PRODUCED-WATER MANAGEMENT IN THE PERMIAN BASIN: HISTORICAL PRODUCTION, FORECAST, WATER QUALITY, AND SCREENING-LEVEL CONSTITUENT VALORIZATION FOR BENEFICIAL REUSE IN WEST TEXAS

Ayann Tiam
Bob L. Herd Department of Petroleum Engineering, Texas Tech University

ABSTRACT

Produced-water management in the Permian Basin is increasingly shaped by three linked pressures: growing unconventional-water volumes, tightening saltwater-disposal constraints, and severe regional water scarcity in West Texas. The herein-used approach shows that these issues cannot be discussed separately. Historical and forecasted PW availability determines how much water exists, spatial chemistry determines how difficult that water is to treat, and reuse planning determines whether that water can arguably relieve local shortages.

Keywords: produced water; Permian Basin; water forecast; beneficial reuse; water quality mapping; lithium; boron; saltwater disposal; West Texas; treatment siting

1. INTRODUCTION

The Permian Basin has become the dominant produced-water (PW) province in the United States, and unconventional development continues to increase both the magnitude and the spatial complexity of PW management (Scanlon et al. 2017; Jiang et al. 2022; Pawar et al. 2022; Reible et al. 2024; Enverus 2026). The research materials provided for this study consistently frame the basin as a setting where water volume, water quality, and water-routing constraints must be evaluated collectively rather than as isolated issues. West Texas faces persistent water shortage, with irrigation accounting for most of the deficit and groundwater supply projected to decline materially through 2070. And saltwater disposal (SWD) remains a common practice, but it is increasingly constrained by localized pressure build-up, induced seismicity, handling cost, and the practical uncertainty of usable injection capacity (Ge et al. 2022; Hennings and Young 2023).In fact, the Permian has contributed to a large part of the recent US seismic activity (Figure 1). PW is simultaneously a liability, a logistics burden, a potential reuse resource, and a possible source of dissolved-value offsets such as lithium or boron (Bechara et al. 2024). In parallel, recycling for hydraulic fracturing (HF) is growing (PW attributes to 70% of HF water use), but even strong recycling still leaves large residual volumes requiring management (B3 Insight 2024; Enverus 2026; FracFocus 2026).

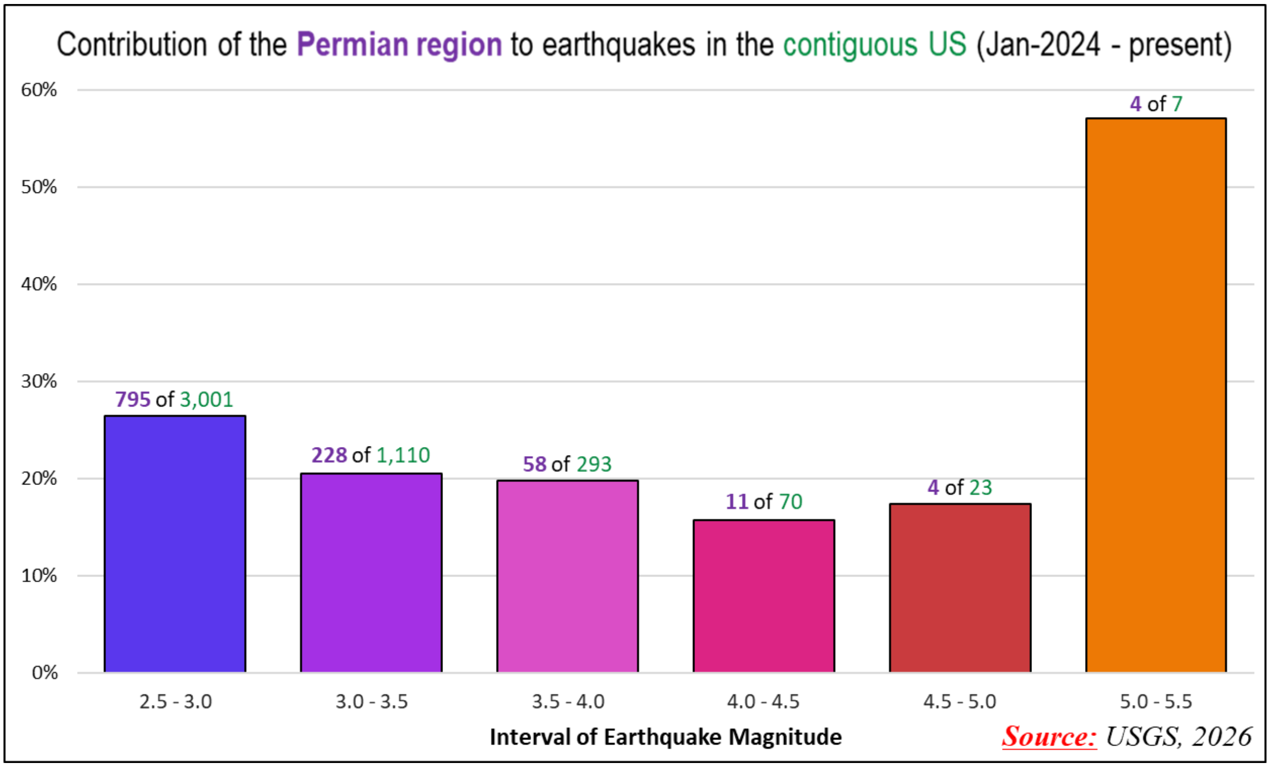


Figure 1. Contribution of the Permian region to earthquakes in the contiguous US (Jan-2024 to present). Source: U.S. Geological Survey (U.S. Geological Survey 2025).

Our study aims to help alleviate PW-management issues by addressing three questions: (1) how much PW is generated historically and forecasted in the Permian Basin?; (2) what net PW may remain available for management after HF use?; and (3) how spatial water-quality heterogeneity changes the plausibility of treatment, reuse, and constituent recovery?

To support the interpretation of our results, a surrogate-assisted valorization is used as a secondary evidence layer (Tiam et al. 2026). It contributes two kinds of support that are directly relevant here: first, public pilot-treatment benchmarks showing that high-salinity Permian waters can be converted to low-salinity product streams; and second, a screening-level interpretation of how lithium, boron, and related dissolved constituents may offset part of the burden of reuse-oriented treatment. In this manuscript however, constituent valorization is treated as a supporting argument rather than the main methodological spine.

2. MATERIALS AND METHODS

2.1. Study Area and management framing

The study area spans the unconventional Permian Basin in West Texas and Southeast New Mexico. We focus herein on the Delaware Basin in New Mexico, the Delaware Basin in Texas, and the Midland Basin (see Figure 2), given the joint lens of unconventional-formation PW growth, SWD concentration in Texas, and arid-region water scarcity. The management context is not solely volumetric, as many regional issues persist: rising seismic concerns, the importance of reliable total-basin water accounting, and the mismatch between water-producing counties and major irrigation-demand areas.

