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NM WRRI Technical Completion Report No. 390

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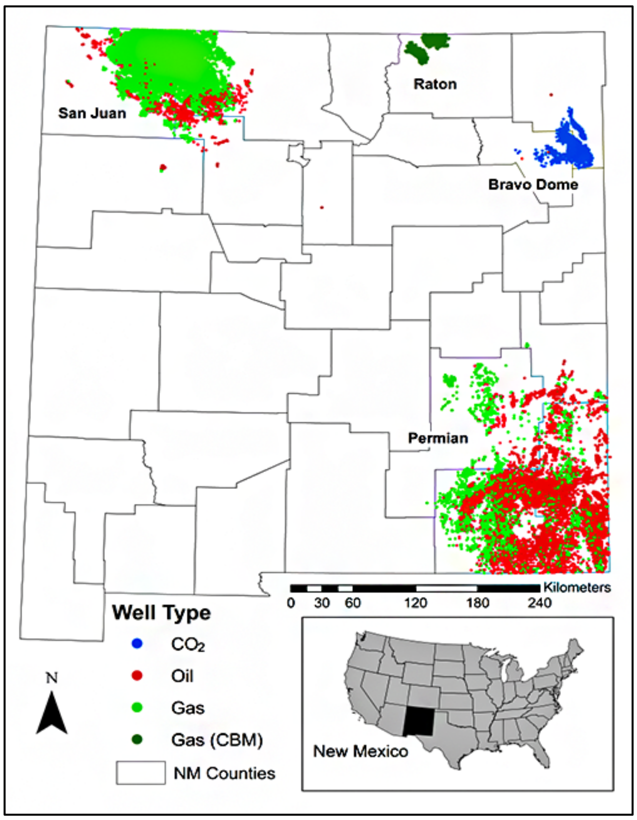

Oil, gas, and CO_2 producing regions of New Mexico (Zemlick, et al., 2018)

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DISCLAIMER

ABSTRACT

The relationship between oil and gas (O&G) production, water supply, and wastewater management in New Mexico is intricate and complicated. Large volumes of water are used for hydrofracturing (HF or fracking) and even larger volumes of wastewater are generated as produced water (PW). This study identified trends in water use and wastewater produced by O&G production.

The analysis found that the number of wells that were fracked approximately doubled between 2015 and 2019, from 623 to 1076, while the volume of water used for fracking increased from 67.6 M bbls/yr (8,700 AF/yr) to 311.4 M bbls/yr (40,000 AF/yr). Although the volume of water used for fracking is large, it constitutes a small fraction, less than 15%, of the total water withdrawn in the O&G producing counties of southeast and northwest New Mexico.

The volumes of PW generated as a part of O&G production increased from 893 M bbls/yr (115,000 AF/yr) in 2015 to 1,240 M bbls/yr (160,000 AF/yr) in 2019. However, the PW-to-oil ratio has dropped steadily from 10 bbls PW/bbl oil in 2008 to 3.1 bbls PW/bbl oil in 2019. Currently half of PW is disposed of by injection into salt water disposal (SWD) wells and the remainder is injected into wells for secondary recovery of oil (SRO).

Information that could not be found for this study includes: (1) data on the volumes of PW used for HF, (2) sources and volumes of PW sent to treatment plants prior to injection for SRO or disposal, and (3) information on transporting fresh water and PW to and from neighboring states.

Keywords: hydrofracturing, produced water

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INTRODUCTION

The importance of the oil and gas (O&G) industry to the economy of NM is widely recognized and cannot be overstated. The NM Legislative Finance Committee reports that the state typically receives more than $2 B/yr direct revenue from oil and gas production through severance and property taxes and royalty and rental income (LFC, 2018). Most of this money is deposited into the state's General Fund. The New Mexico Tax Research Institute reported that $2.2 B was contributed to the general fund in FY 2018 by the O&G industry, which accounted for over 30% of General Fund revenues (NMTRI, 2019). This constituted a $465 M increase over FY 2017 revenues. In addition, the O&G industry provided an additional $1.55 billion to State and Local budgets primarily through gross receipts taxes. The principal O&G and CO_2 producing regions of the state are shown in Figure 1.

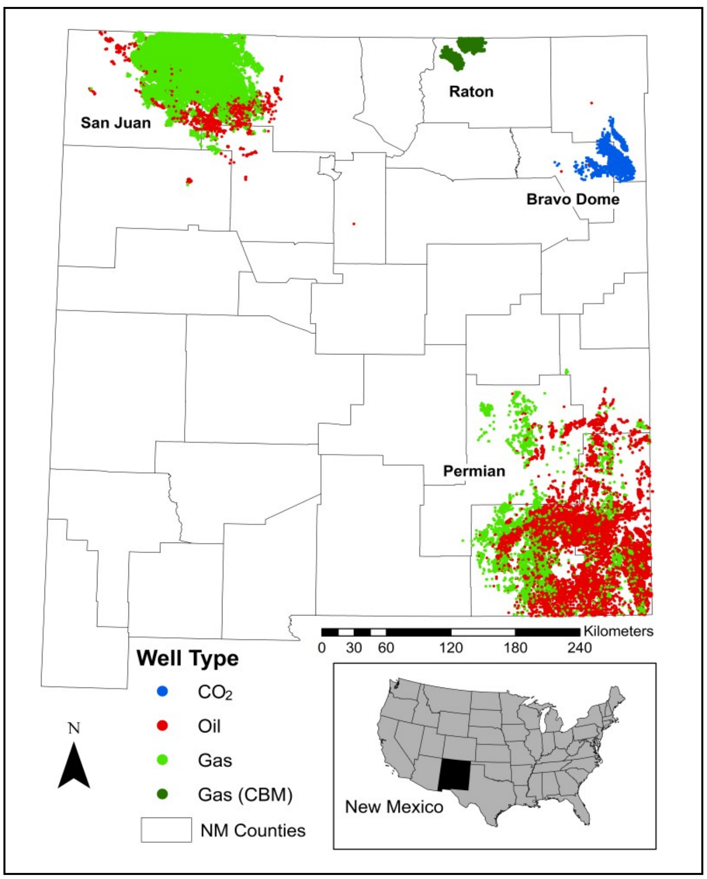


Figure 1. Oil, gas, and CO_2 producing regions of NM (Zemlick, et al., 2018).

Oil and gas production is highly variable and depends primarily on energy prices, but also on production technologies. Annual O&G production in the Permian and San Juan Basins since 2000 are plotted in Figure 2 (data from the NM Oil Conservation Division (OCD) of the NM Energy, Minerals and Natural Resources Department (EMNRD)). Another method of illustrating industry activity in the state is by the number of wells spudded each year. Figure 3 shows the number of wells spudded in New Mexico for production of oil, gas and CO_2, as well as wells drilled for secondary recovery of oil (SRO) and for disposal of produced water (PW) in salt water disposal (SWD) wells. The rapid increase in industry activity since 2009 is due to both an increase in crude oil prices and also due to implementation of new drilling and well completion technologies. Horizontal drilling combined with hydraulic fracturing has enabled O&G production from tight sand and shale formations that could not be developed economically with conventional vertical wells. Horizontal wells in tight sand and shale formations are commonly referred to as unconventional O&G wells. In recognition of these advancements, revised assessments of the O&G reserves in the Permian Basin of southeastern NM and northwestern TX have determined that this basin has the largest O&G reserves in the country and are among the largest in the world (Gaswirth et al., 2018).

There is a strong interdependence between O&G development and water. Large volumes of water are used in O&G exploration and development, and even larger volumes of water are generated as a by-product of O&G production. Understanding the relationship between these resources and especially changes that may occur as the industry adopts new technology and procedures is important to plan for future demands for fresh water (defined as having a total dissolved solids or TDS concentration of 1,000 mg/L or less) and to develop safe strategies for managing wastewater from the industry.

