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Oilfield Water Infrastructure Connectivity: The Case for a 'Hydrovascular' Network in the Permian Basin

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Abstract: The current phase of oilfield water infrastructure buildout in the Permian Basin generally emphasizes each operator or midstream provider building its own water transportation and disposal systems. Accordingly, the overall market is balkanized and inefficient compared to the performance a more interconnected system could achieve. A hydrovascular grid in the Permian Basin could lower oil and gas production costs, conserve scarce freshwater by promoting greater recycling and reuse of produced water, help mitigate seismicity risks, and facilitate movement of produced water at large scale for use outside the oilfield. This paper assesses the barriers to such integration. It concludes by offering a set of practical ideas to overcome these barriers and help transform oilfield water into a resource for West Texas and Southeast New Mexico.
Keywords: hydrovascular grid, oilfield, produced water, market, infrastructure

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** Note: The opinions and ideas expressed in this piece are those of the author alone and do not represent the views or positions of the Baker Institute or Rice University.
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Terms used in paper

Acronym	Descriptive term
AOMD(s)	area(s) of market dominance
bpd	barrels per day
CAPEX	capital expenditures
E&P	exploration and production
EBITDA	earnings before interest, taxes, depletion, and amortization
LIBOR	London Inter-Bank Offered Rate
ROCE	return on capital employed
SWD(s)	saltwater disposal well(s)
TDS	total dissolved solids

INTRODUCTION

The Permian Basin now accounts for nearly 5% of global oil production. To unlock this hydrocarbon bounty, oil companies in the Permian Basin of New Mexico and Texas used about 5 million barrels per day (bpd) of water for hydrologic fracturing frack water as of Q4 2018. This approaches the average annual municipal water demand of San Antonio (Gorzell et al. 2018). On the produced water side—analogous to wastewater in cities—the Permian Basin is even larger. Average daily total water injection volumes are more than twice the volume of wastewater Houston (Texas's largest city and the United States' fourth-largest) treated on an average day in 2018 (Brown and Riggans 2018). The volume of produced water from unconventional wells alone could reach 35 million bpd within the next decade (Addison 2019). To accommodate water volume growth and help facilitate continued robust oil and gas production activity in the Permian Basin, water services providers must be able to economically manage the resulting tsunami. A more interconnected hydrovascular grid in the Permian Basin oilfield can help facilitate economically and hydrologically optimal water management solutions and turn oilfield water from a waste into a true resource for the region.

The hydrovascular grid concept

> "We would create a hydrovascular market, where we would have major arterials to convey water throughout the state. For us to develop this and to develop new water—whether it be desalination or reclaimed water or bring water from out of state—all of that needs to be looked at from a 50,000-foot view," (Schladen 2015).

The idea of large-scale, highly connected water infrastructure to link regions of plenty to regions of scarcity in Texas dates to the 2015 legislative session. House Bill 3298 called for the Texas Water Development Board to study the potential for developing a water market and conveyance network that would eventually become a hydrovascular grid spanning multiple regions statewide (2015). The bill did not become law and the issue has, legislatively speaking, lain dormant for 4 years and running (H.B. 3298 . . . 2015).

Municipal water grids are challenging to interconnect for a range of reasons, including politics and quality concerns stemming from the fact that humans drink the water being transferred across systems. The oilfield water space offers much better near-term potential for creating a regional hydrovascular grid, and the ongoing scale-up and consolidation of water midstream systems in the Permian Basin could potentially create a partial hydrovascular grid in that region within 3–5 years (Collins 2019b).

Pressing needs for larger-scale water solutions, coupled with a market ecosystem that would be driven primarily by commercial interests, creates an environment where systems that are consolidating now for market reasons could be strategically linked together to facilitate wheeling of oilfield water within the Permian Basin. Consolidation in turn can facilitate optimal utilization of disposal well and recycling capacity and, potentially, the construction of larger-scale infrastructure that allows water to be moved outside the Permian Basin to the mutual economic and hydrological benefit of multiple stakeholders.

The core hypothesis underlying the emergence of a Permian Basin hydrovascular grid is that the oilfield water market in the Delaware and Midland Basins will gradually coalesce into several large areas of market dominance (AOMDs) as

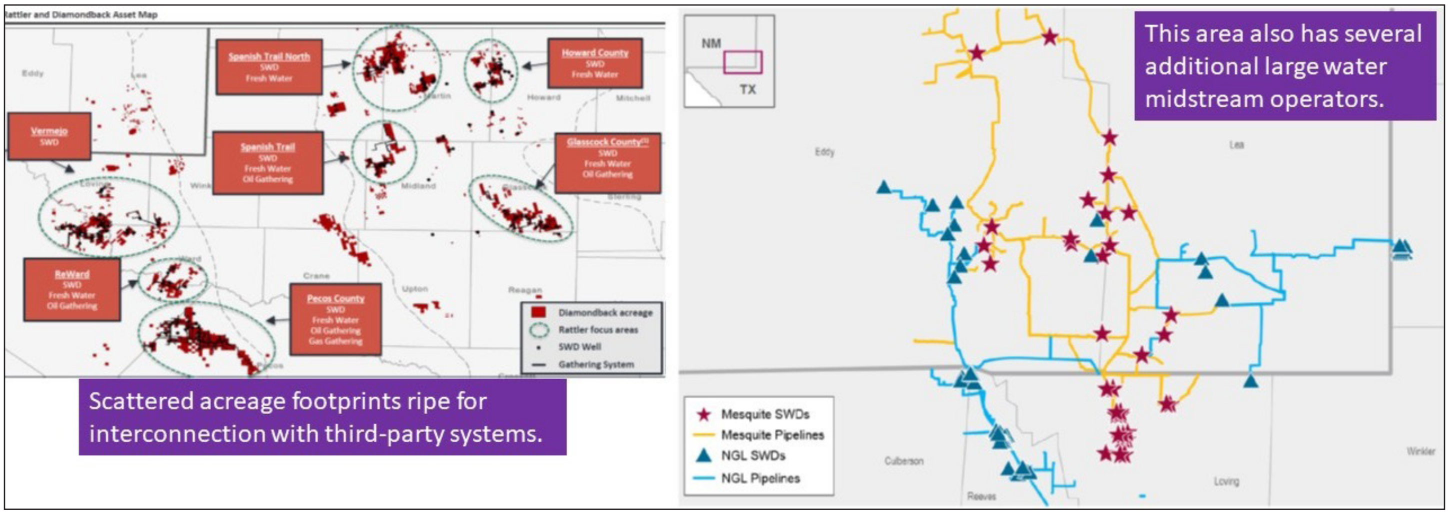

Figure 1. The case for oilfield water interconnectivity. Source: NGL Energy Partners LP 2019, Rattler Midstream 2019, Author’s Analysis.

water midstream firms and their exploration and production (E&P) customers consolidate. The emergence of these broad AOMDs—akin to the watershed feeding a river system—opens the opportunity for optimized pipeline connectivity between the various oilfield watersheds that will, economics permitting, allow wheeling and movement of water in a manner that is largely impossible at present.

The areas of market dominance may also add a self-fulfilling prophecy dimension because they could offer appealing scale to large strategic buyers who possess the financial incentives, operational know how, and finances to further stitch up the Permian Basin oilfield water space. Figure 1 shows two snapshots of how prospective consolidators are beginning to emerge amidst the fragmentation that has characterized oilfield water management in the Permian Basin for much of the past several years. One possible outcome is that the largest midstreams such as Kinder Morgan or Plains All-American Pipeline could conceivably add water to their extensive existing crude, gas, and products midstream portfolios.[1]

It is also possible that the biggest existing players in the Permian Basin oilfield water space at present could bulk up even further and seek to dominate the Permian Basin moving forward. NGL Energy Partners, which has made a strategic decision to focus on the Northern Delaware Basin, appears to be substantially de-emphasizing its traditional hydrocarbon midstream businesses and bulking up instead on Permian Basin water assets. For NGL, water services accounted for 29% of firm-wide earnings before interest, taxes, depletion, and amortization (EBITDA) in Fiscal Year 2018, but this proportion rises to roughly 50% of the firm’s projected Fiscal Year 2020 EBITDA (NGL Energy Partners LP 2019).

[1] See, for instance Wethe D. 21 June 2019. Dirty Water Holds Biggest Promise for Pipeline Companies, Jefferies Says. Bloomberg. Available from: https://www.bloomberg.com/news/articles/2019-06-21/dirty-water-holds-biggest-promise-for-pipelines-jefferies-says.

Among the “pure play” water midstream firms, WaterBridge stands out for its fast-moving and big-dollar mergers and acquisitions activity. Data for the company’s publicly reported transactions suggests that in the central and southern Delaware Basin, it has spent close to $700 million on acquisitions since February 2018 (Collins 2019a). This is almost certainly a significant underestimate, since it includes neither the 2017 purchase of EnWater nor the 100,000 Series-A1 Preferred Units transferred to Concho as part of a December 2018 purchase of produced water assets and acreage dedication (WaterBridge 2017; Concho Resources Inc. 2019). Including the potential value of these two items could reasonably drive WaterBridge’s Delaware Basin entry cost to date as high as $800 to $850 million.

