of the economic implications of widespread groundwater curtailment in the Republican River Basin and to provide guidance to stakeholders on potential outcomes if the irrigated land retirement requirement is not achieved by 2030. The analysis that we present compares short-run economic outcomes in a scenario where all wells in the Republican Basin experience curtailment to the economic outcomes currently being experienced in the Basin.

Table 3: *Irrigated acreage enrolled in CREP and EQIP in the SFFZ and the rest of the Basin (2005 - December 2025)*

Year	CREP		EQIP		Total	
	SFFZ	Rest of Basin	SFFZ	Rest of Basin	SFFZ	Rest of Basin
2005	0	0	500	533	500	533
2006	10,215	9,421	2,579	1,885	12,794	11,305
2007	0	0	360	50	360	50
2008	0	0	4,028	962	4,028	962
2009	0	0	894	1,060	894	1,060
2010	0	120	58	0	58	120
2011	0	0	250	0	250	0
2012	262	341	0	120	262	461
2013	120	0	0	0	120	0
2014	0	0	0	0	0	0
2015	0	0	0	510	0	510
2005-2015	**10,596**	**9,882**	**8,668**	**5,120**	**19,264**	**15,001**
2016	0	0	0	292	0	292
2017	358	985	320	0	678	985
2018	0	0	0	60	0	60
2019	1,005	113	436	0	1,441	113
2020	0	815	0	115	0	930
2021	260	1,761	481	267	741	2,028
2022	1,511	1,214	1,783	1,686	3,294	2,900
2023	704	557	4,589	486	5,293	1,043
2024	732	243	4,942	920	5,674	1,162
2025	0	625	871	0	871	625
2016-2025	**4,570**	**6,314**	**13,421**	**3,825**	**17,991**	**10,139**
Total	15,167	16,196	22,089	8,945	37,255	25,141

Note: *The acreage summarized in the EQIP columns include 1,420 acres in the Agricultural Water Enhancement Program (AWEP), 1,182 in the Ogallala Aquifer Initiative, 2,202 acres in the RRWCD Acreage Management Program (RAMP), and 399 acres in the Well Permit Purchase Program (WPPP).*

...17,991 acres have participated in CREP or EQIP in the SFFZ between 2016 and December 2025, with more than 70% of that land participating in EQIP...suggesting that there remains a considerable gap between the actual enrollment of irrigated acreage and the 25,000 acre requirement.

Methods and Data

Input-Output Analysis and IMPLAN

The economic impact analysis uses an input-output (I - O) model of economic activity in the study region. The data used for the I-O model are provided by the IMPLAN (Impact Analysis for Planning) software, which is a widely used economic data and modeling tool that allows for the estimation of changes in short-run economic activity following an economic shock. In this case, the economic shock is the curtailment of groundwater irrigation in Colorado's Republican River Basin and the cessation of irrigation on 526,431 acres in the region. We simulate the reduction in output from irrigated production that leads to a 526,431-acre reduction in irrigated land.

Input-Output model is used to simulate the primary effect of groundwater curtailment on approximately 526,000 irrigated acres in Colorado's Republican River Basin.

The I-O model traces how spending flows through an economy, capturing the relationships between industries, households, and governments. IMPLAN data provide detailed, region-specific information on how economic activities can create ripple effects across economic sectors and allow us to quantify changes in revenue, employment, wages, incomes, and government revenues. I-O models require quantification of the direct effects of a shock. The model then calculates the total effects of the shock, which include indirect effects that arise from inter-industry purchases as suppliers respond to reductions in demand and induced effects, generated by changes in spending due to the changes in household earnings in the directly (agriculture) and indirectly affected industries. These impacts are computed using multipliers derived using data from IMPLAN and other sources, described below. This allows us to incorporate regional variations in production, consumption, and trade patterns. By modeling these economic dynamics, the output from I-O modeling allows us to assess the broader economic implications of groundwater curtailment. I-O analyses are based on social accounting matrices (SAMs) of local economies. SAMs describe flows of dollars from one industry, factor, household, or external account (e.g., trade) to another.

IMPLAN is a data tool that captures the linkages between sectors and allows us to quantify the economic impacts of groundwater curtailment.

We develop a Multi-Regional I-O (MRIO) model that represents each of the three regions described in Figure 1, including trade flows across sectors both within a region and across the three regions. The first model region (Region 1) is the eight-county region in Colorado that contains wells pumping from the Republican River Basin (Logan, Sedgwick, Phillips, Washington, Yuma, Lincoln, Kit Carson, and Cheyenne counties). The next model region (Region 2) includes all other Colorado counties. This allows us to quantify the impacts of groundwater curtailment in Colorado's portion of the Republican River Basin on the state economy as a whole. The final model region (Region 3) includes all counties in Kansas and Nebraska that border Colorado counties in the Republican River Basin. Including this region allows us to observe the potential cross-state effects of curtailment in Colorado.

To construct the SAM for our 3-region study area, we begin with the IMPLAN data that describe connections between industries identified by 3-digit North American Industry Classification System (NAICS) codes (e.g., crop production, forestry and logging, or chemical

Declines in revenue from irrigated agriculture reduce demand for local inputs and lower household income in the Basin, which impacts other economic sectors.

manufacturing), factor inputs (labor and capital), households based on 9 income classifications, state and local government, and trade outside of the region. The 3-region SAM includes within-region flows in addition to flows from one region to another. For example, our model describes the purchases of manufacturers in Colorado's Republican River Basin counties from other sectors within the Basin separately from purchases from other counties in Colorado, counties in Kansas and Nebraska that border the Colorado portion of the Basin, and purchases from outside our study region, including purchases from other parts of the US as well as imports from other parts of the world (see Figure 3).

To estimate inter-region linkages in the MRIO model, we create a linked SAM using the individual SAMs for each region. These data are combined with data from IMPLAN on the value of each commodity that is exported between regions. Because our individual SAM matrices represent industries and not commodities, we used industry by commodity SAM matrices from IMPLAN to create shares of industry production in each commodity (i.e., the industry market share). We then multiplied these shares by each commodity to get the industry flows. The Industry flows show the value of goods and services flowing from industries in one region to all the sectors in the other region. However, the data do not show how each exported commodity or the industry flows are used in the importing region. Therefore, we assume that imported goods would be used by all sectors in the same proportion as we observe within the region. We created sector use shares from the regional SAMs and multiplied them by the industry flows created earlier. This gives the interregional exports in the linked SAM. To avoid double-counting, exports and imports for each region are subtracted from the domestic trade of each regional SAM, and the remaining regional domestic trade sectors are then combined to form a domestic trade sector for the linked SAM.

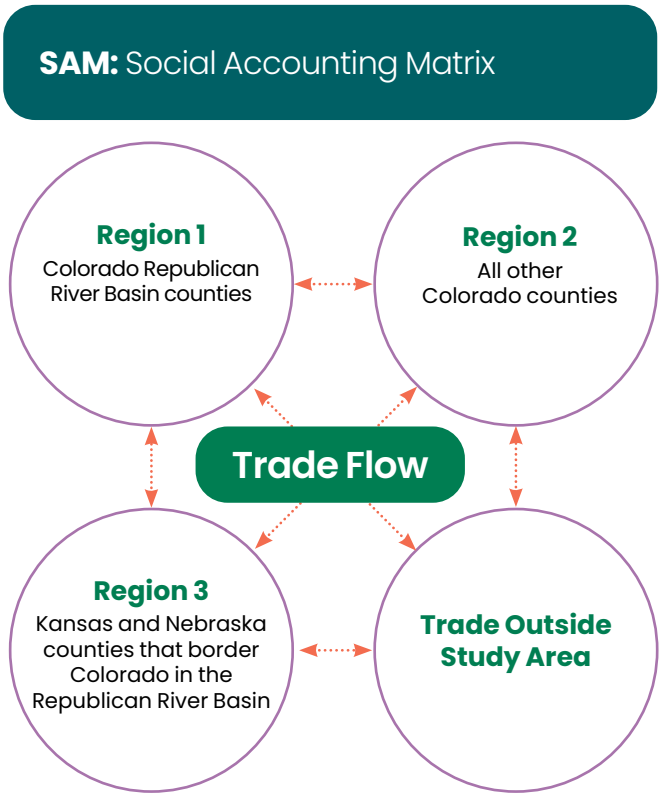


Figure 3: *Inter-region linkages in the MRIO analysis*

For the Republican River Basin of Colorado, we modify the Region 1 SAM to capture the role of irrigated and non-irrigated agricultural production in the local economy. To do this, we disaggregate crop production into separate irrigated and non-irrigated production sectors. Similarly, we separate the livestock sector into grazing and non-grazing (e.g., feedlot) activities. We also add land as a factor of production specifically used by the crop production and grazing sectors.

To disaggregate the crop production sector into separate irrigated and non-irrigated activities, we first calculate the value of total output for each crop using data from the USDA Cropland Data Layer (CDL) on the spatial extent of crop coverages, crop yields from enterprise budgets, and crop prices from the USDA National Agricultural Statistics Service (NASS) database. The value of output for each crop is scaled to reflect the total output of the crop production sector, as reported by IMPLAN. We

then use crop enterprise budgets to determine the value of each input (including payments to land) used in the production of each crop as a share of crop revenue. These input cost shares are then used to distribute the total output for each crop to the different industries in the SAM. These distributed values, down a given column in the SAM, represent the input purchases used to produce a given crop. Across a given row, we distribute the values in the crop production sector into the disaggregated crop sectors (i.e., crop to crop sales) using the proportion of each crop in total production value. We multiply the crop production value by the same proportions to get crop sales to the remaining sectors of the economy.

The economic impacts of groundwater curtailment depend on what the formerly irrigated agricultural land is used to produce once groundwater irrigation is no longer possible.

Similarly, we use the cow-calf enterprise budget for the livestock sector to determine the value of inputs the grazing sector purchases from each sector (including land). The cow-calf enterprise budget gives the cost and output per head on grazing enterprises. We also use data from the USDA NASS database to determine the herd size in the region. We multiplied the cost per head from the enterprise budget by the regional herd size to get the total cost or purchases from each other industry by the grazing sector in the study region. To avoid double-counting, we then subtract the grazing sector purchases from the animal production sector to create an industry of all non-grazing animal production operations (e.g., feedlots).