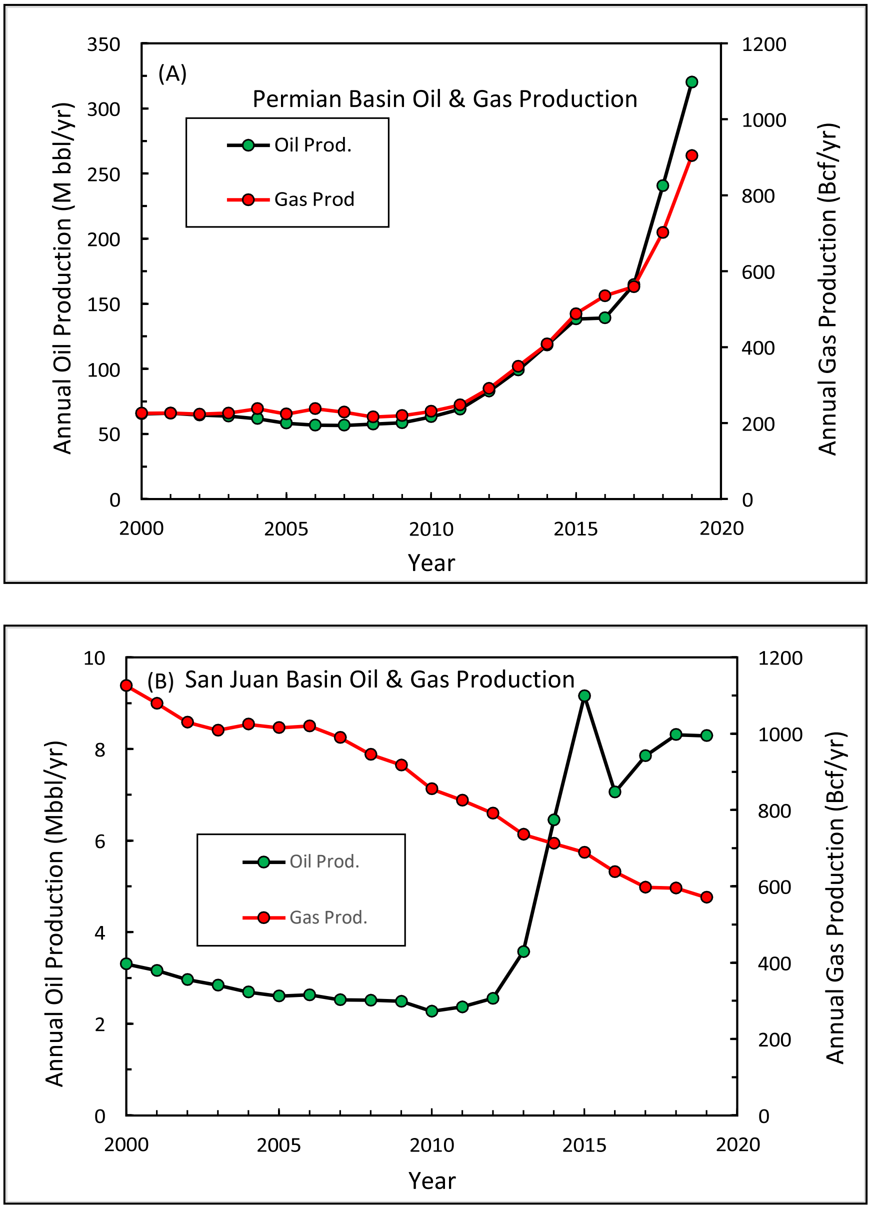


Figure 2. Oil and gas production in the Permian Basin (top) and San Juan Basin (bottom) of New Mexico (OCD data) (oil production is in units of million barrels/year, and gas production is in units of billion cubic feet/year). Data from the NM Oil Conservation Division (OCD, 2020).

Increased development of unconventional oil and gas (O&G) resources from shale and tight sand formations has led to dramatic changes in the relationship between oil, gas, and water. Some of the more notable changes include: (1) Larger volumes of water, sand and chemicals that are required for hydrofracturing (HF); (2) Increasing volumes of produced water (PW are generated; (3) Opportunities for re-use of PW; and (4) Limitations on PW disposal in salt water disposal wells (SWD) primarily due to increased risk of induced seismicity which limits injection pressures and volumes. It is important to understand how future operations will affect water demand and wastewater production. The objective of this project is to identify how the quantities and qualities of water from future O&G production will affect water use, production, treatment, disposal and possible PW reuse.

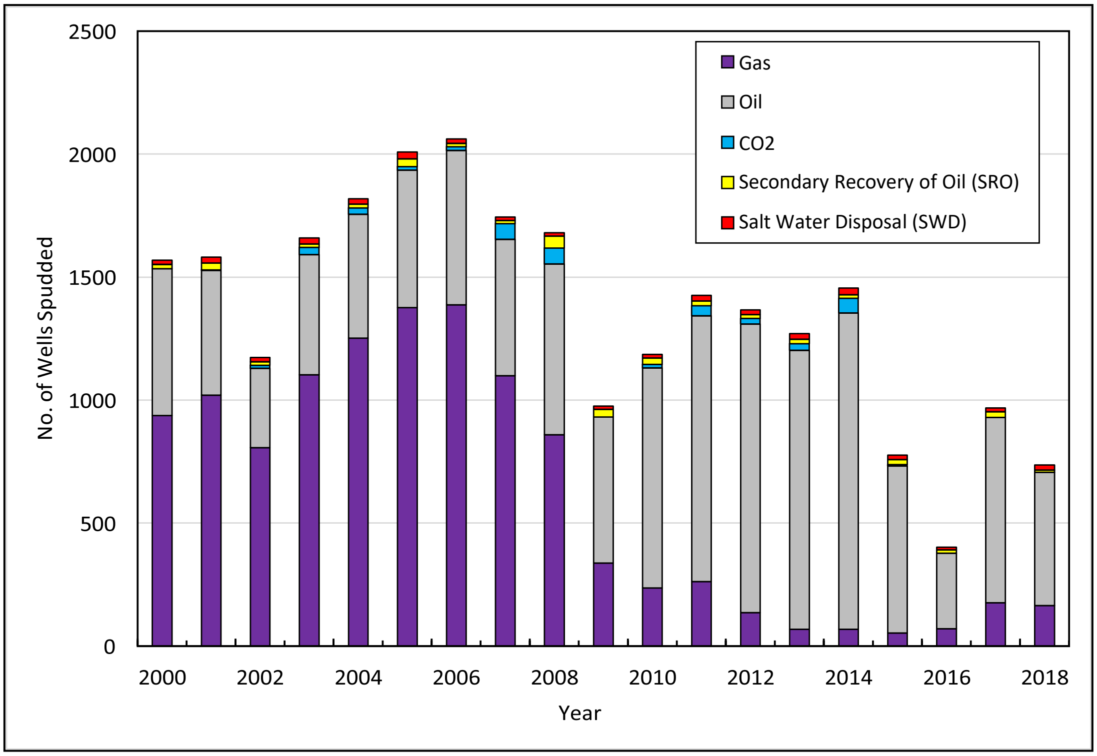


Figure 3. Number of wells spudded in New Mexico each year between 2000 and 2018. Data from the NM Oil Conservation Division (OCD, 2020).

A large amount of data on the relationship between oil, gas, and water has been compiled in databases by NM state agencies, principally the Oil Conservation Division (OCD) of the Energy, Minerals and Natural Resources Department (EMNRD) and the NM State Land Office (SLO). However, because these databases are very large and difficult to access, limited analysis of this data has been conducted to date. Furthermore, due to a number of factors, including the explosive rate of growth of the industry and the limited number employees in the regulatory agencies to confirm industry submitted information, the data are of uncertain accuracy. Furthermore, until promulgation of new regulations in late 2020 (19.15.16.21 NMAC) information on the sources and volumes of water used for HF was not reported.

Note that the O&G industry generally uses units of barrels (bbl) for oil whereas most water resources are reported in units of acre-feet (AF). One barrel is 42 gallons, hence there are 7,758 bbl/AF. Gas is reported in units of MCF, which are defined as units of thousand cubic feet. Usually the prefix "M" denotes million in science and engineering literature, therefore, care must be taken to assure that the correct units of volume are used when analyzing O&G data. FracFocus (www.fracfocus.org) reports volumes of water used for HF in units of gallons. In this report the prefix "M" denotes million (in the O&G industry million cubic feet is noted as MMCF). Sometimes the volumes of oil and gas production are combined into the unit of barrels of oil equivalent (BOE). Thus, when compiling and analyzing data on water, oil, and gas resources it is essential to identify the units of the data being reported and perform all analyses using consistent units.

At its most fundamental level, the objective of this project is to analyze existing data collected by state agencies and other organizations to address the question of the sources and volumes of water used for O&G development, and the volumes and fate of wastewater generated by the industry. The project will use this information as well as industry knowledge to identify water and wastewater management trends including; future water demand for hydraulic fracturing (fracking) of wells, as well as opportunities and incentives for PW reuse within the industry, and trends in PW generation.

Each section of the project is divided into two components: water for O&G development (primarily for fracking), and wastewater (PW) challenges. The focus of the study is on O&G development in the Permian Basin although summary data is also provided on industry activities for the San Juan Basin.

Note that public discussion often conflates the term fracking with all activities by the O&G industry including exploration, drilling, development, production of oil/gas/wastewater, and sometimes transportation of oil/gas/wastewater. This report makes a clear distinction between frack water used for O&G well completion using data reported to FracFocus (FracFocus, 2020) and wastewater associated with production (i.e., produced water) which is reported to OCD (OCD, 2020).