Motivations for promoting greater connectivity between Permian Basin water systems

Before delving into the challenges—many of them substantial—that a Permian Basin hydrovascular grid would face, it is worth considering what is at stake as operators in the Permian Basin search for high-volume, economically advantaged, and stable water solutions.

A more integrated set of water handling networks can help oil and gas producers rationalize investment plans and shift water-related capital investments off their balance sheets. Investors increasingly demand capital spending discipline, while companies must offset the high natural rate of decline in horizontal wells while also trying to grow production (Matthews and Elliott 2019). In such an environment, spending $5–6 million dollars to drill, complete, and equip a shallow disposal well and as much as $10 million for a deep Devonian/Ellenburger disposal well plus additional investment in water pipelines becomes tougher to justify.

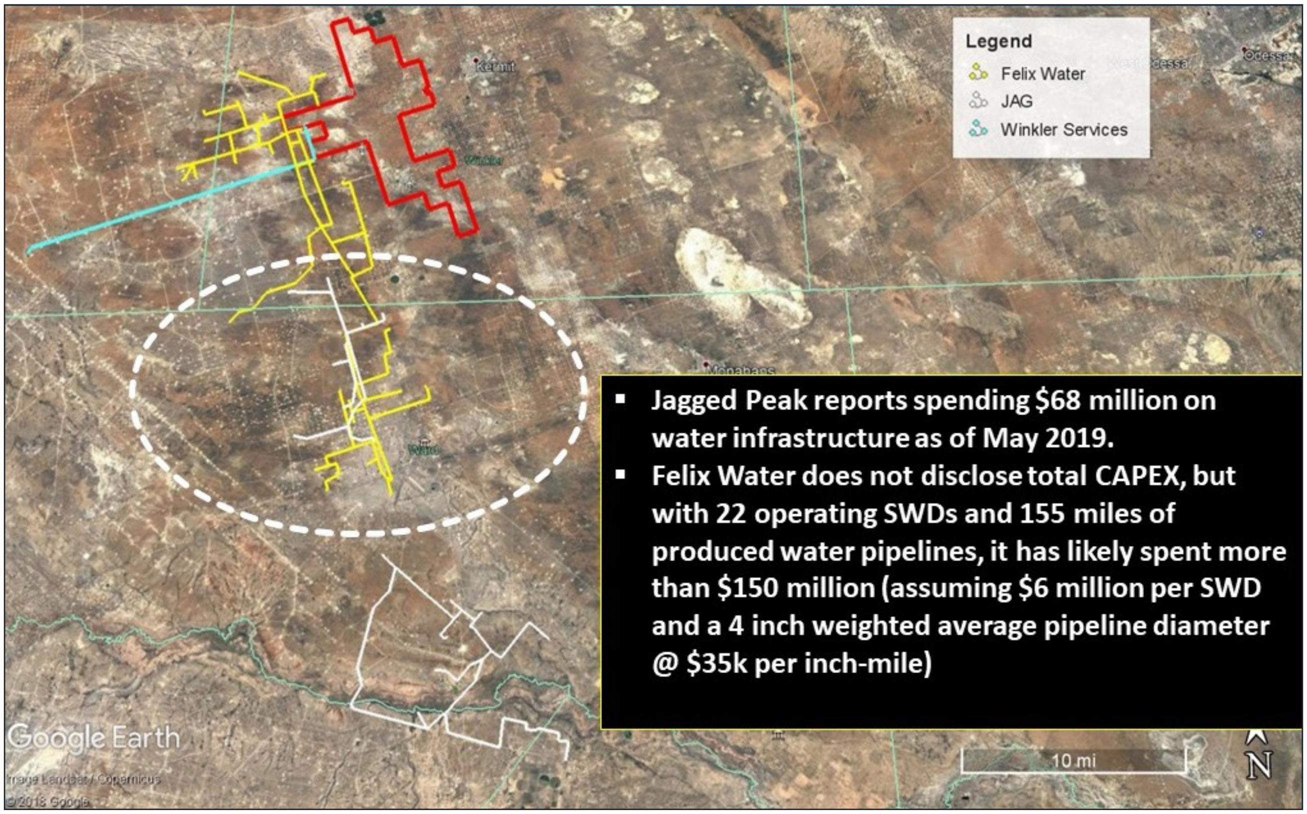

Figure 2. Jagged Peak and Felix Water Delaware Basin pipeline systems. Source: Felix Water n.d., Jagged Peak Energy 2019, Company Reports, Author's Analysis.

The case worsens when one considers proprietary water networks' generally low average utilization rates and that the funds invested in them could otherwise have been used to drill oil and gas wells. Low utilization rates affect the return on capital employed (ROCE) and help illustrate the potential balance sheet consequences of investing funds in self-operated water systems rather than drilling oil and gas wells. ROCE gives a directional sense as to how management may elect to deploy capital on projects, especially in a "live within cashflow" environment such as the one E&Ps now must operate in.

Commercial water systems may well be able to meet the 15% ROCE threshold that the most competitive Permian Basin-focused E&P companies can reap from oil and gas production investments. But most firms will likely fall short of that mark unless their system is optimally utilized and/or they operate in an area where a quasi-monopoly water services provider is charging high prices that create incentives to invest in proprietary water systems on the basis that avoided costs are effectively an economic gain that delivers a form of return on investment.

Legacy investments in proprietary water infrastructure are tempting monetization targets at present in part because recent comparable transactions suggest a higher ROCE on dollars invested in saltwater disposal wells (SWDs) and pipelines than for dollars sunk into oil and gas wellbores.

Water management is also not a core competency or management focus for most oil and gas operators, even though it is operationally critical. Broadly speaking, investors are likely to cast a jaundiced eye on additional water system investments that could have gone to oil and gas development. To that end, the more publicly traded midstream names there are with meaningful water exposure, the more pressure investors will likely exert on E&Ps to focus capital expenditures (CAPEX) on their core business and not plough money into midstream operations (for interested readers, the author can share specific details of selected oil and gas producers' water divestiture transactions and some of the likely reasoning behind them).

Treating water assets as truly commercial systems that are substantively open to third-party commercial volumes sets the stage for a more efficient marketplace. But perhaps the biggest challenge to creating a more interlinked set of Permian Basin oilfield water infrastructure comes from the need to reconcile capital providers' expectations with evolving market realities. Consider the example of Jagged Peak Energy and Felix Water, who have water systems in Ward and Winkler Counties that substantially overlap one another (Figure 2).

Each company has invested sizeable sums of capital. Jagged Peak reports spending $89 million on water infrastructure as of June 30 2019 (Jagged Peak Energy 2019). Felix Water does not disclose total CAPEX, but with 22 operating SWDs and 190 miles of produced water pipelines (Felix Water n.d.), the

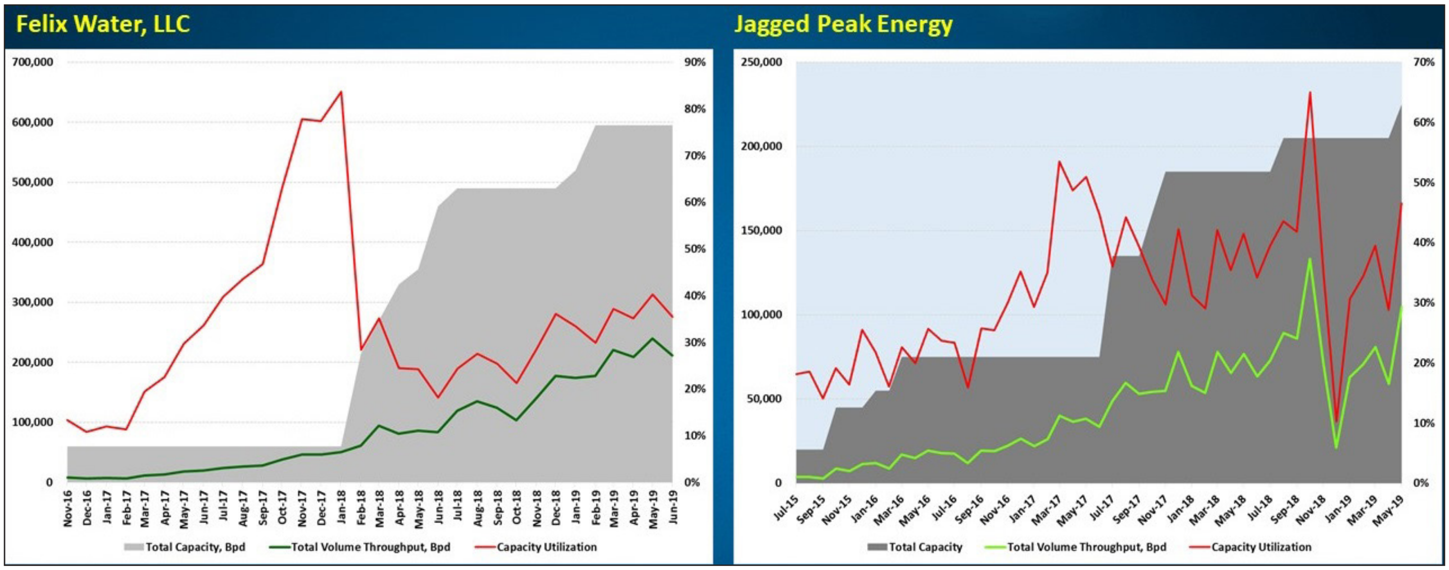

Figure 3. Capacity utilization of Jagged Peak and Felix Water systems. Volume throughput: green line, vertical axis; Capacity utilization: red line, horizontal axis. Source: [Texas Railroad Commission 2019](), Author's Analysis.

author estimates it has likely spent more than $150 million (assuming $6 million per SWD and a 4-inch weighted average pipeline diameter at $35,000 per inch-mile). As such, the combined cost of the two systems could exceed $250 million. Yet the actual Texas Railroad Commission data on water received by the saltwater disposal wells in each system (a proxy for overall flows) suggest that both networks are highly underutilized, with average capacity utilization rates in the neighborhood of 40% over the past 2 years (Figure 3).

