Does Flexibility Save Water?

What Multi-Year Flex Accounts Did to Pumping in Kansas

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Where we are going in the next 50 minutes

1. **Why this matters now** — the aquifer, your balance sheet, and H.B. 2279
2. **What we already know** — technology, land values, and past conservation efforts
3. **What a MYFA is** — and what makes it different from everything else
4. **Why flexibility might conserve** — the economics, in plain language
5. **What the data say** — 20 years of records
6. **What it means** — for you and your district

The short version

Producers who enrolled in a Multi-Year Flex Account pumped about **12.5% less** water per year — voluntarily, with no mandated cutback, and the reduction stuck around after the account expired.

Stop me with questions as we go. This works better as a conversation.

Why This Matters Now

The water under your ground

- The Ogallala is the largest freshwater aquifer in North America — and it has been in decline for decades
- Kansas water levels fell **more than 1.5 feet** in a single recent year (Kansas Geological Survey, 2024)
- In much of western Kansas, saturated thickness — not the water right — is what limits the well
- Recharge in this part of the state is a rounding error against pumping

Two ways to think about it

Hydrology: feet of saturated thickness left in the formation.

Economics: an asset that pays a dividend every year you can still lift water at an affordable cost.

Both views point to the same question: how fast do we spend it down?

Depletion is a balance-sheet problem

- Groundwater access is capitalized into land: irrigated ground carries roughly a **71% premium**, about **$1,445/acre** (Sampson et al., 2019)
- Larger and more senior rights sell for more — the right itself is priced (Edwards et al., 2025)
- Irrigation access is worth an estimated **$3.8 billion** of western Kansas land value
- Lost saturated thickness is projected to cut returns to land **$34 million/yr** by 2050 (Hendricks et al., 2022)

Why that framing matters

Depletion does not show up first as a dry well. It shows up as **equity**, **collateral**, and **borrowing base** — and it shows up in what the ground brings at auction.

And for the people in this room

Landowners hold the asset. Producers carry the operating decision. Suppliers sell into whatever acreage and water regime results.

H.B. 2279 changed the rules in 2023

What the law requires (Kansas Legislature, 2023):

- Every Groundwater Management District must identify **priority areas of concern** — the places where declines are significant enough that the aquifer's usable lifetime is **50 years or less**
- For each of those areas, the district must submit a **water conservation and stabilization action plan** to the chief engineer
- The chief engineer reviews the plan — and if a district does not produce one, he can write it himself

The shift in one sentence

Kansas moved from **voluntary concern** to **required planning**. The question is no longer *whether* your district will have a depletion plan — it is *what goes in it*.

Who decides

GMD boards are elected by water users. The people writing these plans are your neighbors — and, in this room, some of you.

The timeline — and where we sit today

we are here

Apr 2023	Jul 2024	Jul 2026	Ongoing
H.B. 2279 signed	Priority areas of concern identified	**Action plans due to chief engineer**	Review at least every 5 years

- The plans have been submitted and are under review — but plans get revised, and the tools inside them are still being argued over
- Which is exactly why it is worth knowing **what each tool actually delivers**, in acre-feet, on real Kansas ground

What can actually go in a plan?

LEMA	**IGUCA**	**Water bank**	**MYFA**	**Incentives**
local, binding, district-initiated cutback	state-imposed corrective control order	deposit, lease, and *transfer* between users	five-year budget, no annual limit, no transfer	cost-share, retirement, technology programs

Mandatory tools

Deliver known quantities of reduction, but require a cutback somebody has to vote for — or have imposed on them.

Voluntary tools

Face far less resistance. The open question has been whether they deliver anything measurable. That is today's talk.

What We Already Know

A research program on scarcity and adaptation

1. Technology

Does more efficient irrigation equipment save water?

(Cameron-Harp and Hendricks, 2025; Pfeiffer and Lin, 2014)

2. What water is worth

How much of your land value is the water underneath it?

(Sampson et al., 2019; Edwards et al., 2025)

3. Past conservation efforts

What did Sheridan 6 and Walnut Creek actually deliver, and how did operators adjust?

(Orduña Alegría et al., 2024; Drysdale and Hendricks, 2018; Earnhart and Hendricks, 2023)

4. Allocation flexibility — today

Can we change *when* water may be used instead of *how much*, and still conserve?