To include land as a factor input in the model, we create a new land sector that captures the land used by each crop and the grazing sector. This land sector represents agricultural land used for crop production and grazing only. Payments to land are calculated based on enterprise budget shares and then distributed to households according to household capital as reported in IMPLAN. To avoid double-counting, we subtracted the land sector from proprietor income and other property-type income where it is normally captured by IMPLAN. After modifications to the Colorado Republican River Basin Region, the linked SAM is balanced numerically using bi-proportional balancing (often referred to as the RAS method because of the common notation used in the matrix algebra representation of the method).

After creating the SAM, we distinguish sectors that re-spend income locally (e.g., local retailers that receive revenue and spend a portion of that revenue on local wages, building expenses, and other inputs) from those that do not (e.g., sectors from elsewhere in the country that do not spend changes in revenue on local wages and other local inputs). Dollars spent in sectors that re-spend locally become recycled and create additional local economic impacts. Dollars spent in external sectors are "leaked" from the local economy, and do not further impact local incomes or input demands. For a breakdown of which sectors recycle money locally and those that do not, see Table A1 in the appendix. We label sectors that recycle dollars locally as 'endogenous' while other sectors are labeled as 'exogenous.'

The output of I-O models includes changes in payments to different industries, factors, households, and governments. They can also produce estimates of changes in employment in each industry. They do not, however, model changes in prices. In other words, I-O models assume that as demand for inputs or final consumption goods and services increases, they can be supplied at constant marginal costs. This also implies that as demand for inputs or final consumption falls, the quantities purchased fall, but this does not affect local prices. Finally, conventional I-O models capture linkages moving backward along the supply chain but do not quantify downstream impacts. For example, when the demand for irrigated corn falls, producers demand fewer inputs and hire less labor. These effects then ripple through the local economy. The shock to irrigated corn does not, however, affect forward linkages within the economy. For example, demanders of irrigated corn, such as processors, are not impacted by the reduction in irrigated corn acreage. The modeling assumes that they

Table 4: *Distribution of soil type classifications by land use type*

	EQIP Retired Land		Irrigated Ag Land		Non-Irrigated Ag Land	
Soil Texture	Acres	Percentage	Acres	Percentage	Acres	Percentage
Clay Loam	422	1.3	10,484	2.0	197,097	5.4
Loam	4,886	15.2	103,166	19.6	1,503,163	41.0
Loamy Sand	1,467	4.6	67,991	12.9	216,587	5.9
Sand	845	2.6	74,401	14.1	88,159	2.4
Sandy Clay Loam	300	0.9	2,325	0.4	85,944	2.3
Sandy Loam	5,173	16	99,432	18.9	396,596	10.8
Silt Loam	14,267	44.3	139,965	26.6	658,965	18.0
Silty Clay Loam	4,875	15.1	28,668	5.4	519,678	14.2
Total	32,235	100	526,431	100	3,666,188	100

Note: The acreage summarized in the EQIP Retired Land column includes all land in the Basin enrolled through August 2025, including land enrolled in AWEP, OAI, RAMP, and WPPP.

will make up for the missing inputs by purchasing those inputs from outside the region without increasing prices. The fourth land use scenario, described below, relaxes this assumption.

Determining Alternative Land Uses

The economic impacts of groundwater curtailment depend on what the formerly irrigated agricultural land is used to produce once groundwater irrigation is no longer permitted. In this analysis, we assume that surface water will not be used to replace groundwater as a source of irrigation on agricultural operations. This assumption is based on the fact that surface water rights are highly limited within the Basin. As a result, the land use that replaces irrigated agricultural production is assumed to rely only on natural precipitation. In practice, establishing non-irrigated groundcover in the study area likely requires limited irrigation. Not allowing limited irrigation could restrict producers' ability to convert irrigated land into some non-irrigated uses.

Since we cannot predict precisely what will occur on each irrigated parcel following groundwater curtailment, our analysis proceeds by assessing four separate scenarios that cover potential land conversion outcomes in the event of curtailment. We assume that, following curtailment, producers can apply sufficient irrigation to implement the land use transitions that we model. The first scenario (Scenario 1) assumes that all land that comes out of irrigated production is replaced by grazing land. Grazing is currently the most common agricultural land use in the study area (see Table 2),

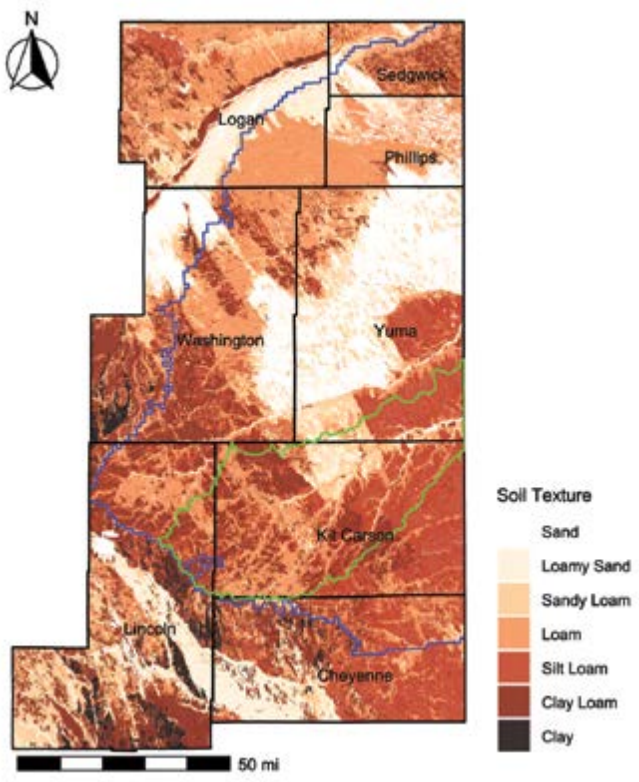


Figure 4: *Soil type classification based on USDA soil texture groups*

in part because it does not require significant external inputs such as irrigation, though grazing can use also occur on irrigated cropland when livestock feed on crop residues.

The second land conversion scenario that we assess (Scenario 2) assumes land use resembles choices on non-irrigated land that is currently being used for agricultural production in the region. While this scenario is informative, growing conditions on non-irrigated land differ from conditions on land that is currently being used for irrigated production. For example, the soil types on irrigated land in the Basin are more likely to have a sandy composition relative to non-irrigated land, which is more likely to occur on soils such as clay loam (see Figure 4 and Table 4). Based on the distribution of wells illustrated in Figure 1, there are a significant number of wells in the region of sandy soil in northern Yuma County.

To control for differences in growing conditions between currently non-irrigated and irrigated agricultural land (Table 4), our third land use scenario (Scenario 3) uses the agricultural land use outcomes on land enrolled in EQIP in conjunction with the characteristics of the EQIP-enrolled parcels to generate a predictive model of land use. The predictive model uses land characteristics of the EQIP -enrolled parcels that are likely to correlate with agricultural land use choices, for example, the parcel's soil type, to estimate a statistical relationship between the characteristic and the probability that a given land use type will occur on a parcel. Specifically, a multinomial logistic regression model is estimated using the characteristics of each EQIP-enrolled parcel and three possible agricultural land use outcomes—fallow, pasture, and dryland crop production. In addition to soil types, the model includes the parcel's elevation, latitude, longitude, field size, precipitation, and whether or not the parcel is located in the SFFZ as explanatory variables. The specification of the multinomial logit model and model estimation results are provided in the appendix.

Soil composition types representing sand, loamy sand, and sandy loam, as well as average precipitation, elevation, latitude, and location in the SFFZ are the variables found to significantly influence decisions to use the land parcels for grazing rather than fallow. On the other hand, decisions to use the land for dryland cropping are significantly influenced by silt loam and silty clay loam soil types as well as the parcel's longitude (see Table A2 in the appendix). Soils classified as loamy sand, sand, and sandy loam are all strongly and positively associated with increased odds of using the land for grazing relative to clay loam soils. However, these variables are not significant predictors of whether the land is likely to be used for dryland crop production.

The estimated model coefficients are applied to all irrigated parcels in the Basin by using each parcel's observable characteristics in conjunction with the coefficient estimates from the multinomial logit model to produce expected probabilities. We multiply the predicted probability at each parcel by the parcel size to determine expected acres in each agricultural land use (fallow, pasture, dryland crop). Finally, for the land use predicted to be planted with dryland crops, the distribution of dryland crops observed on the EQIP-enrolled parcels is used to determine the specific dryland crop types on those parcels.

The 4th scenario is not a new land use scenario. Instead, it is a pessimistic case in which groundwater curtailment results in 50% of non-grazing animal operations (e.g. feedlots) exiting the study region. The Colorado State Engineer's office has identified 42 active, large-capacity wells in the study region that are permitted for commercial or stock watering, which are primarily used by feedlots, swine producers, and dairy operations. Although we are not able to precisely predict the impacts of groundwater curtailment to these operations, the large reduction in corn silage from the region and the potential loss of groundwater used directly by individual operations would likely result in some feedlots, dairies, and swine producers leaving the study area. This assumption is combined with the land use changes described in Scenario 3 and is presented not as a prediction, but as an illustration of how losing downstream demanders of irrigated production could affect the local economy.

In all scenarios, we assume that the loss of irrigated land used for corn production has negative impacts on the activities of existing grazing (cow/calf) operations. Acreage used for irrigated corn production provides important winter forage and wet corn for existing grazing operations in the study area. Without this irrigated

corn production, grazing operations would likely need to reduce their herd size, purchase additional feed from external sources, or both. In our analysis, we assume that the reduction in irrigated land reduces the herd size for grazing operations. Specifically, we carry out a statistical analysis using county level data from the Basin and find that each irrigated corn acre supports approximately 1.29 grazing animals. Given that curtailment is predicted to reduce irrigated corn acreage by nearly 389 thousand acres, this implies that the overall herd size in the eight-county study area would be reduced by approximately 500 thousand animals, a 56% reduction relative to baseline. We account for this loss in grazing productivity in each of the four scenarios described above by assuming that land allocated to grazing is 56% less productive than it is currently. Land that is predicted to transition from irrigated crop production to grazing in each scenario is also assumed to be 56% less productive than current grazing land. The reduction in productivity is due to the lack of irrigated corn acreage for forage. The analysis assumes that land newly converted to pasture has had sufficient time to mature after conversion to support grazing animals.