Capital might have been better deployed building shared infrastructure that connects more producers, with the balance saved either deployed to build a water system with even greater geographical coverage or spun back to shareholders or used to drill oil and gas wells. It bears noting that each of the companies in this example aggressively expanded system capacity between the second quarter of 2017 and the second quarter of 2019, suggesting a temporal overlap that would have offered an ideal window for building infrastructure more collaboratively and thus optimizing capacity investments.

To frame the potential savings in terms of what the capital could have done, consider that 30-inch HDPE pipe likely costs about $1 million per mile installed (assuming $35,000 per inch-mile total installation cost), based on the author's conversations with industry experts. Thus, a Delaware SWD completed with surface facilities is, in CAPEX terms, equal to about 6 miles of large-diameter pipe and a Devonian SWD worth closer to 10 miles of large diameter pipe linking one system to another.

Optimizing CAPEX becomes especially important if the Permian Basin is transitioning into a production regime where activity remains substantial, but production of oil and gas (and by extension, water) grows more slowly. The new normal for annual output growth could be net increases on the order of 200 thousand bpd, as opposed to the heady days of 2017 and 2018 where oil production increased by 733 thousand bpd and 1 million bpd, respectively (calculated using oil production changed from January to December in 2017 and 2018; [Drilling Productivity Report 2013–2019]()).

The output slowdown could stem from at least two core factors, and both matter for water midstream development strategies. First, some analysts suggest that the rate of increase in well productivity may be slowing.[2] Second, operators are encountering what appear to be hard physical limits on how closely wells can be spaced without adversely affecting each other's productivity.[3] This means that at a given price level, operators are likely to drill fewer wells in a given block of acreage than might have been the case previously.

Lower density development means water midstream companies may need to cover larger physical footprints to achieve a given volume and returns profile. Consider, for instance, Wolfcamp A horizontal wells with 1.5 million barrels of expected lifetime water production. Spacing of 440 feet between wells (an aggressive number) would suggest 12 wells per section

[2] For an example of the bullish view, see Rystad Says Permian Well Productivity is Just Fine. 2019 Aug 5. Journal of Petroleum Technology. Available from: https://www.spe.org/en/jpt/jpt-article-detail/?art=5802. For a bearish view, see Analytics Firm: Permian Fracturing Work Underreported by 21% in 2018. 2019 Jul 24. Journal of Petroleum Technology. Available from: https://www.spe.org/en/jpt/jpt-article-detail/?art=5763.

[3] See, for instance Concho Resources. 2019 1 Aug. Investors: SEC Filings (2019, Quarterly). Available from: https://ir.concho.com/investors/financial-reports/sec-filings/default.aspx. Copy on file with author. as well as Olson B. 2019 Jul 4. A Fracking Experiment Fails to Pump as Predicted. The Wall Street Journal. Available from: https://www.wsj.com/articles/a-fracking-experiment-fails-to-pump-as-predicted-11562232601.

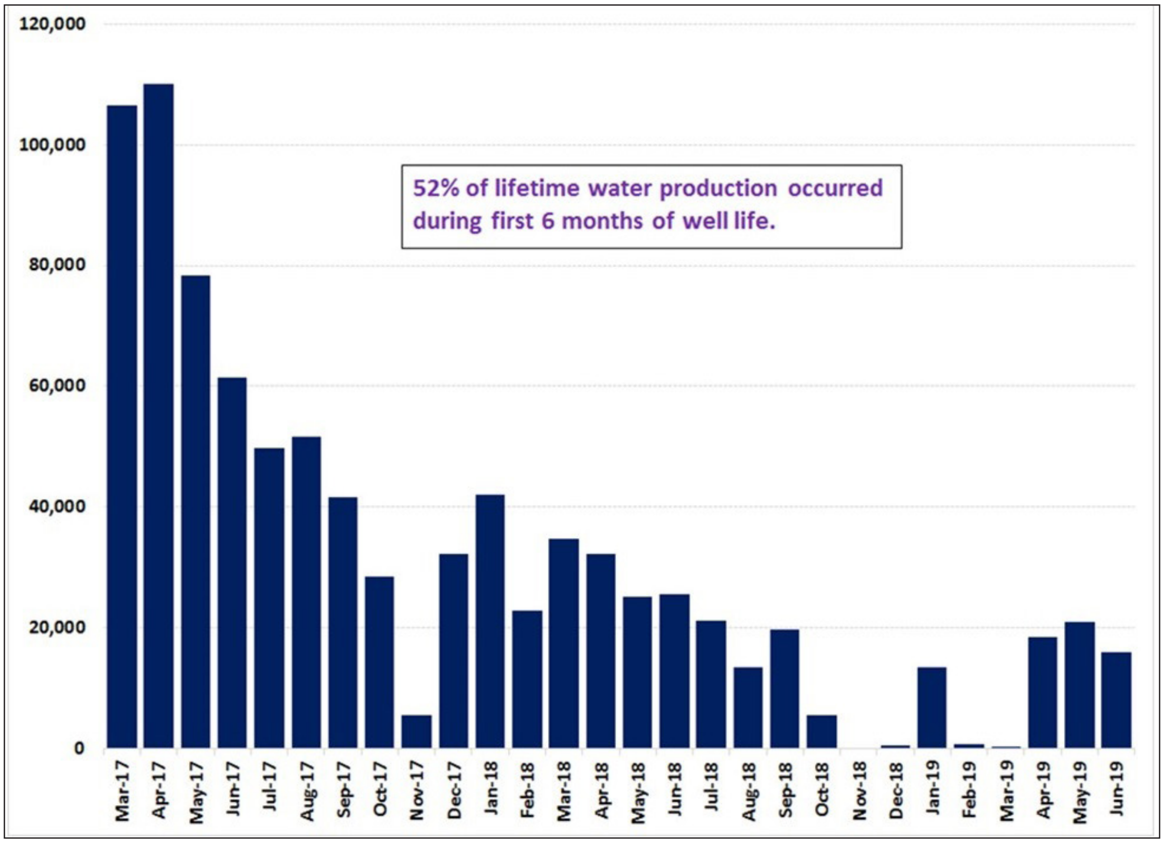

Figure 4. Permian Basin unconventional wells' water production is frontloaded just like oil and gas output is. Source: New Mexico Oil Conservation Division 2019, Author's analysis.

could be drilled in that bench, implying the opportunity for a midstream firm to gather 18 million barrels of lifetime produced water from that single 640-acre section. But conservative spacing of 1,320 feet between wells (4 wells per section per bench) now being tested by multiple Permian Basin operators would chop that cumulative water total down to 6 million barrels (Jagged Peak Energy 2019; Laredo Petroleum 2019).[4] This would force the midstream firm to potentially amass three times as much dedicated acreage to obtain the same volume of water it had expected before.

Needing more acreage to obtain a given produced water volume also exposes water midstream companies to a higher degree of geological risk, as reservoirs can vary dramatically across a tract. This also reinforces how interconnectivity between systems that allows water midstream management teams to potentially minimize their upfront capital investments and adopt a "wait and see" attitude for future capacity additions can enhance capital efficiency, profitability, and reduce investor risk. Interconnectivity can also help water midstream firms more effectively manage temporal risk—namely, the fact that oil and gas wells can be drilled, completed, and brought to sales in 2–5 months, while the time needed to obtain permits to drill disposal wells and actually install the infrastructure can be more than twice as long.

The ability to dynamically share capacity across systems can help developers rightsize systems to maximize capital efficiency. Unexpected peaks could be routed into other networked water systems, thus reducing the need to overbuild capacity on the front end and risk stranding capital if development slows or does not occur at the rate or scale originally planned. Capacity sharing also would help water management firms mitigate risk from commodity price shifts that cause drilling and completion activity to decrease, potentially leaving them with a high capital mortgage on underutilized assets. This risk is more pronounced than commonly acknowledged because the water flows from unconventional wells broadly mimic the wells' oil and gas production curves—heavily frontloaded with a material portion of total lifetime water volume coming in the first 2–3 years of well life (Figure 4).

Being able to wheel water around a larger network might also allow water midstream operators to offer more flexible contract structures to operators by reducing the dependence on any single operator as an anchor customer of the infrastructure. The degree to which this remains true in practice in a given area will depend on the ultimate market concentration that results as E&P operators continue to consolidate.

