RAISE Report 25-01 | Colorado State University | College of Agricultural Sciences & CSU Extension | Department of Agricultural and Resource Economics

Water Conservation on Grass Pastures in the Upper Colorado River Basin is Critical but Complex: Here's What it Will Take




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The RAISE Lab in the Department of Agricultural and Resource Economics at Colorado State University (agsci.colostate.edu/dare/raise) integrates research, teaching, and outreach to advance agricultural production systems and strengthen crop and livestock value chains. Through engaged partnerships and translational science, the lab addresses emerging topics in farm and ranch management, agricultural business and finance, production practices and technology, resource use and conservation, and related markets and policies. In doing so, it bridges CSU's expertise in agricultural economics, complimentary academic disciplines, and outreach/extension with real-world challenges faced by stakeholders. The RAISE Lab is directed by Dr. Daniel Mooney.

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The authors represent a wide range of disciplinary expertise and organizational unis at Colorado State University and beyond, reflecting the multidisciplinary and translational science focus of the RAISE Lab.

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Foreword | RAISE Report 25-01

Water Conservation on Grazed Pastures in the Upper Colorado River Basin is Critical but Complex: Here's What it Will Take

Introduction: Framing the Report

Making Voluntary Irrigation Withdrawals on Grass Pasture Work for Livestock Production and Water Conservation in the Upper Basin

Daniel Mooney[1], Dana Hoag[2], Seth Mason[2], Perry Cabot[3]

Purpose of the Report

This report explores what it will take to make voluntary, temporary, and compensated irrigation withdrawals on grass pastures feasible for livestock producers, with a focus on western Colorado. Our aim is to provide insights that support the development of workable programs and policies that contribute to meaningful regional water conservation, without undermining the long-term viability of irrigated agriculture or livestock operations.

A Realistic and Constructive Perspective

We focus on the field-level perspective—examining technical, operational, economic, and behavioral factors around producer implementation of irrigation withdrawal practices on working pastures. The report does not address broader elements of water conservation planning, such as water shepherding, water rights, or regional and multistate coordination. Nor does it offer normative judgements about whether, or how much water should be conserved through agricultural withdrawals versus alternatives like urban conservation, efficiency improvements, or supply enhancement efforts.

Importantly, this report is also not a prescription for curtailment. Rather, it is an effort to clarify the conditions under which voluntary irrigation withdrawals could work—for producers, for programs, the public, and for the region. Our goal is to inform water conservation strategies that are feasible, effective, and adapted to the realities of pasture-based livestock production in the Upper Colorado River Basin.

By sharing field-based insights and practical considerations with an eye towards implementation, we aim to support more informed decision-making around irrigation withdrawal practices by producers, water managers, conservation organizations, and policymakers—helping each weigh tradeoffs, anticipate challenges, and identify opportunities suited to their own contexts.

Context and Significance

Water scarcity in the Colorado River Basin is intensifying. Persistent drought, a declining snowpack, and growing demand among river water users have pushed water managers, policymakers, and agricultural producers to explore new ways to conserve water while sustaining livelihoods (Udall and Overpeck, 2017). The region contributes nearly $20 billion annually to the national economy (Crespo et al. 2025), underscoring its importance. These stresses pose significant risks across sectors, especially to agriculture in the Upper Basin, where water rights are closely tied to irrigated crop and livestock production (Mooney and Hansen, 2024). With agriculture accounting for over 70% of water use, it is central to conservation efforts.

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The seven basin states are working toward a shared water management vision, but as one observer noted, if they "cannot come to consensus, they will forfeit a chance to have a strong, united voice in their own water future. Without a basinwide proposal, the federal government will move forward with its own management options based on a variety of proposals, letters, climate models and more" (Mullane, 2025).

In response, Upper Basin states have begun investigating voluntary, compensated water-sharing arrangements, and policy makers have pledged millions of dollars in funding to support them (Booth, 2023). Within agriculture, these strategies often focus on temporary practices—such as seasonal fallowing (i.e., full-season irrigation withdrawal), split season irrigation (i.e., standard irrigation early in the growing season followed by irrigation shutoff later in the season), or crop switching—that aim to reduce consumptive water use. These actions can, in turn, support other downstream water uses (hydroelectric power production, urban demand, ecological flows, recreation, etc.) and help meet compact obligations (Upper Colorado River Commission, 2024).

The Challenge

Irrigated grass pastures—grazed by livestock and occasionally cut for hay—make up a significant share of irrigated acreage in western Colorado. As a result, they offer potential opportunities for voluntary, temporary, and compensated irrigation reductions as a strategy to reduce consumptive water use (Cabot et al., 2023). However, managing such reductions poses unique challenges related to livestock operations, pasture recovery, and economic viability.

Livestock-based operations are often overlooked in water conservation planning, yet they are a key component of the Upper Basin's economy, where grass, pasture, and alfalfa dominate land use. Unlike specialized crop or hay producers, livestock producers face higher risks: herds can be quickly downsized in response to forage scarcity, but require years to rebuild, making operations less adaptable to sudden or irregular irrigation cuts. Water programs must therefore go beyond acreage- or yield-based financial breakeven incentives and consider the distinct needs of livestock enterprises.

While implementing voluntary irrigation withdrawal practices on grass pastures may be technically possible, it is also operationally complex and economically uncertain. Producers must weigh how short-term changes in water use affect forage availability, animal performance, and long-term land productivity. At the same time, designing programs that support these efforts requires attention to behavioral factors such as demographic factors associated with producers' willingness to participate, their preferences over program or policy attributes, or attitudes towards water conservation in general. Put simply: water conservation on grass pastures could play a meaningful role in helping the region meet its water goals—but only if solutions are practically feasible, locally grounded, and compatible with producers.

Given this context there is a pressing need for field-scale evaluations of full- versus partial-season irrigation practices tailored to mid-elevation pasture (5,000-7,000 feet)—which account for more than half of consumptive use (CU) in the UCRB. These land areas are central to sustaining cow-calf any haying operations across the region. In response, this project aimed to generate new insight into the feasibility and scalability of voluntary irrigation withdrawal strategies that can support both water conservation and livestock operation viability.

Approach and Structure

The report is the result of a collaborative, multi-stakeholder research partnership between Colorado State University, Western States Ranches, and Conscience Bay Research. The goal was to evaluate the water conservation potential of eight irrigation withdrawal practices designed to maintain hay and livestock production on irrigated pastures—offering alternatives to widespread fallowing in the Upper Colorado River Basin. The project aimed to assess whether these practices could provide a more producer-compatible approach to water conservation, balancing systemwide goals with on-the-ground realities of livestock production.

Our analysis is grounded in field-scale demonstration trials conducted on two Upper Basin states owned by Western States Ranches, supplemented by interviews, field data, producer input, and expert perspectives. We combine a range of sources, including simulation models, climate and evapotranspiration data, market prices, and a survey of over 400 water experts and users---to build an improved understanding of feasibility, outcomes, and barriers. This report summarizes Phase I of the project, presenting preliminary insights. Additional results will follow in forthcoming Phase II.

The report is presented as a series of concise briefs, each examining a key dimension of this issue:

- Technical and agronomic factors, including the water conservation potential and yield effects of split-season and other partial irrigation strategies relative to no- and full-withdrawal alternatives.
- Operational and livestock management challenges, focusing on the complexities producers face when implementing reduced irrigation practices.
- Economic tradeoffs and producer decision-making, with attention to compensation levels necessary to incentivize participation.
- Behavioral and policy design considerations, including which types of producers and operations are most likely to adopt these strategies and what program features support their involvement.

By testing these strategies in real-world conditions, this project reflects the value of on-the-ground demonstration and acknowledges the risks innovative operations like Western States Ranches and project sponsors like Conscience Bay Research take when piloting new water management approaches.

Demonstration scale projects help bridge the gap between theory and practice. They allow stakeholders to observe outcomes, adapt methods, and gain trust through direct experience or learning from others (Mooney et al., 2023)—especially important in sectors like ranching, where variability in terrain, climate, and herd management can affect feasibility. Without field-based trials, it can be difficult to assess how conservation practices perform under real operational constraints or to develop policies that are both effective and translatable. Overall, by generating local evidence, this project helps inform more practical, scalable, and producer-compatible approaches to conservation in the Upper Basin.

In this Issue

The findings and perspectives reported here represent an initial summary of findings, with further research related to the study objectives ongoing.

- The first brief, **"*Estimating the Water Conservation Potential of Voluntary Irrigation Withdrawals on Working Livestock Pastures*,"** prepared by CSU agricultural engineer Perry Cabot and CSU civil and environmental engineers Jose Chavez and Adwoa Serwaa Amankaa, lay the foundation by assessing the technical potential of voluntary withdrawal scenarios to conservation water at the field level. It reports the results from demonstration-scale field trials conducted at two locations in western Colorado in collaboration with Western States Ranches.

- Serving as a companion to the first, the second brief, **"*Evaluating Yield Performance across a Spectrum of Irrigation Withdrawal Scenarios in Pasture-Livestock Systems*,"** prepared by Perry Cabot, presents forage production data from the same demonstration trials. This analysis summarizes data to better understand the agronomic trade-offs associated with the timing of voluntary irrigation withdrawal.

- Expanding the focus to operational considerations, the third brief, **"*Recommending Practical Strategies to Make Limited Irrigation Practices Work on Pasture-Based Livestock***

***Operations*,"** prepared by CSU agricultural economist Daniel Mooney and Perry Cabot, incorporates producer input from Dan Waldvogle and Mike Higuera. It examines how voluntary irrigation withdrawal practices can align with grazing schedules and day-to-day management needs.

- Building on these insights, the fourth brief, **"*Determining the Impact of Limited Irrigation Practices and Water Conservation Payments on Livestock Producers' Bottom Line*,"** prepared by Daniel Mooney, fellow CSU agricultural economists Dana Hoag and Bhishma Dahal, and Perry Cabot, offers an economic perspective. It analyzes breakeven values for water conservation payments at the field level, based on the foregone revenues from hay production and reduced grazing days across different withdrawal scenarios.

- Finally, the fifth brief, **"*Identifying Factors Associated with Farmer Willingness to Participate in Regional Water Conservation Programs*,"** prepared by CSU systems engineer Seth Mason with Dana Hoag and Daniel Mooney, examines the behavioral factors influencing producer participation decisions. It sheds light on the variability in producers' willingness to engage in water conservation efforts across program and policy design attributes as well as producer demographics and attitudes.

The remainder of the report provides an in-depth look at each brief, providing more information on our findings and practical insights to support decision making around voluntary withdrawal practices and to guide the development of feasible and effective regional conservation programs.

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Brief #1: Measuring Conservation

Estimating the Water Conservation Potential of Voluntary Irrigation Withdrawals on Working Livestock Pastures

Perry Cabot[1], Adwoa Serwaa Amankwaa[2], and Jose Chávez[2]

Overview

➢ Irrigated pasture-livestock systems dominate agriculture in Western Colorado, yet data on their water use and water conservation potential under voluntary irrigation withdrawals remains limited.

➢ We partnered with Western States Ranches to test eight irrigation scenarios on two working pastures, Orchard Ranch near Eckert and Banner Ranch near Delta, on Colorado's Western Slope.

➢ Results showed strong potential for voluntary withdrawal practices to reduce water use while maintaining some forage production. The greatest reductions came from early- and shoulder-season cutbacks—up to 47% when compared to fully irrigated reference fields.

Purpose

We evaluated the potential of voluntary irrigation withdrawal strategies, to help inform the design of practical, incentive-based water conservation programs for grazed pastures.