The common thread: producers respond to the **rules and prices they actually face**. Rule design decides the outcome.

1. Efficient equipment does not automatically save water

- Dropped nozzles, LEPA, and low-pressure conversions cut the water *lost* per acre
- But they also cut the **cost of applying an inch** — so the profitable thing to do is often to irrigate more acres, or push a thirstier crop
- Kansas evidence: efficiency adoption can **raise** total extraction (Pfeiffer and Lin, 2014)
- My work with Nathan Hendricks traces the **dynamics**: the water-use path after adoption, not just the average (Cameron-Harp and Hendricks, 2025)

The lesson for policy

A technology subsidy is not a conservation policy unless something also constrains the total.

Why it matters here

It is the reason I care about the **incentive attached to the allocation** — that is where the total actually gets decided.

2. The market already prices the water

- Sampson et al. (2019): irrigated ground carries roughly a **71% premium** over comparable dryland — about **$1,445/acre** of capitalized groundwater value
- Edwards et al. (2025): the **characteristics of the right** matter — quantity and seniority are priced separately from the acres
- Saturated thickness lost is land value lost — and lost permanently on any human time scale

Two-sided reading

Bad news: depletion erodes the asset under your feet.

Good news: conservation that extends the well's life is **not charity** — it defends a priced asset you own.

This is the argument that makes voluntary programs work at all.

3. What past conservation efforts delivered

Sheridan 6 LEMA (2013–)

Irrigator-initiated, binding five-year allocations.

- Pumping fell and water levels stabilized; the aquifer's usable life was extended (Orduña Alegría et al., 2024; Golden and Leatherman, 2015)
- Adjustment came from **applying less per acre**, not from fallowing (Drysdale and Hendricks, 2018; Deines et al., 2019)
- Farm returns largely held up

Walnut Creek IGUCA (1992)

State-imposed corrective controls to protect flow to Cheyenne Bottoms.

- Earnhart and Hendricks (2023): both senior and junior rights cut **depth applied**
- Only **junior** holders cut irrigated acres — they were allocated far less and had to adjust harder
- Seniority shapes **how** you adapt, not just how much

Both are **mandatory** instruments. Both worked. Both required somebody to accept a cut.

So here is the gap

What we knew going in

Mandatory restrictions reduce pumping, and producers absorb them mainly by **watering the same ground more carefully**.

What nobody had measured

Whether a **voluntary** program that imposes **no cutback at all** — one that only changes *when* you may use your water — does anything to the total.

- Kansas has run exactly that experiment since 2012: the **Multi-Year Flex Account**
- Roughly **750** water right groups have enrolled
- Twenty years of metered water-use records let us check what happened

That is the rest of the talk.

What a MYFA Is

Start with the problem: “use it or lose it”

A standard Kansas water right is a **hard cap**: a fixed quantity, **every single year**, and what you do not use by December 31 is gone.

That creates a well-known problem:

- An incentive to run water you do not agronomically need
- Pressure to protect a use history you may need later
- No cushion carried into the next dry year

The core inefficiency

Under an annual cap, an acre-foot you leave in the ground on December 31 is worth **exactly zero to you**.

Not less. *Zero.*

Every conversation about water conservation in Kansas eventually runs into this fact.

What a MYFA actually does

- Your annual limit is **suspended for five years** and replaced with one aggregate budget (a “term permit”)
- **No annual ceiling** inside the term — use it when the crop needs it
- You apply to DWR; the underlying water right is preserved, not surrendered
- At the end of five years you **renew or revert** to your annual allocation
- Metering and reporting requirements continue throughout

The instrument does not tell you to use less. It only changes **when** you may use what you already have.

The novelty: a bank account you cannot transfer out of

A water bank or water market

Moves water **across users**: I lease you my unused allocation, and it also moves **across time**.

Gains come bundled together — you cannot tell which margin did the work.

A MYFA

Moves water **across time only**. Your account is your own. Nothing transfers between accounts — no leasing, no selling, no trading.

It isolates the **time** margin by itself.

- That is what makes this a clean test — and what makes it politically easy: nobody's water moves to a neighbor, a city, or another basin
- It is also the limitation: you get none of the gains from moving water to whoever values it most this year

Think **savings account**, not checking account with wire transfers.