[4] See, for instance Jagged Peak Energy 2019 and Laredo Petroleum 2019.

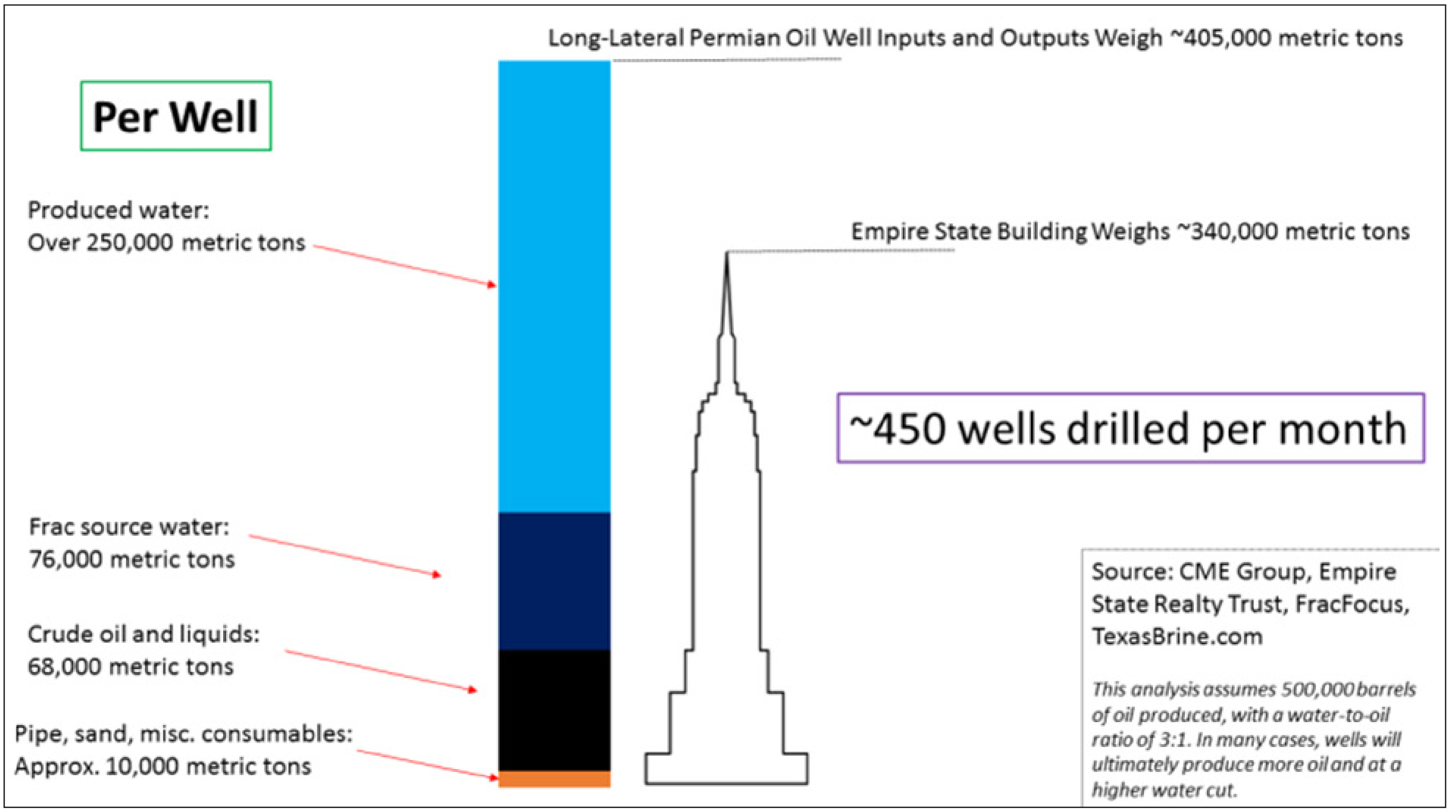

Figure 5. Mass of inputs and outputs from drilling and completion of and production from a 2-mile lateral Delaware Basin oil well. Source: FracFocus 2019, Author's Analysis.

Other benefits of greater oilfield water infrastructure connectivity

An oilfield water hydrovascular grid also yields a number of other benefits beyond capital efficiency, including enhancements to social license to operate, as well as the use of produced water in creative, nontraditional ways outside of the oilfield.

Water movement plays an outsize role in oilfield safety issues, which in turn directly influence firms' social license to operate. The author's modelling of a prototypical Delaware Basin horizontal well with a 2-mile lateral suggests that the combined lifetime mass of inputs used to drill and complete the well and the fluids produced from it exceeds 400 thousand metric tons (Figure 5). Of that total, over 325 thousand metric tons, or nearly the mass of the Empire State Building, comes from water (Collins 2018b). Note here that mass is used instead of volume because mass is what ultimately destroys roads and causes many of the water-driven social impacts currently seen across the oilfield.

Significant amounts of water still move by truck in the Permian Basin. One key end result of this is a road death rate in the core Permian Basin counties of Texas that is on par with that of Russia, one of the world's most dangerous industrialized countries to drive in (Collins 2018a). Water movement in trucks also inflicts severe road damage that outstrips local governments' ability to pay for repairs and, if left unchecked, could negate much of the benefit that planned road investments in the Permian Basin are otherwise poised to provide. Broader interconnectivity between water pipeline systems can help take more trucks off the roads.

Improved connections between oilfield water systems can also help manage seismicity issues. Seismic activity is emerging as a particular challenge in parts of the Delaware Basin, where the Texas Railroad Commission has adopted a risk-based permitting approach that can dramatically increase the time needed to get a saltwater disposal well permit and can also lead to significant cutbacks in allowable daily injection volumes. If cutbacks were imposed after a developer had sunk capital into a disposal well network, the economic impacts could be severe at the project level (Collins 2018d). Thus, being able to weave multiple water networks together with pipelines could allow water services providers in seismically active areas to optimize their investments in tough to obtain disposal wells and allow diversion of water to other disposal wells if future seismic events prompted regulatory cutbacks to injection volumes.

Greater oilfield water system connectivity can also help promote produced water recycling and the conservation of precious local freshwater resources in the Permian Basin. Consolidation

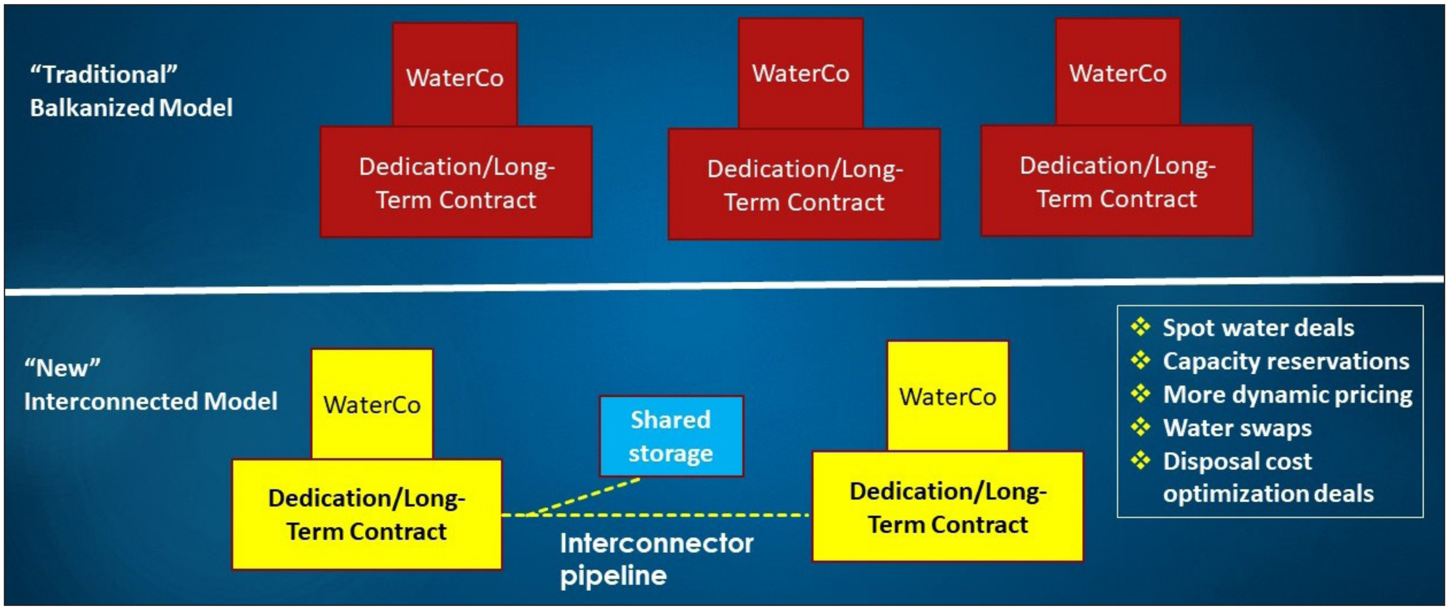

Figure 6. How greater water infrastructure connectivity can facilitate more dynamic commercial and financial structures.

of water systems and the creation of a broader hydrovascular grid will likely promote greater levels of water trading and recycling.