The findings will help stakeholders and policymakers:

- Assess the potential of voluntary irrigation withdrawals on working pastures to meaningfully contribute to regional water conservation efforts.
- Recommend measurement methods and program design features that align water savings goals with operational realities of livestock producers.

Approach

We tested 8 irrigation withdrawal strategies across ranches, using remote-sensing models to estimate actual evapo-transpiration (ETa) and conserved consumptive use (CCU).

- Treatments included full-withdrawal, spring only, fall only, shoulder month, split season (June 1, July 1, and Aug 1 shutoffs), and no-withdrawal strategies.
- Integrated livestock grazing into the study ensured that estimates reflect real-world grazing conditions.

We used NDVI remote sensing to measure ETa, CCU, and spatial variability compared to fully-irrigated reference fields.

Findings

The results provide field-based evidence that voluntary irrigation withdrawals can reduce ETa in grazed pastures.

- Seasonal ET on the fully irrigated reference fields was 33.7 and 35.3 inches at Banner and Harts Basin ranches, respectively.
- Field-scale ETa estimates, derived from NDVI, were correlated with irrigation timing.

Irrigation withdrawal implemented early in the season had the largest CCU benefit, confirming the expected outcomes.

- Full-season withdrawal and late-season only irrigation had highest CCU compared to the fully irrigated reference fields, 40-47% at Banner and 27-30% at Harts Basin.
- Standard irrigation early in growing season with mid- or late-season withdrawal (July 1 or August 1 shutoff) resulted in less CCU, 6-10% at Banner and 15-17% at Harts Basin, indicating diminished returns with delayed withdrawal.
- Irrigation only in May and September (shoulder months) showed moderate CCU, offering a balanced approach between conservation and forage growth.

Strategically implementing reductions can conserve water without fully compromising forage availability.

Insights

The findings are relevant for voluntary water-sharing programs that may compensate producers for water conservation:

- Results help fill key data gaps on ETa and CCU under irrigation curtailment in Western Colorado.
- Accurate estimation of CCU requires careful selection of reference fields, suggesting a potential benefit to using multiple reference zones.

Significant within-field variability, particularly at Orchard Ranch, influenced CCU outcomes.

- This is particularly true for heterogeneous pastures, like Orchard Ranch, where variability is more pronounced.

Combining remote sensing (SIMS and NDVI-based methods) with field data improves accuracy of water use measurements.

- Local field conditions play significant role in conservation outcomes, emphasizing the need for site-specific strategies and flexible program designs.
- ETa estimates can support the scalability and transparency of voluntary, incentive-based water-sharing programs, increasing producers view of the programs.

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Brief #1: Measuring Conservation

Estimating the Water Conservation Potential of Voluntary Irrigation Withdrawals on Working Livestock Pastures

Supplemental Information

Background and Motivation

Effective water resource planning depends on accurate quantification of the water balance, to ensure that policy leads to meaningful outcomes without unintended consequences or unrealistic expectations (Kuhn and Fleck, 2019). In response to this need, Conscience Bay Research launched a study in 2023 to evaluate the water conservation potential of a spectrum of irrigation withdrawal practices integrated with livestock operations, in two actively grazed pastures near Delta and Eckert, CO. These sites featured irrigated fields composed of mostly grasses with interspersed alfalfa, and integrated livestock grazing systems, reflecting real-world conditions where water availability, forage production, and animal growth performance are interconnected.

Although hay and pasture systems account for over 80% of irrigated agricultural acreage in western Colorado, CU rates for these systems have not been widely studied. This study used modeling based on remote sensing to estimate actual evapotranspiration (ETa) on irrigated pastures under simulated irrigation withdrawal. Conserved consumptive use (CCU) was estimated by comparing ETa from the affected fields to contemporaneous, fully irrigated reference sites at each location. The study provides two key contributions: (1) it offers one of the few field-scale evaluations of ETa in grass hay and pasture systems at elevations common to many irrigated areas in western Colorado; and (2) it examines how these systems respond to the timing of irrigation withdrawals. The integration of active grazing adds practical relevance by highlighting implications for forage availability and livestock carrying capacity under water conservation scenarios.

Irrigation withdrawal programs are one strategy for augmenting flows in the Colorado River during periods of natural drought or under negotiated water-sharing arrangements that compensate agricultural producers for temporarily forgoing the use of their irrigation water. These programs aim to conserve CU by reducing beneficial use on irrigated lands with legally recognized water rights--achieved by diverting less water than permitted and thereby increasing in-stream flows or storage elsewhere in the system. However, in working ranchlands where forage production directly supports grazing operations, reductions in CU can impact livestock stocking rates, grazing windows, and the viability of integrated pasture-livestock systems.

Study Sites & Irrigation Withdrawal Scenarios

The study was conducted on irrigated pastures at two sites in western Colorado: Banner Ranch (36.2 acres; 14.6 ha) and Orchard Ranch at Harts Basin (74.7 acres; 30.2 ha), located at elevations of 5,322 ft (1,622 m) and 5,552 ft (1,692 m), respectively. Banner Ranch is irrigated via furrow and gated pipe, while Orchard Ranch employs side-roll sprinkler systems. Both sites were subdivided into eight contiguous treatment zones, each approximately 5 acres in size, within a single managed field. Seven irrigation withdrawal scenarios were implemented across the zones to evaluate the impacts on forage availability and regrowth potential.

(1) Full season irrigation withdrawal [FSIW]: No irrigation after initial grazing (April 25 to May 2). A second grazing in late May/early June was possible, followed by potential fall regrowth depending on precipitation.

(2) One and done [1AD]: A single early-season irrigation was applied, then shut off soon after water became available. Grazing matched FSIW timing.

(3–5) Shutoffs on June 1, July 1, and August 1 [SO0601, SO0701, SO0801]: Irrigation continued until the specified date, then ceased. Each zone was initially grazed April 25–May 2, with possible second grazing and fall regrowth for winter grazing.

(6) Shoulder month [SM]: Irrigation was applied only in May and September. Grazing followed the standard early-season schedule, with potential for forage re-growth and winter grazing.

(7) Put it to bed wet [PITBW]: No irrigation during the growing season, with a single application in fall. Grazing followed the standard early-season schedule, with potential for late-season regrowth and winter grazing.

(8) No irrigation withdrawal (NIW): Served as fully irrigated reference (REF) zone with uninterrupted irrigation throughout the season and followed the standard season-long grazing timeline, allowing for greater forage regrowth potential.

Study Methods

The Banner Ranch study field is characterized primarily by silty clay loam soils, consistent with the dominant soil type found throughout the Public Land Survey System (PLSS) section in which it is located. The Orchard Ranch study field is divided roughly in half, with stony loam soils occupying the elevated western portion and silty clay loam soils found in the lower-lying eastern area. The soil types at this location are similar to the entire Harts Basin field portfolio that is also split rather evenly by silty clay loam and stony loam textures.

Vegetative conditions at Banner Ranch were largely uniform (Figure 1), but Orchard Ranch coverage data exhibited substantial within-field variability (Figure 2), as indicated by spatial mapping of the Normalized Difference Vegetation Index (NDVI). The heterogeneity at Orchard Ranch was primarily driven by sloping of the field in the east–west direction, such that lower-lying areas showed signs of heavy grazing and bare soil, while upper slopes maintained denser canopy cover.

In Figure 1, NDVI imagery is shown for Banner Ranch at six dates: April16, May 19, June 15, and July 19, August 19, and September 20, 2023 (arranged from earliest to latest, moving left to right and top to bottom). Each image is overlaid with zone boundaries and marked enclosures and labeled according to scenario: 1) FSIW; 2) 1AD; 3) SO0601; 4) SO0701; 5) SO0801; 6) SM; and, 7) PITBW. The contemporaneous, fully irrigated reference site is the large zone on the south side of the field.

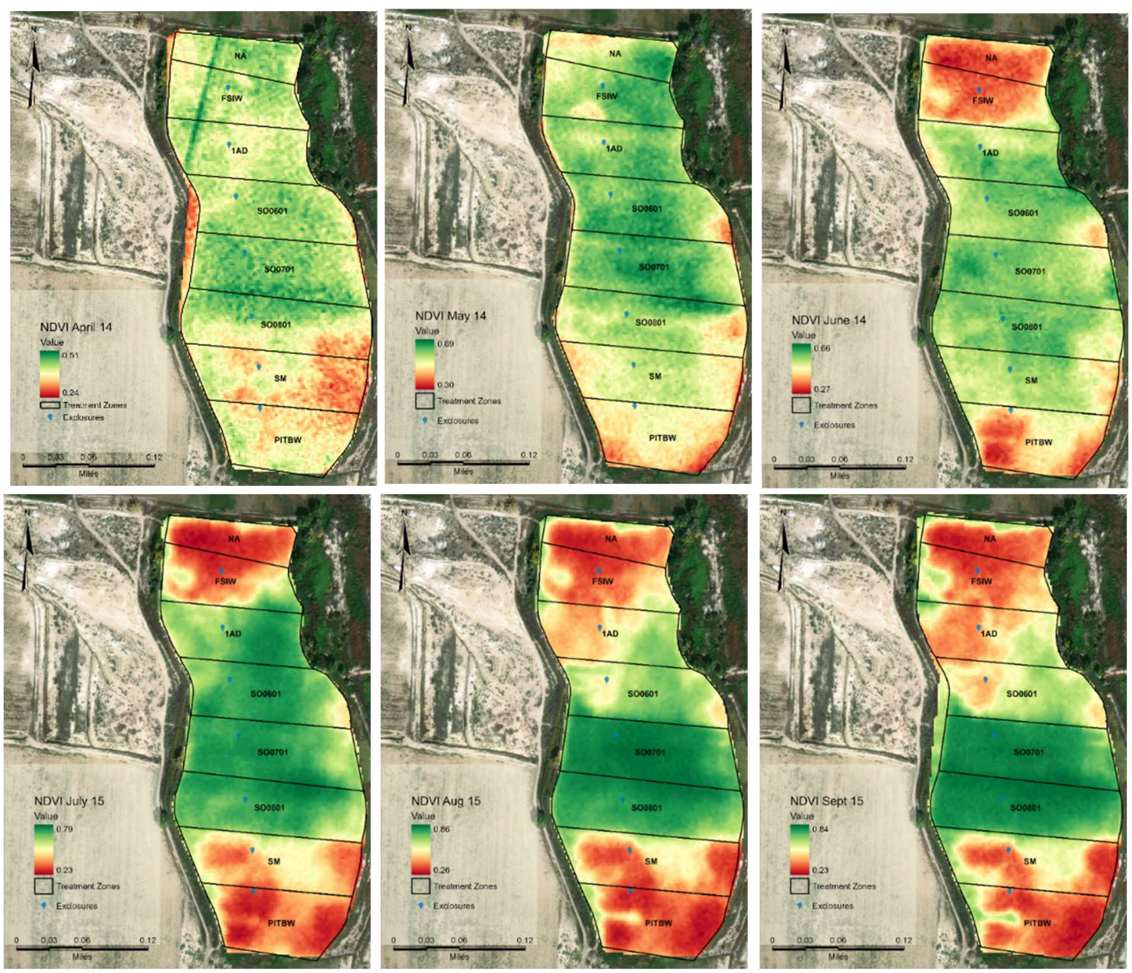

Figure 1. Time series maps of NDVI (Normalized Difference Vegetation Index) for Banner Ranch in Olathe, CO in year of irrigation withdrawal study.