Scenario Implementation

We examine the effects of groundwater curtailment in the study area by reducing external sales from irrigated agricultural production sectors to obtain the required reduction in irrigated land. Specifically, we shock the I-O model by changing the demand for agricultural output that comes from regions outside our study area. This produces estimates of the economic impacts of groundwater curtailment relative to the economy today and not relative to the economy that meets groundwater retirement objectives. We note that our simulations do not account for changes in water levels in Kansas or Nebraska that could occur because of curtailment in Colorado.

While groundwater curtailment represents a change in land use, the amount of land in each sector is determined within the I-O model. We must implement shocks to the study region as demand shocks that lead to targeted changes in land use. To do this, we calculate the change in demand for irrigated and non-irrigated agricultural sectors to obtain the targeted changes in land use. In all scenarios, we decrease demand for irrigated production sectors to achieve a decrease in irrigated acres of 526,431. Depending on the scenario under consideration, we also increase demand for non-irrigated agricultural sectors to induce the target increase in non-irrigated acres as retired irrigated land transfers to other uses. Since agricultural sectors are affected by both external and local demand, we solve simultaneously for the combination of external demand changes that lead to the targeted changes in the use of agricultural land, considering direct, indirect, and induced effects that occur within the 3-region study area (see the appendix for details of the method used to calculate the demand shocks that lead to the targeted land use changes).

In the analysis that we carry out, we refer to the economic impacts of groundwater curtailment experienced by the agricultural sector in Colorado's Republican River Basin as the 'primary effect' of curtailment. These primary effects are those due to changes in external and local demand for both irrigated and non-irrigated production in Colorado's Republican River Basin. They include changes in land use driven by the direct effects of changes in external demand and changes in land use driven by indirect and induced effects that influence demand for land.

We define the 'secondary effect' as the combination of indirect and induced effects impacting other sectors of the economy, including non-agricultural sectors in the Basin and all sectors in the rest of Colorado and in the adjacent counties of Kansas and Nebraska. We call the economic impacts in nearby regions 'spillover effects.' These spillover effects represent secondary effects that occur outside of the Republican River Basin of Colorado. They occur because of the economic linkages that exist between the economic sectors inside the Basin and sectors that lie outside of the Basin. For example, some of the inputs that go into irrigated agricultural production in the Colorado Republican River Basin (e.g., seed and fertilizer) come from suppliers located outside the Colorado portion of the Basin. These suppliers will also experience negative impacts when irrigated agricultural production is reduced due to groundwater curtailment.

Economic Profile of the Basin and Connected Regions

To carry out the IMPLAN modeling, we first simplify the agricultural land uses in Colorado's Republican River region into a smaller subset of irrigated and non-irrigated categories. This allows us to streamline the modeling by reducing the number of agricultural "sectors" that we evaluate. The specific agricultural land use categories for both irrigated and non-irrigated land are corn, hay (alfalfa), "other grain" (which includes sorghum and winter wheat), and "other non-grain" (which includes dry beans, soybeans, and all other field crops). Additionally, the analysis accounts for non-irrigated land use categories for fallow and grazing. Table 5 provides a summary of the acreage in each of the irrigated and non-irrigated land use categories over the 2020-2023 time period, as well as for the year 2022. The acreage data are summarized separately for 2022, since this represents the base year for the IMPLAN analysis.

Land use across the Basin in 2022 is very similar to average land use across the four years from 2020 to 2023 (Table 5). Corn remains the dominant irrigated crop category, and grazing is the dominant non-irrigated agricultural land use, followed by "other grain" (primarily winter wheat) and fallow. The acreage reported for 2022 constitutes the baseline for the economic analysis. The four scenarios are then implemented as changes from these base acres and are discussed in the next subsection.

Alternative Land Use Analysis

To estimate the impacts of groundwater curtailment, we implement four separate scenarios. The changes in acreage associated with the first three scenarios are reported in Table 6. In the fourth scenario, we assume the land use change from Scenario 3, but also assume a 50% reduction in demand for non-grazing livestock sectors. In each case, curtailment causes a reduction in irrigated crop production of 526,431 acres across the Basin. Most of this reduction comes from corn acres, which see a 388,816-acre (84%) decline across the eight-county study area (see the footnote to Table 6). The "other grain" (winter wheat and sorghum) and "other non-grain" categories see a similar proportional decrease in irrigated acreage (92% and 81% respectively), but since these crops represent a smaller number of acres in the baseline, they see a smaller reduction of approximately 50,000 acres in each case. Finally, irrigated hay production is predicted to decrease by 31,777 acres, which represents a 41 percent decrease in the study area. The reason for the smaller proportional decrease for hay is that most of the irrigated hay (alfalfa) production in these counties occurs outside of the boundary of the Republican River Basin in the South Platte River Basin.

In Scenario 1, reported in Table 6, all of the reduction in irrigated land is assumed to be replaced by grazing land. The 526,431 acre increase in grazing land represents only an 11.4 percent increase in grazing land within the eight counties, since pasture/grazing land represents over 4.6 million acres in the baseline.

The second scenario distributes the 526,431-acre decline in irrigated land into the non-irrigated agricultural land use categories in the same proportions as they currently occur on non-irrigated agricultural land in the Basin. In this scenario, the majority (302,060 acres) of the formerly irrigated acres convert to pasture/grazing land. The dryland "other grain" category accounts for the second largest increase in acreage, with 89,570 acres. Fallow land is next with 65,512 acres, followed by increases in dryland corn (41,746 acres) and "other non-grain" (24,429 acres).

In Scenario 3, a predictive model uses outcomes and characteristics on EQIP parcels to predict irrigated land use conversion choices across the Basin. The results, reported in Table 6, show smaller increases in grazing (compared to Scenario 2) and larger increases in acres dedicated to "other grain" (172,159 acres) and dryland corn (159,176). Since these crops tend to be more profitable than land allocated to grazing or left fallow, we expect that Scenario 3 will result in smaller reductions in economic activity compared to Scenarios 1 and 2.

Table 5: *Categories of agricultural land use and revenue across the eight-county study area used in analysis*

		Avg. Acres (2020-2023)	2022 Acres	2022 Annual Revenue
Irrigated	Corn	458,174	462,846	$379,047,390
	Hay	78,259	78,192	$46,098,067
	Other grain	60,811	60,063	$21,785,755
	Other non-grain	66,627	62,772	$6,452,896
Non-irrigated	Corn	640,275	665,185	$206,774,854
	Fallow	1,004,775	1,125,246	$0
	Hay	47,756	45,666	$17,491,189
	Other grain	1,373,763	1,269,414	$180,029,448
	Other non-grain	374,676	354,857	$43,452,851
	Grazing	4,632,787	4,613,419	$162,752,593
	Total	**8,737,901**	**8,737,660**	**$1,063,885,043**

Source: *Summarized agricultural land use categories from USDA CDL data. Annual revenue is calculated using the acreage along with crop enterprise budgets from CSU Extension. The category "Other grain" includes Sorghum and winter wheat. The category "Other non-grain" includes dry beans, soybeans, and "other crops".*

Table 6: *Changes in non-irrigated agricultural acreage following curtailment for Scenarios 1, 2, and 3*

		Baseline Acres	Scenario 1		Scenario 2		Scenario 3	
			Acreage Change	Percent Change	Acreage Change	Percent Change	Acreage Change	Percent Change
Non-irrigated	Corn	665,185	0	0	41,746	6.3	159,176	23.9
	Fallow	1,125,246	0	0	65,512	5.8	79,585	7.1
	Hay	45,666	0	0	3,114	6.8	9,641	21.1
	Other grain	1,269,414	0	0	89,570	7.1	172,159	13.6
	Other non-grain	354,857	0	0	24,429	6.9	34,574	9.7
	Grazing	4,613,419	526,431	11.4	302,060	6.5	71,296	1.5
	Total	**8,737,660**	**526,431**		**526,431**		**526,431**	

Note: *Each scenario involves a reduction in irrigated acreage of corn (388,816 acres), hay (31,777 acres) , other grains (55,220 acres), and other non-grains (50,218 acres) for a total of 526,431 acres. Scenario 4 uses the land use changes from Scenario 3 with the addition of a 50% reduction in demand for non-grazing livestock sectors.*

The irrigated agricultural land in the study area is primarily used to grow corn (69.5% of acreage), alfalfa (10.6%), and winter wheat (7.9%)

IMPLAN Results

This section describes the results from the I-O modeling for each of the four scenarios following the curtailment of groundwater in Colorado's Republican River Basin. We present tables for changes in revenue and employment by sector in each of the four scenarios. We then provide a table that provides results for changes in payments to the factors of production and changes in household incomes in the region for each scenario. The results are provided for the eight-county Colorado Republican River Basin region. We also report disaggregated impacts by county within the region. At the end of the section, we provide and discuss results related to changes in output, employment, and payments in the other two model regions.

The results in Table 7 show how revenue changes for specific activities within the agricultural sector (top portion) and for other economic sectors (bottom portion). Overall, the curtailment of groundwater is found to reduce revenue by $776 million across the Basin in Scenario 1, where all of the irrigated land converts to grazing. This represents a more than 8% reduction in revenue from baseline values. Looking at specific activities within the agricultural sector, irrigated corn production sees the biggest reduction in revenue, with a loss of over $342 million. This represents an 84% reduction in the value of irrigated corn output. The second largest impact within the agricultural sector, at over $83 million, is to revenue from grazing. This occurs because of the large decrease in grazing productivity driven by the loss of irrigated corn residue commonly used for feed. Irrigated other grain and hay also experience large impacts from curtailment, as do support activities for agriculture and non-grazing animal production. These latter two sectors do not experience any primary impacts from curtailment in Scenario 1, but they experience large secondary impacts due to reductions in input demand and spending.

Non-agricultural sectors are also found to experience significant decreases in revenue. These reductions in value are a result of secondary impacts, as reductions in input demand and spending reverberate through the economy. The biggest reduction in private sector revenue is experienced by wholesale trade ($48 million in Scenario 1), which loses significant demand for its output. The utilities and waste removal sector sees a similarly large decrease in revenue of nearly $34 million, given reductions in demand for inputs and changes in spending. State and local government revenue is found to fall by more than $56 million (2.7%) in Scenario 1.

The changes in employment that result from groundwater curtailment are experienced by both agricultural and non-agricultural sectors (Table 8). In Scenario 1, irrigated crop production experiences the largest decrease in employment, with 1,323 fewer jobs. Animal production (including grazing) and support services for agriculture also experience steep declines in employment, with 266 and 425 fewer jobs respectively. Despite the shift towards grazing acres following curtailment in Scenario 1, grazing productivity falls by enough to cause a substantial decrease in grazing employment (a 51% decrease).