System interconnections can facilitate swaps and dynamic trading of water volumes that will help make the oilfield water space more like the developed commodity markets seen in oil and gas midstream or electrical power (Figure 6). Both of these sectors are very CAPEX and infrastructure-intensive, but oil and gas molecules and electrons are generally substantially more fungible than water molecules are in most of today's Permian Basin water systems.

Consider the following illustrative example: E&P Company A delivers water for disposal into Midstream Company A's system at a charge of $0.70 per barrel, while E&P Company B, which is hooked up to Midstream Company B's pipeline system, needs water 15 miles away for a frac. Midstream A is linked by a pipeline to Midstream B and is operating near the capacity of its system, while Midstream B is underutilized and has headroom to work with. Midstream A can thus either allow Midstream B to take a certain volume of water free of charge (because the reduction in SWD operating cost increases its profits) or charge Midstream B a reduced rate relative to freshwater or treated produced water prices in the area—say $0.15 per barrel—and also make an additional profit while avoiding disposal costs on the water sent out of system (Figure 7).

Assume it costs Midstream Company A $0.20 per barrel to dispose of or recycle the water in the most expensive facilities in its system because the low-cost options are full. Further assume that it costs $0.10 per barrel to pipe the raw produced water to Midstream B's system, and Midstream B will pay $0.10 per barrel for delivered raw produced water. Midstream A can thus make a net gain of $0.20 per barrel of water shipped to Midstream B rather than using the highest cost marginal disposal wells available in its own system.[5]

Such a future with pipeline-grade produced water that can be exchanged between systems with minimal to no additional treatment is already rapidly emerging and will only gain steam with further consolidation.[6]

Solutions beyond the oilfield

Consolidation may also open the door for out-of-basin water movement at a scale far larger than what is seen today. Large-scale midstream infrastructure has the potential to enable creative new uses of water beyond disposal and recycling alone.[7] This would likely require utility-scale systems with pipelines that could be 36 inches in diameter or larger. These ideas also presuppose two other developments: (1) a higher degree of interconnection between oilfield water handling footprints,

[5] $0.10 is avoided cost - pipeline shipping cost from sidestepping A's highest cost disposal assets and $0.10 of the total comes from B's actual payment for the raw produced water.

[6] The idea of pipeline grade produced water comes from the natural gas industry, where gas must meet certain quality specifications in order to be considered of pipeline quality and be sold into commercial pipeline systems. See, for instance, Foss MM. 2004. Interstate Natural Gas—Quality Specifications & Interchangeability. Sugar Land, TX: Center for Energy Economics. Available from: http://www.beg.utexas.edu/files/energyecon/global-gas-and-lng/CEE_Interstate_Natural_Gas_Quality_Specifications_and_Interchangeability.pdf.

[7] It is also important to start thinking now about repurposing part of the produced water stream, so that the practices and technologies have a better chance of being deployable at scale when oilfield recycling demand begins to slow in coming years as parts of the Delaware and Midland Basins reach maturity.

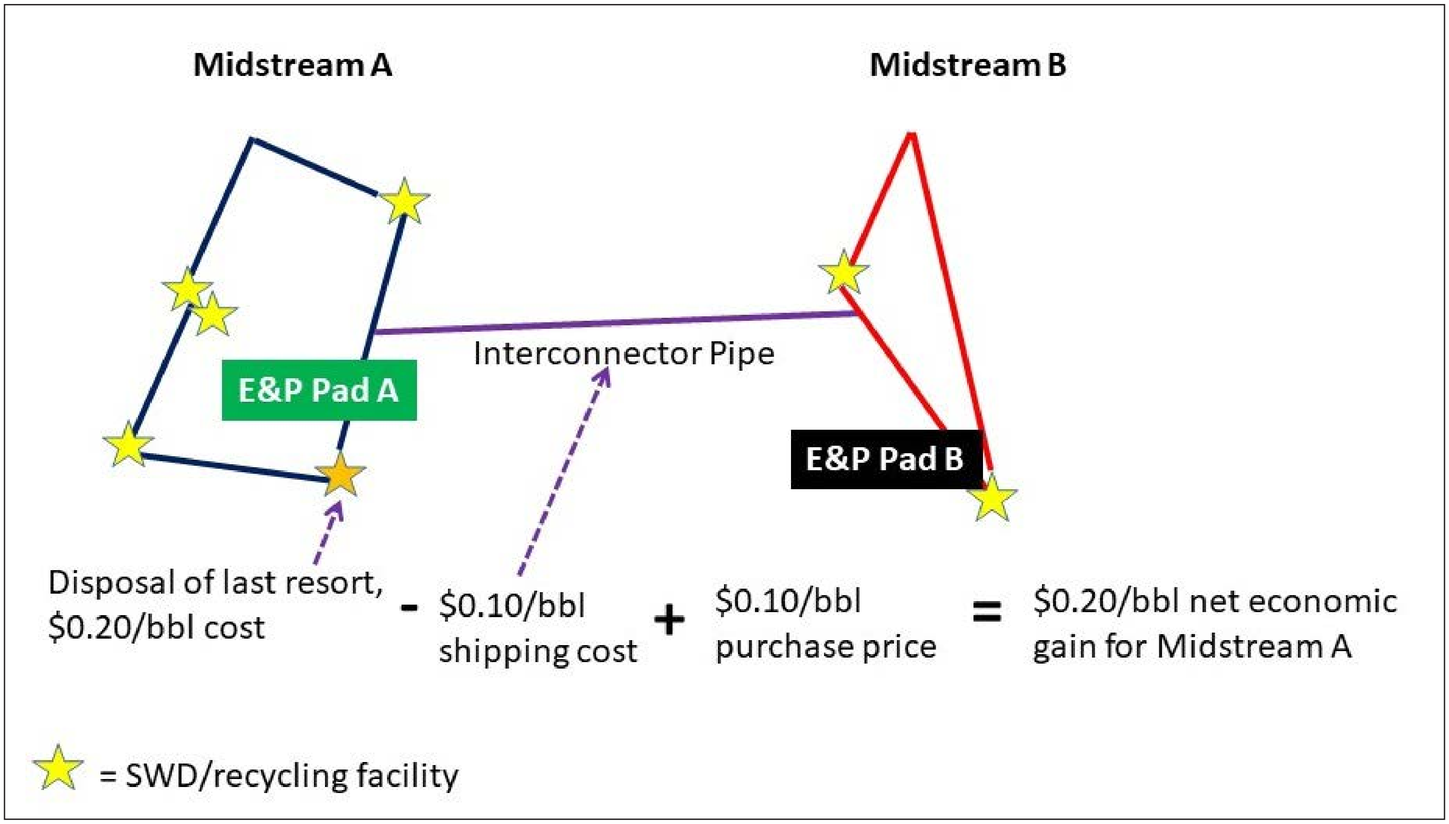

Figure 7. Simple illustration of gains through trade facilitated by interconnectivity.

which at this point in time are highly fragmented, and (2) lower-cost treatments that can provide "upgraded" produced water at scale.

Repurposing may eventually involve local agricultural use, as well as longer distance transport to cities or industrial consumers located far from the oilfield. For liability reasons, the initial agricultural uses of treated produced water are likely to focus on crops such as cotton and biofuel feedstocks (switchgrass or algae, for instance) that humans do not consume by taking into their bodies. The "non-consumption" distinction is made here to clarify that even certain non-food items such as hemp still yield outputs that humans introduce into their bodies. It is also essential to do substantially more research into the potential long-term impacts on soil of irrigating with various concentrations of produced water.

Possible agricultural uses

At least one preliminary trial shows some promise. Texas A&M University researchers and Anadarko (now owned by Oxy) conducted a pilot study near Pecos, TX in 2015 that entailed irrigating cotton plots with a blend of freshwater and treated produced water (Lewis 2015). While the study's results were not peer-reviewed, in its particular case the data showed that cotton lint yields remained stable, and the use of the blended water suggested the potential for better managing soil salinity and potentially improving soil quality (Lewis 2015). There is an urgent need for peer-reviewed scientific studies that span multiple crops and multiple growing seasons on the same land plots, and the plant science community is beginning to deliver these.

At least two recent studies have irrigated spring wheat with blended produced water from the Niobrara Formation in the Denver-Julesburg Basin of Northeastern Colorado. The first analysis irrigated wheat groups with Fort Collins, Colorado municipal tap water, a 10% produced water/90% tap water blend, a 50% produced water/50% tap water blend, and a salinity control solution that incorporated sodium chloride to match the total dissolved solids (TDS) content of the 50% produced water blend (Sedlacko et al. 2019). Wheat irrigated with both produced water blends suffered significant declines in plant size and grain yield relative even to the high salinity control solution, suggesting that chemical components of the produced water other than salinity were adversely impacting plant health (Sedlacko et al. 2019). Some members of the research group then conducted a follow-on study using the same water blends to investigate the impacts varying blends of produced water might have on spring wheat's immune response to one bacterial pathogen and one fungal pathogen (Miller et al. 2019). The research revealed that wheat irrigated with both produced water blends (10% and 50%) experienced significant immune system suppression relative to the tap water and high-salinity irrigated test groups. The researchers hypothesized that the physiological effects on the plants could be explained by both inorganic constituents such as boron and hydrocarbon-related organic compounds in the water (Miller et al. 2019).