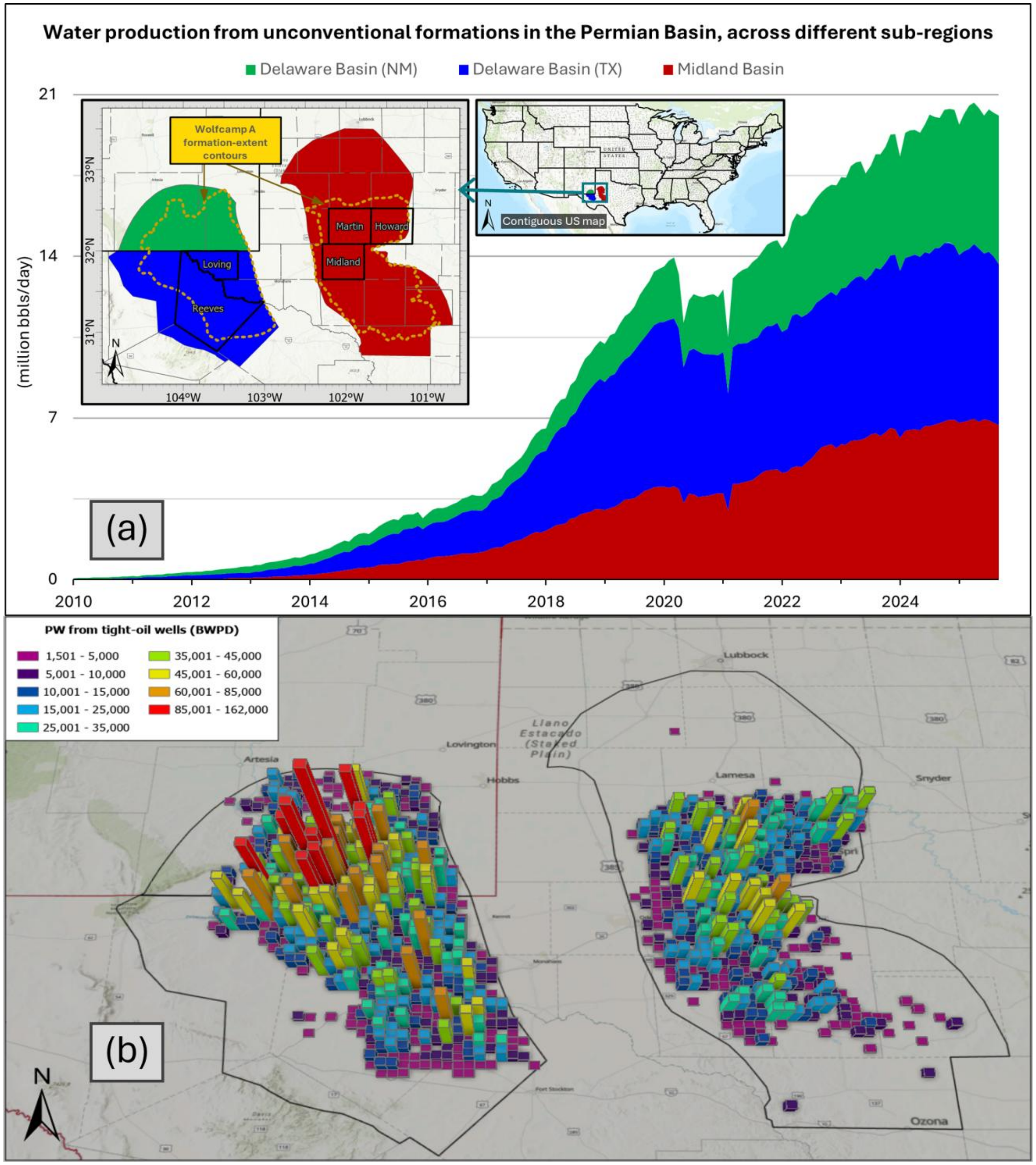


Figure 2. (a) Historical water production from unconventional formations in the Permian Basin through 2025, shown for Delaware New Mexico, Delaware Texas, and Midland Texas. Beyond documenting strong growth, the figure establishes the basic management signal used throughout the paper: produced-water throughput is concentrated in a few subregions, grows over time, and remains large enough that disposal-only planning becomes inadequate. (b) Geospatial distribution of Produced Water (PW) from tight-oil wells in the Permian Basin throughout 2024, as deduced from Enverus (Enverus 2026). Unlike water from conventional wells, this PW requires management due to issues associated with saltwater disposal.

For reuse planning, this study treats HF reuse as the first internal demand sink. Net PW is defined as the remaining water available for other management pathways after accounting for reuse oilfield applications, mainly HF. This distinction is critical because it separates gross PW growth from water that is realistically available for broader reuse, discharge, or treatment-oriented deployment.

2.2. Production dataset and forecast methodology

The accuracy of the production dataset used for our forecast (Enverus 2026) has been validated in previous research and sources (Bechara et al. 2024; Railroad Commission of Texas 2026; Tiam et al. 2026; Oil Conservation Division 2026). Historical production was divided into eight periods for each tight-oil-producing county, and each period was decline-forecasted separately. Future drilling intensity and well lateral length for each county-layer combination were based on 2020–2025 activity, while type curves for future wells in each county-layer pair were derived from gas, oil, and water production of wells drilled between 2019 and 2023. The methodology also assumes an average drilling time of 18 days per well in the Midland Basin and 22 days per well in the Delaware Basin, and county rig counts were estimated from recent drilling activity during 2021–2025.

The study makes the allocation logic more explicit by working at the level of producing layers in a county. Future drilling activity in a county's layer is determined from past drilling intensity until local space is exhausted; once historically active layers fill up, drilling is shifted toward still-unfilled layers according to historical activity. The total production from a county's layer at a certain forecasted time is the sum of the production from existing and future wells, and a county's production is the sum of said county's layers production.

The productive footprint of each layer is bounded using Enverus-derived proven-economic-extent (PE) and geologic viability (GV) contours (Enverus 2026): see Figure 3. The forecast defines the low case as the PE-constrained footprint, the high case as the GV-based upper envelope, and the base case as a midpoint between the two. These area assumptions are paired with minimum, average, and maximum 2021–2025 county rig-count assumptions and with P10, P50, and P90 developed-area wellbore-density assumptions to define low-, base-, and high-case forecasts. Well spacing is therefore not imposed as a single basin-wide constant but is rather inferred from the observed distribution of well density in already developed areas: refer to the example in Figure 4 for a step-by-step guideline to determine well-density distribution. The distribution is put together by collecting well densities in different (1-mi x 2-mi) subdivisions of layers within a county. The well density (mi/sqmi) of county layer's subdivision is the sum of the total lateral length (miles or mi) from different wells coinciding with the subdivision, divided by the layer's surface area (square miles or sqmi). Additionally, Table 1 summarizes the assumptions for the forecast's three cases.