One clearly noticeable attribute of this reference field is the abrupt change in vegetative health that happened during the June period. Conversations with the landowner confirmed that this impact was caused by the mechanical breakdown of the sideroll sprinkler system for a time long enough to affect consistent irrigation rates. Given this issue, only the portion of the field that maintained consistent irrigation throughout the season was isolated for analysis. This decision was made to ensure that the evaluation of vegetative health and water use reflected typical management conditions, rather than being skewed by the localized irrigation failure caused by the sideroll system breakdown.

In Figure 2, NDVI imagery is shown for Orchard Ranch at six dates: April14, May 14, June 14, July 15, August 15, and September 15, 2023 (arranged from earliest to latest, moving left to right and top to bottom). Each image is similarly overlaid with zone boundaries and marked enclosures and labeled according to treatment: 1) FSIW; 2) 1AD; 3) SO0601; 4) SO0701; 5) SO0801; 6) SM; and, 7) PITBW. The contemporaneous, fully irrigated reference site for the Banner Ranch is located nearby about 1,000 ft from the northern boundary of the study field.

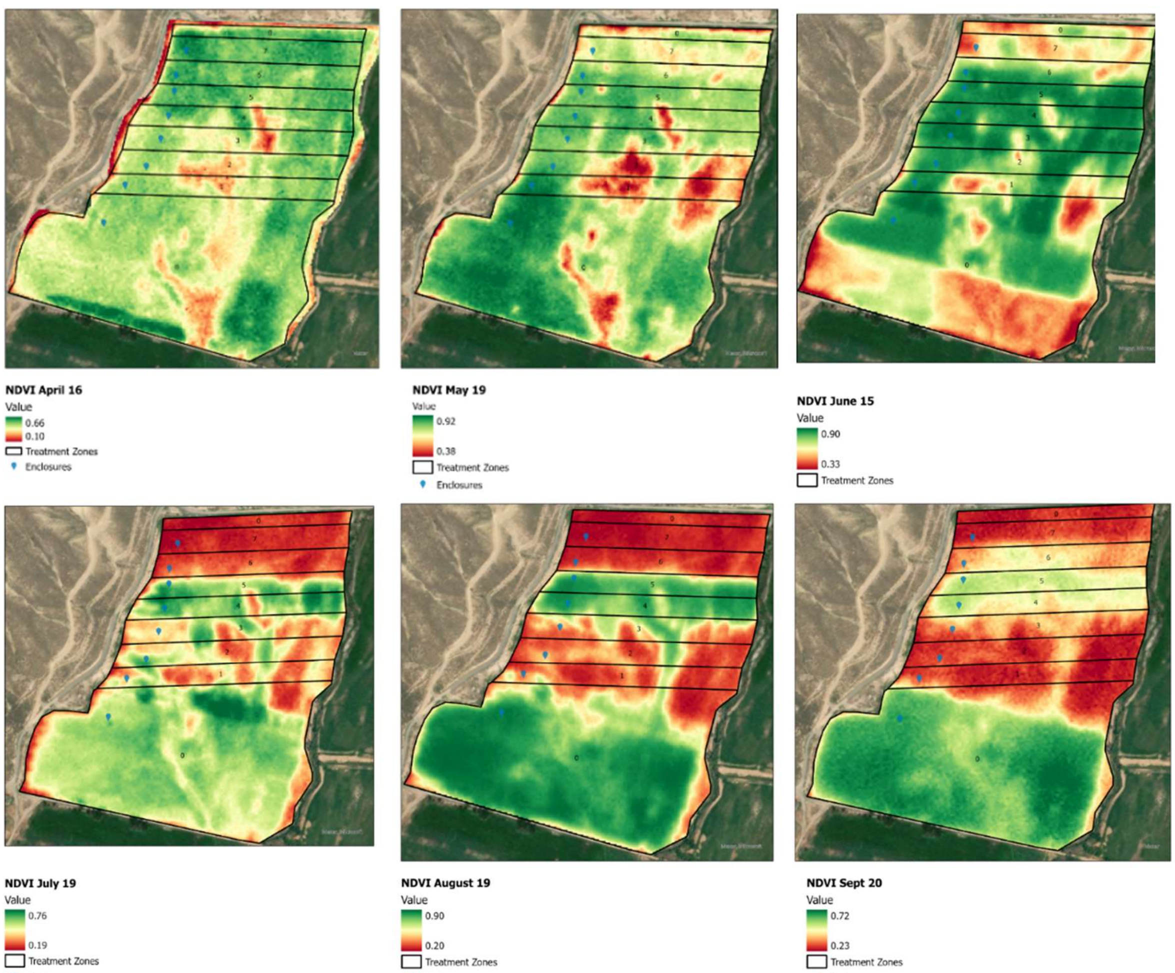

Figure 2. Time series maps of NDVI for Orchard Ranch at Harts Basin in Eckert, CO in year of irrigation withdrawal study.

Stony loam soils have moderate to low water-holding capacity due to their coarse texture and high content of rock fragments, which promote rapid drainage and limit moisture availability in the root zone. These characteristics can make irrigation management more difficult, especially during extended dry periods. However, with thoughtful management practices—including timely irrigation and selection of drought-tolerant or shallow-rooted forage species—stony loam soils can still support productive pasture and hay systems. That said, yields are likely to be more variable across these soils, particularly in years with limited precipitation or under inconsistent irrigation, due to uneven moisture retention and reduced soil depth in some areas. Silty clay loam soils have moderately high to high water-holding capacity, making them well-suited for irrigated agriculture when managed properly. Their fine texture, with a high proportion of silt and clay particles, allows them to retain substantial moisture in the root zone, supporting plant growth during dry periods. These soils are particularly favorable for growing deep-rooted perennial grasses used for grazing, hay, or pasture, if irrigation and soil structure are carefully managed to avoid issues like compaction or waterlogging.

The Satellite Irrigation Management Support (SIMS) model (Melton et al., 2012; Pereira et al. 2020) was used to estimate CU. Conserved CU was calculated by subtracting the seasonal ETa for each treatment zone from the average seasonal ETa of the fully irrigated reference condition (Zone 8). The SIMS model is included in the OpenET platform to estimate crop ETa by using a fractional cover derived from the Normalized Difference Vegetation Index (NDVI) was used to scale grass-based reference evapotranspiration (ETo) using a derived crop coefficient. The NDVI was calculated using high-resolution multispectral imagery acquired from the PlanetScope satellite constellation (www. planet.com/explorer/). The imagery provides approximately 3-m spatial resolution and includes spectral bands for NDVI computation: the red band (Band 3; 620–670 nm) and the near-infrared (NIR) band (Band 4; 820–880 nm). Scenes were selected based on cloud-free conditions and image tiles were downloaded in GeoTIFF format and clipped to the area of interest using QGIS.

Reference ET (ETr) was calculated using data from the CoAgMET stations nearest to each site, Montrose for Banner Ranch and Eckert for Orchard Ranch. Specifically, the ASCE Standardized Reference Evapotranspiration equation was applied using grass reference parameters. The choice of reference condition is critical, especially in heterogeneous fields like Orchard Ranch, where CCU estimates can differ widely across a field because of underlying variability in field conditions.

Where data gaps occurred due to missing satellite passes, continuity in the time series was restored using univariate spline interpolation. This method estimates missing values in single-variable datasets—such as time-series ET readings—by fitting a smooth curve through existing data points. Splines produce more natural and realistic transitions than straight-line (linear) methods, making them particularly well-suited to environmental data. This approach fills data gaps without introducing distortion or artificial patterns, preserving the integrity of sensor-based measurements affected by intermittent satellite coverage.

To account for the spatial variability at Orchard Ranch and exclude areas where extremely low ET was likely unrelated to irrigation deficits, the hottest 25% of pixels were excluded from analysis. It is notable that the OpenET platform also designates this field as two distinct fields. Furthermore, a 9-meter (three-pixel) border was removed along edges of the evaluation area to account for spatial non-uniformity in water application associated with the sideroll irrigation system.

Results and Discussion

NDVI Discussion. For comparison purposes, time series maps of NDVI for the same pastures in the year prior to the irrigation withdrawal study (2022) are shown in the appendix. Field-level NDVI interpretation for Banner Ranch and Orchard Ranch in 2022 provides a pre-treatment baseline, offering critical insight into natural vegetation patterns and spatial variability prior to the implementation of irrigation withdrawal scenarios in 2023 (see Appendix Figures 5 and 6).

At Banner Ranch, the NDVI time series shows that, even under uniform management, the field exhibited distinct spatial gradients in vegetative vigor, with consistently higher NDVI values observed in central and northern areas and lower values along the western and southern edges. These patterns likely reflect underlying differences in slope, soil properties, or irrigation uniformity. Although the field was largely homogeneous in early-season growth, some mid- to late-season variation emerged due to natural field conditions. The NDVI maps of the Orchard Ranch field show a clear seasonal progression in vegetative vigor, with notable contrasts between the eastern and western halves. Early in the season (April and May), the field exhibits generally healthy and uniform growth, though the western half appears slightly more vigorous. By mid-June, a sharp decline in NDVI emerges across the eastern half, indicating a substantial drop in vegetative health likely due to an irrigation disruption. This spatial disparity persists through July and August, with the western side of the field maintaining strong, uniform growth, while the eastern half shows only partial recovery. By September, the western portion continues to exhibit healthy vegetation, whereas the eastern half remains more variable and stressed, reflecting the lasting impact of the underlying field conditions irrigation issue.

Banner Ranch. The CU rates at both sites reflected clear patterns tied to irrigation timing. At the Banner Ranch, ET and CCU values generally followed expected patterns based on the timing and extent of irrigation withdrawal (Table 1). At the reference condition, April ET was lowest at 2.48 inches as grass began breaking dormancy, increasing steadily to a seasonal peak in July with 7.03 inches of ET observed in the reference field (column labeled REF). For comparison, potential evapotranspiration (column labeled PET) is included, providing context for how actual ET compared to modeled weather-based potential demand.

Table 1. Monthly and Seasonal ET (inches) and CCU (inches) by Irrigation Scenario at Banner Ranch (2023).

		REF	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Month	PET	NIW	FSIW	1AD	SO0601	SO0701	SO0801	SM	PITBW
April	5.02	2.48	2.16	2.12	2.1	2.15	1.91	1.56	1.59
May	6.25	4.81	4.32	4.47	4.34	4.47	4.20	3.87	3.43
June	6.75	5.51	3.95	5.90	5.86	5.97	5.69	5.01	3.93
July	8.06	7.03	3.68	5.77	6.01	6.32	6.03	3.88	2.92
August	6.29	6.26	2.98	3.96	4.76	6.05	5.76	3.24	2.43
September	5.06	4.78	2.22	2.57	3.17	4.39	4.37	2.69	2.03
October	3.11	2.9	1.20	1.38	1.67	2.2	2.34	2.01	1.57
TOTAL	40.54	33.77	20.50	26.17	27.91	31.55	30.31	22.25	17.90
CCU*			13.27	7.61	5.86	2.22	3.46	11.52	15.88

PET = Potential evapotranspiration from ASCE Standardized Equation; Montrose CoAgMET station.
*CCU = Conserved Consumptive Use based on SIMS estimated REF ET from neighboring fields.