As other scientists conduct similar analyses using waters derived from Permian Basin wells, more heavily treated produced water, and different crops, sector participants will be able to more clearly assess whether produced water indeed offers upside as an irrigation water source.

If certain waters/crops prove tolerant of irrigation with produced water, a large and ongoing body of work on saline agriculture in other parts of the world potentially offers insights for farmers in the Permian Basin who might contemplate greater use of produced water as part of their irrigation water supply. The International Center for Biosaline Agriculture (ICBA), based in the United Arab Emirates, is a global leader in developing a range of salt-tolerant crops, including quinoa, mustard, *Sesbania*, safflower, triticale, and *Salicornia* (ICBA 2018). These plant strains have generally not yet been commercialized but are sufficiently salt-tolerant that they can even be irrigated with seawater (approximately 35,000 mg/l TDS), suggesting that they could utilize blended produced water if other chemical constituents in the water do not harm them.

Salicornia, a member of the beet and spinach family also known as glasswort, already has at least one variety that grows wild along the Texas coast, and the species more broadly shows promise as a biofuel source (Sea Center Texas 2019). In January 2019, the UAE's flagship airline, Etihad Airways, used *Salicornia*-derived biojet fuel to successfully power a commercial flight on a Boeing 787 from Abu Dhabi to Amsterdam (Etihad Aviation Group 2019). These experiences suggest that there may indeed be a range of non-food crops that could eventually be commercially grown in the Permian Basin with treated produced water as one of the core irrigation water sources. They also highlight a potential point of international engagement and a set of new development opportunities for farmers and water companies in the Permian Basin.

Logistics of moving water beyond the Permian Basin

Current state of the art for out-of-basin movement are the Llano and Rattlesnake Pipeline systems operated by Goodnight Midstream (Goodnight Midstream 2019). Yet with several hundred thousand bpd of capacity and movement beyond basin boundaries of perhaps 25 miles, these pipelines are smaller scale than what may ultimately be required to send water out of the basin, particularly if oil prices remain high enough that the tens of thousands of additional wells are developed.

The next phase of beyond-basin water transportation could involve movements of 100 miles or more, with individual line capacities of 500 thousand barrels per dayor greater. As an example of what the capital investment and transportation economics for such a development could look like, consider the Vista Ridge Pipeline.[8] Vista Ridge is slated to enter service in 2020 and carry freshwater 142 miles from Burleson County to the city of San Antonio (San Antonio Water System 2019). The line will transport approximately 1 million bpd of water, making it broadly representative of the scale likely needed for many long-distance produced water transport projects to be economically viable (Garney 2019b). The author acknowledges that Vista Ridge is a freshwater project and that transporting produced water is more challenging from a physical and chemical perspective and thus can cost significantly more than would be the case for freshwater projects. Nonetheless, freshwater projects still provide useful illustrations of achievable physical scope and scale for future long-distance produced water movement projects. With respect to economic challenges, if future disposal constraints drove the costs of handling the marginal barrels of produced water near their source high enough, export projects would likely be able to overcome the higher cost burdens and still deliver economic returns.

KEY CHALLENGES TO BUILDING A PERMIAN BASIN OILFIELD HYDROVASCULAR GRID

Challenge 1: Capital providers' return expectations diverge from underlying market realities

The single toughest challenge for consolidating Permian Basin water systems will likely be the existing spreads between what many financial sponsors think their project is worth and what the market is likely to actually value the assets at. Bid-ask differentials will be exacerbated by the fact that a large part of both the Delaware and Midland Basins are now claimed under acreage dedications, many of which are now perfected to varying degree with actual built water infrastructure.

In areas without duplicative development, the spread will likely be easier to manage. But in a situation such as that described earlier in this paper, with two adjacent systems each running at 40–50% of nameplate capacity and each developer having sunk large sums of capital into their respective projects, the exercise of trying to rationalize capacity in the face of sponsors who expect a two and a half times return on capital invested may prove impossible in the near-term, absent some type of

[8] Note that the Vista Ridge project transports water purchased under a long-term, price-stable agreement from a private developer for us in a public utility system. Transactions conducted through an oilfield hydrovascular grid would be more analogous to spot and term-based merchant commodity transactions. Furthermore, in an oilfield water context, the party purchasing or selling water is likely to move the molecules to market using its own infrastructure.

financial distress situation that forces the parties to revise prior expectations (Collins 2018c).

Challenge 2: Incentivizing landowners to support a produced water market and freer movement of water across tract boundaries

Capital sponsors will not be the only vested interest that potentially has incentives to challenge consolidation. Oilfield water rents have become a vital source of income to many Permian Basin landowners, particularly those in Texas who control the surface rights (which groundwater runs with as a matter of law) but not the minerals. Geographical distinctions matter greatly because unlike Texas, where surface owners almost certainly legally own the produced water as a matter of law, New Mexico now has specifically legislated that oil and gas operators own the produced water in that state and have the right to dispose, treat, sell, or transfer such water as they please.[9]

Can Texas landowners be incentivized to participate in a hydrovascular grid?

There are strong strategic arguments for treating landowners as real stakeholders in water projects that may span multiple property boundaries. First, landowners will likely increasingly want to be paid in some way for any produced water that is clearly creating value for third parties that they are presently not sharing in. Second, additional creative solutions are likely to find their way into water development agreements between landowners and midstream service providers. For instance, if produced water from multiple surface tracts is processed or disposed of at a central facility, landowners might seek a prorated distribution of a royalty, perhaps apportioned on the basis of surface acreage size or volumes derived from specific tracts (Collins 2017b). Indeed, the available Texas case law strongly supports landowners' ownership rights toproduced water, particularly if an operator seeks to use that water off-lease.[10] The right to compensation will likely follow this affirmed ownership of private property.

Landowners are likely to take a strongly proprietary view of water as being theirs even if it is introduced into a pipeline system that may commingle water from hundreds of leases and many surface owners. Complicating matters further, landowners with surface use agreements that require operators to prioritize the use of freshwater from the tract and dispose of produced water on-tract could conceivably believe that a broader hydrovascular grid threatens their income streams.

The Midland and Delaware Basins present different situations. Midland Basin landowners tend to hold smaller tracts, while the Delaware Basin is dominated by large landowners, who in some cases control more than 50,000 acres (larger than the City of Midland's area). Smaller landowners could be offered a severance fee that makes the water property of the water infrastructure system operator, no further strings attached. Those who were not willing to participate could be bypassed by infrastructure.

Larger landowners are more complicated because bypassing someone who controls 20 or more square miles may not be economically practicable. In cases where a system is connected to leases atop several surface tracts one possibility would be to introduce an inert tracer of some type into water leaving the tract boundaries at a specified concentration. At a monetization point downstream in the water system, the relative change in the concentration of the tracer could then be used to help determine what share of the revenue the landowner whose tract the water originally came from would be entitled to (Figure 8). Disparate tracts of land could also be unitized for produced water management purposes just as is currently done for oil and gas production.

The devil will be in the economic details. It is very possible that some landowners may seek a severance fee so high it destroys the overall economics of a grid-style water project. In practice, landowners are likely to seek severance fees that reasonably approximate what they can currently get paid for water sent down disposal wells. But there is little guidance from publicly available data on potential severance fee rates, and royalty rates/fee structures negotiated in opaque private markets can vary widely. Among other factors, the royalty rates historically paid by E&P operators and water midstream firms may be too high to allow the long-distance, cross-tract transfers that become possible with an interconnected hydrovascular grid.

These rates arose in a period where the parties involved saw produced water as either a byproduct to be rid of as quickly as possible (E&Ps in the pre-recycling era) or as a tolling market where the water should be moved the minimum necessary distance and then be disposed of (water midstreams). Landowners talk to one another and anchor quickly on what are seen to be the prevailing market rates in a given area. Thus, resetting produced water disposal rates is likely to be difficult unless injection disposal becomes regulatorily impossible or at least severely restricted in key parts of the Permian Basin. If such events transpire, the volume and price effects would ripple across the Permian Basin more broadly and could shift price setting power in water developers' favor (in other words, "If I can't dispose of the volumes I thought I could via the SWD on your land, I'm no longer going to pay you $X per barrel. If you

[9] Chapter 70 NMSA 1978, Section 4 (A)(1), The Produced Water Act, which in relevant part states that "The working interest owners and operator shall have a possessory interest in the produced water, including the right to take possession of the produced water and to use, handle, dispose of, transfer, sell, convey, transport, recycle, reuse or treat the produced water and to obtain proceeds for any such uses."

[10] Robinson v. Robbins Petroleum Corp., 501 S.W.2d 865 (Tex. 1973).