In the private non-agricultural sectors, retail and wholesale trade see the largest decreases in employment with 177 and 138 fewer jobs in those sectors. Overall, the non-agricultural private sectors see a decrease in employment of 871 jobs (4%), while the agricultural sector loses 2,014 jobs (24%) following curtailment. There is an additional 209 jobs lost in the local and state government sector. The impacts to the non-agricultural sectors come about from the decreases in demand for inputs and decreased earnings from irrigated agriculture. Overall, employment decreases by 3,093 jobs across the Basin in Scenario 1. This represents an 8.2% decrease in employment in the eight-county region of our study area.

When comparing impacts across scenarios, similar patterns emerge for changes in revenue and employment across all sectors. In all sectors, the smallest negative impacts occur in Scenario 3, which predicts land use

Table 7: *Changes in revenue by sector for each scenario*

Sector	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Irrigated Corn	-342,122,746 (-84.01%)	-342,122,746 (-84.01%)	-342,122,746 (-84.01%)	-342,122,746 (-84.01%)
Irrigated Other Grain	-22,901,559 (-91.94%)	-22,901,559 (-91.94%)	-22,901,559 (-91.94%)	-22,901,559 (-91.94%)
Irrigated Hay	-19,859,356 (-40.64%)	-19,859,356 (-40.64%)	-19,859,356 (-40.64%)	-19,859,356 (-40.64%)
Irrigated Other Crops	-5,706,955 (-84.44%)	-5,706,955 (-84.44%)	-5,706,955 (-84.44%)	-5,706,955 (-84.44%)
Dryland Crops	0 (0%)	32,043,856 (6.52%)	81,347,754 (16.55%)	81,347,754 (16.55%)
Support Activities for Agriculture	-20,980,663 (-38.52%)	-19,742,226 (-36.25%)	-18,261,080 (-33.53%)	-21,494,996 (-39.47%)
Animal Production (Except Grazing)	-19,704,106 (-1.47%)	-18,223,234 (-1.36%)	-15,202,801 (-1.14%)	-674,813,962 (-50.41%)
Grazing	-83,151,946 (-50.98%)	-86,658,746 (-53.13%)	-89,708,847 (-55%)	-89,708,847 (-55%)
Wholesale Trade	-48,400,993 (-11.8%)	-46,101,015 (-11.24%)	-41,836,307 (-10.2%)	-64,857,818 (-15.81%)
Utilities and Waste	-33,934,122 (-7.11%)	-33,632,193 (-7.05%)	-33,136,111 (-6.94%)	-42,911,393 (-8.99%)
Real Estate and Housing	-32,095,025 (-5.01%)	-30,664,224 (-4.79%)	-28,307,842 (-4.42%)	-74,353,583 (-11.61%)
Monetary Authorities	-21,995,406 (-5.66%)	-19,205,645 (-4.94%)	-13,859,212 (-3.57%)	-24,440,363 (-6.29%)
Retail	-20,126,030 (-3.79%)	-18,944,189 (-3.57%)	-17,094,119 (-3.22%)	-29,923,825 (-5.64%)
Other Support Services	-13,890,373 (-3.6%)	-13,017,377 (-3.37%)	-11,562,937 (-3.00%)	-24,542,811 (-6.36%)
Mining, Construction, Forestry	-7,340,910 (-1.58%)	-6,906,030 (-1.49%)	-6,189,337 (-1.33%)	-14,227,570 (-3.07%)
Manufacturing	-7,020,099 (-0.99%)	-6,620,557 (-0.94%)	-5,958,973 (-0.84%)	-20,240,120 (-2.86%)
Transport	-6,210,312 (-3.25%)	-5,740,858 (-3.01%)	-4,998,118 (-2.62%)	-21,731,339 (-11.38%)
Other Private Sectors	-14,180,133 (-2.1%)	-13,365,644 (-1.98%)	-12,061,700 (-1.79%)	-22,801,156 (-3.38%)
State and Local Government	-56,610,493 (-2.71%)	-53,625,937 (-2.57%)	-48,742,028 (-2.33%)	-97,321,248 (-4.66%)
Total Agriculture	-514,427,331 (-20.29%)	-483,170,966 (-19.06%)	-432,415,589 (-17.05%)	-1,095,260,666 (-43.2%)
Total Non-Agriculture	-261,803,895 (-3.76%)	-247,823,670 (-3.56%)	-223,746,683 (-3.22%)	-437,351,226 (-6.28%)
Total	-776,231,226 (-8.18%)	-730,994,636 (-7.70%)	-656,162,272 (-6.91%)	-1,532,611,892 (-16.14%)

Table 8: *Changes in employment by sector for each scenario*

Sector	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Irrigated Corn	-1,159 (-84.01%)	-1,159 (-84.01%)	-1,159 (-84.01%)	-1,159 (-84.01%)
Irrigated Other Grain	-78 (-91.94%)	-78 (-91.94%)	-78 (-91.94%)	-78 (-91.94%)
Irrigated Hay	-67 (-40.64%)	-67 (-40.64%)	-67 (-40.64%)	-67 (-40.64%)
Irrigated Other Crops	-19 (-84.44%)	-19 (-84.44%)	-19 (-84.44%)	-19 (-84.44%)
Dryland Crops	0 (0%)	109 (6.52%)	276 (16.55%)	276 (16.55%)
Support Activities for Agriculture	-425 (-38.52%)	-400 (-36.25%)	-370 (-33.53%)	-435 (-39.47%)
Animal Production (Except Grazing)	-51 (-1.47%)	-47 (-1.36%)	-39 (-1.14%)	-1,745 (-50.41%)
Grazing	-215 (-50.98%)	-224 (-53.13%)	-232 (-55%)	-232 (-55%)
Wholesale Trade	-138 (-11.8%)	-131 (-11.24%)	-119 (-10.2%)	-184 (-15.81%)
Utilities and Waste	-29 (-7.11%)	-29 (-7.05%)	-28 (-6.94%)	-36 (-8.99%)
Real Estate and Housing	-123 (-5.01%)	-117 (-4.79%)	-108 (-4.42%)	-284 (-11.61%)
Monetary Authorities	-110 (-5.66%)	-96 (-4.94%)	-69 (-3.57%)	-122 (-6.29%)
Retail	-177 (-3.79%)	-166 (-3.57%)	-150 (-3.22%)	-263 (-5.64%)
Other Support Services	-114 (-3.6%)	-107 (-3.37%)	-95 (-3%)	-201 (-6.36%)
Mining, Construction, Forestry	-39 (-1.58%)	-37 (-1.49%)	-33 (-1.33%)	-75 (-3.07%)
Manufacturing	-10 (-0.99%)	-9 (-0.94%)	-8 (-0.84%)	-29 (-2.86%)
Transport	-25 (-3.25%)	-23 (-3.01%)	-20 (-2.62%)	-87 (-11.38%)
Other Private Sectors	-108 (-2.87%)	-102 (-2.71%)	-92 (-2.45%)	-163 (-4.34%)
State and Local Government	-209 (-2.71%)	-198 (-2.57%)	-180 (-2.33%)	-359 (-4.66%)
Total Agriculture	-2,014 (-24.25%)	-1,885 (-22.71%)	-1,688 (-20.34%)	-3,460 (-41.67%)
Total Non-Agriculture	-1,080 (-3.66%)	-1,014 (-3.44%)	-902 (-3.06%)	-1,804 (-6.12%)
Total	-3,093 (-8.19%)	-2,899 (-7.68%)	-2,591 (-6.86%)	-5,263 (-13.93%)

change based on observed decisions on acres enrolled in EQIP. Total revenue and employment each fall approximately 6.9%, though agricultural revenue and employment fall by a much larger percent change (17.1% and 20.3% respectively). Scenario 4 is the most pessimistic scenario because of the large decrease in the non-grazing livestock sector, which demands inputs across the economy. Under this scenario, total revenue and employment fall by 16.1% and 13.9% respectively, with agriculture experiencing drops of 43.2% and 41.7%. Scenarios 1 and 2 fall between these two extremes, with Scenario 1 generating slightly larger negative impacts to revenue and employment than Scenario 2.

The changes in production and employment translate into smaller returns to capital and land as well as a decrease in wages. The relative magnitude of the impacts follow the impacts to employment and revenue, with Scenarios 3 and 4 being the best and worst case scenarios, respectively. Wages fall by between 8.5% and 12.1%, land rents fall by 24.8% (they do not vary between Scenarios 3 and 4 because the land use changes are the same by design), and earnings from capital fall by between 2.4% and 7.0%. Taken together, payments to factors of production in the region fall by between 4.8% and 9.0%.

The loss in payments to factors of production means that local households also lose income (Table 9). Taken together, households lose between $143.5 and $241.7 million in income, depending on the scenario, representing drops of 4.3% and 7.2% respectively. Again, Scenarios 3 and 4 are best and worst-case scenarios with impacts in Scenarios 1 and 2 falling in between. We do not have data on the number of households in each income group so we do not know the impacts per household, but the largest impacts are felt by households with incomes between $100 and $150 thousand per year. Collectively, households in this range see a drop in income of between 5.2% and 8.5%. In percentage terms, higher income households (earning more than $200 thousand per year) see bigger drops in income of up to 9.4%.

County Level Impacts

In this section, we disaggregate the economic impacts by county. Specifically, the total impacts are allocated to each county based on a county's share of groundwater-irrigated acres in the Basin. Based on the results in Table 10, Yuma and Kit Carson counties are expected to experience the most negative impacts of groundwater curtailment. In Scenario 1, these counties see a reduction in revenue of $335 million (18.5%) and $186 million (12.9%) respectively. Together, the two counties account for more than 65% of the total reduction in revenue experienced under curtailment. This outcome is not surprising, since these are the two counties that lie fully within the Republican Basin. By comparison, Lincoln and Cheyenne Counties, which have relatively small proportions of land irrigated in the Republican Basin, see the smallest decreases in revenue ($3.9 million for Lincoln and $28.8 million for Cheyenne). The relative impacts across counties remain consistent across the four scenarios, with the largest decreases in revenue occurring in Scenario 4, which involves reductions in output from non-grazing animal production operations.

