Unconventional Oil and Gas: Interactions With and Implications for Groundwater

BRETT A. MILLER
ASSOCIATE ATTORNEY
PHELPS DUNBAR LLP
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Introduction

Much of the tension between science, policy, law, and regulation stems from the uncertainty that characterizes the relationship between groundwater and unconventional production.

Any baseline consensus regarding how and to what extent hydraulic fracturing interacts with groundwater is elusive across disciplines:

  e.g., the standards of legal causation in a judicial context may be heightened when compared with the statistical standards underlying scientific correlation.

Described as “so secret, occult, and concealed that an attempt to administer any set of legal rules [involves] hopeless uncertainty” (Houston & T.C. Ry. Co. v. East (1904)), the Texas Supreme Court’s early venture into the realm of groundwater jurisprudence foreshadowed the regulatory challenges underscoring the intersection of groundwater and the current shale revolution.

Science is on the cusp of understanding the dynamics of groundwater contamination in localized scenarios, both from natural and anthropogenic sources, but law and regulation maintain the tendency to lag behind.
Background

- Public health concerns attributed to fracturing operations stem from the potential for groundwater contamination due to fracturing fluids, natural formation waters, and stray gases (Jackson et al. 2013).

- The debate surrounding hydraulic fracturing and groundwater contamination has focused on distinct categories of interactions that could impact groundwater quality (Vengosh et al. 2013):
  1. stray gas migration to shallow groundwater aquifers (Osborn et al. 2011),
  2. possible connectivity between deep shale formations and shallow aquifers (Warner et al. 2012), and
  3. potential contamination from fracture fluids, flowback waters, and produced brines containing toxic substances during drilling, transport, and disposal (Gregory et al. 2011).

- Research studies near hydraulic fracturing activities have indicated both elevated levels of methane (Osborn et al. 2011) and stray thermogenic natural gas in groundwater samples (Darrah et al. 2014).

- Other studies, however, have found the natural occurrence of dissolved gases in areas that are not close to active hydraulic fracturing activities (Siegel et al. 2015), as well as the presence of methane contamination in groundwater before drilling activities (Molofsky et al. 2013).
Texas
Active Oil and Gas Wells
Surface Wellbores
January 2018

Major Aquifers of Texas

Legend
- Gas Wells
- Oil Wells

- Texas Interstates
- Major Water
- Major Cities
- Counties
Interactions between groundwater and surface oil & gas activities present additional risks with natural hydrological connectivity between surface water and groundwater.

In the Bakken (Lauer et al. 2016) and Marcellus (Warner et al. 2013) formations, groundwater contamination has been attributed to surface spills, documented presence of inorganic constituents and heavy metals in drinking water supplies.

Deficient baseline groundwater quality data may limit the scope of regulatory oversight and may hinder the task of establishing legal causation to assign liability.

Eagle Ford scientists call for more extensive investigations into groundwater quality (Hildenbrand et al. 2017).

Injection wells provide another conduit for fracture fluids and wastewater to contaminate drinking water supplies (Jackson et al. 2015).

2016 report by the EPA found evidence of drinking water contamination in various stages in the fracturing process.

Given the intensive capital and operating expenses, operators have an economic incentive to prevent interactions between hydrocarbon recovery and groundwater.

“[P]ossibility of human error means that the risk of groundwater contamination is not zero.” (Spence 2014).
Potential Risks to Groundwater from Fracturing Operations

1. **Physical Substances That May Threaten Groundwater Supplies**
   - i. Frac fluids
   - ii. Produced water: flowback and formation water
   - iii. Methane and natural gas

2. **Conduits and Methods of Contamination**
   - i. Limited vertical separation between aquifers and shallow operations
   - ii. Natural hydraulic connectivity
   - iii. Leakoff
   - iv. Inadequate mechanical integrity (cracked well casing, fault lines, etc.)
   - v. Wastewater and contaminant disposal in unlined pits
   - vi. Accidental surface spills
   - vii. Frac hits: vertical wells impacted by horizontal drilling
Physical Substances as Potential Threats to Groundwater Supplies

i. Fracture Fluids

>0.5% of mixture includes toxic chemicals and their constituents; companies use a variety of different formulas and range of contaminants for their confidential and proprietary “frac fluids”

Studies have tended to find little to no evidence of frac fluids contaminating groundwater supplies:

• Moniz et al. (2011) who later became Secretary of Energy in the Obama Administration, stated that despite concern that fracturing of shale formations could penetrate shallow freshwater zones and contaminate them with fracturing fluid—there is “no evidence” of the migration of fracture fluids into shallow freshwater zones.