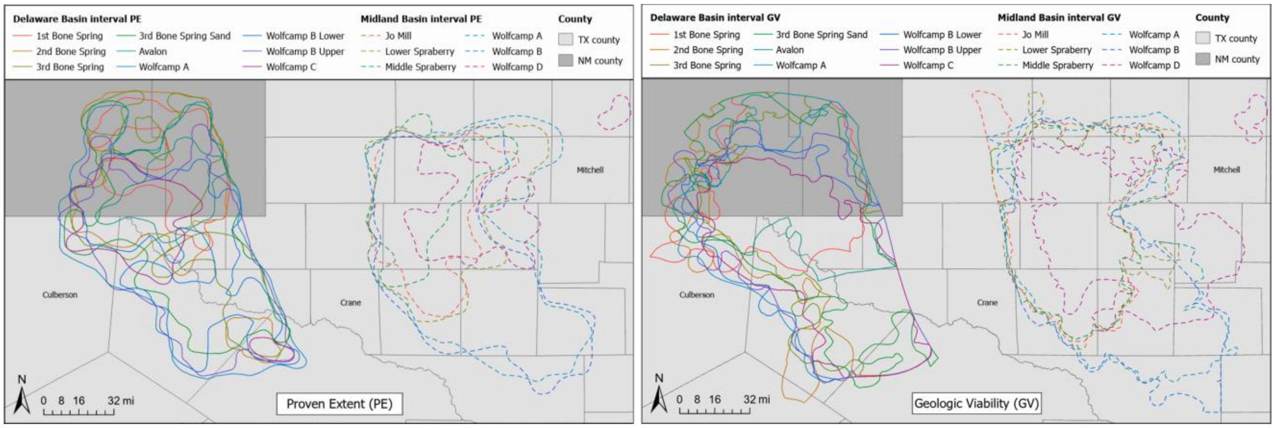


Figure 3. Enverus-derived proven-economic-extent (PE) and geologic-viability (GV) contours.

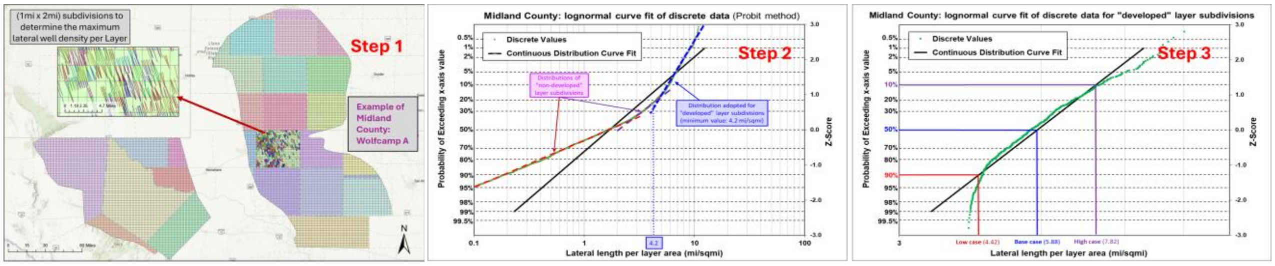


Figure 4. Guideline to determine distribution of well density in a county for the forecast's low, base and high cases. Step 1: determination of the well density of each layer subdivision within a county; Step 2: multimodal distribution of the well density per layer subdivision, in a county; Step 3: choosing the "developed" distribution, to ascertain well density for the forecast's low, base and high cases. The Probit method is used for plotting distribution by Monograph 3 of the Society of Petroleum Evaluation Engineers (Hall et al. 2010).

Table 1. Forecast scenario assumptions.

Case	Rig count	Productive area	Wellbore density
Low	Minimum 2021-2025	Proven extent (PE)	P10 of developed areas
Base	Average 2021-2025	Intermediate / midpoint area	P50 of developed areas
High	Maximum 2021-2025	Geologic viability (GV)	P90 of developed areas

2.3. Recycling assumptions and net produced water

There is yet to exist public data accurate enough to geospatially map PW recycling in HF, but the public data is still sufficient to derive regional hydraulic-fracturing reuse assumptions. As of early 2024, operators have begun reporting ~50% of the water source used in the Permian's HF operations, differentiating between PW ad freshwater (FracFocus 2026, Bechara 2026). FracFocus-based screening and Texas-Produced-Water-

Consortium (TxPWC) survey information are used to establish regional reuse fractions rather than detailed pixel-by-pixel recycling maps (Smith et al. 2022, 2024; FracFocus 2026). The TxPWC reports 54% recycling for the entire Permian Basin in a 2022 survey and 62% recycling in the Midland Basin versus 66% in the Delaware Basin (Texas) in a 2024 survey: recycling percentages that align with FracFocus and estimates from B3 Insight (B3 Insight 2024).

The study therefore distinguishes three related quantities: gross PW volume, consumed PW in hydraulic fracturing, and net PW available for broader management. Freshwater availability is assessed to determine whether fracturing demand can be met throughout the forecast, and the remaining produced water is treated as the management-relevant residual.

2.4. Water-quality atlas and spatial assessment

This paper deliberately locks the mapped-results dataset: 61,069 water samples from 5,530 unconventional wells gathered from operators, service companies, and the U.S. Geological Survey, then mapped geospatially and stratigraphically on a 3 mi × 3 mi grid . The mapped properties in this paper are sample density, total dissolved solids (TDS), lithium, boron: properties needed to interpret treatment suitability.

2.5. Supporting treatment and valorization interpretation

A surrogate-assisted valorization is used to support two interpretive steps that are directly relevant to the PW-management results (Tiam et al. 2026). First, it provides a chemistry-informed rationale for why lower-TDS, lower-hardness Delaware waters are more reuse-favorable than harsher Midland waters. Second, it provides public treatment-pilot anchors and screening-level constituent-valorization language that help translate mapped chemistry into management implications.

In this supporting role, constituent valorization is treated as a conditional value-stacking layer. Lithium, boron, strontium, bromide, and potentially rare earth elements or ammonia can strengthen the case for treatment in selected subregions, but they do not replace the paper's main focus on forecasted water availability and beneficial reuse. The surrogate's practical lesson for the present manuscript is therefore simple: dissolved constituents may offset part of treatment cost, but only within a chemistry envelope that remains compatible with pretreatment, desalination, and reuse objectives.

2.6. Supporting screening-level Monte-Carlo and techno-economic framework from prior published work

To make the valorization layer more explicit, this manuscript also embeds the supporting screening-level techno-economic framework recently published by our group (Tiam et al. 2026). The framework is not reused here as the central forecasting method; instead, it is incorporated as a bounded economic sensitivity layer that translates mapped Permian chemistry into potential value offsets under uncertain lithium price, recovery, and treatment-cost conditions. The Monte Carlo equations, compact input summary, break-even lithium concentrations, and net-advantage results are included herein as adopted from our recent publication (Tiam et al. 2026). The supporting framework computes gross lithium revenue, avoided disposal cost, annual cashflow, net present value, and normalized net advantage using a compact set of equations (1)-(6).

$$Rev_{Li} = k\, C_{Li}\, Q_{DLE}\, \eta_{DLE}\, \gamma_{LCE}\, P_{LCE} \tag{1}$$

$$Avoided_{SWD} = C_{SWD}\left(Q_{pw} - Q_{SWD}\right) \tag{2}$$

$$\Delta CF_{yr} = Rev_{Li} + Rev_{reuse} + Avoided_{SWD} + R_{PRO} - \sum_{k}\left(OPEX_{k,s} + CAPEX_{k,s} * CRF\right) - C_{trans} \tag{3}$$

$$CRF = \frac{r(1+r)^N}{(1+r)^N - 1} \tag{4}$$

$$NPV = \sum_{t=1}^{N} \frac{\Delta CF_{yr}}{(1+r)^t} \tag{5}$$

$$NetAdv = \frac{\Delta CF_{yr}}{Q_{PW}} \tag{6}$$

where ΔCF_{yr} is the annual incremental cashflow, r is the discount rate, N is the project life in years, and CRF is the capital recovery factor used to annualize capital cost. Thus, $CAPEX_{k,s}$* CRF represents the annualized capital cost contribution for pathway k. Using barrels, κ = 1.58987 × 10−4 (kg Li per bbl)/(mg/L) = 0.001 (kg Li per m^3)/(mg/L), which converts C_{Li} (mg/L) to mass per barrel (equation (1)).

