

Water Scarcity and the Future of Rural Communities in West Texas: Economic Correlates of Ogallala Aquifer Depletion

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Research Article

Keywords: Ogallala Aquifer, groundwater depletion, rural economies, employment, Texas High Plains, panel data, irrigated cotton

Posted Date: September 29th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10989188/v1>

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Additional Declarations: No competing interests reported.

Abstract

Groundwater depletion threatens the agricultural base of the Texas High Plains, yet evidence on its broader consequences for rural county economies remains limited. This study links well-level groundwater measurements from the Texas Water Development Board to county employment and wage records from the Quarterly Census of Employment and Wages, county income accounts from the Bureau of Economic Analysis, and climate records from NOAA. The panel spans 49 West Texas counties from 2000 through 2024; groundwater data are available for 44 counties and 1,042 county-year observations. Two-way fixed-effects models relate within-county changes in depth to groundwater to employment, establishments, wages, population, per-capita income, and farm income, controlling for precipitation and temperature. A 10-foot increase in groundwater depth is associated with 0.62 percent lower covered employment and 0.51 percent fewer establishments; neither estimate is statistically significant, and the confidence intervals are wide enough to admit either economically meaningful losses or no effect at all. Wages, population, per-capita income, and farm income show similarly imprecise associations. These null results do not establish that depletion is economically harmless: the design is powered to detect employment declines above roughly 2 percent and establishment decline above roughly 1 percent per 10 feet of depth, so smaller but still consequential effects would go undetected. The findings suggest that sectoral adjustment, dryland conversion, technological adaptation, and nonfarm activity may be masking aquifer stress in county aggregates. An independently reconstructed employment series, built separately from the Bureau of Labor Statistics for all 44 counties and 25 years, reproduces these null county-wide estimates almost exactly and shows no evidence of nonlinear, delayed, or size-dependent effects. A companion case study of three major cotton counties, however, finds that irrigated cotton acreage is substantially lower where groundwater is deeper (within-county correlation as strong as -0.69), indicating that a real agricultural adjustment can be fully masked within a diversified county economy. The study contributes a transparent historical panel and reframes groundwater depletion as a social-economic process whose effects may be heterogeneous, delayed, and nonlinear; stronger causal claims will require exogenous variation in pumping costs or groundwater availability and more detailed agricultural outcomes.

1. Introduction

The Ogallala Aquifer transformed the High Plains from a semiarid landscape into one of the most productive agricultural regions in the United States. Center-pivoted irrigation and high-capacity pumping made intensive production of cotton, corn, sorghum, wheat, and livestock feed possible despite limited rainfall. The same transformation created a structural dependence: agricultural production, input suppliers, processors, transport firms, local governments, and households became connected to a finite groundwater stock. In much of West Texas, withdrawals substantially exceed natural recharge, raising concern not only about future crop production but also about the economic viability of rural communities.

The Ogallala is not unique in this respect. Major irrigated regions dependent on non-renewable or slowly recharging groundwater face comparable trajectories, including California's Central Valley, the North

China Plain, the Indo-Gangetic Basin, and parts of the Arabian Peninsula. In each case, the same underlying question arises: does measurable aquifer depletion translate into detectable local economic decline, or can adaptation, economic diversification, and structural change absorb the loss without a visible aggregate signature? Because the identification challenges documented here—joint determination of pumping, drought, and economic activity; the risk that county- or district-level aggregates mask effects concentrated in a single water-intensive sector; and the difficulty of detecting delayed or nonlinear adjustment—are generic to any region built on finite groundwater, the empirical strategy and findings developed for West Texas offer a transferable template for evaluating similar aquifer systems elsewhere.

Earlier economic studies generally approach Ogallala depletion through optimization, crop-allocation, or input-output models. Terrell (1998) linked projected changes in crop patterns to regional output, employment, and value added. Almas, Colette, and Wu (2004) argued that water management, reallocation toward higher-valued production, and economic diversification could slow rural decline. Almas, Colette, and Park (2006) developed a long-horizon groundwater optimization model, while Almas et al. (2017) compared conservation policies intended to extend the aquifer's economic life. McCullough (2016) documented the large production, processing, and employment contributions of cotton in the Southern Ogallala region. These studies demonstrate the economic importance of groundwater-dependent agriculture, but most rely on simulated future conditions, a single benchmark year, selected counties, or sector-specific multipliers.

A parallel literature emphasizes that groundwater depletion cannot be understood only as a hydrological or farm-management problem. Zwarteveen et al. (2021) call attention to collective care, sharing, and the political foundations of groundwater-dependent agricultural systems. Walsh (2022) emphasizes the heterogeneity and social visibility of groundwater, while Huggins et al. (2023) conceptualize aquifers as parts of connected social-ecological systems characterized by feedback, path dependence, and multiple possible states. In the South Plains, Cavazos (2026) describes how private-property norms, the rule of capture, and economic dependence on high-input agriculture can weaken collective restraint. These perspectives imply that economic effects may emerge unevenly and may be mediated by institutions, culture, technology, and local adaptation.

This paper asks a narrower empirical question: as groundwater becomes deeper within West Texas counties, do observable measures of county economic activity deteriorate? The analysis focuses on covered employment, establishments, total wages, average pay, population, per-capita personal income, and farm income. It uses annual data from 2000-2024 and county and year fixed effects, thereby comparing each county with itself over time while accounting for shocks common to all counties.