• Merrill and Schizer (2013) concluded that the “paucity of confirmed incidents of water contamination from the underground migration of fracturing fluid provides power evidence that the risk is small,” given the more than two million fracture operations in the past sixty years.

• Geological considerations suggest that the risk of groundwater contamination is remote from a practical perspective, as fracturing in low-permeability shale intervals takes place at production zones that are 5,000 – 10,000 feet (1-2 miles) below the surface (cf water table is only 500 – 1,000 feet below the surface).
Physical Substances as Potential Threats to Groundwater Supplies

i.  Fracture Fluids (cont.)

- EPA Report – Pavillion, Wyoming
- 2011 EPA Draft Report – Attributed unconventional drilling activities as the source of groundwater contamination.
- DiGiulio and Jackson (2016) further documented injection of stimulation fluids in groundwater and evaluated the impact to groundwater as a result of acid stimulation and hydraulic fracturing, specifically the potential upward migration of contaminants to depths of current groundwater use for domestic drinking water supplies.
- DiGiulio and Jackson (2016) found that “inorganic and organic geochemical anomalies in the [monitoring wells] appeared to be attributable to production well stimulation.”
Physical Substances as Potential Threats to Groundwater Supplies

ii. *Produced Water: Flowback and Formation Water*

Initial water produced from the well is primarily *flowback water* from fluids injected for hydraulic fracturing.

Eventually, the amount of brine water from the formation itself increases; even though it does not contain toxic fracturing chemicals, produced formation water has natural contaminants.

Along with man-made chemicals that comprise the minority of produced wastewater, naturally occurring brine water contains varying levels of salts, heavy metals, and radioactive elements, and elevated concentrations of chloride, bromide, sodium, and sulfate (Warner et al. 2013).

Elevated levels of chloride and bromide, as well as chloride/bromide mass ratio, in groundwater samples may indicate contamination from anthropogenic origins (Hildenbrand et al. 2015).

Such origins of contamination could be from oil and gas activity (Hudak 2010), as a result of formation water commingling with groundwater supplies (Warner et al. 2013).

Barnett Shale region of Texas, Hildenbrand et al. (2015) found 97 of the total 550 Barnett Shale groundwater well samples had chloride/bromide ratios indicating contamination from oilfield brine formation water.

Akob et al. (2015) detected volatile organic compounds when quantifying chemical composition of produced water samples from Marcellus shale gas wells; but noted that the source is unclear.

Kondash et al. (2017) found that wastewater coming from hydraulically fractured wells is mostly comprised of naturally occurring brines, rather than man-made fracture fluids.
Natural gas itself, primarily methane, constitutes an additional threat of groundwater contamination. Contamination may arise from methane migration along natural fractures unrelated to drilling activities. Methane naturally migrates upwards and gets trapped in shallow porous formations.

Regulatory challenges differentiating between geogenic and anthropogenic contamination pathways. Boyer et al. (2012) found methane in 78% of water samples taken in Pennsylvania before shale drilling began, further noting historical evidence of natural methane migration dating back to the late 1700s.

Some state management regimes require pre-drilling water sampling, such as in Pa.’s “rebuttable presumption” statute.

In the Marcellus Shale, Osborn et al. (2011) documented higher methane concentrations and less negative δ¹³C isotopic signatures for methane, which were consistent with a natural gas source, in domestic water wells that were less than one kilometer from shale gas wells; found evidence that levels of higher thermogenic methane in shallow groundwater aquifers near natural gas production wells than elsewhere in the same aquifers (despite not establishing cause & effect relationship).

Additional research by Jackson et al. (2013) documented significantly higher concentrations of methane in the drinking water of homes near shale gas wells compared to homes farther away.

Molofsky et al. (2013), however, noted the potential correlation between the presence of methane in groundwater and topography, rather than shale gas production.
Physical Substances as Potential Threats to Groundwater Supplies

iii. **Methane and Natural Gas (cont.)**
Conduits and Methods of Contamination

i. **Limited Vertical Separation in Shallow Fracturing Operations**

When hydraulic fracturing occurs at shallow intervals (i.e. when vertical separation is minimal) potential problems exist because chemicals could migrate into overlying drinking water supplies regardless of issues with well integrity.