Similar to the changes in revenue, the largest decreases in employment under curtailment occur in Yuma (1,334 jobs in Scenario 1) and Kit Carson (740 jobs in Scenario 1). The majority of the jobs that are impacted are in the agricultural sector, with losses impacting more than 40% of the jobs in both counties in Scenario 1, rising to approximately 70% of jobs in Scenario 4. Although the biggest job losses are experienced in the agricultural sector, the secondary impacts of curtailment also have a negative impact on non-agricultural employment. Approximately 9.0% and 6.5% of jobs are expected to be lost in the non-agricultural sectors in Yuma and Kit Carson counties respectively in Scenario 1.

Spillover Impacts

In this section, we report the spillover impacts from groundwater curtailment in the Colorado portion of the Republican River Basin on the rest of Colorado and in counties in Kansas and Nebraska that border the Colorado Republican River counties (see Figure 1). Groundwater

Table 9: *Changes in payments to factors of production and payments to households*

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Compensation and Income	-132,033,209 (-9.64%)	-125,065,914 (-9.13%)	-116,124,728 (-8.48%)	-166,062,524 (-12.12%)
Land	-39,386,987 (-32.35%)	-36,502,761 (-29.98%)	-30,219,258 (-24.82%)	-30,219,258 (-24.82%)
Capital	-83,529,071 (-2.73%)	-79,420,298 (-2.59%)	-72,211,242 (-2.36%)	-212,718,183 (-6.95%)
Total	**-254,949,268 (-5.6%)**	**-240,988,973 (-5.29%)**	**-218,555,228 (-4.8%)**	**-408,999,965 (-8.98%)**
Households < 15k	-2,211,432 (-1.49%)	-2,095,641 (-1.41%)	-1,905,968 (-1.28%)	-4,539,224 (-3.06%)
Households 15-30k	-6,251,471 (-2.15%)	-5,915,365 (-2.04%)	-5,389,520 (-1.86%)	-10,221,625 (-3.52%)
Households 30-40k	-7,785,365 (-3.21%)	-7,363,686 (-3.04%)	-6,722,120 (-2.77%)	-11,645,322 (-4.8%)
Households 40-50k	-8,402,265 (-3.89%)	-7,946,477 (-3.68%)	-7,258,327 (-3.36%)	-12,296,533 (-5.69%)
Households 50-70k	-19,851,465 (-4.61%)	-18,767,043 (-4.35%)	-17,123,059 (-3.97%)	-28,626,990 (-6.64%)
Households 70-100k	-31,338,691 (-5.43%)	-29,613,883 (-5.13%)	-26,982,122 (-4.68%)	-44,097,294 (-7.64%)
Households 100-150k	-40,694,533 (-6.02%)	-38,449,187 (-5.69%)	-35,004,921 (-5.18%)	-57,055,437 (-8.45%)
Households 150-200k	-20,229,646 (-6.38%)	-19,101,926 (-6.02%)	-17,331,288 (-5.46%)	-28,293,886 (-8.92%)
Households > 200k	-30,456,693 (-6.4%)	-28,724,654 (-6.04%)	-25,805,558 (-5.42%)	-44,900,318 (-9.44%)
Total	**-167,221,561 (-4.96%)**	**-157,977,862 (-4.68%)**	**-143,522,882 (-4.25%)**	**-241,676,629 (-7.16%)**

Note: *The 'Capital' category includes changes in payments to capital and proprietor income.*

curtailment causes spillover impacts on revenue that range from $85.5 million to nearly $300 million in the case that half of all feedlots, dairies, and swine operations leave the Colorado portion of the Republican River and do not locate elsewhere in our broader study area (Table 12). These represent small percent changes, from 0.01% to 0.03%. The largest share of impacts accrue to the rest of Colorado (93% in Scenarios 1-3; 72% in Scenario 4), but impacts in KS/NE represent larger percent changes in revenue (0.07% to 0.99%), given smaller base levels in KS/NE counties. While the largest absolute impacts are in the non-agricultural sectors ($66.8 to $166.8 million in Colorado; $3.6 to $23.7 million in KS/NE), the percentage impacts are largest in the agricultural sectors, including production and agricultural services (0.02%-0.24% changes in the rest of Colorado and 0.07% to 2.03% in KS/NE). Lost tax revenue ranges from $11.3 to $28.6 million in the rest of Colorado and $0.7 to $7.0 million in KS/NE.

Spillover employment impacts follow similar patterns to revenue, with Colorado experiencing the largest share of lost jobs, but KS/NE experiencing larger percent changes from smaller

bases (Table 12). Total spillover job losses range from 386 to 1,190. Again, non-agricultural sectors lose more jobs in all scenarios and across both regions, but for the rest of Colorado, they represent smaller percent changes than jobs lost in agriculture and supporting services.

Finally, spillover impacts of groundwater curtailment also cause household incomes to fall in the regions that neighbor the Colorado portion of the Republic River Basin (Table 13). Total spillover household income losses range from $28.4 to $86.4 million. Higher income households lose more income in both regions and across all scenarios, though the impact per household is not clear from these aggregate results. Consistent with impacts to revenue and employment, most spillover income impacts accrue to households in the rest of Colorado.

Table 10: *Changes in agricultural and non-agricultural* revenue by county*

County	Sector	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Cheyenne	Agriculture	-19,105,553 (-13.56%)	-17,944,709 (-12.74%)	-16,059,681 (-11.4%)	-40,677,390 (-28.88%)
	Non-Ag	-9,723,255 (-3.00%)	-9,204,037 (-2.84%)	-8,309,831 (-2.56%)	-16,242,988 (-5.01%)
	Total	-28,828,809 (-6.2%)	-27,148,746 (-5.84%)	-24,369,512 (-5.24%)	-56,920,378 (-12.24%)
Kit Carson	Agriculture	-123,091,359 (-24.8%)	-115,612,385 (-23.29%)	-103,467,719 (-20.84%)	-262,072,242 (-52.8%)
	Non-Ag	-62,644,022 (-6.63%)	-59,298,856 (-6.28%)	-53,537,753 (-5.67%)	-104,648,710 (-11.08%)
	Total	-185,735,381 (-12.89%)	-174,911,242 (-12.14%)	-157,005,472 (-10.9%)	-366,720,952 (-25.46%)
Lincoln	Agriculture	-2,587,811 (-1.90%)	-2,430,577 (-1.78%)	-2,175,254 (-1.59%)	-5,509,676 (-4.04%)
	Non-Ag	-1,316,997 (-0.18%)	-1,246,670 (-0.17%)	-1,125,551 (-0.16%)	-2,200,082 (-0.31%)
	Total	-3,904,808 (-0.46%)	-3,677,247 (-0.43%)	-3,300,805 (-0.39%)	-7,709,758 (-0.9%)
Logan	Agriculture	-26,930,415 (-5.21%)	-25,294,135 (-4.89%)	-22,637,077 (-4.38%)	-57,337,203 (-11.08%)
	Non-Ag	-13,705,507 (-0.51%)	-12,973,638 (-0.48%)	-11,713,201 (-0.44%)	-22,895,459 (-0.85%)
	Total	-40,635,922 (-1.27%)	-38,267,774 (-1.19%)	-34,350,279 (-1.07%)	-80,232,662 (-2.5%)
Phillips	Agriculture	-60,220,612 (-33.97%)	-56,561,636 (-31.91%)	-50,620,039 (-28.56%)	-128,214,937 (-72.34%)
	Non-Ag	-30,647,654 (-6.1%)	-29,011,081 (-5.77%)	-26,192,547 (-5.21%)	-51,197,822 (-10.19%)
	Total	-90,868,267 (-13.37%)	-85,572,717 (-12.59%)	-76,812,587 (-11.3%)	-179,412,759 (-26.4%)
Sedgwick	Agriculture	-26,458,916 (-29.03%)	-24,851,285 (-27.27%)	-22,240,747 (-24.4%)	-56,333,341 (-61.81%)
	Non-Ag	-13,465,551 (-5.03%)	-12,746,496 (-4.76%)	-11,508,126 (-4.3%)	-22,494,605 (-8.4%)
	Total	-39,924,467 (-11.12%)	-37,597,781 (-10.47%)	-33,748,873 (-9.4%)	-78,827,946 (-21.96%)