The paper makes three contributions. First, it moves beyond modeled agricultural losses to examine realized changes in broad county outcomes. Second, it integrates well-level groundwater records with administrative labor-market data and official county income and climate series. Third, it treats null results as economically informative by explicitly characterizing the precision of the estimates—rather than treating a nonsignificant coefficient as proof of no effect. Aggregate resilience may coexist with losses

concentrated among irrigated producers, smaller communities, or water-intensive industries, and it may reflect adaptation that postpones rather than eliminates long-run adjustment.

2. Background and Literature

2.1 Groundwater dependence in the Texas High Plains

The Texas High Plains combines limited precipitation, recurrent drought, highly variable weather, and a production system built around irrigation. Groundwater functions as both a productive input and a buffer against rainfall risk. As the water table falls, pumping lifts increase, energy costs rise, well yields can decline, and the feasible set of crops and irrigation strategies narrows. Producers may respond by adopting efficient irrigation, deficit irrigation, changing crop mixes, reducing irrigated acreage, or converting to dryland production. These responses can preserve output for a time, but they can also transfer adjustment costs across farms, workers, and communities.

The economic link extends beyond farms. Irrigated agriculture supports machinery dealers, seed and chemical suppliers, gins, elevators, processors, trucking, finance, and local retail demand. McCullough (2016) estimated that cotton production and processing in the Southern Ogallala region generated substantial output and employment, illustrating the backward and forward linkages through which water availability can affect local economies. Terrell (1998) used similar changes in final demand generated by projected crop adjustments to estimate direct, indirect, and induced effects.

Conservation can change the timing and distribution of those effects. Almas et al. (2017) show that conservation policies may extend the aquifer's economic life, but the outcomes depend on policy design, crop choice, saturated thickness, and producer response. Improved irrigation efficiency can reduce application losses, yet efficiency does not guarantee reduced total extraction if saved water supports additional acreage or more intensive production. The relevant question is therefore not simply whether technology improves water productivity, but whether institutions and incentives translate those improvements into aquifer-level conservation.

2.2 Groundwater as a social-economic system

Social-ecological literature cautions against treating an aquifer as an isolated physical stock. Huggins et al. (2023) argue that groundwater is connected to social, economic, ecological, and Earth systems. Feedback and path dependence imply that the same physical decline may produce different outcomes across communities. A diversified county may absorb agricultural losses through health care, energy, education, or services; an agriculture-dependent county may not.

Governance further shapes adjustment. Molle (2019) describes the persistent difficulty of governing a common pool resource whose users are numerous, withdrawals are difficult to observe, and political incentives often favor continued pumping. Rudestam, Brown, and Langridge (2018) show that place attachment and local identity affect participation in groundwater management. Cavazos (2026) finds that the South Plains' culture of autonomy and private control can turn shared vulnerability into competitive

extraction rather than collective restraint. Sanderson, Griggs, and Schäfer (2025) likewise show how cultural visions of progress can sustain large supply-augmentation proposals even when their economic and legal feasibility is doubtful.

These studies help explain why reduced groundwater availability may not immediately generate a smooth decline in aggregate employment or income. Adjustment can occur through migration, consolidation, substitution, public transfers, new industries, technological change, and capitalization into land values. Effects may also be nonlinear: economic activity may remain stable until saturated thickness or well capacity crosses a threshold, after which irrigation and associated industries contract quickly.

2.3 Research gap and hypotheses

The existing literature establishes that the Ogallala supports agricultural value and that governance influences depletion, but there is limited annual county-level evidence linking observed groundwater conditions to realized measures of the broader rural economy over a long period. Combined, the two literatures reviewed above point to a two-part gap. The first is empirical: realized, rather than simulated, economic outcomes have rarely been tracked at the county level over a long panel. The second is conceptual: production-function reasoning predicts a negative relationship between groundwater depth and economic activity, but the social-ecological literature implies that whether, how quickly, and where that relationship becomes visible depends on institutions, adaptation, and local economic structure. This paper addresses both gaps with a harmonized 25-year panel, and it treats a null or delayed reduced-form relationship as consistent with the systems view rather than as a failure to find the effect the production view predicts. Recent methodological guidance for applied and agricultural economists' stresses that two-way fixed effects control for time-invariant and common shocks but do not by themselves constitute an identification strategy, and that observational estimates should be labeled and interpreted according to the assumptions they actually satisfy rather than the assumptions a causal design would require (Henningsen et al., 2026). The present analysis follows that guidance: it is presented throughout as a reduced-form association, and Section 9 outlines the exogenous sources of variation-geological differences in well depth, energy-price shocks to pumping costs, and jurisdictional boundaries in groundwater-management rules-that a future design would need to isolate the causal effect that H1 and H2 describe.

H1: Within a county, greater depth to groundwater is associated with lower covered employment and fewer business establishments.

H2: Greater depth to groundwater is associated with lower total wages and farm income.

H3: Population and per-capita income effects are weaker or slower because migration, sectoral diversification, and adaptation can offset contemporaneous agricultural losses.

3. Conceptual Framework

Let county production depend on capital, labor, land, groundwater services, climate, and technology. For an irrigated producer, groundwater services depend on the physical stock and the cost of lifting water. A deeper water table raises pumping costs and may reduce attainable well capacity. The direct effect is a reduction in the profitability of water-intensive production. Farms respond along both intensive and extensive margins by changing water application, technology, crops, or irrigated acreage.