Depths of horizontal drilling operations range from 100 ft (30 m) to >15,840 ft (5,000 m) (Jackson et al. 2015).

From a regulatory perspective, it is notable that no state currently has restrictions that place an upper limit on how shallow depth at which a horizontal well may be hydraulically fractured (Vaidyanathan 2016).

Jackson et al. (2014) and (2015) maintain that the lack of vertical separation between hydraulically fractured wells and drinking water in certain instances will increase potential hydraulic connectivity and the likelihood of groundwater contamination.

Davies et al. (2012) found that the greatest upward propagations in the Marcellus, Woodford, and Eagle Ford shales were 536, 588, and 556 m (~1800 to 1900 ft.), respectively.

Jackson et al. (2015) noted that out of 44,000 hydraulic fracturing observations in the U.S. between 2010-2013, more than 80% were at least a mile underground. Conversely, the fact that 16% (n=6,896) of these wells were hydraulically fractured at depths shallower than one mile may increase the potential for contamination events considering the limited vertical separation in particular instances.

In Texas, Jackson et al. (2015) observed 541 cases of hydraulically fractured wells within 1000 feet of the surface (n = 20,267 wells). In Oklahoma, high-volume fracturing occurs as shallow as 2,800 ft below surface (Soraghan 2017).
Conduits and Methods of Contamination

ii. Natural Hydraulic Connectivity

Warner et al. (2012) presented geochemical evidence to indicate the existence of natural hydraulic connections as migration pathways between deep underlying gas formations and overlying shallow drinking water aquifers.

The extent of potential contamination via this particular conduit may be limited as the occurrence of mixing relationships between shallow groundwater and deep formation brine water did not correlate with the location of shale-gas wells (Warner et al. 2012).

Additional evidence of natural hydraulic connectivity between shallow groundwater and brines from deep formations is suggested through the presence of inorganic elements attributed to biogenic sources using noble gas geochemistry to understand migration processes (Darrah et al. 2015) and through geochemical analyses of bedrock permeability (Llewellyn 2014).
Conduits and Methods of Contamination

iii. Leakoff

DiGiulio and Jackson (2016) concluded that migration of fracture fluids into the Pavillion Field drinking water supplies likely occurred during fracture propagation and subsequent leakoff. Leakoff is the loss of fluid into a formation in or near the target stratum.

From a contamination perspective, leakoff may remove or divert much or most of the fracturing fluid from the produced wastewater even for moderate-sized induced fractures; the loss of zonal isolation during well stimulation results in the migration of stimulation fracture fluids into water-bearing units (DiGiulio & Jackson 2016).

In a comprehensive analysis of drilling activities in the Bakken, Marcellus, Barnett, Eagle Ford, and Niobrara formations Kondash et al. (2017) found that most of the fracturing fluids injected into wells do not return to the surface, but are instead retained in the deep shale formations.
Conduits and Methods of Contamination

iv. *Inadequate Mechanical Integrity and Cracked Well Casing*

The drilling process itself may create additional conduits for gas to contaminate overlying aquifers as the wellbore passes through shallower formations if the well lacks proper steel and cement casing (Yoxtheimer 2012).

State regulatory regimes rely on technical standards for casing requirements to protect groundwater from contamination, requiring field-specific minimum surface casing depths or that surface casing be set some distance below the deepest protected groundwater.

Moniz et al. (2011) noted evidence of natural gas migration into freshwater zones that most likely resulted from sub-standard well completion practices (i.e., cracks in well-casing).

Surface casing in production wells is the primary line of defense to protect groundwater during oil and gas extraction from conventional and unconventional resources.

DiGiulio and Jackson (2016) found evidence of casing failure at multiple production wells in the Pavillion Field following well stimulation.
Disposal of drilling fluids (i.e., well completion practices) into unlined pits represents an indirect conduit to groundwater through seepage into shallow aquifers.

When improper, these completion practices create “legacy” issues from a legal perspective when operators move on from particular wells or when companies endure financial hardship. The EPA has documented the existence of production fluids in unlined pits in the Pavillion Field, including flowback, condensate, and produced water (Folger et al. 2012).