PREVIOUS WORK

In recent years a large number of papers and reports have considered the relationship between O&G development and its impact on water resources. These impacts include both fresh water demand for well stimulation, principally fracking, and wastewater generated during production in the form of flowback and PW. Flowback and PW are combined are reported to OCD as PW. This section briefly summarizes work done throughout the U.S. and then focuses on work done in NM.

Water Requirements for Oil and Gas Development

The principal water requirements for O&G development are for drilling, hydraulic fracturing referred to as fracking abbreviated as HF by some studies, and refining, principally for cooling. Smaller volumes are used for dust control, potable water supply, and washing. By far the biggest water demand is that for fracking, which is the focus of this discussion.

Conventional O&G development uses vertical wells. Beginning in about 2005 the industry started using horizontal drilling techniques to recovery O&G from tight sand and shale formations and by 2019 nearly all O&G wells drilled in NM were horizontal wells (see Figure 4). The horizontal length of early wells was a few thousand feet while current wells typically have lateral lengths that range from 5,000 ft to 10,000 ft. Basic Energy Service reported drilling a well with a lateral length of 3.4 mi well (18,000 ft) in July, 2019, the longest in the Permian Basin (Hedden, 2019).

Hydraulic fracturing (fracking) is used to increase the permeability of O&G formations to enhance recovery of oil and gas. As noted above, the term fracking is sometimes conflated with the entire production cycle of O&G, including drilling, well development, production, piping and transportation, and refining. However, the term specifically refers only to fracturing rock near the well itself and that is how it is used in this report.

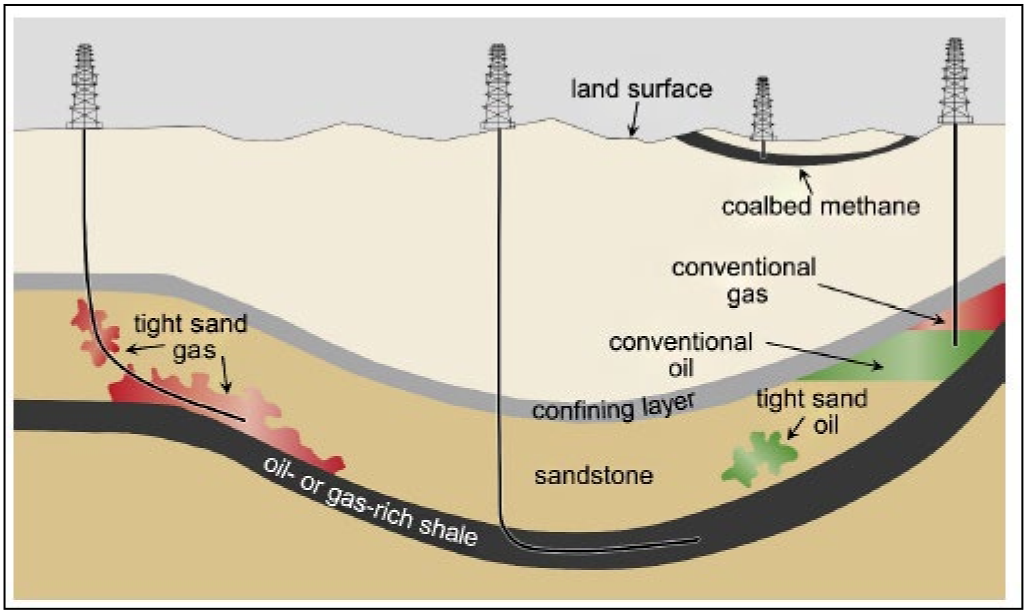


Figure 4. Illustration of the different types of drilling methods used to recover oil and gas (EPA, 2016).

Fracking consists of pumping a slurry of water and fine sand and small concentrations of chemical additives down a completed well under high pressure to fracture the rock near the well to increase its porosity and increase the flow of fluids (oil, gas, and water) to the well. It has been widely used by the industry for over 50 years, but fracking, combined with horizontal drilling, has allowed the development of very low permeability tight sand and oil shale formations. The ability to recover O&G from tight sands and shale is responsible for the explosion of the O&G development in the Permian and San Juan Basins of NM.

A variety of chemicals may be added to the slurry to facilitate and improve the fracking process (see Table 1). A summary description of the characteristics and function of the major additives follows:

- Water – 98% to 99% on a volume basis
- Proppant (i.e., sand) – 1% to 1.9% to hold fractures open after pressure is relaxed (~1 lb/gal)
- Friction reducer – 0.025%: Used to reduce fluid friction to reduce pumping pressure at the high velocities used in slickwater fracks (described below).

- Disinfectant (biocide) – 0.005% to 0.05%: Added to prevent microbial growth that can plug formations and contribute to microbially induced corrosion of the well casing.
- Surfactants – .5 to 2 ppm: Added to modify surface or interfacial tension, break or prevent emulsions, and create foam if gas such as N_2 is used in fracking
- Gelation chemicals (thickeners): Guar gum and cellulose polymers may be added to keep proppant in suspension.
- Scale inhibitors: Phosphates or phosphonates will reduce formation of mineral scaling by compounds such as $CaCO_3$ and $CaSO_4$.
- Hydrochloric acid: Acid is sometimes used to dissolve some minerals, especially carbonates, and for pH control.
- Corrosion inhibitor – 0.2% to 0.5%: If acid is used in the frack fluid corrosion inhibitors may be added to prevent corrosion of iron and steel components.

Table 1. Constituents added to water used for hydraulic fracturing (i.e., fracking) (EPA, 2016).

Additives	Function	Chemicals reported in ≥20% of FracFocus disclosures for additive[a,b]
Acid	Dissolves cement, minerals, and clays to reduce clogging of the pore space	Hydrochloric acid
Biocide	Controls or eliminates bacteria, which can be present in the base fluid and may have detrimental effects on the fracturing process	Glutaraldehyde; 2,2-dibromo-3-nitrilopropionamide
Breaker	Reduces the viscosity of specialized treatment fluids such as gels and foams	Peroxydisulfuric acid diammonium salt
Clay control	Prevents the swelling and migration of formation clays in reaction to water-based fluids	Choline chloride
Corrosion inhibitor	Protects the iron and steel components in the wellbore and treating equipment from corrosive fluids	Methanol; propargyl alcohol; isopropanol
Crosslinker	Increases the viscosity of base gel fluids by connecting polymer molecules	Ethylene glycol; potassium hydroxide; sodium hydroxide
Emulsifier	Facilitates the dispersion of one immiscible fluid into another by reducing the interfacial tension between the two liquids to achieve stability	2-Butoxyethanol; polyoxyethylene(10)nonylphenyl ether; methanol; nonyl phenol ethoxylate
Foaming agent	Generates and stabilizes foam fracturing fluids	2-Butoxyethanol; Nitrogen, liquid; isopropanol; methanol; ethanol

Table 1. Continued.

Additives	Function	Chemicals reported in ≥20% of FracFocus disclosures for additive[a,b]
Friction reducer	Reduces the friction pressures experienced when pumping fluids through tools and tubulars in the wellbore	Hydrotreated light petroleum distillates
Gelling agent	Increases fracturing fluid viscosity allowing the fluid to carry more proppant into the fractures and to reduce fluid loss to the reservoir	Guar gum; hydrotreated light petroleum distillates
Iron control agent	Controls the precipitation of iron from solution	Citric acid
Nonemulsifier	Separates problematic emulsions generated within the formation	Methanol; isopropanol; nonyl phenol ethoxylate
pH control	Affects the pH of a solution by either inducing a change (pH adjuster) or stabilizing and resisting change (buffer) to achieve desired qualities and optimize performance	Carbonic acid, dipotassium salt; potassium hydroxide; sodium hydroxide; acetic acid
Resin curing agents	Lowers the curable resin coated proppant activation temperature when bottom hole temperatures are too low to thermally activate bonding	Methanol; nonyl phenol ethoxylate; isopropanol; alcohols, C12-14-secondary, ethoxylated
Scale inhibitor	Controls or prevents scale deposition in the production conduit or completion system	Ethylene glycol; methanol
Solvent	Controls the wettability of contact surfaces or prevents or breaks emulsions	Hydrochloric acid

Until recently the chemicals added to frack fluids was considered proprietary information by fracking companies, which led to much public concern about the safety of these fluids in the event that they contaminate nearby surface or groundwaters. In 2012, the OCD promulgated the hydraulic fracturing fluid disclosure rule (19.15.16.19 NMAC), which requires the industry to report the volume of water used for each frack job and identify all chemicals used to frack a well to FracFocus within 45 days of completion of the frack job (www.FracFocus.org). A Safety Data Sheet (formerly called a Material Safety Data Sheet or MSDS) for each chemical used is required but not the actual recipe of the frack fluid to avoid revealing proprietary information. A link to the FracFocus database for information on NM O&G wells is provided on the OCD website. Regulations requiring reporting of the source of water used for fracking became effective in October, 2020 (19.15.16.21 NMAC) and are described below.