The legislation behind it

2012	2021	2025	Jul 1, 2025
SB 272 creates MYFAs (K.S.A. 82a-736)	**HB 2172** expands eligibility	**SB 58** rewrites the allocation formula and the carryover rule	SB 58 effective

- The statutory bargain has been the same since 2012: flexibility is allowed so long as it **neither impairs existing rights nor increases the total amount diverted** (Kansas Legislature, 2012)
- My study period is **2012–2021** — so it measures the program *as it was originally written*

What SB 58 changed in 2025

How the budget is now set

Deposit is capped at **5 × (net irrigation requirement × authorized acres × 110%)**, and may not exceed **5 × your authorized annual quantity** (Kansas Legislature, 2025).

The old rule keyed off average actual use in 2000–2009. The new rule keys off *crop need* on your authorized acres.

Carryover at expiration

If water is left in the account when the term ends, you may roll it into the **next** five-year term — up to the lesser of one year's net irrigation requirement or your authorized annual quantity.

Two conditions: the new term's total cannot exceed your annual quantity × the number of years, and you must re-enroll in the same calendar year the old account expires.

In plain terms: **roughly one year's worth of unused water can now follow you into the next account** — if you do not let the account lapse.

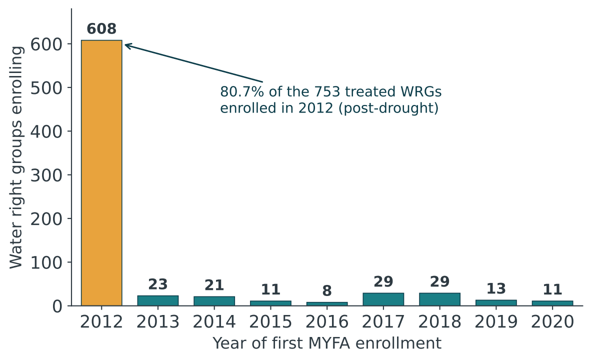
Why the carryover rule matters for what follows

- Everything I estimate today comes from the program **before** the 2025 changes
- Under the old rules, water banked and unused at the end of five years was largely at risk of being lost unless you rolled straight into a new account
- The economics I am about to walk through says the value of saved water is what drives conservation — so a rule that makes saved water **easier to keep** should, if anything, **strengthen** the effect
- That is a prediction, not a finding. It is testable once post-2025 data exist

Practical note for anyone considering enrollment

The re-enrollment timing condition is easy to miss. Carryover requires enrolling in the subsequent account **during the calendar year the existing one expires** — let it lapse a year, and the banked water does not follow you.

Who has actually enrolled



Year of first MYFA enrollment; 753 water right groups.

- **753** water right groups enrolled between 2012 and 2020
- **608 of them (81%)** signed up in **2012** — the program's first year, right after the 2012 drought
- Later cohorts are small: 8 to 29 groups per year
- **GMD 5** alone accounts for about half of all enrollees

Uptake is real but concentrated — roughly **6%** of eligible water right groups in the GMDs.

Why Flexibility Might Conserve

Two stories, both perfectly sensible

Story 1: it conserves

Once leftovers carry forward, there is no reason to run the pivot in September just to protect next year's allocation. Water left in the ground **keeps its value**, so you leave more of it there.

Story 2: it just reshuffles

Pump less in wet years, more in dry ones, and the five-year total lands in the same place. Flexibility buys resilience, not conservation.

- Story 2 is a serious concern, not a straw man: simulation work finds soft caps raise drought-year pumping and streamflow depletion, even while raising farm profits (Young et al., 2021)
- A third possibility: flexibility makes irrigating more profitable, so more water gets used overall

You cannot settle this by arguing. You settle it by writing down the decision and then going to the data.

The key idea: saved water gains a price

Under an **annual cap**, an acre-foot you do not pump by December 31 is worth zero.

Under a **five-year budget**, that same acre-foot is **insurance against the next dry year**. It has a price *even if you never pump it*.

That price is a real **cost of pumping today**. It is the one thing a soft cap has that a hard cap does not — and it is entirely absent from the annual system.

Three consequences

1. **You stop short.** The last acre-inch now competes with its value next season
2. **You build a cushion** bigger than any single-year allocation could give you
3. **Dry years cluster.** A dry season makes saving *more* valuable, not less

Conservation is not a side effect of the MYFA. It is built into what a multi-year budget *is*.