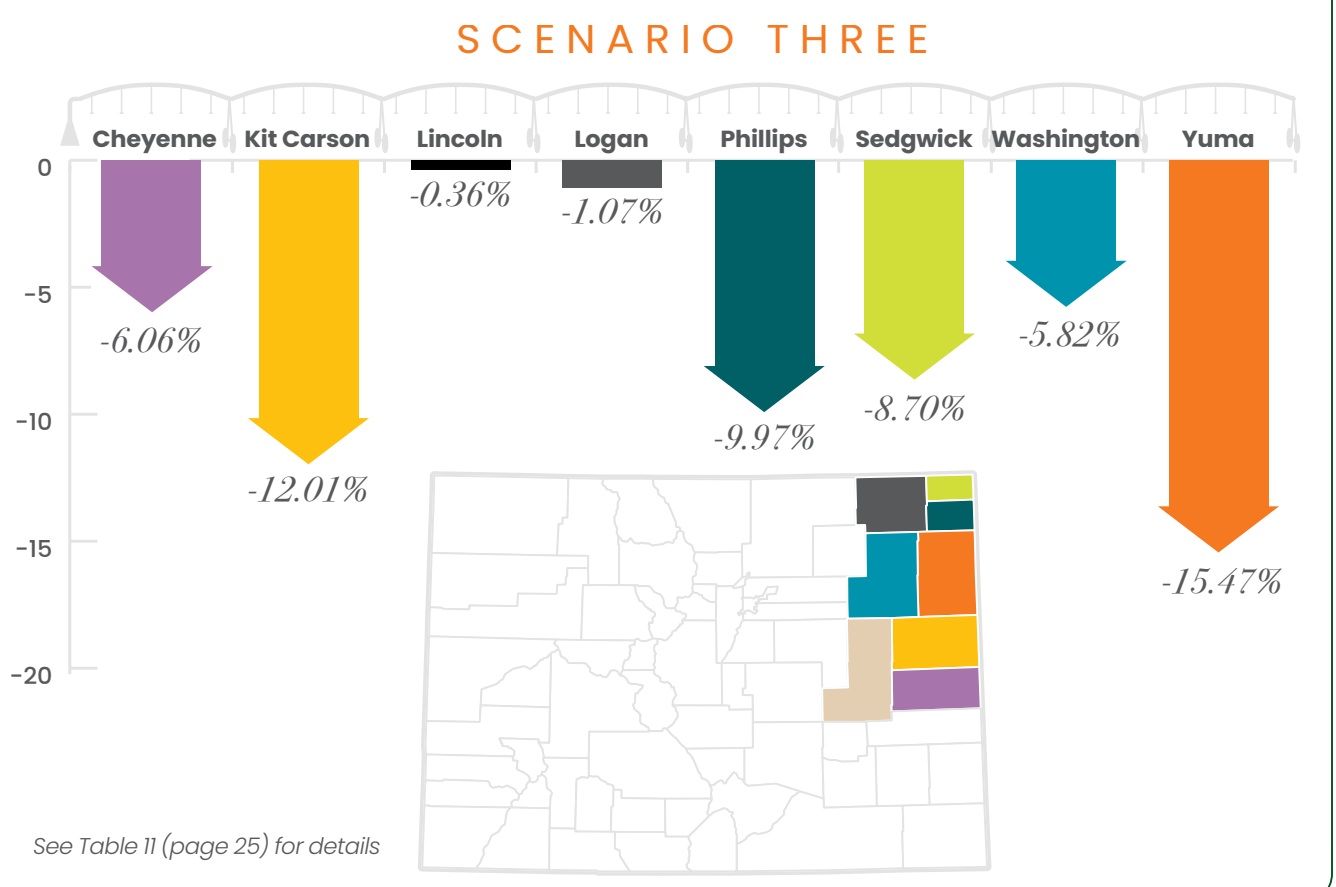
Table 10: *Continued*

County	Sector	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Washington	Agriculture	-34,240,417 (-14.01%)	-32,159,985 (-13.16%)	-28,781,694 (-11.77%)	-72,900,835 (-29.82%)
	Non-Ag	-17,425,735 (-3.99%)	-16,495,208 (-3.78%)	-14,892,637 (-3.41%)	-29,110,211 (-6.67%)
	Total	-51,666,152 (-7.58%)	-48,655,193 (-7.14%)	-43,674,331 (-6.41%)	-102,011,046 (-14.98%)
Yuma	Agriculture	-221,792,247 (-30.31%)	-208,316,253 (-28.47%)	-186,433,378 (-25.48%)	-472,215,043 (-64.54%)
	Non-Ag	-112,875,173 (-10.5%)	-106,847,683 (-9.94%)	-96,467,035 (-8.98%)	-188,561,348 (-17.55%)
	Total	-334,667,420 (-18.53%)	-315,163,937 (-17.45%)	-282,900,414 (-15.66%)	-660,776,391 (-36.58%)
Totals	Agriculture	-514,427,331 (-20.29%)	-483,170,966 (-19.06%)	-432,415,589 (-17.05%)	-1,095,260,666 (-43.2%)
	Non-Ag	-261,803,895 (-3.76%)	-247,823,670 (-3.56%)	-223,746,683 (-3.22%)	-437,351,226 (-6.28%)
	Total	-776,231,226 (-8.18%)	-730,994,636 (-7.7%)	-656,162,272 (-6.91%)	-1,532,611,892 (-16.14%)

Note: *Revenue impacts are allocated based on each county's share of groundwater-irrigated acres in the Republican Basin—Cheyenne: 3.7%, Kit Carson: 23.9%, Lincoln: 0.5%, Logan: 5.2%, Phillips: 11.7%, Sedgwick: 5.1%, Washington: 6.7%, Yuma: 43.1%.*

***Includes change in government sector.**

Total Changes in Employment by County



See Table 11 (page 25) for details

Table 11: *Changes in agricultural and non-agricultural* employment by county*

County	Sector	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Cheyenne	Agriculture	-75 (-13.75%)	-70 (-12.87%)	-63 (-11.53%)	-128 (-23.62%)
	Non-Ag	-40 (-3.84%)	-38 (-3.61%)	-34 (-3.21%)	-67 (-6.42%)
	Total	-115 (-7.24%)	-108 (-6.78%)	-96 (-6.06%)	-195 (-12.31%)
Kit Carson	Agriculture	-482 (-40.41%)	-451 (-37.84%)	-404 (-33.89%)	-828 (-69.43%)
	Non-Ag	-258 (-6.50%)	-243 (-6.11%)	-216 (-5.44%)	-432 (-10.87%)
	Total	-740 (-14.33%)	-694 (-13.44%)	-620 (-12.01%)	-1,259 (-24.39%)
Lincoln	Agriculture	-10 (-1.25%)	-9 (-1.17%)	-8 (-1.05%)	-17 (-2.15%)
	Non-Ag	-5 (-0.19%)	-5 (-0.18%)	-5 (-0.16%)	-9 (-0.32%)
	Total	-16 (-0.43%)	-15 (-0.4%)	-13 (-0.36%)	-26 (-0.73%)
Logan	Agriculture	-105 (-7.62%)	-99 (-7.13%)	-88 (-6.39%)	-181 (-13.09%)
	Non-Ag	-57 (-0.5%)	-53 (-0.47%)	-47 (-0.42%)	-94 (-0.84%)
	Total	-162 (-1.28%)	-152 (-1.2%)	-136 (-1.07%)	-276 (-2.18%)
Phillips	Agriculture	-236 (-29.56%)	-221 (-27.68%)	-198 (-24.79%)	-405 (-50.78%)
	Non-Ag	-126 (-5.63%)	-119 (-5.29%)	-106 (-4.7%)	-211 (-9.4%)
	Total	-362 (-11.9%)	-339 (-11.15%)	-303 (-9.97%)	-616 (-20.25%)
Sedgwick	Agriculture	-104 (-23.87%)	-97 (-22.35%)	-87 (-20.02%)	-178 (-41.01%)
	Non-Ag	-56 (-5.06%)	-52 (-4.75%)	-46 (-4.23%)	-93 (-8.45%)
	Total	-159 (-10.39%)	-149 (-9.74%)	-133 (-8.70%)	-271 (-17.67%)
Washington	Agriculture	-134 (-11.97%)	-125 (-11.21%)	-112 (-10.04%)	-230 (-20.56%)
	Non-Ag	-72 (-3.89%)	-67 (-3.66%)	-60 (-3.25%)	-120 (-6.51%)
	Total	-206 (-6.94%)	-193 (-6.51%)	-172 (-5.82%)	-350 (-11.82%)
Yuma	Agriculture	-868 (-42.96%)	-813 (-40.22%)	-728 (-36.02%)	-1,492 (-73.8%)
	Non-Ag	-465 (-8.96%)	-437 (-8.41%)	-389 (-7.49%)	-778 (-14.96%)
	Total	-1,334 (-18.48%)	-1,250 (-17.32%)	-1,117 (-15.47%)	-2,269 (-31.44%)
Totals	Agriculture	-2,014 (-24.25%)	-1,885 (-22.71%)	-1,688 (-20.34%)	-3,460 (-41.67%)
	Non-Ag	-1,080 (-3.66%)	-1,014 (-3.44%)	-902 (-3.06%)	-1,804 (-6.12%)
	Total	-3,093 (-8.19%)	-2,899 (-7.68%)	-2,591 (-6.86%)	-5,263 (-13.93%)

Note: *Impacts to employment are allocated based on each county's share of groundwater-irrigated acres in the Republican Basin - Cheyenne: 3.7%, Kit Carson: 23.9%, Lincoln: 0.5%, Logan: 5.2%, Phillips: 11.7%, Sedgwick: 5.1%, Washington: 6.7%, Yuma: 43.1%.*

**Includes change in government sector.*

Table 12: *Impact of groundwater curtailment on revenue in neighboring regions*

County	Sector	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Rest of CO	Ag	-1,747,307 (-0.02%)	1,640,245 (-0.02%)	-1,474,246 (-0.02%)	-1,719,1851 (-0.24%)
	Non-Ag	-77,450,734 (-0.01%)	-73,472,081 (-0.01%)	-66,794,423 (-0.01%)	-166,784,214 (-0.02%)
	State and local government	-13,064,788 (-0.01%)	-12,399,331 (-0.01%)	-11,288,733 (-0.01%)	-28,586,111 (-0.02%)
	Total	-92,262,829 (-0.01%)	-87,511,656 (-0.01%)	-79,557,102 (-0.01%)	-212,562,176 (-0.02%)
Border NE/KS	Ag	-2,074,410 (-0.08%)	-1,937,503 (-0.08%)	-1,666,483 (-0.07%)	-49,872,592 (-2.03%)
	Non-Ag	-4,351,154 (-0.1%)	-4,083,895 (-0.09%)	-3,639,399 (-0.08%)	-23,726,140 (-0.55%)
	State and local government	-814,332 (-0.06%)	-763,256 (-0.06%)	-675,733 (-0.05%)	-7,049,440 (-0.52%)
	Total	-7,239,896 (-0.09%)	-6,784,654 (-0.08%)	-5,981,616 (-0.07%)	-80,648,172 (-0.99%)
Total		-99,502,725 (-0.01%)	-94,296,310 (-0.01%)	-85,538,718 (-0.01%)	-293,210,348 (-0.03%)

Note: *Ag includes crop and livestock production, in addition to agricultural support services. Non-ag does not include state and local government.*

Table 13: *Impact of groundwater curtailment on employment in neighboring regions*

County	Sector	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Rest of CO	Ag	-34 (-0.07%)	-32 (-0.06%)	-30 (-0.06%)	-118 (-0.23%)
	Non-Ag	-332 (-0.01%)	-315 (-0.01%)	-286 (-0.01%)	-703 (-0.02%)
	State and local government	-48 (-0.01%)	-46 (-0.01%)	-42 (-0.01%)	-105 (-0.02%)
	Total	-414 (-0.01%)	-393 (-0.01%)	-357 (-0.01%)	-926 (-0.02%)
Border NE/KS	Ag	-5 (-0.09%)	-5 (-0.08%)	-4 (-0.07%)	-116 (-2.06%)
	Non-Ag	-27 (-0.14%)	-25 (-0.13%)	-22 (-0.12%)	-122 (-0.64%)
	State and local government	-3 (-0.06%)	-3 (-0.06%)	-2 (-0.05%)	-25 (-0.52%)
	Total	-35 (-0.12%)	-32 (-0.11%)	-29 (-0.10%)	-264 (-0.89%)
Total		-449 (-0.01%)	-425 (-0.01%)	-386 (-0.01%)	-1,190 (-0.03%)