Breaches in flowback wastewater pits can occur from overflow or faulty linings, and may introduce dichloromethane and other species into the surface environment (Vengosh et al. 2014).

The lateral extent of groundwater contamination attributed to disposal in unlined pits is magnified when uncontaminated water overlies portions of a contaminated plume via a process known as “plume diving” (DiGiulio & Jackson 2016).

Acetate has been detected in produced water contained in storage pits on numerous occasions (Orem et al. 2014) (Cluff et al. 2014). In the Marcellus Shale, acetate has been detected in impoundment pits used to contain flowback water (Mohan et al. 2013). The potential for toxicity in wastes that are present in storage impoundments underscores the importance of proper barriers and best-management practices to protect groundwater.

Permits are generally required for storage and disposal of oil and gas waste (16 TEX. ADMIN. CODE §3.8(d)(1)-(2)). Texas requires that fluid recycling pits be lined, routinely monitored, and designed to prevent any migration of materials from the pit into adjacent groundwater (16 TEX. ADMIN. CODE §3.8(d)(4)(G)(i)-(v)).
In some regions, hydrogeologic factors outside the control of operators may magnify connections between surface water and aquifers, making certain aquifers more susceptible to contamination. In the Bakken and Marcellus formations, groundwater contamination has been attributed to surface spills as researchers have documented the presence of inorganic constituents and heavy metals in water supplies (Lauer et al. 2016; Warner et al. 2013).

Shallow water wells may be vulnerable to contamination from surface sources, such as mishandled produced water or fluid spills during stimulation and completion processes (Hildenbrand et al. 2015).

Accidents involving trucks are particularly dangerous with regards to groundwater contamination because they transport biohazard chemicals in concentrated form.
The combination of older vertical wells constructed without groundwater protections and high-volume fracturing along long horizontal wellbores could increase the probability for “frac hits” resulting in potential groundwater contamination (Soraghan 2017).

Frac hits occur when the hydraulic treatment from one well communicates with another well (McEwen 2018). In a 2017 study, the Oklahoma Energy Producers Alliance estimated that more than 400 frac hits occurred in just one Oklahoma county (OEPA Study 2017).

Although modern cementing techniques are designed to protect groundwater—older vertical wells may have been drilled and plugged well before the current cementing regulations were introduced.

Small producers in Oklahoma allege that hundreds of their older vertical wells have been flooded by high-pressure fracturing of horizontal wells. Oklahoma’s spacing and pooling provisions allow horizontal wells to be fractured within 600 feet of older vertical wells (OKLA. ADMIN. CODE 165:10-1-21).
The Texas Administrative Code makes it unlawful for a person conducting oil and gas activities to cause or allow pollution of surface or subsurface water in the state (16 TEX. ADMIN. CODE §3.8(b)).

Pollution is defined as an alteration of the water that renders the water harmful, detrimental, or injurious to humans, vegetation, property or public health, safety, or welfare (16 TEX. ADMIN. CODE §3.8(a)(28)).

Violations of this rule may result in criminal penalties under the Texas Natural Resources Code or other law (16 TEX. ADMIN. CODE §3.8(h); TEX. NAT. RES. CODE §91.002).

In any well drilled for oil and gas, hydrocarbon resource fluid must be confined in its original stratum until it can be produced and utilized without waste, such that each stratum must be adequately protected from infiltrating waters (16 TEX. ADMIN. CODE §3.7).

The RRC requires each stratum to be cased off and protected (16 TEX. ADMIN. CODE §3.7).

Operators that encounter gas-bearing strataums when drilling oil or gas wells must confine the gas to its original stratum and protect the gas-bearing strata from infiltrating water (TEX. NAT. RES. CODE §91.016).
In response to the City of Denton’s 2014 ordinance prohibiting fracking operations within city limits, the Texas legislature in 2015 passed an express preemption statute providing that oil and gas operations are subject to the exclusive jurisdiction of the state (TEX. NAT. RES. CODE §91.0523).

Regulatory authority over drilling activities is deferential to the RRC. Specifically, the RRC and TCEQ have adopted a memorandum of understanding ("MOU") regarding the division of jurisdiction between the agencies over wastes associated with exploration, development, and production of oil and gas (16 TEX. ADMIN. CODE §§3.30, 3.8(i)).