In the supporting Monte-Carlo analysis, uncertain inputs are sampled from bounded distributions rather than treated as fixed values. The key Permian inputs include lithium concentration, lithium-carbonate-equivalent (LCE) price, direct-lithium-extraction (DLE) recovery efficiency, reuse net value, annualized CAPEX intensity, OPEX intensity, SWD fee, transport cost, and retrofit/greenfield cost multipliers. These parameters are then propagated through the net-advantage (*NetAdv*) calculation to produce uncertainty envelopes for retrofit and greenfield deployment scenarios. Table 2 summarizes the compact input parameters.

Table 2. Key uncertain inputs in the supporting Monte Carlo sensitivity adapted in compact form from our recent publication (Tiam et al. 2026).

Input	Distribution	Range used in supporting sensitivity
Permian lithium concentration	Uniform	8–22 mg/L
LCE price	Triangular	\$10 / \$20 / \$35 per kg LCE
DLE recovery efficiency	Uniform	0.50–0.90
Reuse net value	Triangular	\$1.26 / \$5.03 / \$12.58 per m³

Annualized CAPEX intensity	Triangular	$1.26 / $3.77 / $7.55 per m³ treated
OPEX intensity	Triangular	$1.89 / $5.03 / $10.06 per m³ treated
SWD fee	Triangular	$3.15 / $9.44 / $31.45 per m³
Transport and handling cost	Triangular	$0.31 / $1.26 / $5.03 per m³
Retrofit CAPEX multiplier	Uniform	0.60–1.00
Greenfield CAPEX multiplier	Uniform	1.20–2.00
Retrofit OPEX multiplier	Uniform	0.80–1.00
Greenfield OPEX multiplier	Uniform	1.00–1.40

Note: values are reproduced in compact form from the published supporting screening study and are used here only to interpret how constituent recovery may offset treatment cost under uncertainty. The source study is Tiam, Bechara, Watson, and Poda (2026), Water, 18(6), 739.

3. RESULTS

3.1. Historical production and basin concentration

Historical production shows a steep increase in unconventional-water production across all three main subregions, with especially strong growth in Delaware New Mexico and Delaware Texas and a sustained Midland contribution (Figure 2). We link this increase directly to the unconventional expansion of the Permian, which now represents a major share of U.S. hydrocarbon output and therefore a major share of associated produced-water generation (Enverus 2026). After HF use, roughly 70% of PW still requires management, and even a limiting case in which produced water supplies all HF demand would still leave 57% requiring non-HF management (likely SWD). The Texas Delaware is highlighted as a particular pressure point because of higher water–oil ratio, lower HF demand than the Midland, and increasing PW inflow from New Mexico (estimated to attribute to 25% of the SWD in Delaware Texas (B3 Insight 2024; Enverus 2026; FracFocus 2026)). The resulting forecasting task is therefore both geologic and data-integration driven: reliable Permian management requires a basin-wide assessment rather than isolated Texas state summaries.

3.2. Forecasted PW availability through 2070

Across the production-forecast results, substantial unconventional-water production persists through 2070 (see Figure 5). Even though the exact low-, base-, and high-case trajectories differ, the main conclusion does not: unconventional PW remains large enough that long-run management planning must include treatment, reuse, and logistics—not only disposal capacity.

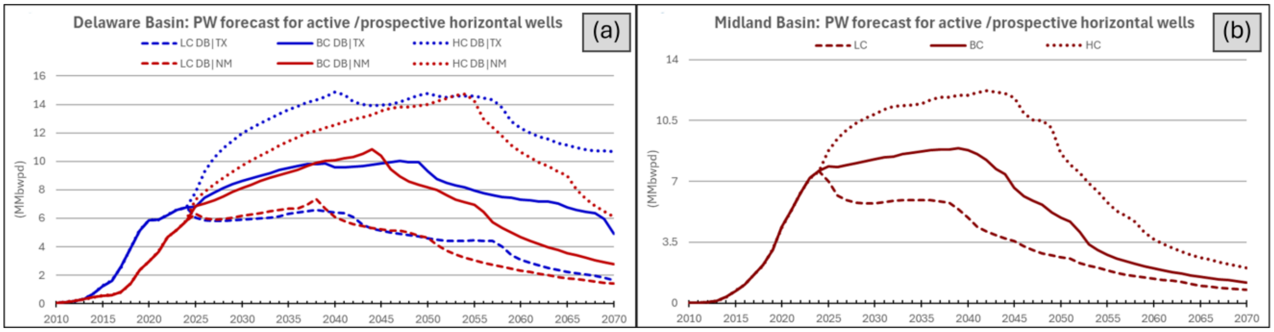


Figure 5. Projected produced water (PW) from: (a) the Delaware Basin (NM & TX), and (b) the Midland Basin, through 2070. LC: low case; BC: base case; HC: high case; DB | NM: the Delaware Basin in New Mexico; DB | TX: the Delaware Basin in Texas; MMbwpd: million barrels of water per day.

The methodology also implies that future produced-water patterns will not simply mirror historical ones. Because drilling is redistributed when historically active layers reach their spacing limits, and because low/base/high cases change productive area and density assumptions, the forecast becomes a structured scenario analysis rather than a single decline-curve extrapolation. This is a major strength of the methodology and should be read as one of the study's core contributions.

The forecast can be used as reference by water-management experts to further their planning. But the main implications on the West-Texas region thorough 2050 can be summarized in Table 3.

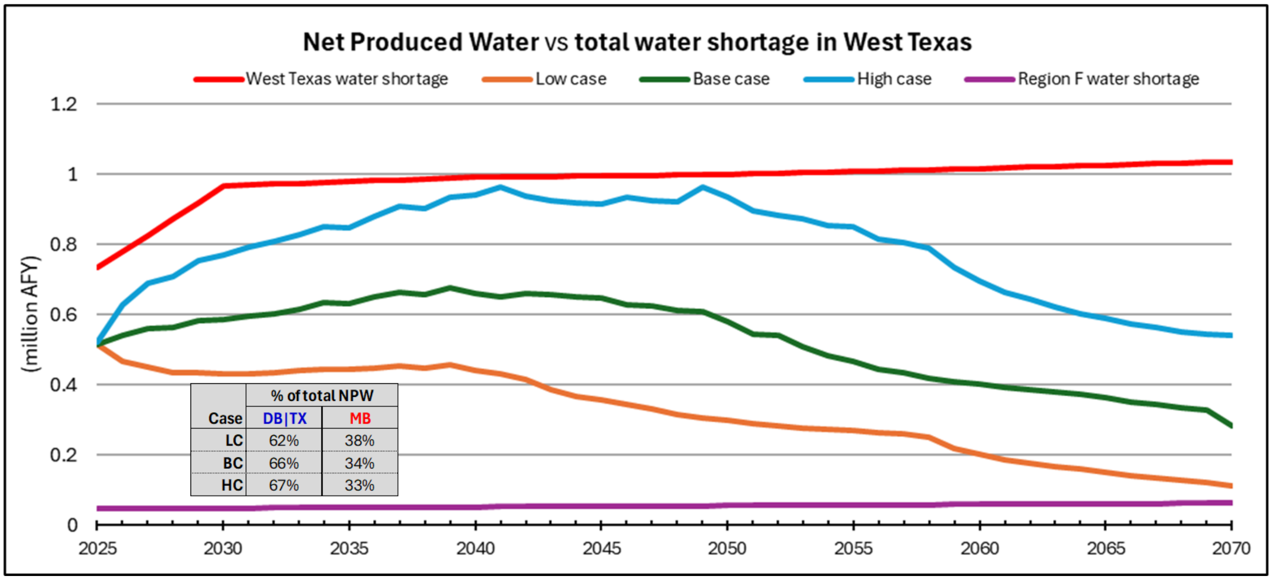
Table 3. Subregional planning synthesis reported from the forecast's base-case averages through 2050, with net produced water inferred as produced water (PW) minus hydraulic-fracturing (HF) use.