Scenarios simulating more restrictive irrigation withdrawal showed lower total ETa and higher CCU. The full-season irrigation withdrawal [FSIW] scenario had the lowest total ET (20.50 inches) and one of the highest CCU values at 13.27 inches. Scenarios in the next two columns simulated early cutoff strategies (“one and done” [1AD] and June 1 shutoff [SO0601]) moderately conserving water, with CCU values of 7.61 and 5.86 inches per acre, respectively. The scenarios with more extended irrigation periods retained higher total ET and had lower CCU. The July 1 shutoff [SO0701] scenario and the August 1 shutoff [SO0801] scenario had CCU values of 2.22 and 3.46 inches, respectively, as more water was applied during peak demand.

The scenario with irrigation only during the shoulder months [SM] showed a seasonal ET pattern like FSIW, with total ET of 22.25 inches and CCU of 11.52 inches, reflecting limited water use during the core summer months. The last column, representing a late-season irrigation only “put it to bed wet” strategy [PITBW], displayed a total ET of 17.90 inches, and showed the highest CCU at 15.88 inches, indicating that withholding irrigation resulted in considerable water conservation, regardless of late-season irrigation.

Relative to the reference condition, both FSIW and PITBW exhibited substantially lower ET totals, highlighting the water rates possible through both early-season irrigation withdrawal. FSIW, with full-season irrigation withdrawal, had an ET total of 20.50 inches, which is 39.3% lower than the reference ET of 33.77 inches. PITBW, irrigated only late in the season, showed a slightly greater reduction, with 17.90 inches of ET, or 47.0% lower than the reference. On average, these two strategies reduced ET by 43.15%.

Orchard Ranch at Harts Basin. At Orchard Ranch at Harts Basin, ET and CCU values also followed expected patterns although conservation rates were estimated as being lower (Table 2). The early season ETa rates were also lower and peaked in July at 7.23 inches per acre of ET observed at the reference field (column labeled REF). Similar to the Banner Ranch, the full-season irrigation withdrawal FSIW scenario had the lowest total ETa (24.71 inches) and a CCU value of 10.58 inches. Scenarios that simulated early cutoff strategies (“one and done” [1AD] and June 1 shutoff [SO0601]) exhibited slightly greater CCU of 9.98 and 9.08 inches per acre, respectively. Scenarios that received greater seasonal irrigation had higher total ETa and had lower CCU. The July 1 shutoff [SO0701] and the August 1 shutoff [SO0801] scenarios had CCU values of 5.47 and 5.89 inches, respectively. The shoulder month [SM] scenario showed a seasonal ETa pattern like FSIW, but with slightly lower total ET of 23.23 inches and CCU of 12.07 inches, reflecting limited water use during the core summer months. Finally, the late-season only scenario representing a “put it to bed wet” [PITBW] strategy displayed a total seasonal ET of 25.85 inches, and a somewhat low CCU at 9.44 inches, evidently due to the irrigation that occurred in August that boosted ET.

Relative to the reference condition, both FSIW and SM exhibited the lowest seasonal ET totals, again highlighting the impact of intensive irrigation withdrawal. The FSIW scenario, which involved a full-season irrigation withdrawal, resulted in a total ET of 24.71 inches, representing a 31.0% reduction compared to the reference ET of 35.78 inches. The SM scenario, which limited irrigation to the shoulder months, produced a slightly greater reduction, with 23.23 inches of ET per acre, or 35.1% below the reference. On average, these two strategies reduced ET by 33.0%, based on data refined using a spatial filtering and masking approach to exclude non-irrigation-related variability.

Table 2. Monthly and Seasonal ET and CCU by Irrigation Scenario at Orchard Ranch/Harts Basin (2023).

		REF	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Month	PET	NIW	FSIW	1AD	SO0601	SO0701	SO0801	SM	PITBW
April	5.93	3.16	3.08	3.03	2.99	2.97	2.96	2.96	3.02
May	7.88	5.79	3.08	3.03	2.99	2.97	2.96	2.96	3.02
June	9.44	6.53	4.73	4.61	4.60	4.63	4.65	4.55	4.40
July	8.01	6.85	4.72	4.89	5.05	5.14	5.08	4.61	4.40
August	6.25	6.13	3.89	4.29	4.21	5.20	4.91	3.24	6.82
September	4.9	4.80	3.05	3.17	3.72	5.31	5.19	2.54	2.40
October	3.22	2.52	2.17	2.29	2.63	3.59	3.64	2.37	1.80
TOTAL	45.63	35.78	24.71	25.31	26.21	29.82	29.4	23.23	25.85
CCU*			10.58	9.98	9.08	5.47	5.89	12.07	9.44

PET = Potential evapotranspiration from ASCE Standardized Equation; Eckert CoAgMET station
*CCU = Based on Gatum (2018) average estimated REF ET from neighboring fields.

Irrigation Timing Patterns. The irrigation simulation exercise was executed very well at both sites – a credit to the ranch managers - as evidenced by the distinct and consistent ETa patterns that emerged across treatment zones throughout the growing season. The ETa rates at both sites reflected clear patterns tied to irrigation timing (See Figures 3 and 4).

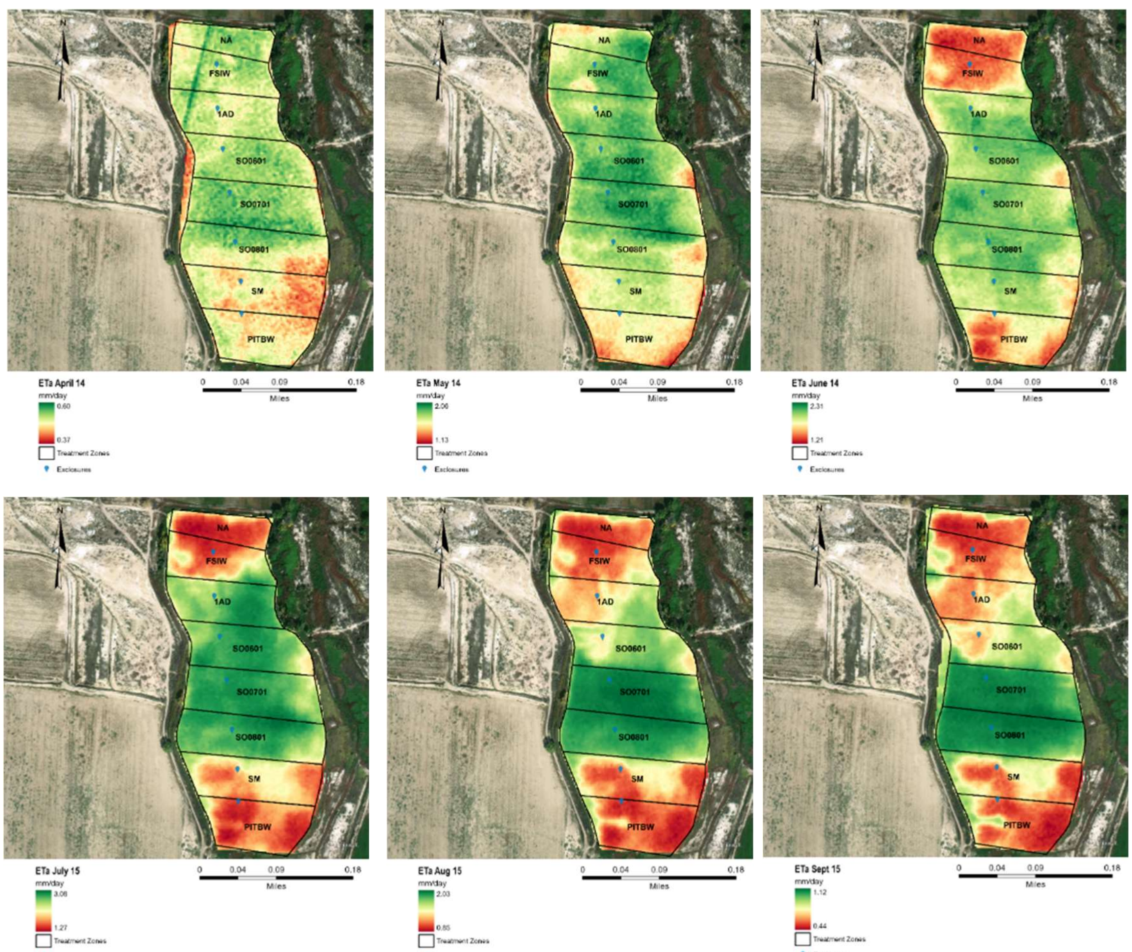

Figure 3. Time series maps of ET (mm/day) for Banner Ranch in Olathe, CO in year of irrigation withdrawal study.

In Figure 3, for Banner Ranch, imagery is shown at six dates: April 14, May 14, June 14, July 15, August 15, and September 15, 2023. Each image is overlaid with zone boundaries and marked enclosures. The image is labeled using scenario codes: 1) FSIW; 2) 1AD; 3) SO0601; 4) SO0701; 5) SO0801; 6) SM; and, 7) PITBW. In April and May, ETa values are relatively uniform across the field, with slightly reduced water use in the FSIW and PTIBW zones, indicating the early impacts of limited irrigation. By June, clear differences emerge, with the FSIW zone in the north and the PTIBW zone in the south showing substantial reductions in ETa, reflecting the intended irrigation withdrawal strategies. These patterns persist through July, August, and September, with the FSIW and PTIBW zones consistently displaying lower ETa relative to the reference and shoulder-month-only (SM) irrigation zones. The uniformity of treatment effects within each zone and across time highlights the success of the simulation and provides confidence in the integrity of the water management treatments applied. The only modest exception is the difference between the 1AD and SM scenarios, which should have received irrigation at roughly the same time. The 1AD treatment appears to have received irrigation in May, however, while the SM ETa spike did not occur until June, suggesting a later irrigation timing. Notably, September ET levels were also strong.

In Figure 4, for Orchard Ranch at Harts Basin, imagery is shown at six dates: April 16, May 19, June 15, July 19, August 19, and September 20, 2023. Each image is overlaid with zone boundaries and marked enclosures.