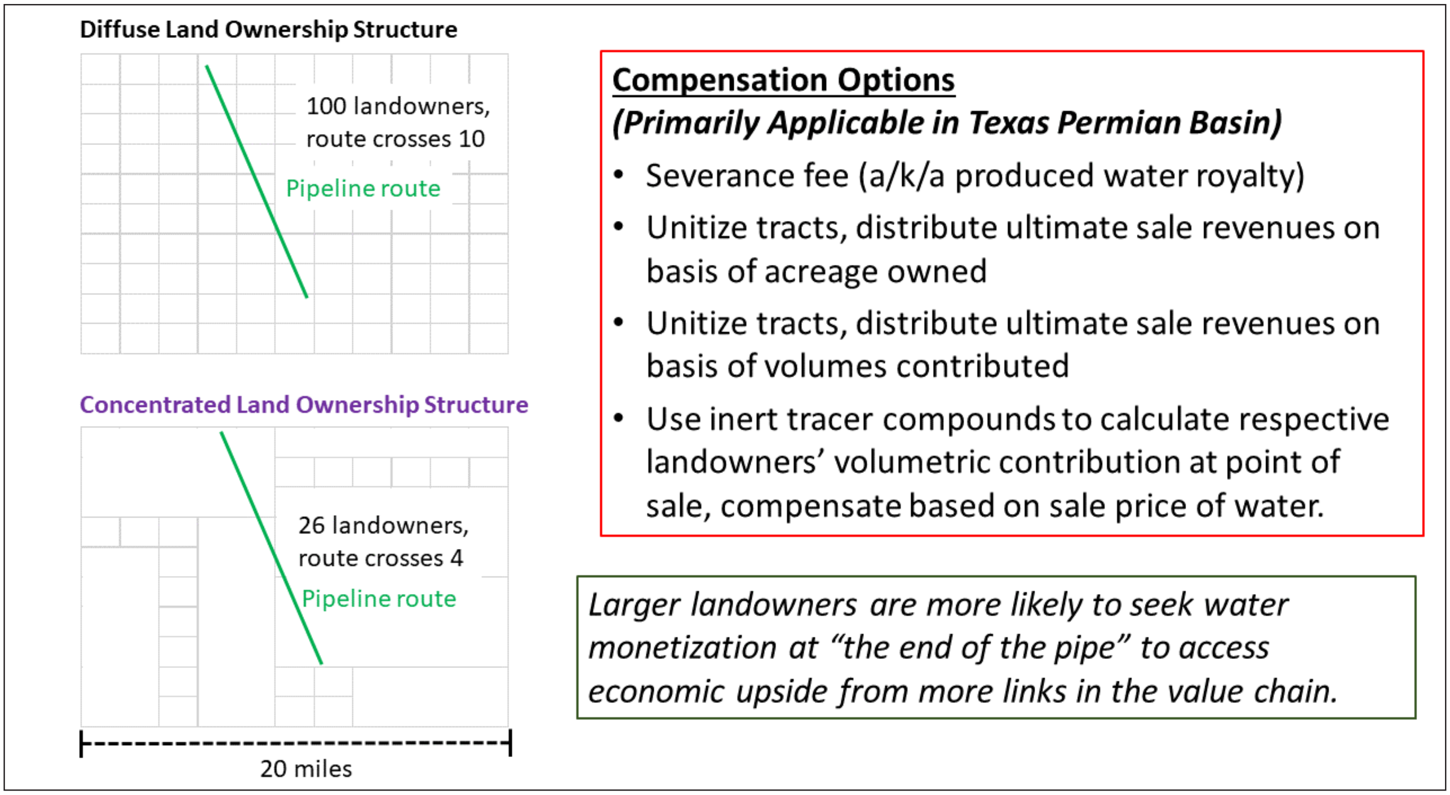

Figure 8. Incentivizing Texas landowners to buy in to a broader, more interconnected hydrovascular grid.

want the activity, the new price will have to be $0.8X or whatever is necessary to allow me, the developer, to unlock value.").

One of the few pieces of currently available produced water pricing data come from the agreement signed in January 2019 between University Lands and UL Water Midstream, LLC (composed of H2O Midstream and Layne Water Midstream). This agreement contains a royalty schedule for a range of water-related activities (Figure 9). Note that University Lands is the largest single landowner in West Texas, managing the surface and mineral interests of 2.1 million acres of land across 19 counties in West Texas (University Lands 2019).

The University Lands contract sheds some light on the rents sought by a party that is both an institutional landowner and also owns the mineral rights. However, a private, multigenerational ranch family (particularly one that does not control the mineral estate under their property) would likely find many of the royalty rates specified above to be unacceptably low.

University Land's agreement also does not address the elephant in the room for a hydrovascular grid—what, if any, rent is to be paid for moving water into a pipeline system that would take it off-tract? If UL Water Midstream wants to move produced water into other water systems, it must execute an amendment "containing mutually agreeable terms for the allocation of revenue" associated with such a water movement (Preferred Water Service Provider Agreement 2019). But no actual rates are set forth.

Challenge 3: Building the Permian Basin-produced water marketplace

If the number of discrete oilfield water networks in the Permian Basin continues to consolidate and become more tightly interlinked, the corresponding number of parties who could transact with each other also decreases. Consequently, the emerging market will likely be a more condensed version of what currently exists—a "speed dial marketplace" where most participants either already actually know each other, or if not, are an introduction and a phone call away.

The key market creation challenges will thus not be the need to bring buyers and sellers together in an "eBay" sense. Rather, the five key challenges will be: (1) building supersized oilfield water infrastructure and (2) financing water infrastructure at larger scale, and for projects that are more predicated upon sharing than is presently the case, (3) ensuring a baseline set of water quality standards, (4) pricing water transferred between systems whose underlying capital and operating cost structures could be substantially different, and (5) managing legal liabilities associated with transferring water that may be extremely saline and contain leftover completion chemicals and other contaminants.

Physical construction challenges are likely to be highly surmountable. In 2012 and 2013, a consortium of water infra-

Percent of Gross Revenues to University Lands				
	Years 1-5	Years 6-7	Year 8	Years 9-10
Gathering	5%	7%	8.5%	10%
Re-Use	0%	5%	5%	5%
Disposal	7%	10%	10%	10%
Sourcing & Delivery	20%	25%	30%	30%
Skim Oil	10%	15%	15%	15%
Other Revenue	5%	5%	5%	5%

Figure 9. University Lands comprehensive water royalty schedule. Source: Preferred Water Service Provider Agreement 2019.

structure-focused firms needed only 10 months to build a 60-mile, 48-inch diameter freshwater pipeline linking the T-Bar Ranch in Winkler County to the City of Midland, as well as emplace all of the necessary supporting infrastructure (Garney 2019a). Multiple of these same firms are currently working on the Vista Ridge Project in Central Texas, which upon entering service in 2020 will be capable of moving 1 million bpd of water into the San Antonio area.

Financing water infrastructure at a larger scale will require baseline cashflow assurances. In essence, can lenders be confident that the project will be able to service its debts? One wrinkle is that for out-of-basin projects done in conjunction with municipalities, project developers may be able to avail themselves of the municipal entities' credit ratings (if strong) and secure more advantageously priced financing as a result. Capital providers are interested in the space—witness WaterBridge's $1 billion Term Loan B announced in June 2019 (WaterBridge 2019). However, the transaction also suggests that lenders are attaching a meaningful risk premium. The WaterBridge Term Loan B priced at Libor + 575 basis points, a total interest rate of nearly 8% (WaterBridge 2019).

Debt issuances provide valuable insights into how the market currently perceives the risk profile of a water midstream firm. WaterBridge, one of the Permian Basin's water midstream titans, currently receives a long-term issue credit rating of B from S&P Global (Figure 10) (AC Investment 2019). S&P explains a B rating as meaning the "obligor currently has the capacity to meet its financial commitments on the obligation. Adverse business, financial, or economic conditions will likely impair the obligor's capacity or willingness to meet its financial commitments on the obligation" (S&P Global 2019).

In other words, the firm's financial condition is likely to remain in good shape in a stable macro environment, but if oil and gas prices decline and/or the company cannot secure stable long-term contracts to assure cashflows, such events can quickly threaten its financial health. The significant ratings disparity—and implications for cost of capital—between a large oilfield water firm like WaterBridge and a local municipality (such as the City of Midland) also help illustrate the attractiveness of public-private partnerships from the perspective of the lower-rated party who may need help financing infrastructure and other items.