Subregion	Produced water (AFY)	HF use (AFY)	Maximum possibly Inferred net PW (AFY)	Primary management implication
Midland Basin	365,300	144,300	221,000	Typical TDS is about 130,000 ppm. High throughput remains important, but treatment is chemically harder; the region is better framed as selective treatment with possible value-stacking.

Delaware Basin	433,500	72,600	360,900	Typical TDS is about 67,000 ppm. Lower salinity and larger inferred net PW make Delaware the clearest treatment-oriented reuse target near the Texas–New Mexico border.

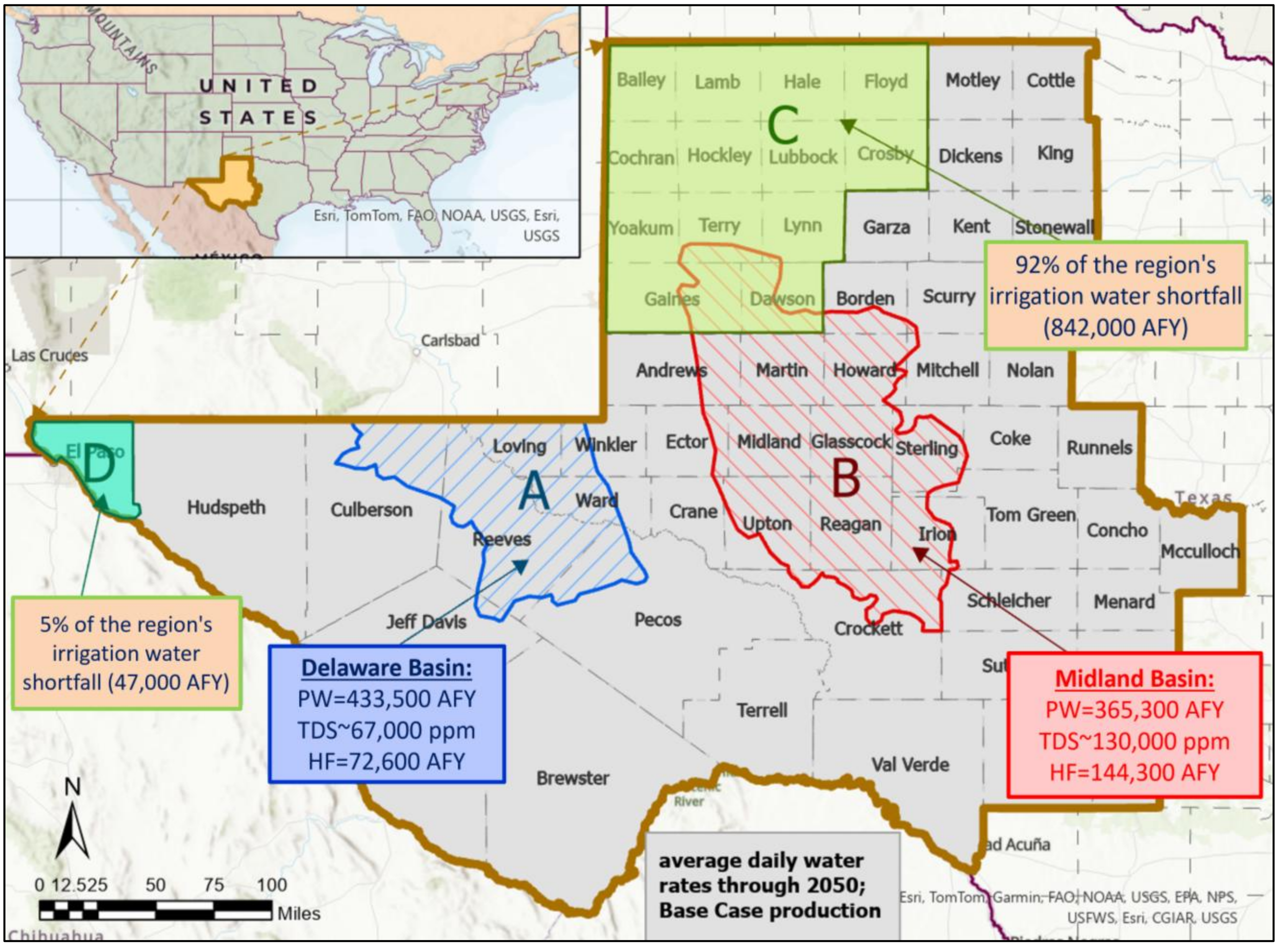
3.3. Net produced water and west texas shortage

Figure 6 contains one of the study's clearest practical findings. Based on B3-Insight study (reaching ~90% PW recycling in HF by 2034), we suggest a recycling percentage of 83% overall, rising from about 65% in 2025 to about 94% in 2070 (with TxPWC surveys also indicating substantial HF reuse in recent years (Smith et al. 2022, 2024)). Under the assumption that net PW is treated at 50% recovery and the remaining concentrate is disposed, the treated effluent could meet about 16% to 40% of projected West Texas water shortage through 2070 (Texas Water Development Board 2022). Figure 7 also shows why the paper cannot stop at a simple abundance argument. The management challenge is geographic as well as volumetric: water-producing counties are substantially distant from some of the areas with the largest irrigation shortfall. As a result, the manuscript interprets PW as a meaningful but spatially constrained contributor to regional water planning rather than as a one-for-one replacement for freshwater scarcity.



	% of total NPW	
Case	DB|TX	MB
LC	62%	38%
BC	66%	34%
HC	67%	33%

Figure 6. Contextual management results drawn from the forecast: the West Texas water-management comparison between net produced water and projected shortage under low-, base-, and high-case trajectories; and panel (c) provides the broader produced-water / shortage / water-oil-ratio context map used to interpret spatial mismatch between water supply and irrigation demand.



92% of the region's irrigation water shortfall (842,000 AFY)

5% of the region's irrigation water shortfall (47,000 AFY)

Delaware Basin:
PW=433,500 AFY
TDS~67,000 ppm
HF=72,600 AFY

Midland Basin:
PW=365,300 AFY
TDS~130,000 ppm
HF=144,300 AFY

average daily water rates through 2050; Base Case production

Figure 7. Geospatial summary of the West-Texas region concerning forecasted produced water (PW) supply and regional water shortages. The map represents the broad produced-water/ shortage context map used to interpret spatial mismatch between water supply and irrigation demand. Areas A and B represents the respective maximum extents of the Delaware Basin and the Midland Basin, i.e., the geospatial unions of the geologically-viable extents provided by Enverus.