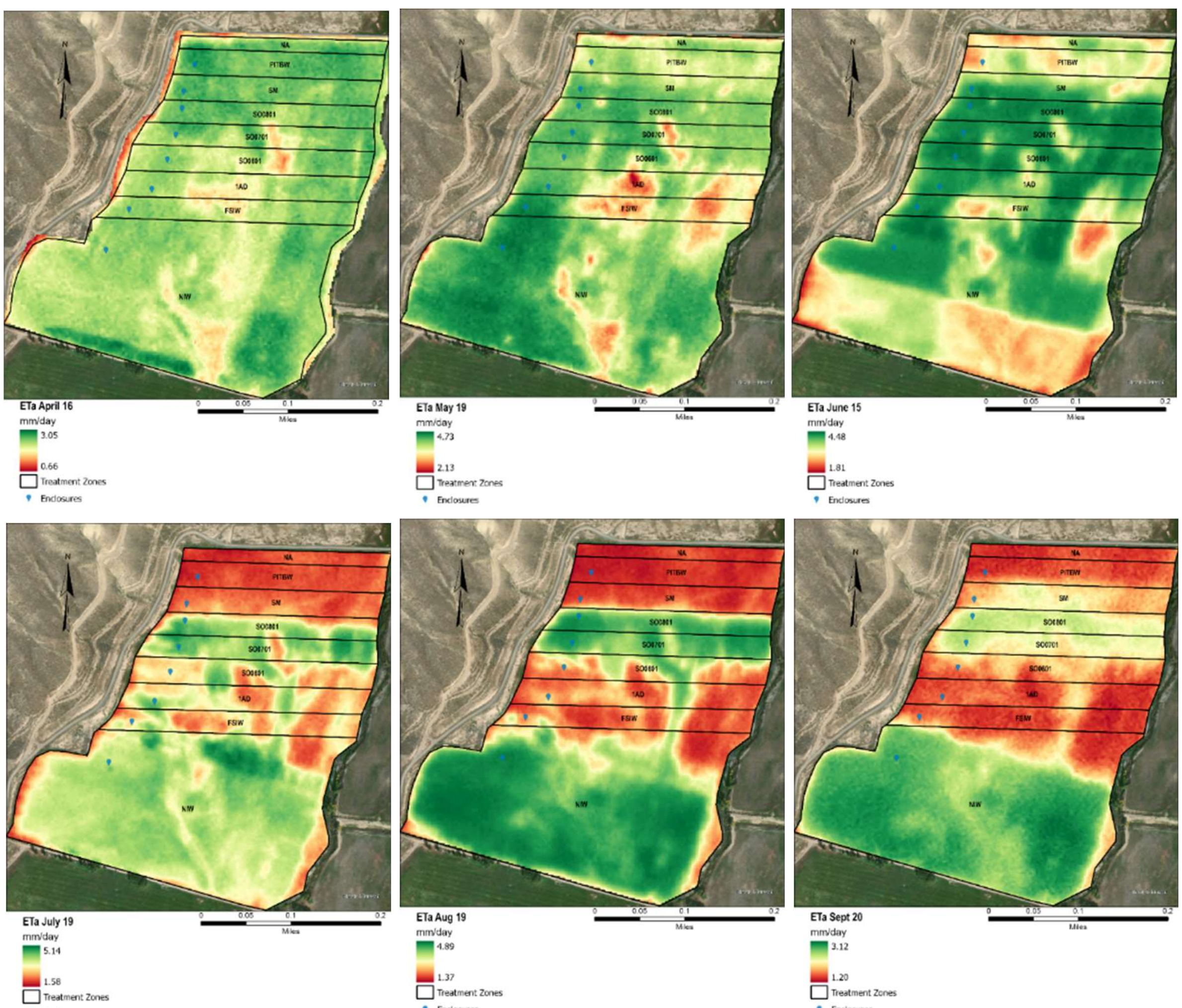

Figure 4. Time series maps of ET (mm/day) for Orchard Ranch in Eckert, CO in year of irrigation withdrawal study.

The image is labeled using scenario codes: (1) FSIW; 2) 1AD; 3) SO0601; 4) SO0701; 5) SO0801; 6) SM; and, 7) PITBW. Two distinct spatial patterns are evident in the field: a north-to-south gradient resulting from the deliberate irrigation treatments applied using the side roll system, and an east-to-west gradient driven by underlying field conditions and infrastructure limitations. Th ETa maps illustrate these seasonal patterns of water use, showing how CU varied spatially and temporally under different irrigation management strategies. In the early season (April 16 and May 19), ETa values are relatively uniform across the field, with only minor spatial variation. However, by June 15, a pronounced divergence appears, with ETa dropping sharply in the eastern half of the field, indicating significantly lower water use compared to the west. This east–west contrast persists through July, August, and September, suggesting sustained vegetation stress or limited water availability in the eastern zones. The mechanical failure in the side roll system disrupted water delivery to the eastern half of the field for an extended period, unrelated to the experimental design. To ensure a valid evaluation of treatment effects, only the northwestern portion of the field, where irrigation remained consistent throughout the season, was used in the core analysis. This approach ensured that ETa estimates more accurately reflected management-driven outcomes rather than confounding factors such as irrigation system failure or spatial variability in soil and topography.

Closing Takeaways

On working ranchlands where forage production directly supports grazing operations, reductions in CU can impact livestock stocking rates, grazing windows, and the viability of integrated pasture-livestock systems. The 2023 evaluation of CCU across Banner and Orchard Ranch demonstrates that irrigation withdrawal strategies can produce measurable reductions in crop evapotranspiration (ET) on these pastures, especially when implemented early in the season. Overall, these results align with anticipated outcomes: earlier or more limited irrigation produced greater conserved consumptive use, while sustained mid- and late-season irrigation reduced the conservation. Treatment scenarios that experienced full-season irrigation withdrawal or received only limited early- or late-season irrigation consistently exhibited the highest CCU values. These outcomes validate the foundational assumption that reduced water application, when properly timed, translates into reduced consumptive use.

While this general pattern held true across both sites, the results also underscore the importance of local field conditions in shaping water conservation outcomes. For instance, at Orchard Ranch, where the field was more heterogeneous in terms of soil characteristics and crop vigor, the choice of reference conditions had a notable effect on CCU estimates. This highlights the need for careful reference field selection and potentially the use of multiple reference zones in operational programs.

Overall, the findings provide clear evidence that strategically timed irrigation reductions, especially in early- and shoulder-season periods, can conserve water without entirely forfeiting forage production. These results are especially relevant for voluntary water-sharing programs, where producers may be compensated for foregone irrigation. The study also reinforces the value of combining remote sensing with site-specific ground data to inform water policy decisions rooted in the realities of working agricultural landscapes.

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Appendix

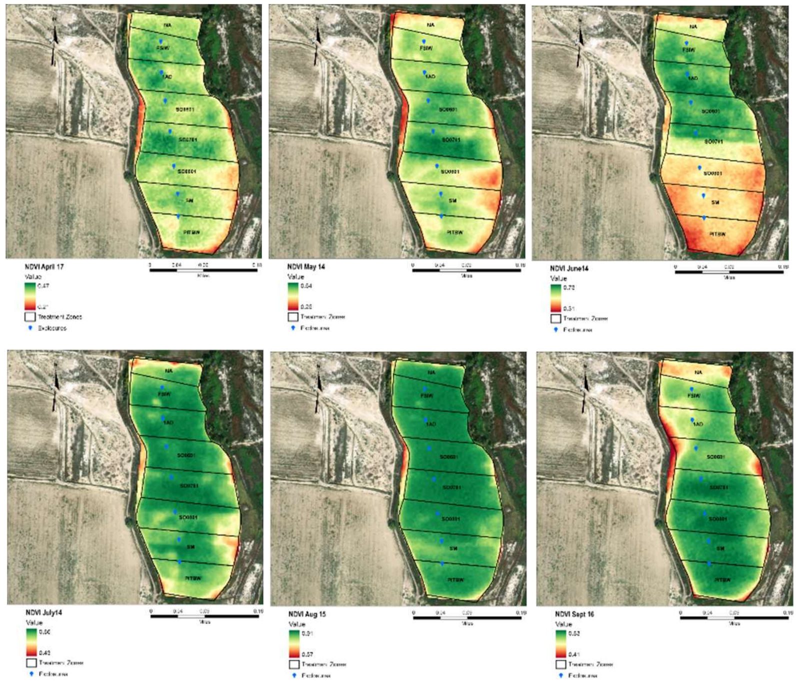

Figure 5. Time series maps of NDVI for Banner Ranch in Olathe, CO in year prior to irrigation withdrawal study. Imagery is shown at six dates: April 19, May 18, June 15, July 19, August 21, and September 19, 2022. Each image is overlaid with zone boundaries and marked enclosures. The image is labeled using scenario codes: 1) FSIW; 2) 1AD; 3) SO0601; 4) SO0701; 5) SO0801; 6) SM; and, 7) PITBW.

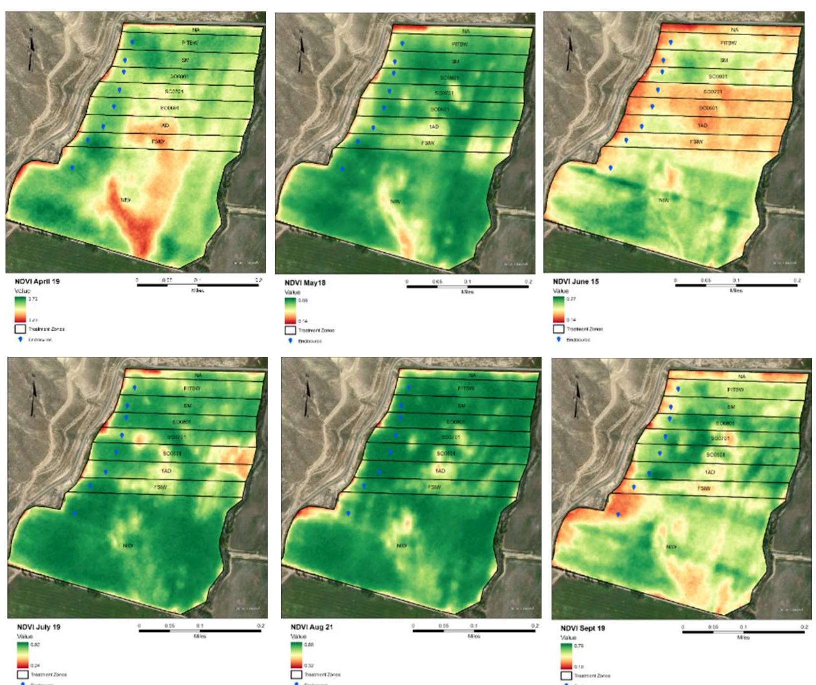

Figure 6. Time series maps of NDVI maps for Orchard Ranch in Eckert, CO in year prior to irrigation withdrawal study. Imagery is shown at six dates: April 19, May 18, June 15, July 19, August 21, and September 19, 2022. Each image is overlaid with zone boundaries and marked enclosures. The image is labeled using scenario codes: 1) FSIW; 2) 1AD; 3) SO0601; 4) SO0701; 5) SO0801; 6) SM; and, 7) PITBW. The contemporaneous, fully irrigated reference site is the large field on the south side of the field.

Brief #2: Assessing Forage Impacts

Evaluating Yield Performance across a Spectrum of Irrigation Curtailment Scenarios in Pasture-Livestock Systems

Perry Cabot[1]

Overview

➢ We evaluate how different irrigation curtailment scenarios affect forage yields in pasture-livestock systems across two ranches in western Colorado. This is a companion to Brief #1 that estimated water conservation.

➢ Biomass yields were measured across eight irrigation treatments—from full irrigation to complete season withdrawal—at each location across large, field-scale plots.

➢ The results offer producers and policy makers insight on maintaining forage production while contributing to water conservation—especially under voluntary compensation programs for reduced consumptive use.

Purpose

This brief presents data on forage yields in pasture-livestock systems for a range of irrigation curtailment strategies.

The insights gained can assist producers, policy makers, and other stakeholders:

- Assess the trade-offs between maintaining forage production and conserving water resources in pasture-livestock systems through voluntary irrigation curtailment.
- Provide data to inform the design and implementation of flexible, site-specific water management practices that support voluntary compensation programs.

Approach

A pasture at each ranch was divided into 8 zones, about 5 acres each, with zones receiving specific irrigation treatments.

- Treatments ranged from full irrigation to complete withdrawal, including a fully-irrigated control for comparison.
- Pastures were actively grazed according to typical schedules to replicate real-world conditions.

Forage biomass was measured using exclosure-based sampling methods to more accurately capture production without grazing influence.

- Biomass data were analyzed using ordinal ranking techniques to account for variability across sites.

Findings

The results support tailored irrigation strategies that optimize forage production while contributing to water conservation

- A tradeoff will be required under voluntary compensation programs for reduced CU.

Full-season irrigation and July 1 shutoff treatments consistently ranked highest in yield performance.

- Late season shutoffs demonstrated strongest forage production

Early-season (June 1s shutoff) and shoulder-month strategies (May/September irrigation only) also performed well

- Show potential for water conservation while maintaining some forage output

Insights

Some treatments showed large variation between sites

- Example was the “one-and-done”.
- Underscores influence of local soil, species, and irrigation conditions.