County-level effects operate through local multipliers. Reduced agricultural revenue lowers demand for inputs and services and may reduce labor demand. However, the observed aggregate response depends on the share of local activity connected to irrigated agriculture and on compensating growth in other sectors. Consequently, the coefficient on groundwater depth in a county-level employment equation is a net reduced-form association: it combines direct agricultural losses, indirect spillovers, adaptation, and sectoral reallocation.

The empirical model therefore does not assume a one-to-one translation from a foot of groundwater decline to a fixed economic loss. It tests whether changes in groundwater accessibility covary with changes in economic outcomes after removing permanent county characteristics, common annual shocks, and contemporaneous climate conditions.

4. Data

4.1 Study area and panel construction

The balanced study frame contains 49 counties in the Texas Panhandle and South Plains for each year from 2000 through 2024, yielding 1,225 county-year records. Economic, population, income, and climate variables are complete for the study frame. Publishable Ogallala-related groundwater measurements are available for 44 counties, producing 1,042 observations in the main estimation sample. The five counties without usable groundwater records remain in the master panel but do not identify the groundwater coefficients.

4.2 Groundwater

Groundwater measurements come from the Texas Water Development Board Groundwater Database. The extraction retains records designated publishable and associated with the Ogallala aquifer. Multiple measurements for the same well and year collapsed to annual well values; county-year medians are then calculated to limit the influence of outliers and irregular measurement frequency. Depth to water, measured in feet below land surface, is the main exposure: a larger value indicates that groundwater is less accessible. The data also includes annual matched-well depletion, calculated only from wells observed in consecutive years, and cumulative change relative to 2000 among baseline-matched wells. This matched-well construction reduces spurious changes caused by shifts in the set of measured wells.

4.3 Economic and demographic outcomes

Employment, establishments, total annual wages, average annual pay, and average weekly wages come from the U.S. Bureau of Labor Statistics Quarterly Census of Employment and Wages. The series uses annual county high-level records for total covered ownership and all industries. The source provides complete coverage for all 1,225 county-years in the study frame. Population, personal income, per-capita personal income, earnings by place of work, wages and salaries, farm income, and farm proprietors' income come from the Bureau of Economic Analysis County income accounts. Farm income can be negative, so it is transformed with the inverse hyperbolic sine rather than the natural logarithm.

4.4 Climate controls

Annual precipitation and average temperature come from NOAA's Climate at a Glance County time-series product. These variables control contemporaneous weather that may independently affect agricultural production, labor demand, and groundwater pumping. They do not fully capture drought intensity, soil moisture, extreme heat, or lagged climate conditions; those omissions remain priorities for extension. Descriptive statistics for the main study variables are reported in Table 1.

Table 1
Descriptive statistics

Variable	N	Mean	Std. dev.	Minimum	Maximum
Depth to groundwater (ft)	1,042	178.81	97.96	14.84	487.00
Annual matched-well depletion (ft)	960	0.70	1.72	-10.56	10.72
Covered employment	1,225	10,899.53	24,719.39	123.00	151,811.00
Establishments	1,225	718.84	1,382.93	34.00	8,341.00
Annual wages (\$)	1,225	494,215,666.01	1,254,560,556.17	3,323,952.00	11,497,127,714.00
Average annual pay (\$)	1,225	39,388.92	13,580.86	18,757.00	98,977.00
Population	1,225	25,142.91	51,635.50	557.00	327,394.00
Per-capita personal income (\$)	1,225	44,026.95	21,703.11	14,960.00	180,072.00
Farm income (\$000)	1,225	49,703.02	75,181.00	-24,491.00	618,208.00
Annual precipitation (in)	1,225	18.63	6.07	3.65	39.88
Average temperature (F)	1,225	60.75	2.69	54.80	67.90

Notes: Statistics are unweighted across county-years. Monetary variables are nominal; year fixed effects absorb common annual price changes in the regressions. Groundwater measures have fewer observations because five counties lack usable publishable Ogallala records and some county-years lack repeat well measurements.

5. Empirical Strategy

The baseline specification is:

$$\ln(Y_{ct}) = \beta \text{Depth}_{ct} + \gamma_1 \text{Precipitation}_{ct} + \gamma_2 \text{Temperature}_{ct} + \alpha_c + \lambda_t + \epsilon_{ct}$$

where Y_{ct} is an economic outcome in county c and year t ; Depth_{ct} is median depth to groundwater divided by 10, so β represents the log-point change associated with a 10-foot increase in depth;

α_c denotes county fixed effects; and λ_t denotes year fixed effects. Standard errors are clustered by county to allow arbitrary serial correlation and heteroskedasticity within counties. In plain terms, the model asks whether a given county's economic outcomes changed from year to year in step with that same county's own groundwater depth, after subtracting out whatever is constant about the county over time and whatever is common to all counties in a given year-so the estimate reflects within-county change over time, not a comparison across different counties.

The fixed-effects design removes time-invariant differences such as geography, average soil quality, historical settlement, and persistent industrial composition. Year effects remove common shocks to the region, including macroeconomic cycles, commodity-price movements shared across counties, and common inflation. Precipitation and temperature account for observable annual climate variation.