3.4. Spatial water-quality heterogeneity

Figure 8 makes the chemistry argument visually explicit. The mapped chemistry results show that treatment-oriented decision making in the Permian cannot be basin-average. The sample-density map indicates that data support is uneven but still broad enough to distinguish practical subregional chemistry behavior. The TDS map shows lower salinity in substantial parts of the Delaware trend, while the lithium and boron maps show that constituent opportunity does not overlap perfectly with the most reuse-favorable water. The map patterns lead to a clear management interpretation: the Delaware Basin near the Texas–New Mexico border appears to be the most suitable subregion for PW treatment. That conclusion is not driven by a single constituent. It emerges from the combination of lower salinity, large residual water availability, and better apparent fit with reuse-oriented treatment. By contrast, Midland waters remain important not because they are easy to treat, but because they pair strong water availability with high lithium potential and therefore invite a more selective value-stacking interpretation.

Figure 7 reports this contrast numerically. Midland Basin conditions are summarized as approximately 365,300 AFY of produced water, TDS near 130,000 ppm, and about 144,300 AFY of hydraulic-fracturing use, whereas the Delaware Basin is summarized at about 433,500 AFY of produced water, TDS near 67,000 ppm, and about 72,600 AFY of hydraulic-fracturing use. These values support a consistent planning interpretation: Midland is volumetrically important but chemically harsh, while Delaware combines high practical water value with more favorable treatment chemistry.

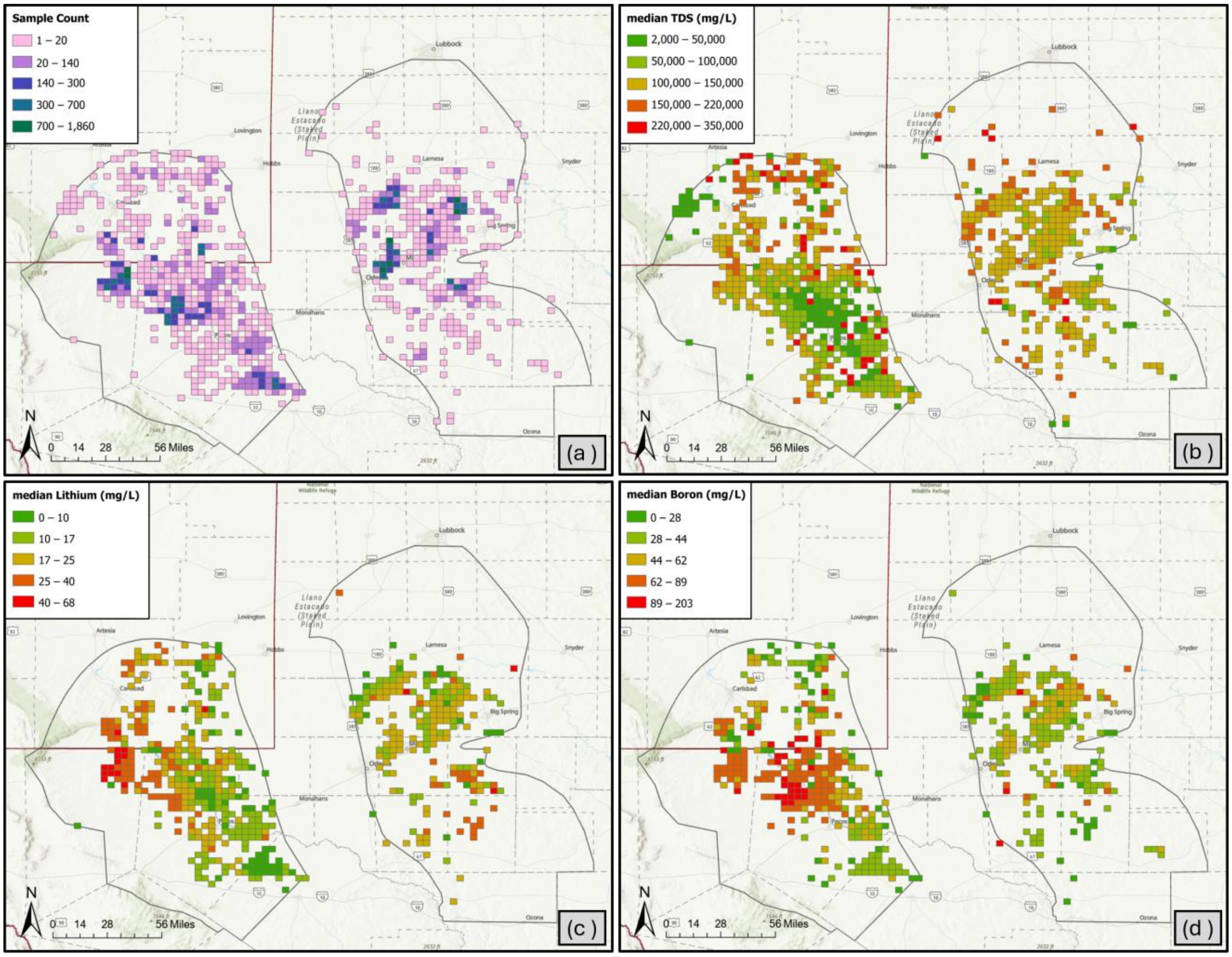


Figure 8. Water-quality atlas for the current mapped unconventional-well dataset. Panels show sample density, median TDS, median lithium, and median boron across the mapped 3 mi × 3 mi grid. The figure is used for treatment siting and management rather than as a purely descriptive chemistry plate: lower-TDS Delaware areas support reuse-first interpretation, whereas harsher Midland waters favor more conservative treatment or value-stacking screens.

3.5. Screening-level treatment and constituent valorization implications

Whilst the forecast and water-quality results establish where water is produced and where the chemistry is more or less favorable, the surrogate-assisted valorization helps interpret what those patterns mean operationally but it is deliberately kept in a supporting role. In this manuscript, valorization is not the primary reason to treat water. Instead, it is treated as a screening-level economic offset that may strengthen the case for reuse-oriented treatment in selected subregions.

The supporting surrogate-assisted valorization also clarifies how constituent value should be used in such a study. Lithium, boron, strontium, bromide, and possibly rare-earth elements or ammonia are best interpreted as value-stacking opportunities that may improve the economics of treatment, not as standalone justifications for full regional deployment. A higher-lithium area is not automatically the best treatment target if salinity, hardness, scaling tendency, or distance to demand are unfavorable.

The supporting surrogate is especially useful here because it provides two concrete anchors. First, the TxPWC chemistry envelope places Delaware-Basin (TX) median conditions at about 54,964 mg/L TDS, 10 mg/L Li, 53 mg/L boron, and 2,203 hardness, whereas Midland-Basin median conditions rise to about 134,925 mg/L TDS, 18 mg/L Li, 44 mg/L boron, and 10,205 hardness. Second, public pilot-treatment data show that very high-salinity Permian waters can still be converted to low-TDS product streams, but often with heavier pretreatment and energy burden for Midland-like waters than for the more reuse-favorable Delaware chemistry window. These insights are summarized in Table 4.

Table 4. Screening-level treatment and constituent-valorization interpretation used only to support the results of the forecast and the water-quality atlas.