Ordinal ranking helps with data comparisons

- Mitigated the influence of outliers (e.g., unexpectedly high 1AD yield at Banner)
- Assisted with capturing treatment trends in heterogenous field conditions, supporting real-world application in agricultural research.

Affiliations: [1]Western Colorado Research Center, Colorado State University

Brief #3: Managing Implementation

Practical Guidance for Implementing Voluntary Irrigation Withdrawals on Pasture-Based Livestock Operations

Daniel Mooney[1], Perry Cabot[2], Dan Waldvogle[3], Mike Higuera[4]

Overview

- Livestock producers need practical, experience-based guidance on how voluntary irrigation reductions affect haying and grazing schedules, along with strategies for successfully implementing these practices.
- This brief presents key insights and lessons from demonstration-scales trials of limited irrigation practices implemented on working pastures in Colorado's West Slope region.
- We highlight tradeoffs in hay and grazing outcomes to inform both producers considering these strategies and program designers aiming to reduce disruptions to pasture-based operations.

Purpose

Drawing on demonstration-scale trials at Western States Ranches, we assessed workable approaches to sustaining pasture operations under voluntary irrigation withdrawals.

The findings will help stakeholders and policymakers:

- Understand how participating in water conservation programs may affect livestock operations, including forage availability and grazing schedules.
- Identify program design features that better align conservation objectives with the operational needs and constraints of pasture-based livestock systems.

Approach

We compared four scenarios: full-season irrigation, shut off on July 1, shut off on June 1, and no irrigation (full withdrawal).

Used expert judgement to estimate likely impacts of each scenario on forage production and grazing outcomes.

- Considered spring, early summer, late summer, & winter periods. Trials conducted on pastures at two locations.

Assessed potential ranges of effects on hay yield, stocking days, and pasture recovery.

- During both the implementation year and the following year.

Findings

Observed tradeoffs: Forage reductions increased with earlier irrigation shutoffs, resulting in lower hay yields, fewer grazing days (from winter stockpiles), and greater pasture fragility.

Late shutoff (July 1) supported hay potential and stocking days similar to full-season irrigation.

- Expect moderate reductions in winter grazing days (up to 25-50% lower compared to full-season irrigation).

Earlier shutoff (June 1) required more active management to adapt to less irrigation.

- Expect reduced crossover grazing and eliminating hay cutting in year of reduction, leave forage for winter grazing.
- Less regrowth in late summer results in reduced winter grazing days (up to 50-75% lower compared to full-season).

Full-season withdrawal (no irrigation) likely necessitates fully resting pastures.

- Mostly eliminates crossover grazing in implementation year and year after, and haying in implementation year.
- Expect very restricted winter grazing days (up to 75-100% lower compared to full-season irrigation).

Insights

Limited irrigation can work on pasture-based systems, but requires planning and adaptive management

- Within and across years in response to water availability and pasture recovery conditions
- No one-size-fits-all solution: Programs should accommodate varying pasture types, elevations, and grazing systems.

Timing matters:

- Late shutoff improves forage outcomes, less disruption.
- Early shutoff achieves greater water conservation but requires adaptation and may increase herd/pasture stress.
- Full curtailment is likely incompatible with pasture use.

We observed additional factors for producers to consider:

- Pasture fragility can persist into the year after irrigation reduction, especially with early or full-season cutoffs.
- Early shutoff and no-irrigation plots showed increased weed pressure and shifts plant communities, potentially complicating long-term pasture management.

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Brief #3: Managing Implementation

Practical Guidance for Implementing Voluntary Irrigation Withdrawals on Pasture-Based Livestock Operations

Supplemental Information

Background and Motivation

Previous studies on limited irrigation often overlooked how the timing of irrigation reductions interacts with pasture-based livestock operations, especially among the remarkably varied and unique livestock grazing operations in the Upper Colorado River Basin. Grazing system performance depends on multiple interrelated factors such as forage yields, herd size, weather, and post-grazing pasture recovery time. Seasonal shifts in precipitation, forage demand, and irrigation availability further complicate herd and pasture management. Therefore, evaluating the feasibility of limited irrigation practices across grazing periods is important for understanding its practical impacts.

Such assessments help producers weigh tradeoffs and make informed decisions about the timing of implementation of voluntary irrigation reduction practices. In years with limited irrigation, adjustments may be needed to irrigation practices, winter stocking rates, forage supplementation, and grazing schedules. These changes can extend into the following year due to yield drag and increased pasture fragility, which may reduce hay yield and stocking days while requiring extended rest periods. A single irrigation strategy is unlikely to work uniformly throughout the season without prompting intra-annual management shifts.

Without this information, producers may hesitate to join water conservation programs due to concerns about disrupting forage production and grazing schedules. This brief addresses that gap by offering practical guidance for Colorado's Western Slope, including an example grazing schedule and potential forage and herd management responses to irrigation curtailments at different times of the year.

Example Grazing Calendar

Table 3.1 describes an example grazing calendar for a mid-elevation pasture (5,000 – 7000 feet) in Colorado's Western Slope region. It presents a stylized version of a schedule used by Western States Ranches on some of their pastures.

Table 3.1 Example grazing calendar for a mid-elevation grass pasture (5,000–7,000 feet) in Colorado's Western Slope region

Period	Season/name	Approximate dates	Description of management activities
1	Spring/crossover period	April to May	• Irrigation season begins, and the pasture begins to green up. Some residual forage from prior year may be available. • Livestock move to this pasture from winter permits or another farm. • Livestock consume a mix of new growth and old residues over 1-2 grazing rotations in small paddocks where they are grazed for three days and then moved.
2	Early summer/ initial growth period	June	• Grazing and irrigation cycles continue as forage growth accelerates and reaches maturity. • Livestock move off this pasture to summer permits as they become available.
3	Late summer/ regrowth period	July to October	• Livestock remain off this pasture with forage regrowth ending by late October. • One cutting is common in late July or August. • Forage regrowth left standing as stockpile for winter grazing period.
4	Winter/winter grazing period	November to March	• Livestock graze standing (stockpiled) forage, typically limit consumption to 25% of the stockpiled biomass. • Leave another 25% of stockpiled biomass for the crossover grazing period. • Feeding of hay may occur in late winter if grazing resources are depleted.

Notes: Stylized example grazing calendar based on recent experience at Western States Ranches near Delta, CO.

Table 3.2 Description of four irrigation scenarios		
Scenario	**Description**	**Treatment**
1	Standard irrigation (SI)	Full-season irrigation (non-limited)
2	Limited irrigation 1 (LI1)	Shut off irrigation on July 1 (early season)
3	Limited irrigation 2 (LI2)	Shut off irrigation on June 1 (late season)
4	Limited irrigation 3 (LI3)	Full-season curtailment (no irrigation)
Notes: The standard irrigation (SI) treatment serves as the reference strategy for comparing the performance of the three LI strategies		

Livestock producers in this region commonly divide the grazing season into four periods, summarized in the table under what we term a full-season or 'standard' irrigation (i.e., non-limited) scenario.

The "crossover" period (Period 1) occurs in spring when cattle are typically brought onto the pasture following early forage growth. Residual forage from the previous year is often still available, and intensive systems (e.g., rotational grazing) may support up to two grazing rotations through this pasture. In "early summer" (Period 2), livestock are moved off the pasture to summer USFS permits, typically available by June or early July.

During "late summer" (Period 3), the focus shifts to promoting hay development, with a cutting common in late July or August. Livestock remain off the pasture; any regrowth after haying is stockpiled for winter grazing. In the "winter" period (Period 4), pastures are grazed to meet herd needs while maintaining enough residual forage for recovery during the crossover grazing period in the following season. In all periods, forage removal (grazing, haying) is managed with sufficient rest to promote forage recovery the following year without reducing pasture health.

Limited Irrigation Practices and Expected Impacts

To explore feasible opportunities for livestock producers to participate in agricultural water conservation programs, we evaluated four limited irrigation scenarios and their anticipated impact on the example calendar. Table 3.2 summarizes these scenarios, which mirror a subset of the scenarios we implemented in the on-farm demonstration trials with Western States Ranches. Two scenarios (LI1 and LI2) use a split-season approach: irrigation is applied normally until a designated shutoff date, after which it is fully curtailed.

We then assess how these limited irrigation practices may alter livestock grazing systems compared to the standard irrigation (SI) scenario, outlined in Table 3.1. The analysis is divided into two parts: Table 3.3 presents the anticipated

Table 3.3 Expected effects of voluntary irrigation reductions on the affected pasture during the year of implementation

Practice implemented	Grazing period			
	Spring/crossover (Mar – May)	Early summer (Jun)	Late summer (Jul – Oct)	Winter (Nov – Feb)
Shut off July 1	• No effect on grazing, shutoff comes later in the summer • Expect two grazing rotations like SI	• Saturate soil water profile in late June • Evaluate profitability of hay cutting vs stockpiled forage	• Expect less forage regrowth than SI • Expect stockpiled yields 25-50% lower than SI	• Expect fewer grazing days based on less stockpile • Adapt by finding other pastures, supplementing hay, backgrounding fewer calves
Shut off June 1	• Proactively reduce grazing pressure • Expect one less grazing rotation than SI	• Expect forage yields 25-50% below SI • No hay cutting, leave for grazing	• Expect less forage regrowth than SI • Expect stockpiled yields 50-75% lower than SI	• Expect fewer grazing days based on less stockpile • Adapt by finding other pastures, supplementing hay, backgrounding fewer calves
Full season curtailment	• No crossover grazing due to pasture fragility • Some forage growth occurs due to precipitation	• No hay cutting, leave for grazing	• Expect stockpiled yields 75%-100% lower than SI	• Expect fewer grazing days based on less stockpile • Adapt by finding other pastures, supplementing hay, backgrounding fewer calves

effects during the year of implementation, while Table 3.4 outlines potential impacts in the following year, reflecting the first year of recovery under resumed standard irrigation.

Impacts in Year of Implementation

During the implementation year, we observed that earlier irrigation curtailment had more pronounced impacts on pasture and herd management (Table 3.3). For example, a July 1 shutoff had no effects during the crossover and early summer forage growth periods because there were no irrigation restrictions and only minimal to moderate effects on late-season and winter grazing. This latter observation is because producers can saturate the soil water profile around the end of June, helping to sustain hay production and forage regrowth even after irrigation stops.

With a June 1 shutoff, producers may need to proactively reduce grazing intensity during the crossover period and consider forgoing haying in mid-summer—even if conditions appear favorable—to preserve pasture health for later in the season. In many cases, leaving the forage standing as stockpile may be more economically beneficial than attempting to cut hay. Under full-season curtailment, producers will likely skip crossover and summer haying entirely, relying instead on limited precipitation-driven forage growth to support some winter grazing—if conditions allow. In dry years, the pasture may need to remain fully rested for the entire season.

Impacts in Year After Implementation

In the season following irrigation reduction, lingering effects on forage production and grazing management will likely depend on the timing (how early irrigation was curtailed) and severity (how much natural precipitation occurred) of the previous years' curtailment (Table 3.4). Later shutoff dates will generally result in fewer carryover impacts, while earlier or full-season curtailments may require ongoing management adjustments. In contrast, earlier cutoffs or full-season curtailments will require ongoing management adjustments to maintain pasture health and productivity.