Walk it through with numbers

Illustration — round numbers chosen for clarity, not estimates from the data.

Annual right: 200 af per year

Wet year — crop needs 150 50 af unused	pump **150** forfeited
Dry year — crop needs 250 short by 50 af	pump **200** yield loss

Two-year total: **350 af**, and you still came up short when it counted.

Five-year budget: 1,000 af

Wet year — crop needs 150 you trim the last inch	pump **140** **it has value now**
Dry year — crop needs 250 drawn from the budget	pump **250** no shortfall

Two-year total: **390 af** — but the crop got covered, *and* you stopped 10 af short of need in the wet year.

- The **reshuffling** is obvious: the dry year got more water
- The **conservation** is the subtle part — in the wet year you stopped short of what the crop would have taken, because the water was worth more in the account

When does the saving motive win?

The saving motive beats the drawdown motive when rainfall is **variable**, has a **bad left tail**, and **dry years cluster** — and when producers are planning more than one season ahead.

Western Kansas, May–Sept rainfall

Year-to-year variability (CV)	0.34
1 year in 10 at or below	47 mm
against a median of	76 mm
Dry-follows-dry correlation	+0.24
positive in	83% of groups

Every condition is satisfied here

Rainfall varies a lot, bad years are common enough to worry about, and a dry year makes the next year more likely to be dry too.

Western Kansas is close to the **best case** for a soft cap to conserve rather than merely reshuffle.

If the model is right anywhere, it should be right here. That makes this a fair test.

What the theory tells us to look for

Prediction 1

Average pumping falls after enrollment.

If a MYFA only moved water between years, the average effect would be about zero. A negative average is the signature of genuine conservation.

Prediction 2

The effect is weaker for producers who enroll in a drought.

Sign up in a dry year and you are already pumping near the cap — there is nothing left over to bank.

Why Prediction 2 is the sharper test

Lots of things could make enrollees pump less. Only the **option-value story** predicts that the size of the effect should track **how much slack the weather left you**. That is a fingerprint, not just a direction.

Data and Approach

The data

- Kansas **WIMAS** annual water use reports — what was actually metered and reported
- **13,328** water right groups; **2001–2021**
- Estimation panel: **239,947** group-years across 12,948 groups in the five GMDs, excluding LEMAs
- MYFA start and end dates from **KDA Division of Water Resources** records
- Growing-season rainfall (PRISM, May–Sept) at each group's location

What we can see

Water used, acres irrigated, crops planted, and the authorized quantity on the right.

What we cannot see

Yields, costs, or profits. That limits what I can say about whether producers were better off — I will come back to this.

The panel is stable: 81.5% of groups appear in all 21 years.

The typical operation in the sample

	Mean	Std. Dev.
Annual water use (acre-feet)	167	140
Irrigated acres	161	160
Authorized quantity (acre-feet)	376	320
Authorized acres	248	210
Growing-season precipitation (mm)	78	26

- Note the gap between **authorized** (376 af) and **actual** use (167 af) — most rights are not pumped to the paper limit in an average year
- That slack is exactly what a five-year budget lets you do something with
- Water use per irrigated acre averages about **1.15 acre-feet**, or roughly 13.8 acre-inches

Two things make this hard to measure

1. Enrollment is a choice

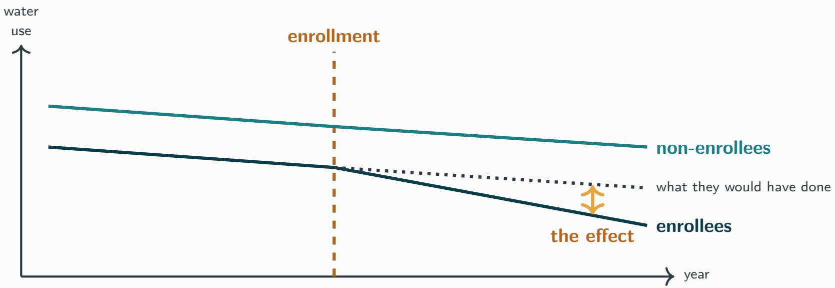
The producers who signed up are not a random sample. If conservation-minded operators are the ones who enroll, comparing them to everyone else confuses **the program** with **the person**.