Region / pilot context	median TDS (mg/L)	median Li (mg/L)	median Boron (mg/L)	median Hardness	Interpretation for this paper
Delaware Basin (TX) chemistry envelope	54,964	10	53	2,203	Lower salinity and hardness support reuse-first treatment; dissolved constituents are secondary offsets.
Midland Basin chemistry envelope	134,925	18	44	10,205	Higher lithium supports screening-level valorization interest, but only with heavier pretreatment.
TxPWC Pilot A / Delaware	111,000-140,000 feed	—	—	—	Advanced thermal desalination produced

					about 311 mg/L finished water, supporting feasibility for Delaware-type hypersaline feed.
TxPWC Pilot B / Midland	125,000-190,000 feed	—	—	—	Thermo-mechanical desalination produced about 36 mg/L finished water, showing that Midland-type feed is treatable but likely more burdensome.

3.6. Monte Carlo sensitivity and break-even critical-mineral interpretation

The surrogate-assisted valorization also contributes a published-results layer that is useful to embed directly in the present manuscript. The main reason to include it here is not to replace the production forecast or the mapped chemistry atlas, but to test whether constituent recovery is likely to stand on its own economically or whether it should be interpreted as a secondary offset to reuse-oriented treatment.

The break-even lithium screen from Tiam et al. (2026) is especially informative for the present paper because it can be compared directly with the mapped Permian lithium ranges. Under a DLE recovery of 0.7, the lithium concentration needed for gross lithium revenue alone to equal avoided disposal cost remains far above most mapped Permian values except under unusually favorable combinations of low disposal cost and high product price (see Table 5). This reinforces the interpretation that critical-mineral recovery in the Permian is best treated as a supplemental value stream rather than the sole basis for regional treatment deployment. Compared with the seminar atlas, these break-even thresholds (Table 5) are substantially higher than typical mapped Permian lithium values, which supports a reuse-first and value-stacking interpretation rather than a lithium-only deployment logic.

Table 5. Break-even lithium concentration from the supporting surrogate paper: lithium concentration required for gross lithium revenue to equal avoided saltwater-disposal (SWD) cost (Tiam et al. 2026)

Assumed LCE Price (\$/kg)	SWD cost = \$6.3/m^3	SWD cost = \$18.9/m^3	SWD cost = \$31.4/m^3
10	169	506	844
20	84	253	422
30	56	169	281
40	42	127	211

A second supporting result from Tiam et al. (2026) is the Monte-Carlo distribution of net advantage for retrofit and greenfield cases (see Figure 9). The boxplots show that the Permian can achieve positive median net advantage under screening assumptions, but the Permian remains less advantaged than higher-lithium Smackover and Salton-Sea benchmark systems. This is exactly the interpretation needed here: the Permian PW case is strengthened by constituent recovery, but its main planning value still comes from water management, shortage offset, and reduced disposal dependence.

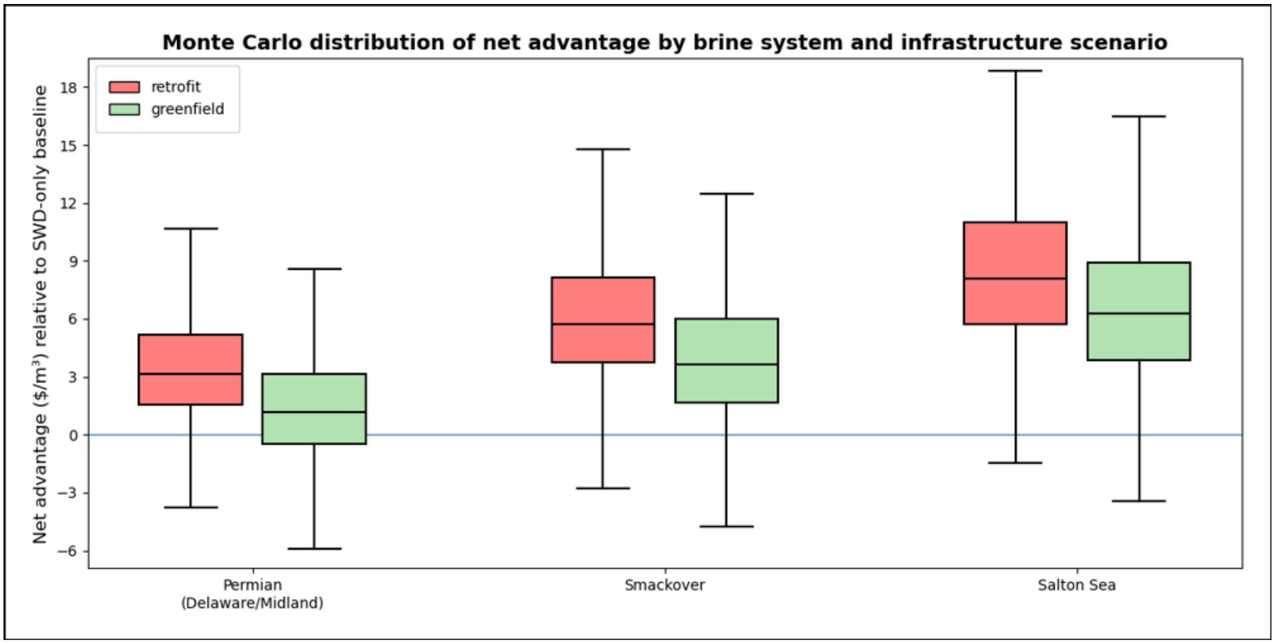


Figure 9. Screening-level Monte Carlo net advantage by brine system and infrastructure scenario (Tiam et al. 2026). The Permian retrofit and greenfield cases remain positive on median but less favorable than Smackover and Salton Sea benchmarks.

Table 5 and Figure 9 make the argument for considering critical minerals in the Permian's PW (such as lithium and related constituents) for treatment. But this argument suggests improving the economics of treatment and reuse rather than overturning our study's central conclusion which states that beneficial reuse planning should start with water availability, water quality, and spatial mismatch with demand. Only after assessing the central conclusion, do we suggest constituent recovery as a conditional economic enhancer where chemistry and infrastructure permit.

4. Discussion

The main strength of the multi-faceted manuscript is that it does not ask a single dataset to “do everything”. The results provide a spatiotemporal backbone: how production is forecasted, how hydraulic-fracturing reuse is treated, where produced water is generated, how much net water may remain after internal oilfield use, and how chemistry varies across the basin. The surrogate-assisted valorization then supplies a narrower but highly useful supporting interpretation: which chemistry envelopes are comparatively easier to treat, which constituent patterns may improve treatment economics, and why public pilot data matter when converting map-based observations into management claims.

The forecast and atlas results define where the water is, how much net water remains after HF use, and the PW-treatment feasibility. The supporting surrogate economics then test a narrower question: whether constituent recovery could materially improve treatment economics. Because the break-even lithium thresholds remain high relative to typical mapped Permian concentrations and because the Monte-Carlo comparison places the Permian below higher-lithium benchmark brines, we can make a strong claim: critical minerals are relevant in the Permian, but are mostly value-stacking support for reuse-oriented treatment rather than as a stand-alone regional business case.

This combined framing also prevents a common mistake in PW papers. It would be easy to move too quickly from high water volume to optimistic reuse claims, or from lithium presence to a mineral-extraction narrative: a more disciplined interpretation is needed. Forecasted net PW is large enough to matter materially for West Texas, but geographic mismatch, treatment requirements, and infrastructure constraints remain decisive. Likewise, constituent valorization can strengthen the case for treatment in selected areas, but it should not displace the basic reuse-oriented planning problem. The discussion also highlights a useful subregional contrast. Delaware Texas appears to offer the most attractive reuse chemistry in the combined materials: lower TDS, lower hardness, and a strong treatment-oriented regional narrative. Midland Texas, by contrast, may offer a more compelling constituent-recovery screen because lithium is stronger there, yet that same region also carries a more difficult salinity and hardness burden. That contrast is exactly why future pilot planning should be location-specific rather than basin-average.