For example, for pastures with a July 1 shutoff, producers may benefit from choosing to graze more conservatively during the crossover period—for example completing one rotational pass instead of two—to allow for pasture recovery. Otherwise, normal operations, including haying and winter grazing, can generally resume under standard irrigation. In the case of a June 1 shutoff, producers may need to reduce grazing pressure across multiple periods. Crossover grazing, haying, and winter use are possible but occur at lower rates to prevent stressing recovering stands. To help mitigate potential declines in pasture performance, a cautious approach is warranted, with delayed grazing, limited haying, and close monitoring of recovery indicators recommended before resuming typical stocking levels.

Table 3.4 Expected effects of voluntary irrigation reductions on affected pasture in year after implementation (that is, in the year of return to full-season irrigation)

Scenario	**Grazing period**			
	Spring/crossover (Mar – May)	**Early summer (Jun)**	**Late summer (Jul – Oct)**	**Winter (Nov – Feb)**
Shut off July 1	•Graze conservatively •Expect 1 less rotation compared to SI	•Expect no yield drag on hay •Hay yield similar to SI	•Expect no yield drag on regrowth •Stockpile yield similar to SI	•Expect no yield drag on winter stockpile •Grazing days similar to SI
Shut off June 1	•Allow recovery, pasture will be fragile •Minimal crossover grazing	•Expect small yield drag on hay •Example: 10% after 1 year, 5% after 2 years	•Expect small yield drag on regrowth •Example: 5% after 1 year, 0% after 2 years	•Graze less based on reduced stockpile •Minor management challenges (weeds, plant mix shifts)
No irrigation	•Allow recovery, pasture very fragile •No crossover grazing	•Expect moderate hay yield drag on hay •Example: 15% after 1 year, 7.5% after 2 years	•Expect small yield drag on regrowth •Example: 10% after 1 year, 5% after 2 years	•Graze less based on reduced stockpile •Management challenges (weeds, plant mix shifts)

Following full-season curtailment, recovery is likely to take longer. Grazing should be delayed until sufficient regrowth is evident, and haying and grazing may not be feasible in the recovery year. Producers will need to closely monitor pasture conditions and recovery progress before returning to normal stocking levels.

Additionally, one significant, but difficult to quantify, observation from the demonstration plots was the increase in weed pressure and shifts in plant community composition in response to limited irrigation. These observations were most pronounced in the no-irrigation zones, but early-season shutoff scenarios-like June 1—also showed similar signs. Such changes may pose longer-term management challenges and could further affect forage quality and productivity.

Producer Timing Considerations for Voluntary Irrigation Reductions

The main outcome of this discussion is that livestock producers must carefully consider the shutoff timing when implementing voluntary irrigation reductions to contribute to regional water conservation goals. Different irrigation shutoff dates will present distinct tradeoffs in terms of forage availability, adjustments to grazing schedules, and water conservation performance. To navigate these timing considerations while keeping their livestock operations running, producers will need to coordinate their grazing plans around the modified irrigation schedules but also taking into consideration their additional grazing permit availability and the forage supplementation (e.g., find other grass, purchase hay) strategies available to them. Future tools such as long-term water contracts are being explored in the region and could support water conservation strategies and that work in tandem with reduced stocking rates.

The irrigation shutoff scenarios discussed in this brief present opportunities for livestock producers to participate in agricultural water conservation programs. Late-season shutoffs preserve early-season forage growth and minimize disruptions to livestock operations (i.e., adjustments to haying and grazing calendars) but have smaller water conservation potential compared to earlier shutoff dates. Later curtailment means the forage plants have adequate time to grow, making the affected pastures relatively resilient to grazing pressure and water stress. Mid-season shutoffs, however, are likely to offer a balanced approach that enables some forage utilization and moderate water conservation. Continuing irrigation for part of the season should provide for some forage growth and winter stocking days, but does not maximize the total amount of water conserved. Early season shutoffs or full-season fallow do maximize water conservation but significantly reduce or eliminate all forage availability. This slows pasture recovery and increases the risk of stress, particularly under drought conditions, making it harder to restart grazing in subsequent years.

Takeaways

This brief explored the tradeoffs between voluntary irrigation reductions and pasture management in grazing systems on Colorado's Western Slope, with a focus on mid-elevation pastures that support livestock operations. While water conservation initiatives aim to lower consumptive water use, limited irrigation practices can affect forage growth, grazing calendars, and pasture recovery. To promote wider use of voluntary curtailment practices, the timing of irrigation reductions must be carefully aligned with other livestock management activities. Drawing on on-farm trials at Western States Ranches, we highlighted how the timing of irrigation cutoffs—across spring, early summer, late summer, and winter grazing periods—influenced forage outcomes and operational adjustments. Producers implementing voluntary irrigation restrictions will need to adapt grazing strategies seasonally, to align grazing plans with irrigation schedules, permit availability, and forage supplementation strategies. Proactive management and future tools such as long-term water contracts will further support producer irrigation decisions and related stocking adjustments and minimize impacts on those working ranches.

Brief #4: Incentivizing Participation

Determining the Impact of Voluntary Irrigation Withdrawals and Water Conservation Payments on Livestock Producers' Bottom Line

Daniel Mooney[1], Dana Hoag[1], Bhishma Dahal[1], and Perry Cabot[2]

Overview

Purpose

Approach

Findings

Insights

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Brief #5: Predicting Participation

Identifying Factors Associated with Farmer Willingness to Participate in Regional Water Conservation Programs

Seth Mason[1], Dana Hoag[2], Daniel Mooney[2]

Overview

➢ While the feasibility of limited irrigation practices is important, achieving regional water conservation targets will also depend on farmers' willingness to participate in conservation programs.

➢ We summarize the findings from a survey of 500+ agricultural water users across Colorado's West Slope to highlight factors associated with their likelihood to enroll in an agricultural water conservation program.

➢ The findings can provide a foundation for forecasting how participation rates may impact the region's ability to meet conservation targets.

Purpose

This study examines how characteristics of producers, land parcels, and program design features influence willingness to participate in voluntary conservation efforts.

The findings will help stakeholders and policymakers:

- Better anticipate participation levels and water conservation outcomes.
- Identify opportunities to improve program participation and meet regional targets through strategic program adjustments.

Approach

Through our survey, we collected information about demographics, operational characteristics, and attitudes toward water conservation.

We used a Discrete Choice Experiment to assess preferences for different water conservation practice features.

- Practice options included full season withdrawal, full season limited irrigation, and split season withdrawal
- Compensation rates varied from $150 to $1600/acre.

We applied Bayesian statistical models to analyze how various factors influence participation decisions.

Findings

The demographic profile of respondents aligned with 2022 USDA Census data for producers on Colorado's West Slope.

- Most respondents reported irrigating primarily for hay or grass pasture production.

Among examined policy/practice features, the compensation rate was the strongest predictor of participation.

Other results:

- Programs requiring full-season withdrawal had reduced participation, regardless of compensation rate.
- Adding an East Slope match to the amount of water conserved increased likelihood of participation about 10%.

A significant factor for participation was respondents' attitudes toward water conservation programs.

- Respondents with negative attitudes were unlikely to opt-in to participation, even at high compensation levels.
- For respondents with neutral or favorable attitudes, compensation became increasingly important.

Insights

The findings offer guidance for designing more effective and appealing water conservation programs. For example, participation could rise if:

- Negative perceptions are addressed through outreach, trust building, & transparency.
- Program officials maintain a focus on hay and pasture acres, which dominate irrigated agriculture in the region.
- Competitive compensation is offered, with rates up to $1,200/acre showing potential to drive participation.
- Program features are offered, like East Slope water conservation matches and Water Shepherding, which increased appeal and opt-in rates.
- Flexible irrigation options are offered, as producers had more interest in limited irrigation practices than full-season curtailment practices.
- Incentives are strategically combined; for example, split-season irrigation paired with $600/acre compensation yielded a 2% opt-in rate, but that jumped to 37% for $1,200/acre and an East-Slope match.

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Brief #5: Predicting Participation

Identifying Factors Associated with Farmer Willingness to Participate in Regional Water Conservation Programs

Supplemental Information

Background and Motivation

Widespread agricultural water conservation programs have yet to be implemented on Colorado's West Slope. There is limited qualitative research evaluating water users' opinions about participating in such programs (Bennett et. al, 2023). Quantitative data on participation rates in response to different practice options, policy and program attributes, economic conditions, or environmental contexts is lacking. This absence of information makes it difficult to estimate how likely users are to take part in proposed conservation efforts. As a result, expectations for the effectiveness of large-scale programs—in reducing the risk of a Compact Call, mitigating drought impacts, etc.—remain speculative.

Arriving at meaningful outcomes in terms of water conserved will depend on voluntary participation from a wide range of individuals and groups. The complexities involved are not unlike those arising in other areas of natural resource management, where local context plays a critical role. An individual's decision to participate in any given year is likely mediated by personal attitudes, the characteristics of their natural environment, financial considerations, and the nature of their social networks. Many of these factors change over time, adding further complexity to the situation. Research that probes how social, environmental, and economic contexts interact with individual decision-making can yield new insights into potential water conservation program participation rates under different policy and program scenarios.

Study Approach

To examine the factors influencing potential participation in water conservation programs among diverse agricultural water users on Colorado's West Slope, a survey questionnaire was developed with two main components. The first gathered information on respondents' demographics, farm characteristics, and personal attitudes toward water conservation. The second part featured a Discrete Choice Experiment (DCE) where respondents were asked to choose between alternative water conservation programs, each defined by unique combinations of policy and program attributes. In the DCE, each respondent encountered twelve choice sets. Each set consisted of two water conservation alternatives and a status quo (no conservation) option. The water conservation alternatives varied based on unique policy and program attributes designed to reflect various risks and benefits from the perspective of agricultural water users. The assessed policy and program attributes included:

- <u>Conservation Action</u> – The type of irrigation reduction activity to be enacted for a single irrigation season: full-season limited irrigation, split-season curtailment, full-season curtailment.
- <u>Compensation</u> - Payment received for land placed under water conservation ranging from $150 to $1,600 per acre.
- <u>Conserved Acreage</u> - The portion of a user's irrigated land affected by conservation program activities, ranging from 25% to 100%.
- <u>East Slope Match</u> – A binary option indicating the inclusion of a 1:1 match in conserved consumptive use water volume by curtailment of trans-mountain water diversions to the Front Range.
- <u>Water Shepherding/Protection</u> – A binary option indicating the presence of administrative water shepherding to ensure that any conserved water moves downstream past other junior users and is controlled by Upper Basin states to help reduce the risk of a Compact Call on the Colorado River.

The survey generated 573 high-quality responses. Demographic data from survey participants was compared to similar data from the 2022 U.S. Department of Agriculture Census. This qualitative comparison helped assess how well the sample represents the broader population of Western Slope producers. Most respondents reported irrigated water use tied to hay/grass pasture production (Figure 1), consistent with water use patterns on Colorado's West Slope when viewed by land areas under various crop types.

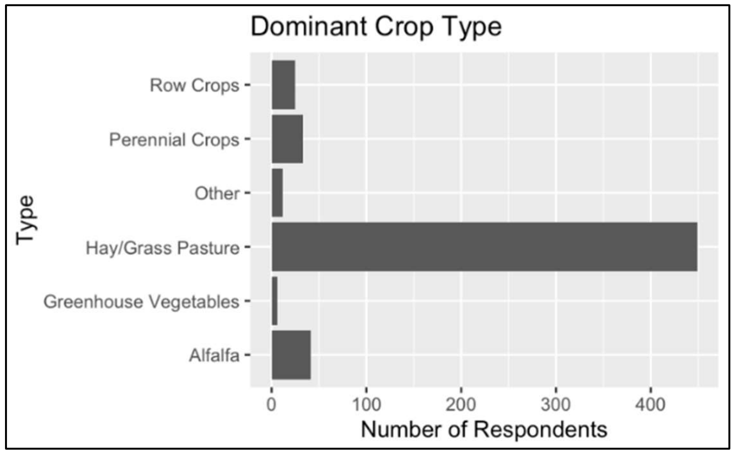

Figure 1.Distribution of irrigated area by crop type, among survey respondents.