Note: *Ag includes crop and livestock production, in addition to agricultural support services. Non-ag does not include state and local government.*

Table 14: *Impact of groundwater curtailment on household income in neighboring regions*

County	Income	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Rest of CO	< 100k	-8,749,036 (-0.01%)	-8,296,819 (-0.01%)	-7,542,746 (-0.01%)	-18,859,275 (-0.01%)
	> 100k	-22,431,424 (-0.01%)	-21,270,314 (-0.01%)	-19,334,383 (-0.01%)	-48,532,590 (-0.02%)
Border NE/KS	< 100k	-762,857 (-0.06%)	-715,118 (-0.06%)	-632,279 (-0.05%)	-7,350,589 (-0.59%)
	> 100k	-1,049,772 (-0.07%)	-983,971 (-0.07%)	-868,123 (-0.06%)	-11,639,398 (-0.79%)
Total		-32,993,089 (-0.01%)	-31,266,222 (-0.01%)	-28,377,531 (-0.01%)	-86,381,852 (-0.02%)

Discussion and Conclusion

Groundwater provides a critical input to irrigated agriculture in the Republican River Basin of Colorado. If the state falls short of reducing irrigated acres by 25,000 acres in the South Fork of the Republic River watershed, then the State Engineer has threatened groundwater curtailment throughout the Basin. This report documents the economic consequences associated with the curtailment of groundwater irrigation. These consequences will in-part depend on what economic activity occurs on the land that is currently being irrigated with groundwater resources. Since alternative surface water irrigation sources are not available, the land currently irrigated with groundwater will necessarily switch to a non-irrigated land use. We model four scenarios that provide alternative land and economic transition outcomes in the event of curtailment.

Using an input-output modeling framework, the economic analysis accounts for impacts to the economy in the agricultural sector, which is directly impacted by curtailment, as well as other sectors of the economy, which are indirectly affected as incomes and demand for inputs decline. Not surprisingly, the largest impacts are experienced in the agricultural sector, where revenues decline by between $432 and $1,095 million per year. These losses are particularly concentrated in irrigated corn production, which sees a decline in revenue of 84% across all four scenarios in the eight-counties that contain land in the Republican River Basin of Colorado (though relative losses are largest for other irrigated grains, at 92%).

The economic losses in the agricultural sector generate secondary declines in revenue in other economic sectors, with particularly large impacts in the wholesale trade, utilities, and real estate sectors. In summary, our model finds that groundwater curtailment will result in a decline of between $656 and $1,533 million in annual revenue, depending on the scenario. Accompanying these declines in revenue are decreases in employment. The primary study area sees a loss of between 2,591 and 5,263 jobs following curtailment, which represents a decline of approximately 6.9% to 13.9%. The reductions in revenue and employment are particularly concentrated in Yuma and Kit Carson counties, which see the majority of the impacts from curtailment given that the counties are fully located within the Republican Basin. Lower revenue and employment due to curtailment ultimately means lower household incomes and negative impacts to tax revenues throughout the primary study region.

Neighboring regions to Colorado's Republican River Basin are also found to see diminished economic activity as a result of curtailment. Specifically, other counties in Colorado, outside of the eight that comprise the Republican Basin, see a loss of between $80 and $213 million in revenue and between 357 and 926 fewer jobs. Counties in Nebraska and Kansas that share a border with the impacted counties in Colorado are also see negative impacts, with a decline of between $6 and $81 million in revenue and between 29 and 264 fewer jobs. These losses imply household income losses of between $28 and $86 million across the two regions.

We note that I-O modeling does not capture all potential impacts of shocks to the economy. For example, our estimated impacts in Scenarios 1 through 3 do not account for downstream impacts in the supply chain. If reduced local agricultural production increases local prices and causes large demanders of output (e.g., feedlots) to exit the region, we do not fully capture these impacts. Scenario 4 is meant as an illustration of the implications of potential downstream impacts. Further, if losing local supply causes these large demands to shift purchases from the Republic River Basin

of Colorado to the other regions we model, we do not capture these impacts. We also cannot estimate price effects and assume no substitutability of different inputs as economic activity falls. I-O models also assume constant returns to scale in all sectors.

Another potentially large impact of groundwater curtailment involves impacts to electricity suppliers in the region. We find that the utilities and waste sectors lose 7-9% of their baseline revenue because of groundwater curtailment. 92% of irrigation wells in Colorado, however, rely on electricity. In the Highline Rural Electric Cooperative, irrigation demand represented 59% of the total kilowatt-hours sold in 2022[1]. While this was a particularly dry year that led to an increase in electricity sales for irrigation, it demonstrates the importance of revenue from irrigation. If wells do not pump, local utilities will lose revenue. To continue covering large fixed costs, residential and commercial customers will likely face higher rates. These higher rates could have further economic impacts that are not reflected in our estimates.

The large economic consequences of curtailment that are documented in the report suggest that a benefit exists to avoiding such a scenario. It is beyond the scope of the analysis to make specific recommendations in this regard.

The I-O modeling in this analysis accounts for the economic linkages between sectors and geographic regions. This allows us to determine how changes in the agricultural sector may ripple through other economic sectors and regions. As stated previously, the approach does not estimate changes in the prices of inputs and outputs over time. Instead, the model assumes that technologies, production processes, and relative prices remain constant and is therefore unable to capture the dynamic effects of inflation, shifts in relative prices, or changes in input costs. This limitation makes the modeling more suited for short-term or static analyses rather than for evaluating long-term economic trends or scenarios where price fluctuations play a significant role. In the longer-term, it is likely that other types of production could enter or exit the study area as investments are made in capital and land. The economic analysis described in this report is not able to make these longer-term predictions of sectoral and population changes that result from such investments.

Overall, the analysis presented here describes a range of potential outcomes from groundwater curtailment. Results are meant to inform policymakers and other stakeholders as they consider the near term economic consequences associated with losing access to groundwater for irrigation.

1 https://www.hea.coop/sites/default/files/2024-09/annualmeetingunapprovedminutes.pdf

The North Fork of the Republican River photographed near Wray, Colorado. Photo by Jeffrey Beall/Wikemedia Commons.

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The South Fork of the Republican River (below) photographed near Hale, Colorado. The Republican River Compact governs the flows of the North and South Fork of the Republican River, as well as the Arikaree River. All three rivers join to form the main stem of the Republican River in Nebraska. Photo by Jeffrey Beall/Wikemedia Commons.

Appendix

Table A1: *Mapping of IMPLAN sectors to groups for output*

Sector	Presentation Group	Sector Type	NAICS Code
Broadcasting (except Internet)	Communications	Endogenous	515
Couriers and Messengers	Communications	Endogenous	492
Data Processing, Hosting, and Related Services	Communications	Endogenous	518
Other Information Services	Communications	Endogenous	519
Printing and Related Support Activities	Communications	Endogenous	323
Publishing Industries except Internet	Communications	Endogenous	511
Telecommunications	Communications	Endogenous	517
Gasoline Stations	Retail	Endogenous	447
Oil and Gas Extraction	Energy	Endogenous	211
Administrative and Support Services	Government	Endogenous	561
Administrative Government	Government	Endogenous	9B
Government Enterprises	Government	Endogenous	9A
State Local Govt Education	Government	Endogenous	
State Local Govt Hospital and Health	Government	Endogenous	
State Local Govt Investment	Government	Endogenous	
State Local Govt Other	Government	Endogenous	
Tax on Production and Imports	Tax on Production and Imports	Endogenous	
Ambulatory Health Care Services	Health Industry	Endogenous	621
Hospitals	Health Industry	Endogenous	622
Nursing and Residential Care Facilities	Health Industry	Endogenous	623
Households 100-150k	Households	Endogenous	
Households 15-30k	Households	Endogenous	
Households 150-200k	Households	Endogenous	
Households 30-40k	Households	Endogenous	
Households 40-50k	Households	Endogenous	
Households 50-70k	Households	Endogenous	
Households 70-100k	Households	Endogenous	
Households GT200k	Households	Endogenous	
Households LT15k	Households	Endogenous	
Apparel Manufacturing	Manufacturing	Endogenous	315

Sector	Presentation Group	Sector Type	NAICS Code
Beverage and Tobacco Product Manufacturing	Manufacturing	Endogenous	312
Chemical Manufacturing	Manufacturing	Endogenous	325
Computer and Electronic Product Manufacturing	Manufacturing	Endogenous	334
Electrical Equipment, Appliance, and Component Manufacturing	Manufacturing	Endogenous	335
Fabricated Metal Product Manufacturing	Manufacturing	Endogenous	332
Food Manufacturing	Manufacturing	Endogenous	311
Furniture and Related Product Manufacturing	Manufacturing	Endogenous	337
Machinery Manufacturing	Manufacturing	Endogenous	333
Miscellaneous Manufacturing	Manufacturing	Endogenous	339
Nonmetallic Mineral Product Manufacturing	Manufacturing	Endogenous	327
Paper Manufacturing	Manufacturing	Endogenous	322
Petroleum and Coal Products Manufacturing	Manufacturing	Endogenous	324
Plastics and Rubber Products Manufacturing	Manufacturing	Endogenous	326
Primary Metal Manufacturing	Manufacturing	Endogenous	331
Textile Product Mills	Manufacturing	Endogenous	314
Transportation Equipment Manufacturing	Manufacturing	Endogenous	336
Wood Product Manufacturing	Manufacturing	Endogenous	321
Construction	Mining, Construction, Forestry	Endogenous	23
Forestry and Logging	Mining, Construction, Forestry	Endogenous	113
Mining except Oil and Gas	Mining, Construction, Forestry	Endogenous	212
Support Activities for Mining	Mining, Construction, Forestry	Endogenous	213
Credit Intermediation and Related Activities	Monetary Authorities and Banking	Endogenous	522
Funds, Trusts, and Other Financial Vehicles	Monetary Authorities and Banking	Endogenous	525
Insurance Carriers and Related Activities	Monetary Authorities and Banking	Endogenous	524
Lessors of Non-financial Intangible Assets except Copyrighted Works	Monetary Authorities and Banking	Endogenous	533
Monetary Authorities	Monetary Authorities and Banking	Endogenous	521
Securities, Commodity Contracts, and Other Financial Investments and Related Activities	Monetary Authorities and Banking	Endogenous	523
Educational Services	Other Support Services	Endogenous	611
Inventory Additions Deletions	Other Support Services	Endogenous	
Management of Companies and Enterprises	Other Support Services	Endogenous	551
Professional Scientific and Technical Services	Other Support Services	Endogenous	541
Repair and Maintenance	Other Support Services	Endogenous	811