Fracking is commonly done with foams, gelling agents, or slickwater (Barati and Aghababa, 2016; Barati and Liang, 2014; Al-Muntasheri, 2014). Foams use a gas such as nitrogen, carbon dioxide, or natural gas along with a small volume of water and a surfactant to keep the proppant particles in suspension (Fu and Liu, 2019; Wanniarachchi et al., 2017). A consequent reduction of up to 90% in water needed for fracking with the use of foams has been reported. Barati and Liang (2014) report that the use of foams, which they refer to as energized fluids, is of increasing interest in tight and unconventional formations because they reduce the damage to the rock caused by conventional frack fluids, in addition to greatly reducing the volume of water required. The addition of nanoparticles of silica to increase the stability of foams has been considered but is in an early stage of development (Wanniarachchi et al., 2017). Foams may be more appropriate than water-based fluids for fracking shales and formations with high clay content because they cause less swelling of clay particles. The EPA (2016) analyzed FracFocus data and found that nationally 84% of fracks done with non-aqueous fluids used nitrogen, and that roughly half of the frack jobs using nitrogen were done in NM, most commonly for gas wells. Use of nitrogen for fracking in NM is primarily limited to stimulation of gas wells in the San Juan Basin. Information on the number of wells completed using this method in NM is not available.

Gel-based frack fluids have been widely used and are familiar within the industry. A gelling agent, typically guar gum, is added to the solution to maintain the proppant in suspension. One of the challenges is that guar-based gels degrade under the high temperatures occurring in deeper wells (Barati and Liang, 2014). Guar based polymers have historically been used but are limited to temperatures less than 150 °C (302 °F). Furthermore, commercial guar often contains up to 5% residue which may damage proppant packs by plugging small cracks and pores. As a result, the industry is turning to use of synthetic polyacrylamide-based polymers. Once a formation has been fracked the high viscosity of gel needs to be reduced to allow the proppant to flow into the fractures. This is achieved by adding chemical breakers that break down the gelling agent.
The third type of fracking fluid is slickwater, which uses little or no gelling or foaming agent but instead relies upon high fluid velocities to maintain the proppant in suspension. Fracking of tight sand and shale formations have increasingly been done with slickwater fracks. In order to keep

the proppant in suspension, velocities up to 30 m/sec (100 ft/sec) are used at a flow rate of 16,000 L/min (100 bbl/min) are used (Yang et al., 2019; Nguyen et al., 2018; Palisch et al., 2010). To overcome the extremely high friction losses produced by these velocities, friction reducers are added. Friction reducers include natural polysaccharides such as hydroxypropyl guar, guar gum, and xanthum gum, polyethylene oxide, and more recently, polyacrylamide polymers (Yang et al., 2019). Use of friction reducers can reduce head losses by up to 50%.

Because slickwater fracking uses a very large volume of water there would be cost advantages to using PW instead of more expensive fresh water. However, the very high salinity of PW causes the molecular polymer chains of traditional friction reducers to curl about themselves which limits their effectiveness. This occurs at concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) greater than 200 mg/L and 100 mg/L respectively (Yang et al., 2019). This has limited the use of PW for slickwater fracking in the Permian Basin as PW from this basin has very high concentrations of these ions. In addition, the curled or clumped polymers may damage the formation by blocking small pores in the media. Development of friction reducers, which are compatible with the very high salinity of PW, is an active area of research by the O&G industry. As these materials become available it will enable increased use of PW in place of fresh water for fracking operations, thereby reducing the impact on regional freshwater resources.

The actual fracking process is quick and typically takes just a couple of days. However, it requires a lot of water, ranging from less than 10 bbl per foot of horizontal length (420 gal/ft) to more than 100 bbl/ft (4,200 gal/ft) (Kondash et al., 2018; Kondash and Vengosh, 2017; Scanlon et al., 2017). The amount of water depends on the geology of the formation, the type of well, and whether a gel based on slickwater frack is done. Scanlon and others (2017) report a Permian Basin average of 32 bbl/ft for fracking. The amount of water used per well (706,000 gal) is substantially less than in the neighboring states of CO (1,410,000 gal), OK (3,430,000 gal) and TX (2,490,000 gal) (Jackson et al., 2015; Scanlon et al., 2017). Scanlon and others (2017) report that approximately 1.5 bbl of water is used for fracking per barrel of oil ultimately recovered from a well in the Permian Basin.

The impact of large water requirements for fracking on regional water resources in arid west TX was discussed by Scanlon and others (2017) and Nicot and Scanlon (2012). They concluded that, though the volumes are large, water needed for fracking represents a small fraction of total water demand and should not limit shale energy production. The volume of water used for fracking in NM is discussed in a subsequent section of this report.

Note that trends in the volume of water used for fracking as a result of new technologies or new approaches to O&G development and production are limited to summary statistics for entire basins.

Hydraulic fracturing has received much national attention and has been blamed for causing contamination of surface and groundwater resources as well as earthquakes in some locations. The EPA (2016) provided an extensive review of the potential impacts of fracking on drinking water resources in the U.S. and concluded that nearly all instances in which frack fluids contaminated groundwater resources were the result of failure of the mechanical integrity of poorly cased wells or corrosion of well casings. There is little evidence of fractures from deep (>5,000 ft) O&G wells propagating upwards to overlying aquifers and providing a path for flow offrack fluids (Davies et al., 2012; Birdsell et al., 2015; Awal and Fares, 2016). Earthquake clusters associated with O&G development are believed to be primarily due to underground injection of PW not fracking (Scanlon et al., 2019).

Produced Water from Oil and Gas Production

Oil and gas reserves are located in geologic formations that contain large volumes of extremely salty water that are brought to the surface along with the oil and/or gas. This water is referred to as produced water (PW).

Two recent high-level reviews of issues associated with PW, in particular its generation and management, have been published by the National Academies of Science (NAS, 2017) and the Ground Water Protection Council (GWPC, 2019). Both reviews have extensive discussions of the challenges of managing these fluids from a national perspective and contain summary information that allows placing Permian Basin water challenges in the context of those in other regions.

A fraction of the water injected during fracking operations returns to the surface when production first begins and is referred to as flowback. Initially, the water consists primarily of drilling and fracking fluids. With continued pumping this water is removed and replaced by water from the O&G formation. The amount of time to remove all fracking fluids varies from a few weeks to several months. Kondash and others (2017) analyzed nationwide data and found that 85% of the water from producing wells consisted of formation water after 60 days of pumping.

Because there is not a clear distinction between flowback and PW they are almost always subject to the same management strategies and most reports do not distinguish between the two fluids. Following this convention, this report uses PW to refer to both flowback and produced water.

In their analysis of the water footprint of hydraulic fracturing, Kondash and others (2017) summarized data on the PW production in the Eagle Ford (south TX), Marcellus (PA and WV), Bakken (WY), Niobrara (CO), Haynesville (AR), and Permian (TX and NM) regions. These include both gas and oil producing regions, most of which are from shale formations. A summary of their data is presented in Figure 5, which compares the volumes of gas (A), oil (C), and produced water (B and D) for the Eagle Ford, Permian, Niobrara and Bakken formations. Note that Kondash and others (2017) report water volumes as FP, which stands for flowback and produced water. Permian Basin wells produce substantially higher volumes of PW per well than the other formations.