Water quality issues will also likely pose challenges as produced water from different formations is commingled in water systems gathering from potentially hundreds of discrete leases. However, these operational and engineering challenges are likely to be overcome as the economic incentives for water infrastructure connectivity continue to grow. Multiple examples of "raw" produced water being sold out of gathering lines as frac fluid feedstock, as well as the recent Concho-Solaris recycled water supply deal, make the author optimistic that market participants are already well on their way to hammering out the

Rating	Characteristics	Examples
AAA	The obligor's capacity to meet its financial commitments on the obligation is extremely strong.	Microsoft
AA	An obligation rated 'AA' differs from the highest-rated obligations only to a small degree. The obligor's capacity to meet its financial commitments on the obligation is very strong.	City of Midland, Texas (AA+)
A	Somewhat more susceptible to the adverse effects of changes in circumstances and economic conditions than obligations in higher-rated categories. However, the obligor's capacity to meet its financial commitments on the obligation is still strong.	American Water
BBB	Exhibits adequate protection parameters. However, adverse economic conditions or changing circumstances are more likely to weaken the obligor's capacity to meet its financial commitments on the obligation.	Kinder Morgan
BB	Less vulnerable to nonpayment than other speculative issues. However, it faces major ongoing uncertainties or exposure to adverse business, financial, or economic conditions that could lead to the obligor's inadequate capacity to meet its financial commitments on the obligation.	
B	More vulnerable to nonpayment than obligations rated 'BB', but the obligor currently has the capacity to meet its financial commitments on the obligation. Adverse business, financial, or economic conditions will likely impair the obligor's capacity or willingness to meet its financial commitments on the obligation.	**WaterBridge Operating**
CCC	Currently vulnerable to nonpayment and is dependent upon favorable business, financial, and economic conditions for the obligor to meet its financial commitments on the obligation. In the event of adverse business, financial, or economic conditions, the obligor is not likely to have the capacity to meet its financial commitments on the obligation.	
CC	Currently highly vulnerable to nonpayment. The 'CC' rating is used when a default has not yet occurred but S&P Global Ratings expects default to be a virtual certainty, regardless of the anticipated time to default.	
C	Currently highly vulnerable to nonpayment, and the obligation is expected to have lower relative seniority or lower ultimate recovery compared with obligations that are rated higher.	
D	In default or in breach of an imputed promise. Also used upon the filing of a bankruptcy petition or the taking of similar action and where default on an obligation is a virtual certainty, for example due to automatic stay provisions. A rating on an obligation is lowered to 'D' if it is subject to a distressed exchange offer.	

Figure 10. S&P Global long-term issuer credit ratings, WaterBridge vs. other selected corporates and an oilfield municipality. Source: S&P Global 2019, City of Midland 2019.

water quality issues likely to be faced by more systematically connected water systems.[11]

How to price water as it moves across systems will be a substantial but surmountable challenge. Crude oil pipeline systems already provide an excellent working example of how to differentially assess commodity movement charges over varying distances and producer commitment levels in a networked infrastructure ecosystem (Figure 11).

Perhaps the most challenging part of the market design puzzle will be figuring out pricing and rent sharing across systems so that infrastructure owners and the original water owners (i.e. surface owners) can be sufficiently compensated to incentivize cross-system water movements. Continued low oil prices will sharpen the discussion because the final economic structure also needs to avoid overly burdening oil and gas producers with water-related operating costs. Ideally, the structures developed will ultimately help E&P companies lock in lower water services costs that can endure through multiple commodity price cycles and help ensure that the Permian Basin remains globally competitive and can fulfill its formidable long-term productive potential.

A final portion of the market puzzle is how legal liability will be treated. New Mexico law appears to provide a clear and comprehensive set of incentives for the aggregation, treatment, and movement back to market of produced water, even across tract boundaries. The Produced Water Act (House Bill 546) passed in the 2019 New Mexico Legislative Session clarifies E&P operators' de facto ownership of the water, gives them and subsequent transferors the ability to transfer produced water with clean title, prohibits private parties from charging transit fees to entities moving water across surface lands owned by the state of New Mexico, and makes agreements that mandate use of on-tract freshwater or that otherwise would restrict the use of recycled produced water void as against public policy.[12]

[11] See, for instance Cimarex's use of "raw" untreated produced water from its SWD system as feedstock for frac fluid and also Concho Resources Inc. and Solaris Water Midstream Form Joint Venture for Produced Water Management in the Northern Delaware Basin. 2019 Jul 31.Solaris Water Midstream. Available from: https://www.solarismidstream.com/news/concho-resources-inc-and-solaris-water-midstream-form-joint-venture-produced-water-management (Solaris will provide Concho with "blended reuse source water" derived from multiple operators on Solaris's gathering and disposal network).

[12] "Fluid Oil & Gas Waste Act," H.B. 546, https://nmlegis.gov/Legislation/Legislation?Chamber=H&LegType=B&LegNo=546&year=19.

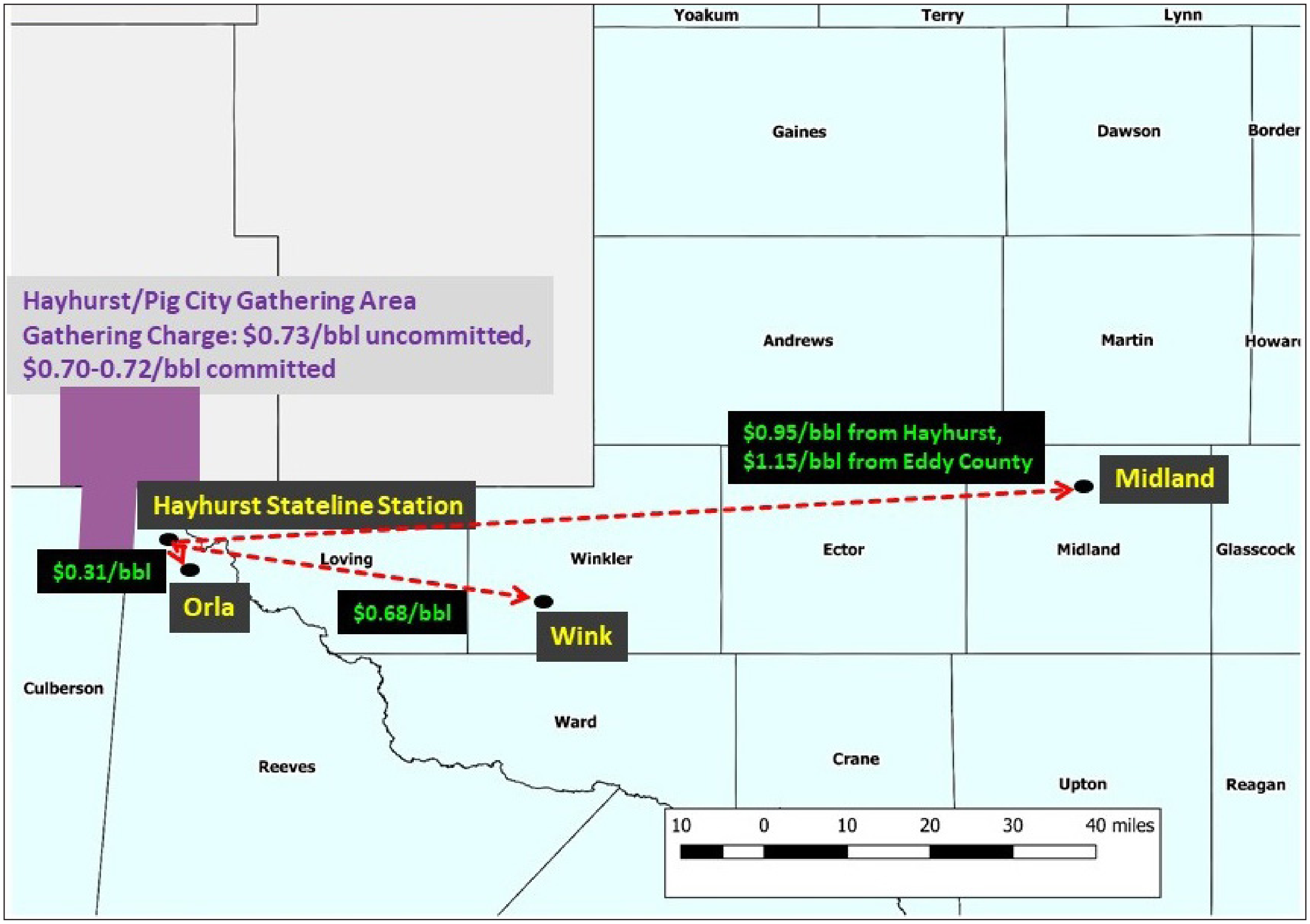

Figure 11. Commodity logistics pricing at basin-wide level (case of crude oil). Source: Federal Energy Regulatory Commission 2019, Author's Analysis.

Texas's limited body of law on produced water has evolved very differently due to the predominantly private ownership of surface lands in the state, as well as the fact that surface owners in Texas own all groundwater as a matter of law, including produced water (Collins 2017a). The author is currently working on a follow-on deep dive analysis of produced water ownership law in Texas, how it has developed, and how private property owners are likely to respond to recent legislation that allows E&P operators to attain ownership of produced water by capturing and recycling it. As such, the author will reserve further comment on Texas-specific produced water legal issues until the publication of that analysis, noting only that the legal basis exists for building a Permian Basin-scale hydrovascular system, and that any future legislation is unlikely to derail this emerging trend.

CONCLUSIONS

The emergence of a broader Permian Basin oilfield water hydrovascular grid faces several significant challenges. Nonetheless, the burgeoning volumes of produced water in the Permian Basin, pressure to optimize CAPEX in the face of commodity price uncertainty, E&Ps' need to manage water-related costs, and the ever-present prospect of drought are among the powerful incentives that will likely drive sector participants to develop creative solutions. Oilfield activity evolves fast, and the services business supporting it—water management first and foremost—evolve with equal velocity. Some of the solutions posited in this paper will come to pass, some will not, and many others we have not even thought of yet will be developed as entrepreneurs flock to the Permian Basin's uniquely large oilfield water marketplace. As consolidation ripples through the oilfield water space, a fascinating ecosystem of mutually reinforcing academic, policy, investor, and producer interests will continue evolving and spinning off opportunities.

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