2. The treatment turns off

A MYFA expires after five years. Most statistical tools assume that once you are treated you stay treated forever — which would mislabel every post-expiration year.

- Problem 1 is why I compare each enrollee to **similar non-enrollees in the same GMD**, before versus after enrollment — rather than just comparing enrollees to non-enrollees
- Problem 2 is why I use an estimator built for treatments that **switch on and off**. It also means I can see what happens **after** the account expires — which turns out to be one of the more interesting findings

How the comparison works



- We do not compare enrollees to non-enrollees. We compare the **change** in enrollees' use to the **change** for similar operations in the same district
- That differences out anything permanent about who enrolls — soil, aquifer, management style
- It does not difference out anything already *changing* before they signed up — the honest weak point, and I will show you what it costs

The estimators, in one slide

Main tool (de Chaisemartin and D'Haultfœuille, 2024)

- Handles treatment that **switches on and off** — so post-expiration years are labeled correctly
- Comparisons restricted to **within the same GMD**
- Reports an effect for each year after enrollment

Second tool (Callaway and Sant'Anna, 2021)

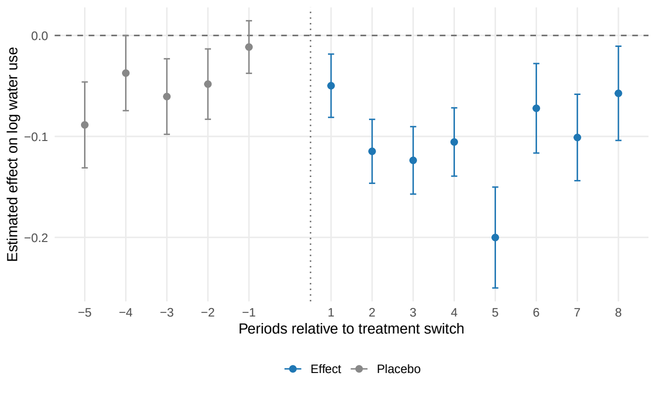
- Lets me break the effect out by **enrollment year** and by **calendar year**
- That is what tests the weather story
- Treats enrollment as permanent — a caveat, so I use it for patterns, not the headline

Both control for growing-season rainfall. Standard errors account for the fact that a given operation's years are related to each other.

More detail in the backup slides — and I am happy to go deeper in questions.

What the Data Show

Result 1: enrollment cut withdrawals about 12.5%



- Reduction in **every year** after enrollment
- Shows up **immediately** — not after a learning period
- Still there **after the account expires** and the annual right comes back
- Average across all years: -12.5%

Years 1–5 are inside the flex term; years 6–8 are after it expired. Vertical bars are 95% confidence intervals.

The same result as a table

	Estimate (log pts)	Approx. %
Inside the five-year flex term		
Year 1	−0.050**	−4.9%
Year 2	−0.115***	−10.9%
Year 3	−0.124***	−11.7%
Year 4	−0.106***	−10.1%
Year 5	−0.200***	−18.1%
After the account expired		
Year 6	−0.072**	−6.9%
Year 7	−0.101***	−9.6%
Year 8	−0.057*	−5.5%
Average	−0.133***	−12.5%

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. $N = 239{,}947$ group-years.

Why the persistence is the interesting part

- Years 6–8 are years when the 2012 cohort was back on an **ordinary annual allocation**
- The reduction is smaller, but it is still there and still statistically significant
- Something learned or installed during the flex term appears to have **stuck**

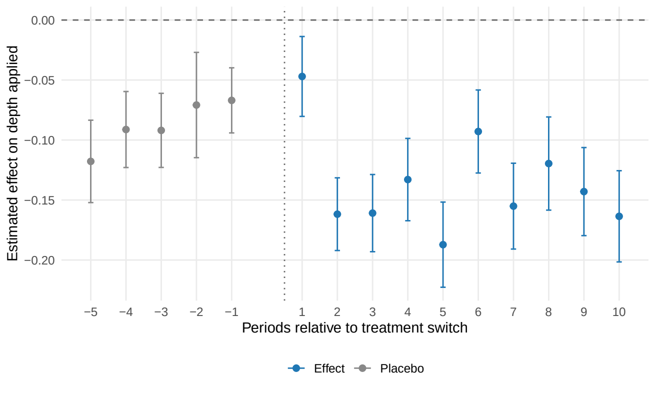
Plausible explanations

- Equipment or scheduling investments made during the term
- Better information about what the crop actually needs
- Habit — once you stop irrigating to protect an allocation, you stop

I can measure the persistence. I cannot yet separate these three explanations.