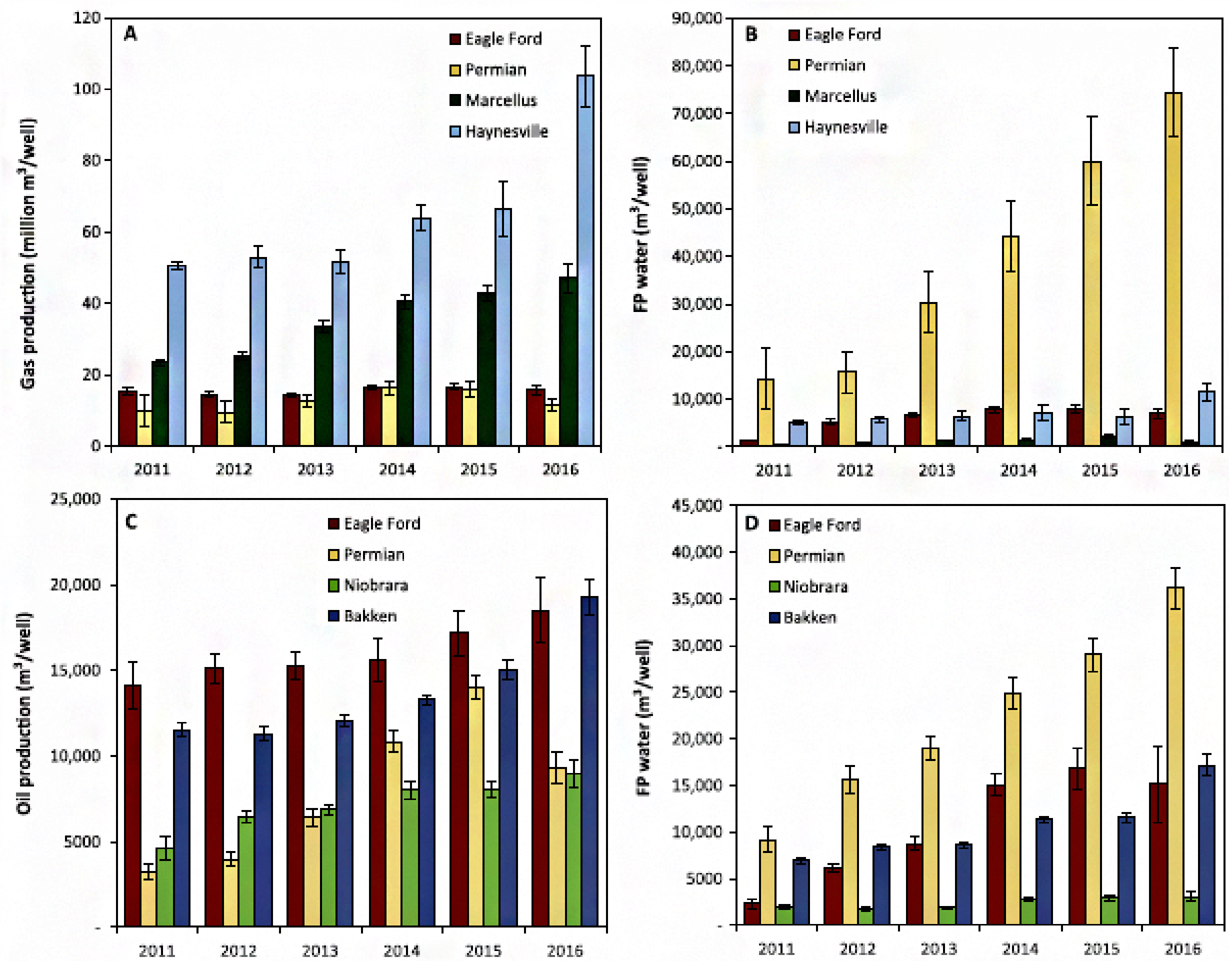


Figure 5. Annual shale gas (A), tight oil (C), and PW (B and D) in shale gas-producing regions (A and B) and oil producing regions (C and D). Whiskers represent 95% confidence intervals (Kondash et al., 2017).

A more focused study of the relationships between O&G production and water in the Permian Basin was published by Scanlon and others (2017). The study published estimated volumes of water required for fracking and the production of oil, gas, and water for the entire basin. These values were used to estimate the water intensity measured as volume of water per unit of oil, oil and gas, and the PW-to-frack water ratio. Information contained in the databases was used to characterize wells as vertical conventional, unconventional vertical wells, and unconventional horizontal wells (see Figure 4).

The Permian Basin covers a very large area with multiple distinct hydrocarbon producing regions, the most productive of which are the Delaware Basin, the Central Basin Platform, and the Midland Basin (Figure 6, from Scanlon et al., 2017). Each region has a different relationship between oil, gas, and water, which is illustrated in the HF water-to-oil, PW-to-oil, and PW-to-HF water ratio (see Table 2). This data also shows trends in these ratios over the period of 2005 to 2015.

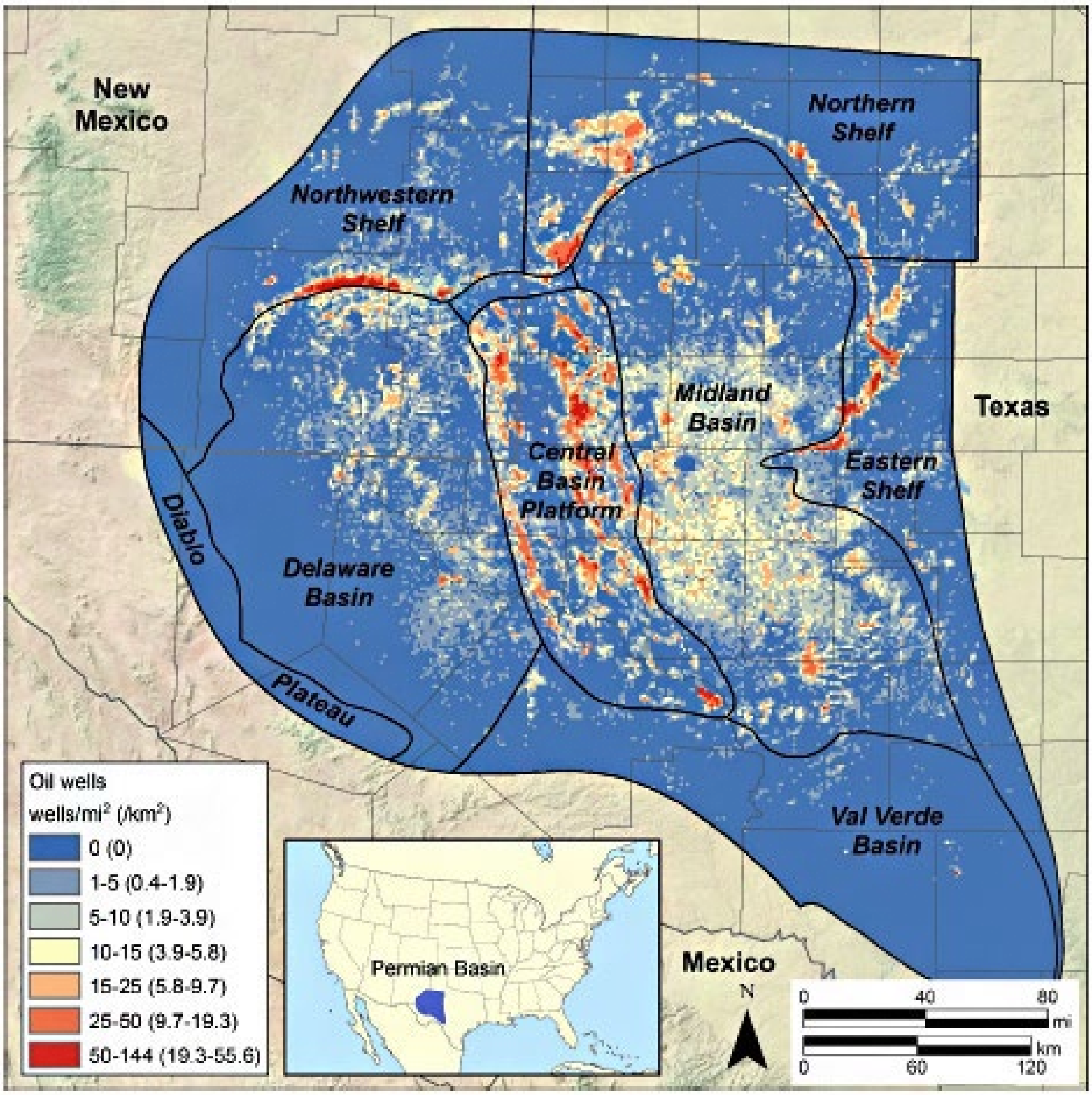


Figure 6. Oil well density in the Permian Basin that shows the main hydrocarbon bearing regions (Scanlon et al., 2017).

Table 2. Selected ratios between water for hydraulic fracking (HF) and produced water (PW) forthree regions in the Permian Basin (Scanlon et al., 2017).

Ratio	Period	Entire Permian Basin	Midland Basin	Delaware
HF Water-to-Oil Ratio				
HF Water/Oil 12-mo	2005-2015	2.5	4.1	1.4
	2008	0.7	1.0	0.4
	2015	3.5	4.7	2.4
HF Water/Oil EUR	2008	0.2	0.5	0.1
	2015	1.5	2.2	1.0
PW-to-Oil Ratio				
PW-to-Oil Ratio	2005-2015	1.3	1.6	2.1
	2008	0.5	2.0	1.8
	2015	1.4	1.3	2.2
	2008	0.5	2.0	1.8
	2015	1.3	1.3	2.2
PW EUR-to-Oil EUR	2008	1.4	3.5	0.9
	2015	1.7	1.3	2.0
PW to HF Water Ratio				
PW 12-mo/HF Water	2005-2015	0.8	0.4	1.5
	2008	1.5	1.8	2.7
	2015	0.5	0.3	0.9
PW EUR/HF Water	2008	7.1	13.0	7.4
	2015	1.1	0.6	1.9

EUR = Estimated Ultimate Recovery Volume

RESEARCH METHODS

This project primarily consisted of compilation and analysis of large amounts of data on the development of O&G resources in NM, and the water resources that are associated with this development. Especially important are the freshwater sources and volumes used for HF and the volumes and strategies used to manage PW, including its disposal. Some of the major sources of data pertaining to water used for HF and PW generation are listed in Table 3.