Identification comes from within-county deviations in groundwater depth over time. The coefficient should not be interpreted as fully causal. Pumping responds to agricultural demand and drought, well measurements are not collected randomly, and unobserved county-specific changes may affect both groundwater and outcomes. The analysis therefore reports conditional associations and uses annual matched-well depletion and its one-year lag as robustness measures.

6. Results

6.1 Descriptive patterns

Across observed county-years, median depth to groundwater averages 178.8 feet and ranges from 14.8 to 487 feet. Mean annual matched-well depletion is 0.70 feet, although annual changes are volatile and include periods of partial recovery. The typical county in this heterogeneous sample is small: median employment is 2,545 and median population is 7,129, while a few larger counties create substantial dispersion. This heterogeneity motivates logarithmic transformations and county fixed effects. Figure 1 displays the annual county means of groundwater depth and covered employment over the study period.

6.2 Baseline fixed-effects estimates

Table 2
Groundwater depth and county economic outcomes

Outcome	Coefficient	Clustered SE	Approx. %	N	R-squared	95% CI (%)
Employment	-0.0062	(0.0075)	-0.62	1,042	0.991	-2.09 to 0.85
Establishments	-0.0051	(0.0032)	-0.51	1,042	0.992	-1.14 to 0.12
Total wages	-0.0066	(0.0080)	-0.66	1,042	0.987	-2.23 to 0.91
Average annual pay	-0.0004	(0.0015)	-0.04	1,042	0.949	-0.33 to 0.25
Population	0.0019	(0.0016)	0.19	1,042	0.997	-0.12 to 0.50
Per-capita personal income	0.0020	(0.0051)	0.20	1,042	0.900	-0.80 to 1.20
Farm income (IHS)	0.1290	(0.1060)	13.77	1,042	0.456	-0.079 to 0.337 (IHS units)

Notes: Each row is a separate OLS regression. The exposure is depth to groundwater divided by 10. All models include county and year fixed effects plus annual precipitation and average temperature. Standard errors are clustered by county. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

The estimated employment coefficient is -0.0062 (95% CI: -2.09 to + 0.85 percent), so a 10-foot increase in groundwater depth is associated with an employment change that could plausibly range from a 2.1 percent decline to a 0.9 percent increase; the estimate is not statistically significant ($p = 0.412$). The establishment coefficient is -0.0051 (95% CI: -1.14 to + 0.12 percent), also statistically insignificant ($p = 0.111$), though closer to conventional thresholds and with a confidence interval that admits only a narrow range of positive effects.

The estimated associations for total wages and average annual pay are small and statistically insignificant. Population and per-capita personal income have slightly positive point estimates, but neither differs statistically from zero. Farm income is highly volatile and its inverse-hyperbolic-sine coefficient is positive but imprecisely estimated. Taken together, the estimates provide no robust evidence that gradual increases in groundwater depth produced contemporaneous, uniform declines in aggregate county outcomes during 2000–2024. Formally, the data do not support H1 or H2 as stated. The pattern is compatible with H3, but not a direct confirmation of it: population and per-capita income are themselves statistically flat rather than showing the delayed decline H3 anticipated, so the evidence is consistent with either genuine resilience or with effects too small or too slow for this design to detect.

The absence of conventional statistical significance is not evidence that groundwater depletion has no economic cost. Given the estimated standard errors, the design has 80 percent power (two-sided, 5 percent test) to detect employment declines of roughly 2.1 percent and establishment declines of roughly 0.9 percent per 10-foot increase in depth; true effects smaller than these thresholds could exist and

remain statistically invisible in a panel of this size. These thresholds follow the standard minimum-detectable-effect formula, $(z_{0.975} + z_{0.80})$ times the clustered standard error—approximately 2.8 times the reported SE for each outcome—applied to the employment and establishment coefficients in Table 2. Moreover, broad county aggregates combine water-dependent and water-independent industries. Losses to irrigated production may be offset by oil and gas activity, health care, government, education, services, farm consolidation, or temporary commodity-price gains. Figure 2 summarizes the baseline point estimates and their 95 percent confidence intervals.

6.3 Robustness using annual depletion

Table 3 reports the robustness estimates using current and one year lagged matched well annual depletion.

Table 3
Robustness: matched-well annual depletion

Outcome	Exposure	Coefficient	Clustered SE	N
Employment	Current depletion	0.0156	(0.0421)	960
Establishments	Current depletion	0.0430	(0.0275)	960
Total wages	Current depletion	0.0195	(0.0569)	960
Average annual pay	Current depletion	0.0036	(0.0178)	960
Employment	Lagged depletion	0.0409	(0.0364)	920
Establishments	Lagged depletion	0.0415*	(0.0225)	920
Total wages	Lagged depletion	0.0567	(0.0464)	920
Average annual pay	Lagged depletion	0.0157	(0.0147)	920

Notes: The depletion measures are divided by 10. Specifications include county and year fixed effects, precipitation, and average temperature; standard errors are clustered by county. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Current annual depletion and its one-year lag do not produce the expected consistently negative pattern. The lagged establishment coefficient is positive and marginally significant at the 10 percent level. This isolated result should not be interpreted as a beneficial effect of depletion. Annual matched-well changes are noisy, short-run pumping may rise during profitable agricultural years, and increased production can simultaneously draw down groundwater and support local businesses. This simultaneity illustrates why the present estimates are associational and why an external source of variation is necessary for causal identification.