Survey responses were analyzed by coupling a pair of Bayesian statistical models fitted to different portions of the data. One model evaluated the role of demographics and farm/ranch characteristics in predicting attitudes toward water conservation. The second model assessed conservation program opt-in probabilities based on these attitudes and the inclusion of various policy and program attributes. This approach allowed investigators to estimate the probability that a water user would choose to participate in a conservation program based on their demographic profile, farm or ranch characteristics, and the specific attributes of the proposed program (as defined in the DCE). The results also highlighted the relative influence of each attribute in shaping participation decisions by reporting 'marginal means' of opt-in probabilities for each level of each attribute. The marginal mean calculated for a given level of any attribute reflects the average probability of opting in to a conservation program possessing that level, holding the effects of all other attributes constant.

Study Findings

Compensation rates and an East Slope water match drove the largest differences in participation probabilities among the evaluated policy and program attributes. Increasing compensation from $600 to $1,200 per acre drove about a 10% increase in opt-in rates. Notably, measures of attitude toward water conservation were also major drivers of participation likelihood (Figure 2). Water users with a favorable attitude toward water conservation were more than four times as likely to indicate a willingness to participate than users with an unfavorable attitude, holding other attributes constant. While favorable views toward water conservation programs significantly increased participation probabilities, only a small fraction of the surveyed population reported favorable or very favorable views.

The structure of the coupled statistical models also provided investigators with an avenue for exploring the interactions between policy and program attributes, demographic characteristics, and attitudes. For example, compensation rates positively affected opt-in rates up to $1,200/acre but, within a given compensation rate, the required conservation activity produced predictable differences in the likelihood of participation (Figure 3). For a $600/acre compensation rate, a program requiring full-season irrigation curtailment depressed opt-in likelihoods by approximately 5-8% compared to programs that required split-season curtailment or limited full season irrigation. Across all compensation levels, the inclusion of an East-Slope match drove about a 10% increase in participation probability. Conversely, compensation rates had relatively little effect on opt-in rates among users with unfavorable attitudes toward water conservation (Figure 4), suggesting the need for other non-financial means to attract these users to conservation programs.

Overall, predicted opt-in rates for various combinations of policy attributes and attitudinal characteristics exhibited a wide distribution, centered around a mean of approximately 6%. A hypothetical conservation program requiring split-season irrigation at a compensation rate of $600/acre and lacking an East-Slope match returned about a 2% opt-in rate among users with a neutral attitude toward water conservation. Opt-in rates increased to above 37% among the same users for a conservation program that required split-season irrigation at a compensation rate of $1,200/acre and included an East-Slope match, indicating the positive effect of these policy attributes. However, when the more favorable policy was presented to users with an unfavorable attitude towards water conservation programs, participation probability fell to about 1%. These results suggest a significant role for attitudes in determining the likelihood of program participation. That is, increasing compensation rates induced relatively little corresponding increase in program participation among users with an unfavorable view of water conservation programs.

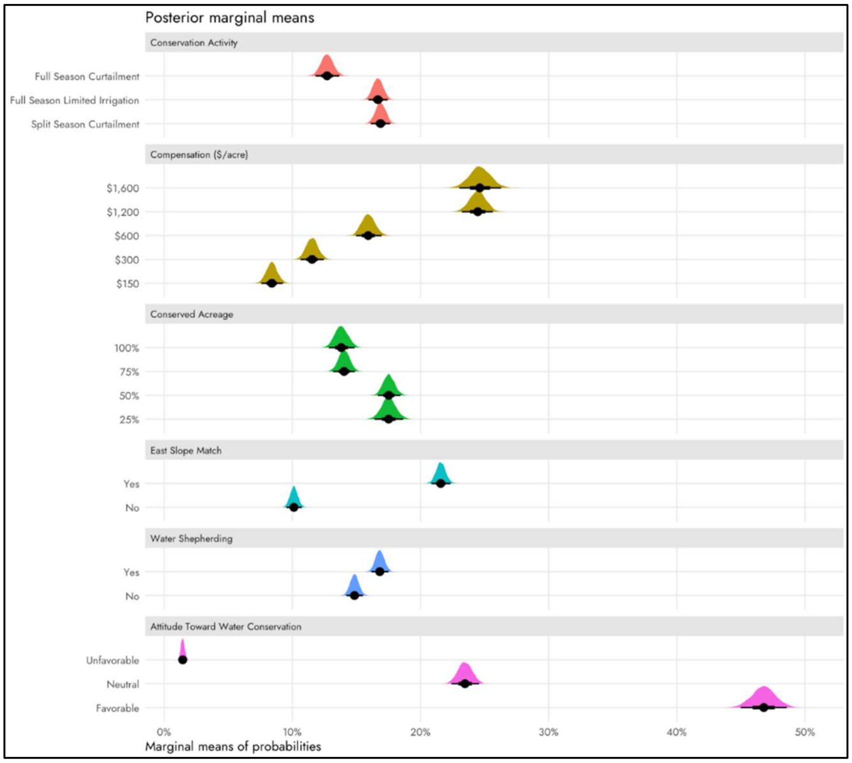

Figure 2. Marginal means (black dots) and attendant distributions (colored areas) of water conservation program opt-in likelihood assessed for a suite of policy, attitudinal, and farm/ranch related attributes.

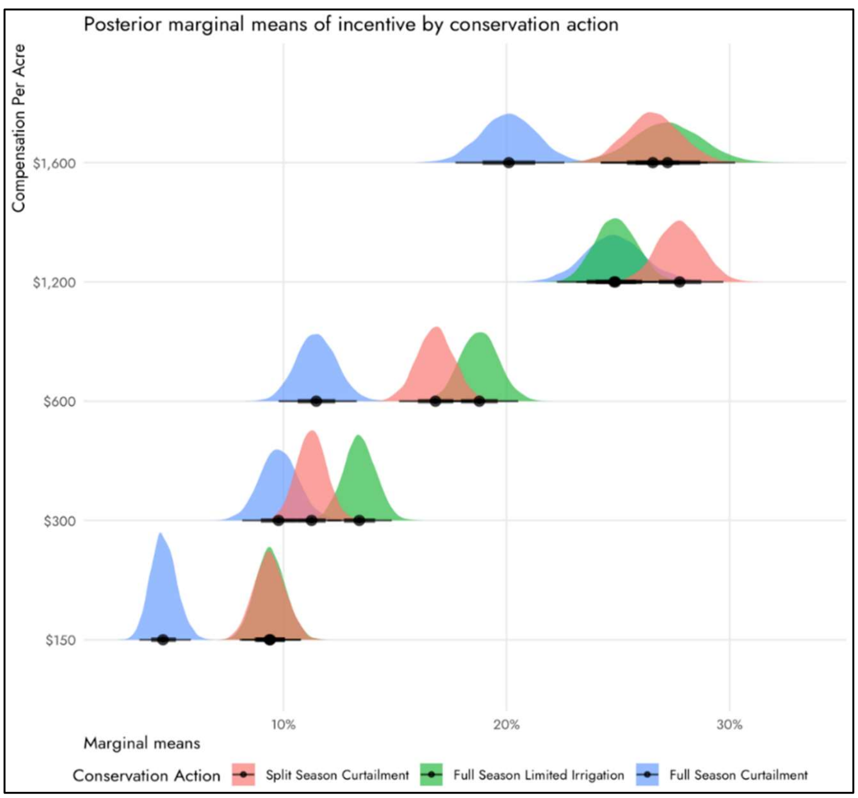

Figure 3. Marginal means (black dots) and attendant probability distributions (translucent and overlapping colored areas) of water conservation program opt-in likelihood assessed across a range of a range of compensation rates and conservation action policy attributes, holding all other attributes constant.

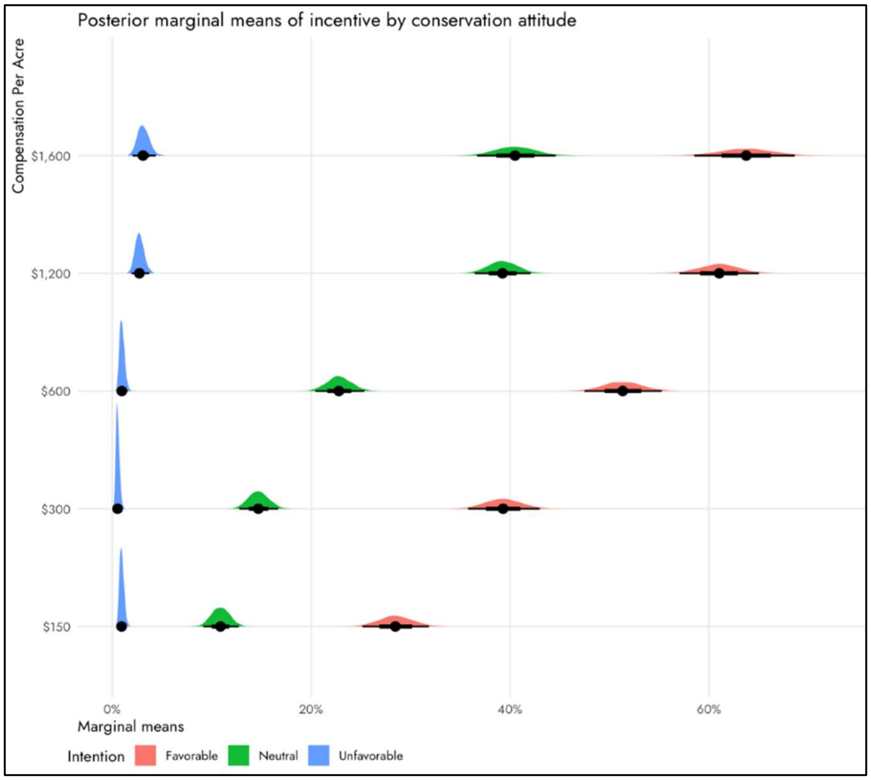

Figure 4. Marginal means (black dots) and attendant probability distributions (colored areas) of water conservation program opt-in probabilities assessed across a range of compensation rate and attitudinal factors, holding other attributes constant.

Insights

The scale of the regional challenges facing water users in the Upper Colorado River Basin is widely recognized by policy makers, water administrators, and academic researchers (e.g., Udall and Overpeck, 2017). The magnitude of projected water conservation needs in western Colorado (Colorado River Water Conservation District, 2019) suggests that the beneficial impacts of voluntary, temporary, and compensated water conservation programs will be greatest when high levels of program participation are sustained over the medium to long term. Achieving such sustained participation will, in turn, require thoughtfully designed policies that reflect the preferences and perceptions of water users on Colorado's West Slope. This study helps identify the policy attributes most likely to influence water conservation program participation rates. Policymakers can use these findings as they work to design conservation programs that appeal to the broadest range of water users. Importantly, the results also suggest that addressing widespread negative perceptions of water conservation programs may be as critical—if not more so—than adjusting program attributes like compensation rates if the aim is to significantly boost participation.

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