Table 3. Important sources of data on exploration, drilling, and production by the oil and gas industry in New Mexico, and water associated with these activities.

Data Source	Description	Web Address
Institutional Sources		
Energy Information Agency	Federal compilation of all forms of energy for the U.S.	https://www.eia.gov/state/data.php?sid=NM
NM Oil Conservation Division	Extensive database of all O&G activity in NM, but difficult to access	http://www.emnrd.state.nm.us/OCD/statistics.html
NM State Land Office	Extensive database of O&G activity on state lands	http://dataaccess.nmstatelands.org/DataAccess/
NM Office of the State Engineer	Data on fresh ground and surface water supplies in NM	https://www.ose.state.nm.us/
GoTech	Petroleum Recovery Research Center @ NM Tech, contains much of OCD & SLO data but is easier to access	http://octane.nmt.edu/gotech/
Other Sources		
FracFocus	Data on HF activities in NM since 2010 including HF chemicals used	https://fracfocus.org/ (see also link to NM data on OCD Statistics page)
IHS EDM Data	Commercial data vendor (See HIS Enerdeq data)	https://ihsmarkit.com/products/edm-energy.html?utm_campaign=PC015475&utm_medium=ppc&utm_source=googlenonbrand&gasc_id=697011707&gasc_label=k-9jCLiZnsMBEPubrswC&gclid=CjwKCAjw26H3BRB2EiwAy32zhcMVtlmA9dIocOyVThHiqQTk9EW1uyDsAcBT8MVKngiJg8MNLWOpShoCTk0QAvD_BwE
Enverus (formerly Drilling Info)	Commercial data vendor	https://www.enverus.com/industry/exploration-and-production/
B3	Commercial data vendor	https://www.b3insight.com/
SourceWater, Inc. (formerly Digital H2O)	Commercial data vendor	https://www.sourcewater.com/

Most of the data used in this report was obtained from the OCD, SLO, GoTech, and FracFocus databases. Data from commercial vendors was not purchased as it appears that most of it simply was a compilation of data from public sources. However, work is continuing to determine if other useful information may be available that will help in understanding the relationship between oil, gas, and water in NM. Much of the data contained in these databases is reported electronically by O&G companies, however, some, such as information on PW treatment facilities, required manual review of pdf forms with subsequent entry into a spreadsheet.

Because of its very large size, much of the OCD data is stored as compressed XML files. A computer code was written using the Java development kit (https://jdk.java.net/14/) to download the data and convert it to a comma-separated values (CSV) format. Once in this format the data could be processed using a MySQL code (www.MySQL.com). Data relevant to this study was extracted and converted to spreadsheets to facilitate processing. Data from 2005 to May 2020 was downloaded and processed using these procedures. Once extracted the data collected for this project consists of a large number of files with a total size of 13 GBytes.

Processing of the data primarily consisted of plotting relevant information versus time to enable visual identification of trends. This was done for both gross data (i.e., total O&G production, total volume of water used for HF, total PW generation) as well for the calculation of normalized data (i.e., volume of water for HF per well, PW per well). The study focused on the three O&G producing counties in NM, Eddy County, Lea County, and San Juan County.

In addition to data acquired from public sources, a number of industry experts were contacted to help identify questions important to understanding the oil/gas/water relationships, and to help explain the trends that were identified. Professional conversations with these individuals have continued.

Annual O&G production (Figure 2) is an important measure of industry activity in the state, however, in a sense it integrates activity over several years by combining data from both old and new wells. A measure of impending industry activity over the near term is captured in the number of applications for permits to drill (APD). In 2019, 2,228 APDs were submitted to OCD of which 1,655 were for oil wells and 534 were for gas wells. The rest were for CO_2 wells (1), injection wells (3) salt water disposal wells (29), and miscellaneous wells (3). In 2019, 914 wells were spudded. Plots of the APDs submitted and wells spudded are presented in Figure 7 and Figure 8. The large drop in the number of APDs filed and wells stimulated by HF in 2016 was likely due to a sharp decrease in the price of oil. A similar but even more pronounced drop in the number of APDs is expected to occur in 2020 as the price of oil dropped from about $60/bbl at the beginning of the year to less than $40/bbl in October 2020.

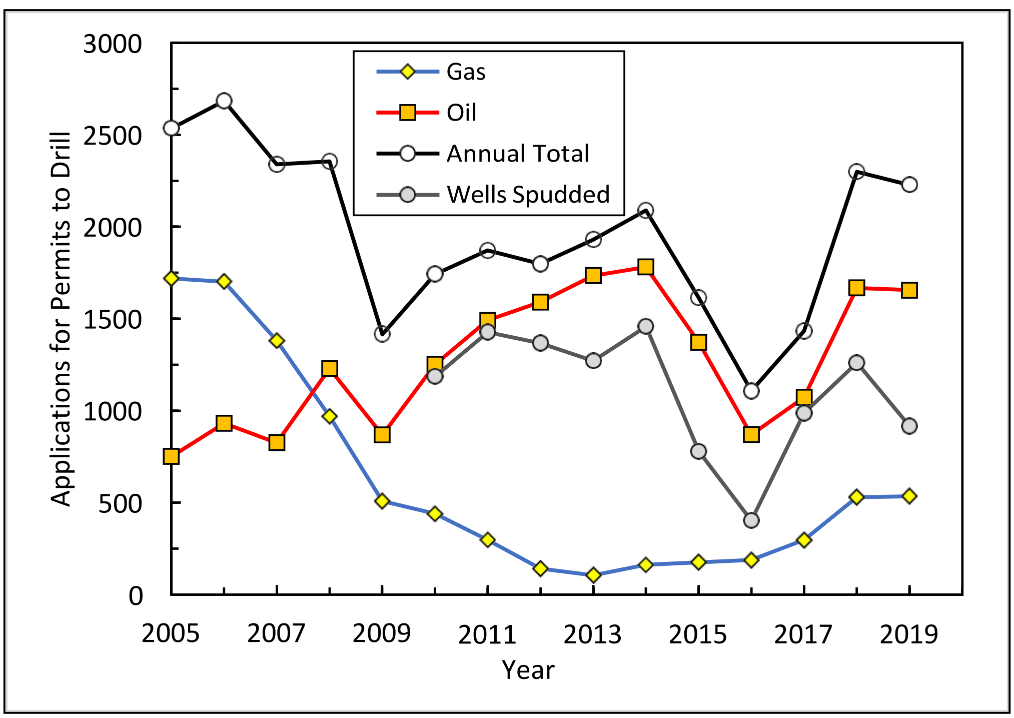


Figure 7. Number of applications for permits to drill (APD) oil and gas wells, and the actual number of wells spudded each year. Data from the NM Oil Conservation Division (OCD, 2020).

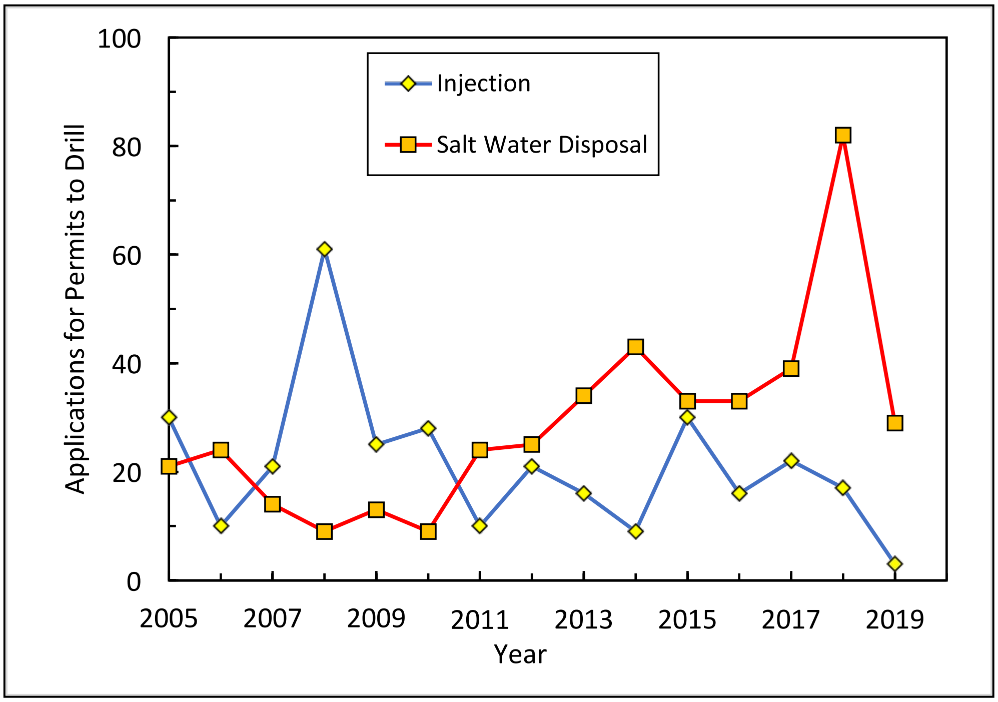


Figure 8. Number of applications for permits to drill (APD) injection and salt water disposal (SWD) wells each year. Data from the NM Oil Conservation Division (OCD, 2020).