6.4 Robustness: nonlinear, heterogeneous, and delayed specifications

The employment and establishment series used in Sections 6.2 and 6.3 were independently reconstructed from the U.S. Bureau of Labor Statistics QCEW county high-level annual files for all 49 study counties and all 25 years (2000–2024), then merged to the groundwater panel by county and year. The reconstructed sample matches the original estimation sample exactly (N = 1,042) and reproduces the baseline coefficients in Table 2 to within rounding even without precipitation and temperature controls (employment: -0.0061 versus -0.0062; establishments: -0.0050 versus -0.0051), indicating that the null result in Table 2 is not an artifact of the climate controls. This reconstruction is used here to test the nonlinear, heterogeneous, and delayed specifications called for in Sections 2.3 and 9 but not previously estimated.

Table 4 represents the nonlinear, heterogenous, and delayed specification checks based on the independently reconstructed QCEW panel.

Table 4
Extended specification checks (independently reconstructed QCEW panel)

Outcome	Specification	Coefficient	Clustered SE	N
Employment	Baseline (Table 2 replication)	-0.0061	(0.0075)	1,042
Establishments	Baseline (Table 2 replication)	-0.0050	(0.0032)	1,042
Employment	Nonlinear: depth/10	0.0120	(0.0097)	1,042
Employment	Nonlinear: (depth/10) ²	-0.0004	(0.0003)	1,042
Employment	Heterogeneity: depth/10 (small counties)	-0.0146	(0.0126)	1,042
Employment	Heterogeneity: depth/10 × large county	0.0158	(0.0130)	1,042
Employment	Delayed: depth/10, lagged one year	-0.0051	(0.0071)	969

Notes: Depth is divided by 10. All specifications include county and year fixed effects; standard errors are clustered by county. These specifications do not include precipitation and temperature controls, which have not yet been independently reconstructed (see Section 9). Nonlinear specification adds a quadratic term in depth/10 to the baseline. Heterogeneity specification interacts depth/10 with an indicator for counties above the median of mean employment across observed years; the large-county coefficient equals the sum of the two reported rows. Delayed specification regresses the outcome on depth/10 lagged one year, restricted to true consecutive-calendar-year county-pairs (N = 969) so that gaps in well measurement are not mistaken for a one-year lag. *** p < 0.01, ** p < 0.05, * p < 0.10.

None of the extended specifications overturns the baseline null result. The quadratic term is small and statistically indistinguishable from zero, providing no evidence of a threshold at which depletion begins to affect employment more sharply within the observed range of depth (14.8 to 487 feet). The interaction between depth and county size is also insignificant, so this analysis does not find that smaller counties bear disproportionately larger employment losses, though the median-employment split used here is a coarse proxy for agricultural dependence and a sharper test would use the irrigated-acreage and crop-

value measures described in Section 9. The one-year lag shows no delayed effect beyond what the contemporaneous estimate already captures. Taken together, these checks strengthen rather than resolve the paper's central claim: the absence of an effect at conventional levels of statistical and specification flexibility is itself informative, but it remains consistent with effects that are smaller, slower, or more geographically concentrated than this design can detect.

As a final check, precipitation and temperature were independently reconstructed for four counties (Hale, Hutchinson, Lamb, and Lubbock; $N = 94$) from NOAA county climate records, allowing the employment specification to be estimated with and without the climate controls used in Table 2. The depth coefficient moves from -0.0086 to -0.0069 for employment and from -0.0033 to -0.0023 for establishments once precipitation and temperature are added, similar in sign and order of magnitude to the county-wide estimates in Table 2 and Section 6.4. This is reported only as a directional check: with four counties, cluster-robust inference is not reliable, and no p-values or significance claims are drawn from it. It does not extend to the other 40 study counties, for which climate reconstruction was not completed.

6.5 A disaggregated case study: irrigated cotton acreage in three major cotton counties

Sections 6.1–6.4 measure agricultural response only through county-wide farm income and total covered employment, which Section 9 already identifies as too coarse to isolate effects concentrated in irrigated agriculture. As a targeted complement, this section links groundwater depth to irrigated cotton acreage, irrigation water applied per acre, and cotton yield for Hale, Lamb, and Lubbock counties—the three largest irrigated-cotton counties in the study region and the counties on which the cotton-specific literature cited in Section 2.1 focuses (McCullough, 2016). Irrigated cotton acreage and irrigation water use come from the Texas Water Development Board irrigation survey. Cotton yield, planted acreage, and production come from USDA NASS county-level cotton estimates, which are available for 2018–2023 within this window. Groundwater depth is the same TWDB series used throughout the paper. Because the case study covers three counties, it supports descriptive, within-county correlations rather than a clustered panel regression, and the correlations below are reported as such rather than as hypothesis tests.

Table 5 summarizes groundwater depth, irrigated cotton acreage, and within county correlations for Hale, Lamb, and Lubbock counties.