Worth noting: no absorbing-state method could have found this. It required an estimator that knows the account **turned off**.

Result 2: efficiency, not fallowing



Water applied per acre

- Down **about 17%**
- Roughly **2.3 acre-inches** less per acre per year
- From a base of 13.8 acre-inches

Irrigated acres **hold steady**. Producers are watering the same ground more carefully — not idling it.

The same intensive-margin adjustment found under Sheridan 6 (Drysdale and Hendricks, 2018; Deines et al., 2019) and Walnut Creek (Earnhart and Hendricks, 2023).

Result 3: crop mix barely moved

Crop	Change in acres
Wheat	+10.2*
Sorghum	+6.3
Alfalfa	+5.2
Soybeans	−2.1
Corn	−4.2

* $p < 0.05$. All others statistically indistinguishable from zero.

What this rules out

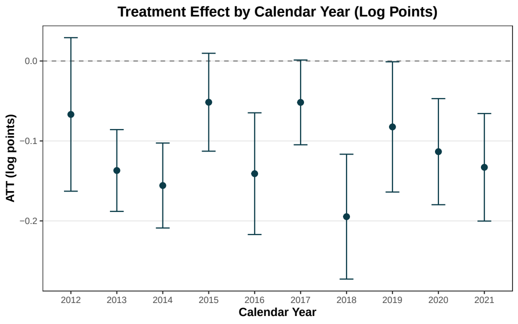
The water savings did not come from abandoning corn for something cheap to water. Corn acres barely moved.

What it points to

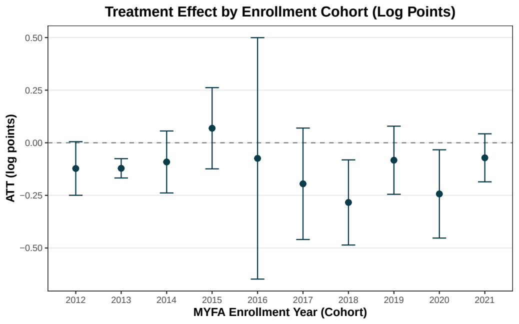
A modest shift toward wheat, and otherwise the **same rotation, watered more carefully**. Consistent with the depth result.

For an operation, that is the reassuring version of the story: savings from management, not from giving up your best crop.

Result 4: the effect follows the weather



By calendar year — largest in mixed-to-favorable years



By enrollment year — the 2013 signers are the best measured

- Conservation concentrates in years when rainfall left something **worth banking** — strongest across 2013–2019
- The enrollment-year pattern points the same direction, but the drought cohorts are small — suggestive, not settled

Reading the weather pattern

- This is the **fingerprint** Prediction 2 called for: the effect is largest exactly when the weather left slack worth saving
- It is not what you would expect if the reduction were simply "conservation-minded people sign up"
- Those operators would pump less in **every** year — not disproportionately in the years with something to bank

Honest caveat

The **calendar-year** evidence is precise. The **enrollment-cohort** evidence is not — the drought cohorts have only a handful of operations and one to three years of data each.

I treat the cohort ordering as suggestive.

The mechanism story rests mainly on the calendar-year result, and I want to be clear about that.

How solid is the 12.5%?

The honest problem: enrollees' water use was already drifting down slightly **before** they enrolled.

Two readings, and they pull in opposite directions:

- If that drift is *who they are*, the true effect is smaller
- If that drift is people *already starting to conserve* ahead of signing up, the true effect is larger

Assumption	Implied effect
Drift is all selection	$\approx -4\%$
Headline	-12.5%
Drift removed entirely	$\approx -23\%$
Drop GMD 5	-9%

GMD 5 supplies about half of all enrollees; dropping it attenuates the effect by roughly a third but leaves it clearly negative.

The headline is a **conservative midpoint** — negative and meaningful under every reading I can construct.