Sector	Presentation Group	Sector Type	NAICS Code
Social Assistance	Other Support Services	Endogenous	624
Warehousing and Storage	Other Support Services	Endogenous	493
Accommodation	Real Estate and Housing	Endogenous	721
Personal and Laundry Services	Real Estate and Housing	Endogenous	812
Private Households	Real Estate and Housing	Endogenous	814
Real Estate	Real Estate and Housing	Endogenous	531
Rental and Leasing Services	Real Estate and Housing	Endogenous	532
Amusement, Gambling, and Recreation Industries	Recreation	Endogenous	713
Fishing, Hunting, and Trapping	Recreation	Endogenous	114
Motion Picture and Sound Recording Industries	Recreation	Endogenous	512
Museums, Historical Sites, and Similar Institutions	Recreation	Endogenous	712
Performing Arts, Spectator Sports, and Related Industries	Recreation	Endogenous	711
Religious Grant-Making, Civic Professional, and Similar Organizations	Recreation	Endogenous	813
Building Material and Garden Equipment and Supplies Dealers	Retail	Endogenous	444
Clothing and Clothing Accessories Stores	Retail	Endogenous	448
Electronics and Appliance Stores	Retail	Endogenous	443
Food and Beverage Stores	Retail	Endogenous	445
Food Services and Drinking Places	Retail	Endogenous	722
Furniture and Home Furnishings Stores	Retail	Endogenous	442
General Merchandise Stores	Retail	Endogenous	452
Health and Personal Care Stores	Retail	Endogenous	446
Miscellaneous Store Retailers	Retail	Endogenous	453
Motor Vehicle and Parts Dealers	Retail	Endogenous	441
Non-store Retailers	Retail	Endogenous	454
Sporting Goods, Hobby, Musical Instrument, and Book Stores	Retail	Endogenous	451
Animal Production Except Grazing	Animal Production Except Grazing	Endogenous	112
Capital	Capital	Endogenous	
Dryland Corn	Dryland Corn	Endogenous	111
Dryland Hay	Dryland Hay	Endogenous	111
Dryland Other Crops	Dryland Other Crops	Endogenous	111
Dryland Other Grain	Dryland Other Grain	Endogenous	111
Employee Compensation	Employee Compensation	Endogenous	
Grazing	Grazing	Endogenous	112

Sector	Presentation Group	Sector Type	NAICS Code
Irrigated Corn	Irrigated Corn	Endogenous	111
Irrigated Hay	Irrigated Hay	Endogenous	111
Irrigated Other Crops	Irrigated Other Crops	Endogenous	111
Irrigated Other Grain	Irrigated Other Grain	Endogenous	111
Land	Land	Endogenous	
Proprietor Other Less Land	Proprietor Other Less Land	Endogenous	
Support Activities for Agriculture and Forestry	Support Activities for Agriculture and Forestry	Endogenous	115
Wholesale Trade	Wholesale Trade	Endogenous	42
Air Transportation	Transport	Endogenous	481
Pipeline Transportation	Transport	Endogenous	486
Rail Transportation	Transport	Endogenous	482
Scenic and Sightseeing Transportation	Transport	Endogenous	487
Transit and Ground Passenger Transportation	Transport	Endogenous	485
Truck Transportation	Transport	Endogenous	484
Water Transportation	Transport	Endogenous	483
Utilities	Utilities and Wastes	Endogenous	221
Waste Management and Remediation Services	Utilities and Wastes	Endogenous	562
Domestic Trade	NA	Exogenous	
Enterprises (Corporations)	NA	Exogenous	
Federal Government Defense	NA	Exogenous	
Federal Government Investment	NA	Exogenous	
Federal Government Non-Defense	NA	Exogenous	
Foreign Trade	NA	Exogenous	

NAs indicate sectors that we do not report in our impacts because they are not affected by local economic activity.

Land Use Choices

The activities that a producer can choose after irrigated land is retired can be grouped into 3 main categories: fallow, grazing, or dryland crop production. The question is, what factors influence the producer's land use decisions after the land has been taken out of irrigated crop production? We assume that producers choose the activity that maximizes their utility. Since there are more than two alternatives to choose from, we can apply the Multinomial discrete choice model to estimate the effects of explanatory variables on the adoption of different land uses. In this study, we use a Multinomial Logit (MNL) model. In the model specification, fallow is considered the base category, and all the estimates are calculated relative to the base category. When category k is taken as a base category, let be the Multinomial probability of an observation falling in the j^{th} category, then the MNL model is specified as follows:

$$Pr = P(Y_i = j|X) = \frac{exp(x_i\beta_j)}{1+\sum_{(k-1)}^{n} exp(x_i\beta_k)} \text{ For } j = 1, 2,..., (k\text{-}1), \text{ and } i = 1,2,..., n.$$

Where Y_i is the land use decision β_i is the vector of parameters and x_i all explanatory variables that can influence the probability of converting

Table A2: *Estimation results from the multinomial logit model*

	Pasture			Dryland Crop		
Variable	Coefficient	SE	P value	Coefficient	SE	P value
Elevation	-0.0135	0.0055	0.0140	0.0059	0.0040	0.139
Field Size	-0.0045	0.0059	0.4399	0.0031	0.0045	0.4961
Field Size Squared	0.0000	0.0000	0.4923	0.0000	0.0000	0.5831
Latitude	-6.5453	1.2261	0.0000	0.2723	0.3761	0.4690
Loam	-0.2585	0.5278	0.6243	-0.4704	0.4236	0.2668
Loamy Sand	4.8103	0.7277	0.0000	-0.4105	0.4938	0.4058
Longitude	0.4843	1.8364	0.7920	2.5101	1.1613	0.0307
Precipitation	-0.0814	0.0311	0.0090	0.0147	0.0162	0.3636
Sand	6.6624	0.8763	0.0000	-0.0727	0.6630	0.9127
Sandy Loam	2.2440	0.5589	0.0001	0.0078	0.4481	0.9862
Silt Loam	-0.1010	0.5570	0.8561	-0.8409	0.4470	0.0600
Silty Clay Loam	-15.8283	483.4721	0.9740	-1.1621	0.4880	0.0173
South Fork	1.4556	0.3461	0.0000	-0.0004	0.2065	0.9983
Intercept	340.1539	166.2578	0.0408	237.8928	107.2512	0.0270
Reference Category = Fallow						
N = 1860						
Log Likelihood = -1284.44						

The Arikaree River photographed near Yuma, Colorado. Photo by Jeffrey Beall/Wikemedia Commons.

land to alternative uses. Estimates of the coefficients in \beta_i are presented in Table A2.

Input-output modeling and calibrating demand shocks to simulate land use changes

Input-output (I-O) models use a matrix that describes the flows of payments from each sector in the economy to all other sectors in the economy. This matrix is often called the Social Accounting Matrix (SAM) of a region. It contains payments to all intermediate inputs (e.g., seed, fertilizer, and support services), factors (machines, land, and labor), and governments. In our three-region model, the SAM also describes purchases in each sector and region. Let this matrix contain sectors, including exogenous and endogenous accounts. This matrix provides the information needed to parameterize the model.

Let total value in sector i be y_i, with $y_o = [y_1, \ldots y_N]'$. A matrix of input-output coefficients is defined as

$$A_0 = \begin{bmatrix} a_{11} \cdots & a_{1N} \cdots \\ \cdots & \cdots \\ a_{1N} \cdots & a_{NN} \end{bmatrix}$$

where a_{ij} describes the amount of good/factor i used in producing 1 unit of good/factor J. It is often referred to as an input-output coefficient. aij can be obtained from the SAM by dividing element i, j in the SAM by the total of column j. For the I-O analysis, we focus on a subset of the sectors represented in the SAM. $X_0 = [x_1, \ldots X_N]'$ is a vector of exogenous demand for sectors/factors in the economy.

Let $n < N$ be the number of endogenous sectors in the local economy. The endogenous sectors are those that spend some portion of changes in their revenue in the local economy. They include most production sectors, factors, and households. We define A as the $n \, x \, n$ matrix of input-output coefficients for endogenous sectors of the economy. Similarly, define y and X as $n \, x \, 1$ vectors corresponding to the endogenous sectors of the economy. Given this, total output in the economy is described as:

$$y = Ay + X \qquad \text{(A1)}$$

y is a vector of quantities produced while $Ay+X$ is a vector of quantities demanded locally (Ay) and externally (X). Therefore, equation A1 states that the quantity produced equals the quantity demanded (equivalently, the quantity sold equals the quantity bought).

Equation A1 can be solved for :

$$y = [I - A]^{-1} X \qquad \text{(A2)}$$

And the change in y with a change in X is:

$$\Delta y = [I - A]^{-1} \Delta X \qquad \text{(A3)}$$

$[I\text{-}A]^{-1}$ describes the total change in y with a change in X. It captures the direct, indirect, and induced effects from a change in X. Since it contains factors like labor and land in addition to production activities, we can use this to estimate changes in wages and rents paid. With the linear production structure, we can also calculate sector specific changes in employment by applying proportional changes in total revenue (y) to base employment levels in a given sector. Similarly, we can apply the proportional changes to obtain sector-specific land use changes. We leverage this to solve for sector-specific demand shocks that lead to specific changes in land use by irrigated and non-irrigated agricultural production sectors, s_k.

Since we know the resulting change in land (sector l),

$$a_{lk}\, dy_k = s_{lk}, \quad k = 1, \ldots m \qquad \text{(A4)}$$

Therefore, we solve the system of equations described by equation A4 for the m elements of dX that differ from 0, where dy_k is the k^{th} element of $dy = [I\text{-}A]^{-1} \, dX$.

Where there are m equations and m unknown elements of dx that we solve for.

To obtain s_l, we use targeted proportional changes in acreage and apply them to the base data in our SAM. In other words, $s_{lk} = (1 + \phi_{lk}) * a_{lk} y_k$ where $a_{lk} y_k$ is the base quantity of land in sector k and ϕ_{lk} is the proportional change in acreage in sector in a given scenario.





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