Table 5
Groundwater depth and irrigated cotton acreage, three major cotton counties (2003–2024)

County	Depth range (ft)	Irrigated cotton acres range	Within-county r (depth, acres)	Years
Hale	221–262	59,400 – 241,377	-0.689	2003–2024
Lamb	142–201	33,940 – 154,165	-0.307	2003–2024
Lubbock	118–163	72,030–169,312	-0.267	2003–2024

Notes: r is the Pearson correlation between groundwater depth and irrigated cotton acreage within each county over 2003–2024 (22 annual observations per county). The pooled within-county correlation (county-demeaned depth against county-demeaned irrigated acreage, N = 66) is -0.486. The corresponding pooled within-county correlations are -0.347 for irrigation water applied per acre and -0.220 for cotton yield (N = 18, 2018–2023 only, the years with published NASS yield data).

In these three counties, deeper groundwater is associated with markedly less irrigated cotton acreage: the within-county correlation ranges from -0.27 in Lubbock to -0.69 in Hale, the county with the deepest water table and the widest range of observed depth. This is consistent with the extensive-margin adjustment described conceptually in Section 3-farms reducing irrigated acreage as pumping costs rise-and it is the first outcome in this paper for which the association with depth is both large and directionally consistent across counties. The weaker and noisier association with water applied per acre and with yield is consistent with producers protecting yield on a shrinking irrigated base rather than uniformly reducing water intensity, though the short yield series (six years) limits what can be concluded. This case study cannot be generalized to the other 41 study counties without the same crop- and irrigation-level data, and with three counties it cannot support formal significance testing or fixed-effects estimation; it is offered as evidence that the null county-wide results in Table 2 are compatible with a real and substantial extensive-margin response concentrated in irrigated agriculture, which is exactly the kind of effect that Section 6.4 shows the county-wide employment and establishment measures are not well powered to detect.

7. Discussion

The results refine, rather than contradict, earlier work. Simulation and input-output studies show that groundwater-dependent agriculture supports substantial output and employment and that a transition toward dryland production can generate losses (Terrell, 1998; McCullough, 2016). The present study asks whether those mechanisms are already visible as a stable average relationship in annual county aggregates. The answer is not yet definitive. Point estimates for employment and establishments are negative, but statistical uncertainty is substantial.

Several mechanisms can produce this pattern. First, technological change and improved irrigation management can maintain output with less applied water, delaying measurable labor-market decline. Second, producers may change crops or consolidate operations, preserving aggregate revenue while redistributing gains and losses. Third, nonfarm sectors may offset agricultural contraction. Fourth, economic effects may occur only after hydrological thresholds are crossed. Finally, county averages may hide concentrated harm among small towns, hired farmworkers, domestic-well users, or producers with shallow saturated thickness. Section 6.5 provides direct evidence for this last mechanism: within Hale, Lamb, and Lubbock counties, deeper groundwater is associated with substantially less irrigated cotton acreage (r as strong as -0.69), an association the county-wide employment and establishment measures in Table 2 do not detect. Cotton is one sector within a county economy that also includes oil and gas, health care, education, and government, so a real and sizable sectoral adjustment can coexist with, and be fully absorbed by, a null result at the county-wide level. This is consistent with, rather than contrary to, the paper's central claim: the null in Table 2 describes the county-wide aggregate, not the absence of adjustment within agriculture.

The findings align with the groundwater-connected-systems perspective of Huggins et al. (2023): hydrological change interacts with institutions, markets, ecological conditions, and community structure. They also support the governance literature's concern with path dependence. When regional employment does not fall immediately, policymakers and users may perceive depletion as a distant problem, weakening incentives for conservation. Short-run resilience can therefore contribute to long-run vulnerability.

The cultural evidence from Cavazos (2026), Walsh (2022), and Sanderson et al. (2025) adds a further interpretation. Communities do not respond to groundwater scarcity only through prices. Ideas about property, autonomy, progress, and agricultural identity influence acceptable policies and adaptation strategies. Economic diversification and conservation policies will be more durable when they acknowledge those values and distribute costs transparently.

8. Policy Implications

First, policy evaluation should track community outcomes as well as acre-feet saved. Groundwater districts and state agencies should monitor agricultural employment, establishments, population, domestic-well vulnerability, and local fiscal capacity alongside saturated thickness and pumping.

Second, conservation incentives should be designed around aquifer-level water savings. Subsidies for efficient irrigation can improve farm-level water productivity, but without enforceable pumping limits or collective targets they may not reduce total withdrawals. Metering, locally credible allocations, multi-year conservation contracts, and payments for verified reductions can strengthen the connection between efficiency and conservation.

Third, rural adjustment policy should begin before aggregate decline becomes obvious. Investments in workforce skills, value-added processing, broadband, health care, and nonfarm entrepreneurship can

reduce dependence on water-intensive production. Transition assistance should recognize that smaller producers and communities may have less capacity to finance technology or absorb income volatility.

Fourth, governance must be place-sensitive and participatory. Uniform rules may encounter resistance where groundwater is strongly associated with landownership and autonomy. Local institutions should make depletion trends visible, communicate distributional consequences, and include producers, municipalities, domestic-well users, and community organizations in target setting.

9. Limitations and Research Agenda

The study has six principal limitations, two of which have since been partially addressed by the additional analysis in Sections 6.4 and 6.5. First, the observational fixed-effects design does not isolate exogenous groundwater variation. Drought, crop profitability, energy prices, and pumping decisions can jointly determine groundwater levels and economic activity. Second, monitoring wells are not a random sample, although county medians and matched-well measures reduce compositional error. Third, the groundwater sample omits five study counties and contains gaps; the employment and establishment series used to measure economic outcomes, by contrast, have since been independently reconstructed from BLS QCEW county high-level files for the full 2000–2024 period and match the original estimation sample exactly (Section 6.4), so the remaining gap is specific to the groundwater measurements themselves and to the precipitation, temperature, population, income, and farm-income series that have not yet been independently rebuilt.