What it adds up to

- Average water right group pumps **167 acre-feet** per year
- A 12.5% cut is about **21 acre-feet per group, per year**
- Across the ∼750 enrolled groups: roughly **15,000 acre-feet a year**
- That is about what a small Kansas town uses annually
- One acre-foot = 325,851 gallons

Put it in perspective

That is real water — but it is **one program** at **6% uptake**. Scaling it up is where the policy conversation actually lives.

And the important part

Every acre-foot of it came from producers **volunteering**. Nobody was told to cut back.

What It Means

For your operation

What enrollees appear to have gained

- Cover the crop in a drought year without hitting a wall at the annual limit
- No forced end-of-season pumping to protect an allocation
- The underlying water right stays intact
- Under SB 58, unused water can now follow you into the next term

What to weigh against it

- Five years is a commitment; the paperwork is real
- Your budget is set by a formula — run the numbers for *your* right before assuming it is generous
- Nothing transfers to a neighbor: the water is only worth what it is worth to you
- Overdraw early and the back end of the term gets tight

The revealed-preference evidence: 753 groups signed up voluntarily, and some re-enrolled.

For the plans your district is writing

The case for including MYFAs

A **voluntary** tool with **no mandated cutback** that delivered roughly -12.5% withdrawals and -17% water per acre, immediately, with some persistence after expiration.

- Very few conservation instruments can go into an action plan without a fight. This is one of them
- It is not a substitute for a LEMA where a large, certain reduction is needed — the effect is smaller and it depends on who signs up
- Uptake is the binding constraint, not the per-enrollee effect. At 6% participation, the aggregate is modest
- Outreach, and the new carryover rule, are the levers on uptake

One important caution

Flexibility also lets pumping concentrate in a drought

The very feature that conserves on average — freedom to move water across years — is what lets an operator draw hard in the worst year.

- Young et al. (2021) find soft caps raise **drought-year** pumping and streamflow depletion, even while raising farm profits
- My estimate is a **multi-year average**. It does not rule out their result — the two are compatible
- Where the aquifer and a stream are connected, the **peak** drawdown is what does the damage, not the five-year total

The design fix

Pair the multi-year budget with a **ceiling on annual pumping** — high enough to preserve the value of banked water, low enough to cap the drought-year draw.

You keep the conservation incentive and bound the hydrologic risk.

What I still cannot tell you

Profits

I see water, acres, and crops — not yields or margins. Whether the saved water was waste or foregone production is not something these data settle.

Scaling

Early adopters may be the most conservation-inclined. The next 6% may not behave like the first 6%.

The aquifer

I measure pumping, not water levels. Translating acre-feet into feet of saturated thickness takes a hydrologic model.

The long run

The panel ends in 2021, before most accounts finished a full cycle of expiration and renewal — and before SB 58.

Each of these is a reason to extend the work, not a reason to discount what is already measured.

Three Things to Take Home

Three things to take home

1. The economics says flexibility can conserve — it is not a loophole

A multi-year budget puts a **price on water you leave in the ground**. Under an annual cap that water is worth zero. That price is a real cost of pumping today, and it is built into what a multi-year budget *is* — not a hoped-for side effect.

2. Enrollees actually did save water — and some of it stuck

Withdrawals fell roughly **12.5%**, water per acre fell roughly **17%**, and irrigated acres held steady. The reduction appears **immediately** and remains detectable in the years **after the account expired**.

3. Weather at enrollment drives the size of the effect — so design in a safeguard

The calendar-year and cohort results both point to **how much slack the weather left you** as the main driver. The effect is smallest exactly when water is scarcest — so where groundwater and surface water are **coupled**, pair the multi-year budget with an annual ceiling.

Where this leaves us

- Temporal flexibility — often viewed with suspicion — can **line up private incentives with aquifer conservation**
- It is voluntary, it preserves the right, it requires no cutback, and by the participants' own choices it left them better off
- It is not a silver bullet. It is one credible, low-conflict tool among several, and its aggregate impact is limited by **uptake**

The question I would leave you with

Your district's action plan is being reviewed and will be revised.

What tools do you want in it — and what evidence do you want behind them?

Happy to take questions — on the numbers, the program mechanics, or what this means for your own right.