Several limitations remain explicit. First, the forecast depends on rig activity, lateral length, type curves, productive-area boundaries, and well-density assumptions. Those assumptions are reasonable and sourced, but they still define scenarios rather than a single deterministic future. Second, public data indicate that geospatial recycling percentages are not yet mapped with high confidence, so net-PW estimates remain scenario-level regional calculations rather than fully spatialized recycling forecasts. Third, the mapped chemistry atlas aggregates samples collected across years, operators, and analytical campaigns; it is appropriate for regional treatment interpretation, but not for lease-level facility design. Fourth, the treatment and valorization discussion remains screening-level. It supports siting and management logic, but it should not be read as a bankable techno-economic design for any specific operator or facility.

A final scope boundary is therefore important. The main claims of this paper are basin-scale and planning-oriented: where PW is likely to remain abundant, where chemistry is relatively favorable or difficult, and where screening-level treatment or value-stacking appears most plausible. The paper does not claim to resolve exact future county-level reuse contracts, site-specific pipeline routing, or facility-level process economics.

5. Conclusions

This manuscript recasts production forecast, geospatial water quality and supporting surrogate valorization into a single argument about PW management in the Permian Basin. The results shows that the basin is both a long-lived water-production system and a promising, but spatially constrained, source of reuse water for the arid West Texas region.

The main conclusions are: (i) unconventional-water production in the Permian remains substantial and persistent through 2070; (ii) after HF use, forecasted net PW would still meet approximately 16% to 40% of projected West Texas water shortage under the treatment assumption of a 50% recovery; (iii) water quality is not uniform across the basin, as the Delaware Basin near the Texas-New Mexico border appears most favorable for treatment-oriented reuse, whereas Midland waters are chemically harsher; and (iv) constituent valorization is best understood here as a supporting economic layer, not as the core management objective.

The practical implication is that rigorous Permian water planning should link forecasted water availability, mapped chemistry, and screening-level treatment/value interpretation in one framework. Reuse remains the primary management objective, while constituent valorization remains a secondary lever that can improve treatment economics in selected subregions, but does not replace the need for sound siting, conveyance, and disposal planning.

Acknowledgements

The author acknowledge Elie Bechara , Dr. Watson, and the Texas Produced Water Consortium for publicly reporting the basin chemistry percentiles and pilot summaries used for this manuscript.

References

B3 Insight (2024) Water Market Trends and Forecast Report. In: B3 Insight. https://www.b3insight.com/. Accessed 3 Sep 2024

Bechara, E. Developing a Basis for Rigorous Produced Water Management in the Permian-Basin Region: A Spatiotemporal/Stratigraphic Assessment of Current/Projected Production and Water Quality. Ph.D. Dissertation Proposal Defense, Texas Tech University, 30 January 2026. Contact: elie.b.bechara@ttu.edu

Bechara, E. Produced-Water Management in the Permian Basin to Accommodate the Arid West Texas Region: Historical Production, Forecast, and Water Composition.

Texas Tech University Petroleum Graduate Seminar, 27 February 2026. Contact: elie.b.bechara@ttu.edu

Bechara E, Watson M, Arbad N (2024) Unlocking Sustainability: Transforming Tight-Oil Produced Water into a Lifeline for West Texas. Environmental Processes 11:26. https://doi.org/10.1007/s40710-024-00704-8

Enverus (2026) PRISM. In: Enverus. https://www.enverus.com/solutions/energy-analytics/ep/prism/. Accessed 30 Mar 2026

FracFocus (2026) FracFocus - Data Download. In: FracFocus. https://fracfocus.org/data-download. Accessed 30 Mar 2026

Ge J, Nicot JP, Hennings PH, et al (2022) Recent water disposal and pore pressure evolution in the Delaware Mountain Group, Delaware Basin, Southeast New Mexico and West Texas, USA. J Hydrol Reg Stud 40:. https://doi.org/10.1016/j.ejrh.2022.101041

Hall R, Bertram R, Gonzenbach G, et al (2010) Guidelines for the practical evaluation of undeveloped reserves in resource plays. Society of Petroleum Evaluation Engineers

Hennings PH, Young MH (2023) The TexNet-CISR collaboration and steps toward understanding induced seismicity in Texas. Recent Seismicity in the Southern Midcontinent, USA: Scientific, Regulatory, and Industry Responses. https://doi.org/10.1130/2023.2559(06)

Jiang W, Xu X, Hall R, et al (2022) Characterization of produced water and surrounding surface water in the Permian Basin, the United States. J Hazard Mater 430:. https://doi.org/10.1016/j.jhazmat.2022.128409

Oil Conservation Division (2026) OCD Forms. https://www.emnrd.nm.gov/ocd/ocd-forms/. Accessed 30 Mar 2026

Pawar R, Zhang Z, Vidic RD (2022) Laboratory and pilot-scale studies of membrane distillation for desalination of produced water from Permian Basin. Desalination 537:115853. https://doi.org/10.1016/J.DESAL.2022.115853

Railroad Commission of Texas (2026) Data Sets Available for Download. In: Railroad Commission of Texas. https://www.rrc.texas.gov/resource-center/research/data-sets-available-for-download/. Accessed 30 Mar 2026

Reible D, Rao B, Rasporic K, et al (2024) Technology Evaluation for Midland and Delaware Basin Produced Water. In: Texas Tech University. https://www.depts.ttu.edu/research/tx-water-consortium/TxPWC-2024technologyreview-Reible-Rao.pdf. Accessed 30 Mar 2026

Scanlon BR, Reedy RC, Male F, Walsh M (2017) Water Issues Related to Transitioning from Conventional to Unconventional Oil Production in the Permian Basin. Environ Sci Technol 51:10903–10912. https://doi.org/10.1021/acs.est.7b02185

Smith R, Bernard E, Watson M, et al (2022) Beneficial Use of Produced Water in Texas: Challenges, Opportunities and the Path Forward. In: Texas Produced Water Consortium. https://www.depts.ttu.edu/research/tx-water-consortium/2022-report.php. Accessed 28 Apr 2024

Smith R, Mauldin W, Bernard E, et al (2024) Beneficial Use of Produced Water in Texas: Texas Produced Water Consortium Report to the Texas Legislature 2024. Lubbock, TX, USA

Texas Water Development Board (2022) 2022 State Water Plan: Water for Texas. In: Texas Water Development Board. www.twdb.texas.gov/waterplanning/swp/2022. Accessed 15 Jan 2023

Tiam A, Bechara E, Watson M, Poda S (2026) Surrogate-Assisted Techno-Economic Optimization to Reduce Saltwater Disposal via Produced-Water Valorization: A Permian Basin Case Study. Water (Basel) 18:739. https://doi.org/10.3390/w18060739

U.S. Geological Survey (2025) Induced Earthquakes. In: U.S. Geological Survey. https://www.usgs.gov/programs/earthquake-hazards/science/induced-earthquakes. Accessed 29 Dec 2025