Fourth, county aggregates may be too coarse to detect distributional effects or impacts concentrated in agriculture; Section 6.5's three-county cotton case study is a first, partial answer, since it finds a substantial within-county association that the county-wide measures do not, though extending it to the remaining 41 counties would require the same crop- and irrigation-level data merged county-by-county. Future work should merge annual crop acreage, yields, irrigated acreage, farm employment, land values, and crop insurance indemnities. Fifth, annual average temperature and precipitation do not capture extreme heat, soil moisture, drought duration, or lagged recharge. Sixth, effects may be nonlinear and spatially connected; declining activity in one county can affect neighboring counties through commuting, processing, and input markets.

A stronger causal design could exploit changes in pumping costs generated by energy-price shocks interacted with pre-existing lift depth, hydrogeological boundaries, well-capacity thresholds, or differential exposure to groundwater-management rules. None of the data assembled for this paper currently supports such a design: precipitation and temperature are themselves controls because they plausibly affect the outcomes directly, not only through pumping, so they cannot double as instruments, and the cotton-specific measures in Section 6.5 are themselves outcomes of depth rather than sources of independent variation in it. A valid instrument would require county- or well-level geological data (for example, saturated thickness or well-completion depth from the TWDB well-construction records) or a state-year energy-price series interacted with each county's baseline exposure to groundwater pumping, neither of which has yet been obtained. Event-study and spatial-panel approaches could test adjustment

dynamics and spillovers. Distributional analysis should examine whether smaller counties, agriculture-dependent counties, and places with limited alternative employment experience larger losses.

10. Conclusion

The Ogallala Aquifer remains foundational to agricultural production and rural life in West Texas. This study builds a 2000-2024 county panel linking observed groundwater conditions to administrative labor-market data, county income accounts, population, and climate. A deeper water table is associated with modestly lower employment and fewer establishments, but neither estimate is statistically precise, and the same holds for wages, population, income, and farm income.

This is not evidence that depletion is harmless. The study's own precision limits mean it could not reliably detect employment losses below roughly 2 percent per 10 feet of decline, and county aggregates can mask adaptation, consolidation, and losses concentrated in particular places or industries. An independently reconstructed employment series confirms the null county-wide result rather than overturning it, but a case study of three major cotton counties finds a substantial decline in irrigated cotton acreage as groundwater deepens—real evidence of exactly the kind of sector-specific adjustment that a county-wide aggregate is built to absorb. The more useful question this reframing raises is not whether groundwater matters, but when, where, and for whom its decline becomes economically binding.

Rural resilience should not be judged solely by the absence of a current aggregate decline. Policies that extend the aquifer's usable life, support equitable adaptation, and diversify local economies can reduce the risk that seemingly manageable annual changes accumulate into abrupt, irreversible community losses.

Declarations

Author Contribution

P.E is the sole author for this manuscript.