Thank you

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Does Flexibility Save Water?
Multi-Year Flex Accounts in Kansas

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Backup: how the effect is estimated

Preferred: de Chaisemartin and D'Haultfœuille (2024)

- Treatment **switches on *and* off** — MYFAs expire, so most modern DiD estimators mis-code post-expiration years as treated
- Switcher–stayer comparisons **within GMD**: a weaker parallel-trends requirement
- Recovers post-expiration dynamics

Complement: Callaway and Sant'Anna (2021)

- Doubly-robust group-time ATTs
- Clean **cohort** and **calendar-year** aggregation
- Absorbing-state coding (a caveat) — used for heterogeneity, not the headline

Sample: WRGs in GMDs, 2001–2021, non-LEMA, deduplicated ($N = 239{,}947$). SEs clustered at the water right group.

Backup: headline estimates across specifications

	Estimate (log pts)	Approx. %
dCdH within-GMD (preferred)	−0.133***	−12.5%
Depth applied (dCdH, ac-ft/acre)	−0.192***	−16.7%
Callaway–Sant'Anna (baseline)	−0.116***	−11%
C–S not-yet-treated only	−0.242***	−21%
C–S + pre-treatment use control	−0.087***	−8.3%
Bilinski–Hatfield residualized (V1)	−0.229	−20%

*** $p < 0.001$.

Sample: WRGs in GMDs, 2001–2021, non-LEMA, deduplicated ($N = 239{,}947$).

Backup: is it real? A conservative reading

- Within-GMD comparisons shrink the worst pre-enrollment placebo from -0.128 to -0.089, but a residual pre-trend remains (joint $p = 0.0002$)
- Formal bounds (Rambachan and Roth, 2023; Bilinski and Hatfield, 2024) *bracket* the effect:

Counterfactual assumption	Implied ATT
Pre-trend = 100% selection	$\approx -4\%$
Headline (within-GMD)	-12.5%
Pre-trend residualized out	$\approx -23\%$

The headline is a **conservative midpoint** — if anything biased *toward* zero, not away.

Backup: leave-one-GMD-out

	Log water use	Depth applied
Full sample	−0.133***	−0.192***
Drop GMD 1	−0.136***	−0.196***
Drop GMD 2	−0.117***	−0.187***
Drop GMD 3	−0.164***	−0.212***
Drop GMD 4	−0.139***	−0.208***
Drop GMD 5	−0.095***	−0.128***

GMD 5 supplies 50.7% of treated WRGs and 52% of active-MYFA observations. Dropping it attenuates the effect by about a third but leaves it negative and significant — and it shrinks the pre-trend violation by a similar fraction.

Backup: enrollment by GMD

GMD	Total WRGs	Treated	% treated	Share of treated	Share of WRG-yrs
1	955	23	2.4%	3.1%	6.7%
2	1,348	131	9.7%	17.4%	10.2%
3	4,921	161	3.3%	21.4%	38.9%
4	2,258	56	2.5%	7.4%	15.0%
5	**3,466**	**382**	**11.0%**	**50.7%**	**29.2%**
Pooled	12,948	753	5.8%	100%	100%

Uptake is far higher in GMD 5 (11%) than anywhere else. Half the identifying variation in the headline comes from that district.

Backup: program term and treatment reversibility

Program term

- Each MYFA runs **five consecutive years**
- Then **renew** or **revert** to annual allocation — treatment is **reversible**
- Non-consecutive re-enrollers excluded for a clean treatment definition

Why it matters

The 2012 cohort's term (2012–16) plus its post-2016 reversion is what identifies the **post-expiration** dynamics in Years 6–8.

Adoption is front-loaded: 608 of 753 treated groups entered in 2012, immediately after the severe 2012 drought.

Backup: precipitation moments by GMD

GMD	Mean (mm)	SD (mm)	CV	p10 (mm)	Skewness
1	69.9	19.0	0.27	43.1	−0.15
2	105.0	32.3	0.31	67.3	+0.45
3	67.2	21.3	0.32	42.5	+0.51
4	69.6	18.8	0.27	43.0	−0.07
5	90.3	24.2	0.27	57.4	+0.02
Pooled	78.4	26.7	0.34	46.7	+0.63

May–September PRISM precipitation at the WRG centroid. Within-WRG year-to-year autocorrelation averages 0.24 and is positive in 83% of groups; the AR(1) coefficient on the statewide annual mean is 0.49.