Data compiled by FracFocus lists 1076 wells that were fracked in NM during 2019 (see Figure 9) using a total of 311 M bbls (40,100 AF) of water (Figure 10, FracFocus). The source of water and whether it is fresh water, PW, or brackish water is not reported to FracFocus. Figure 11 shows the average volume of water used for fracking per well. The 2019 average was 289,000 bbls/frack (12.1 M gals/frack or 37 AF/frack). The large increase in both the total annual volume of water for HF and the volume of water used per well reflects the increase in the number of wells drilled and increasing length of horizontal unconventional wells. Note that the requirement to report fracking chemicals and water volumes to FracFocus began in 2010, hence almost no data was submitted to this database until near the end of 2011. Even in 2012, there are numerous wells in the FracFocus database with no HF water volumes reported.

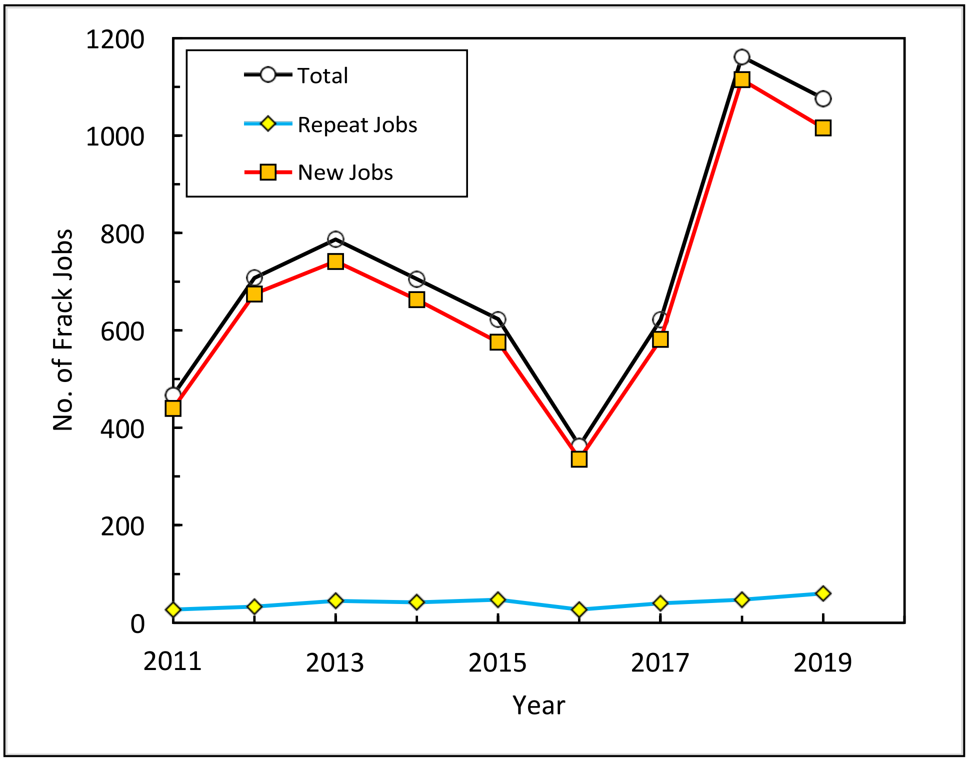


Figure 9. Number of O&G wells fracked in New Mexico each year (FracFocus data).

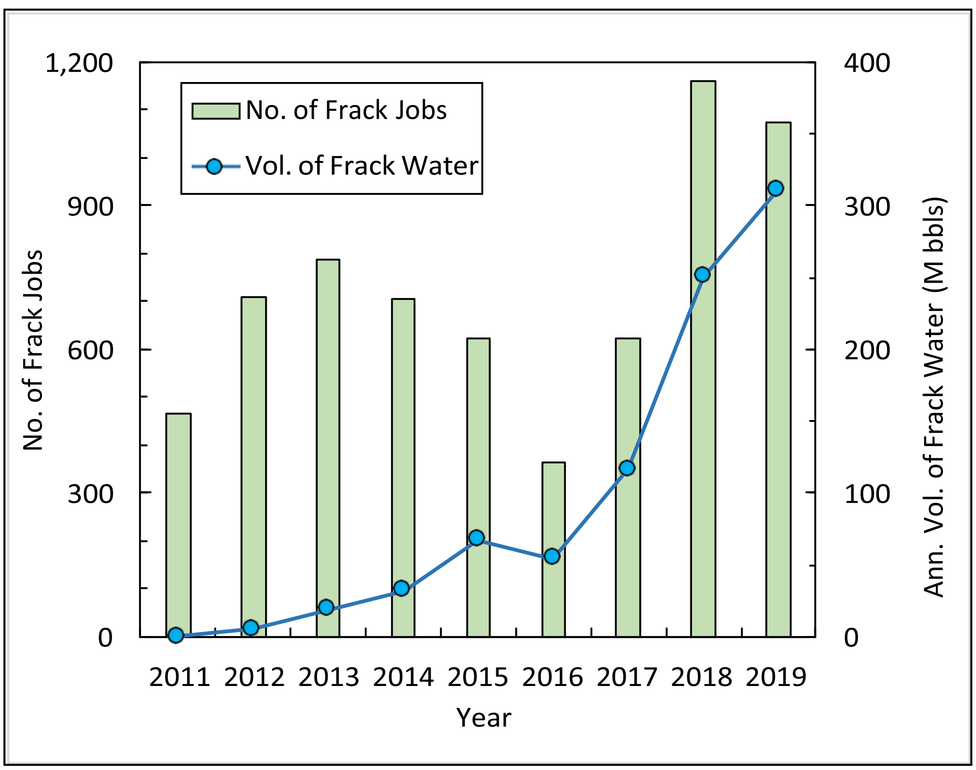


Figure 10. Annual number of fracked wells and the annual volume of water used for HF in NM (data from FracFocus, 2019).

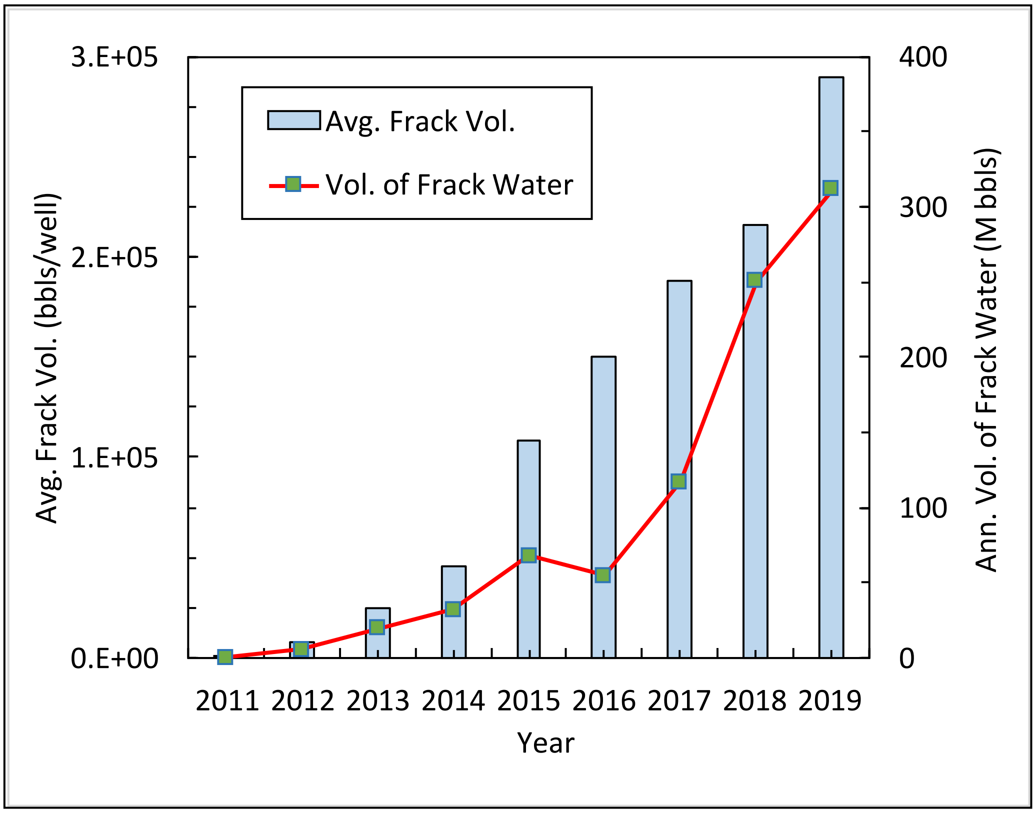


Figure 11. Total annual volume of water used to hydraulically fracture wells in NM (units of million bbl/yr) and the average total volume of water used per well. Data from FracFocus, 2019).