Founding Declaration

The author received no funding for this research

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Figures

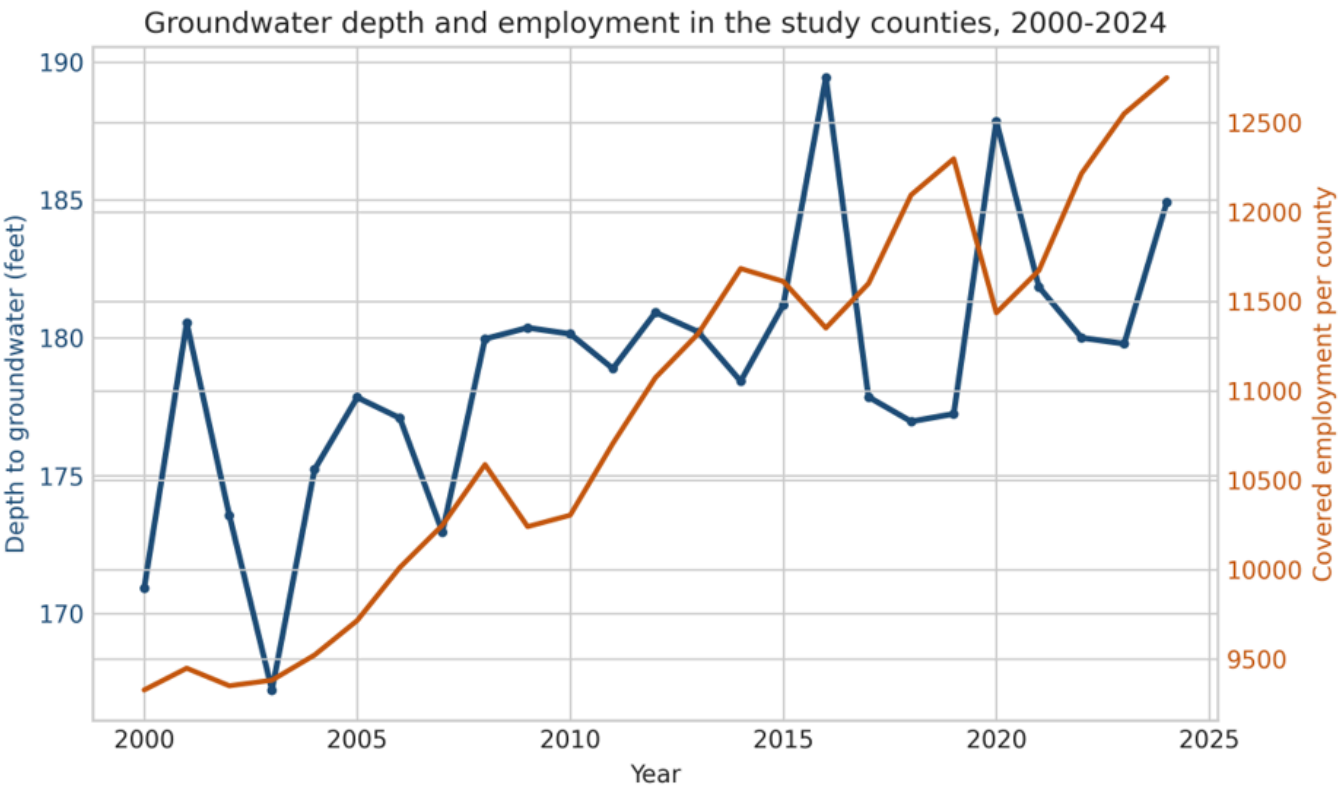


Figure 1

Unweighted annual county means. Groundwater averages use counties with available measurements; employment comes from QCEW.

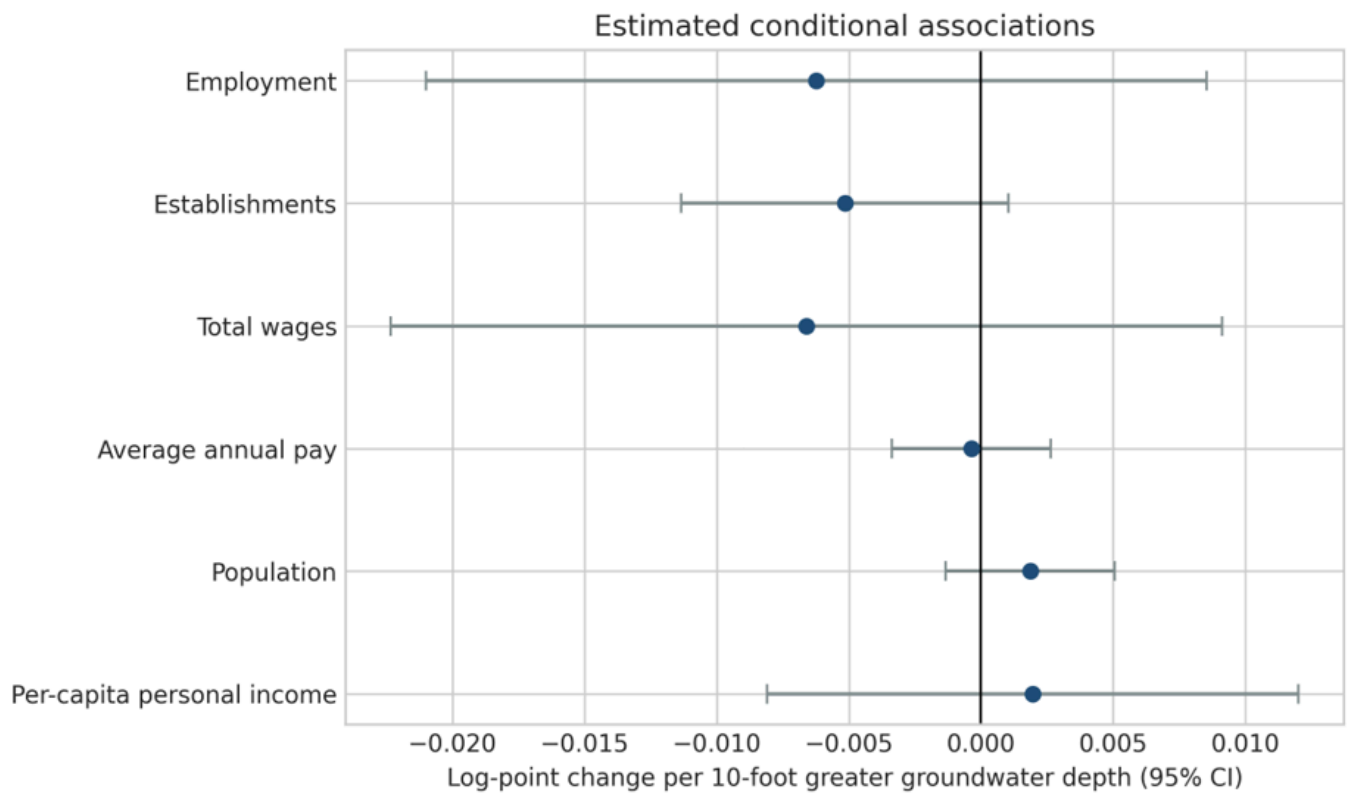


Figure 2

Point estimates and 95 percent confidence intervals from Table 2. Farm income is omitted because its inverse-hyperbolic-sine scale is not directly comparable with logged outcomes.