Under the MOU and Texas Water Code, the RRC must submit a written notice to the TCEQ of any documented cases of groundwater contamination that may affect a drinking water well (16 TEX. ADMIN. CODE §3.30(e)(7)(A)).

In the Permian Basin, the Middle Pecos Groundwater Conservation District maintains additional rules that prohibit the pollution or degradation of groundwater quality by means of saltwater or other deleterious matter admitted from another stratum, or by activities which cause pollutants to enter the groundwater, whether natural or manmade (Rule 14.3 Middle Pecos GCD).
Casing must be securely anchored for well control in order to isolate and seal off all usable-quality water zones to effectively prevent contamination or harm (16 TEX. ADMIN. CODE §3.13(a)(1)).

Operators must set and cement sufficient surface casing to protect all usable-quality water strata as defined by the Groundwater Advisory Unit of the RRC’s Oil and Gas Division and prevent upward migration of deeper formation fluids into protected water (16 TEX. ADMIN. CODE §3.13(b)(1)(A)-(B)).

The RRC establishes field-specific requirements for surface casing depths that must be set below the base of usable quality water, and with regards to groundwater protection requirements (TEX. NAT. RES. CODE §§91.011, 91.1015).

If oil and gas wastes cause the pollution of groundwater, the RRC may use the oil and gas cleanup fund for site investigation, environmental assessment, and cleanup if the responsible person has failed to or is unknown (TEX. NAT. RES. CODE §91.113(a)). In addition to any lease forfeiture provided by law, violations of prohibitions on groundwater pollution will subject operators to penalties of not more than $10,000 when the rule pertains to the prevention of pollution, and the applicable maximum penalty may be assessed for each and every day of violation and each and every act of violation (16 TEX. ADMIN. CODE §3.8(h); TEX. NAT. RES. CODE §85.381(a)(1)-(b)).
Regulatory Framework

Pennsylvania

In 2012, the Pennsylvania General Assembly recodified the state’s Oil and Gas Act to include language that explicitly targeted the development of unconventional natural gas drilling operations that use hydraulic fracturing (58 Pa.C.S. §§ 3201-3274).

Operators are required to complete a fracturing fluid chemical disclosure form and post the information to a publicly available registry (i.e., FracFocus) (Pa. HB 1950, 58 Pa.C.S. § 3222.1). Operators applying for an unconventional well drilling permit are required to send notice to all surface landowners and water suppliers that are within 3000 feet of the vertical well bore (Pa. HB 1950, 58 Pa.C.S. § 3222.1 (b)(2)).

Pennsylvania’s “rebuttable presumption” statute presumes that, unless rebutted by an established defense, well operators are responsible for groundwater pollution if (1) the water supply is within 2500 feet of the unconventional vertical wellbore and (2) the pollution occurred within 12 months of the latter of completion, drilling, stimulation, or alteration of the unconventional well (58 Pa.C.S. § 3218(c)(2)).

To rebut the presumption of responsibility for groundwater pollution, operators must affirmatively prove that either the pollution existed prior to drilling activities as determined by a predrilling survey, or that the landowner refused to allow the operator access to conduct the predrilling survey, or that the pollution occurred as the result of a cause other than drilling activity (58 Pa.C.S. § 3218(d)).
Pennsylvania statutes require well operators who pollute a public or private water supply to restore or replace the affected water supply with an alternate source of adequate quantity and quality that meets the standards set forth in the Pennsylvania Safe Drinking Water Act (58 Pa.C.S. § 3218(a)).

Landowners that suffer pollution of a water supply as a result of drilling activities may request an investigation, in which the Pennsylvania DEP must investigate within 10 days and make its determination within 45 days (58 Pa.C.S. § 3218(b)).

To protect groundwater sources, operators are obligated to control and dispose of brines and produced water in compliance with the Clean Streams Law (58 Pa.C.S. § 3217(a)). Well-casing regulations are designed to prevent migration of methane gas or fluids into groundwater sources, such that strings of casing are required to be permanently cemented in each well drilled through the fresh water-bearing strata to depths required by Pennsylvania DEP (58 Pa.C.S. § 3217(b)).

The Pennsylvania DEP also publishes an updated list of water supply determination letters that record when a private water supply was impacted by unconventional oil and gas activities, including any case that results in confirmed water supply contamination from hydraulic fracturing or an increase in constituents above background conditions (Pennsylvania DEP 2014).