The accuracy of the volume of water used for fracking is suspected of being underreported by as much as 20% (Kayrros, 2019). The challenge of determining accurate water volumes for HF has been noted by other investigators (Kondash et al., 2017; Scanlon et al., 2017). In New Mexico, this uncertain accuracy is possibly due to three reasons. First, water use for fracking is reported through a third-party non-regulatory organization (i.e., FracFocus) and reported volumes are difficult to verify. Second, there is uncertainty regarding how diligently O&G companies and commercial water vendors report water used for HF. And finally, some water supply wells, notably private domestic wells, are not metered so that water from those sources that is used for fracking may not be reported to the Office of the NM State Engineer.

Although the amount of water used for HF is large, it is less than 11% of total regional water use. As noted, nearly all of the new well activity occurred in the Permian Basin. For comparison, the total volume of freshwater diverted in Eddy and Lea counties in SE NM in 2015 was 366,000 AF (2.8 B bbls) and 78% of that (285,000 AF, 2.2 B bbls) was used for irrigated agriculture

(Magnuson et al., 2019). Similarly, in 2015, 168,000 AF (1.3 B bbls) of groundwater was withdrawn for agricultural use in Eddy and Lea counties (Magnuson et al., 2019). A distribution of the total volume of fresh water diverted in these counties is presented in Figure 12. The small fraction of the Permian Basin's fresh water resource that is used for fracking that is consistent with the finding by Scanlon and others (2020) for other western O&G basins.

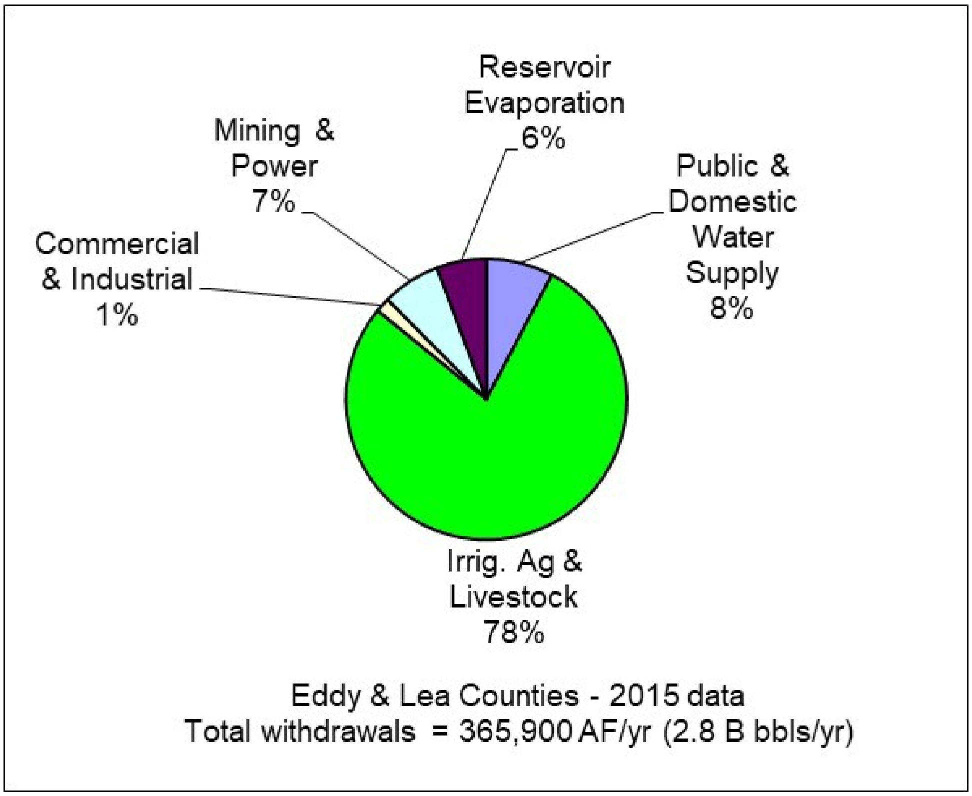


Figure 12. Total surface and groundwater withdrawals of fresh water in Eddy and Lea counties in 2015 (Magnuson et al., 2019).

In October 2020 the Oil Conservation Commission passed a new regulation that requires the industry to report the sources of water used for fracking in addition to the volumes (19.15.16.21 NMAC). The categories of water used for fracking are fresh water (TDS < 1,000 mg/L), brackish water (TDS between 1,000 mg/L and 10,000 mg/L), brine (TDS > 10,000 mg/L), and PW. Prior to promulgation of this regulation, information on the sources of water used for fracking was not reported. Data collected under this new regulation is just starting to be reported and compiled by OCD (OCD, 2020) but is quite revealing. It is summarized in Table 4 and shows that fresh water constitutes 13% of the total volume of water used for fracking. The preliminary nature of this data cannot be over emphasized as it is the result of implementation of a reporting requirement that is new to the industry. Nevertheless, it provides strong evidence of the industry's success at reducing its impact on fresh water resources.

Table 4. Volumes and sources of water used for fracking in Eddy and Lea counties in November and December, 2020. Data from the NM Oil Conservation Division (OCD, 2020).

Source of Water	Volume (AF)	Percent of Total Volume
Fresh water[1]	302	13
Brackish Water[2]	1107	47
Saline Water[3]	0	0
Produced Water	931	40
Total	2,340	100

Notes:
[1]Fresh water has a TDS of less than 1,000 mg/L
[2]Brackish water has a TDS of between 1,000 mg/L and 10,000 mg/L
[3]Saline water has a TDS of greater than 10,000 mg/L

Providing water to the O&G industry in NM has become a profitable business model for a number of companies such as Select Energy Service, Solaris Water Midstream, NGL Energy Partners, Oilfield Water Logistics, and others. Market prices for fresh water were reported to be over $1/bbl in 2018 (Schneider, 2018) roughly 25 times greater than paid by residents of Albuquerque, NM for tap water delivered to their homes. Because of the demand for water some midstream operators are buying up ranches in the area both to acquire their water rights and also to locate salt water disposal wells (SWDs) for deep well disposal of produced water. For example, NGL Energy Partners announced a $93 M acquisition of 122,000 acres of ranchland in NM to acquire 1,500 AF of water rights and locations to drill 20 SWDs (Cision, 2018). This type of activity may have a significant impact on the agricultural economy as land is taken out of production solely for the purpose of water supply and wastewater disposal for the O&G industry.

No information could be found on the volume of water for HF brought to NM from sources in TX or conversely, water from NM that was transported to TX. Lack of information on transfer of water to or from TX is of concern to the NM State Engineer.

PRODUCED WATER GENERATED IN NEW MEXICO

The amount of PW from a well primarily depends on the formation and the type of well as well as its age; both oil production and PW generation decrease over the life of a well. Zemlick and others (2018) summarized produced water generated by O&G operations in the four basins of NM. The annual average wastewater generated from oil production is summarized in Table 5. Much less water is produced from gas wells than oil wells; the water ratio is approximately 0.1 bbl water per bbl of oil equivalent (BOE). The data show that vertical wells have a PW-to-oil ratio of 7.12 while that for horizontal wells is 1.68. This reflects the fact that conventional O&G production is from more permeable formations whereas horizontal wells primarily produce from tight sands and shale formations. Scanlon and others (2017) report that the PW-to-oil ratio in the entire Permian Basin was 2.6 for horizontal wells in 2015.

Table 5. Summary of annual produced water volumes generated by oil and gas production from 2006 to 2016 (Zemlick et al., 2018).

Well Location & Well Type	No. of Gas Wells	No. of Oil Wells	Produced Water (Mbbl)	Produced Water:Oil (bbl/bbl)
Producing Basin				
Bravo Dome	N/A	3	0.06	1.72
Permian	7,080	26870	401.64	4.98
Raton	841	N/A	N/A	N/A
San Juan	21,536	2133	2.83	1.21
Well Type				
Not Assigned	596	1744	29.12	2.54
Directional**	453	510	17.61	8.84
Vertical	27,418	24107	315.22	7.12
Horizontal	990	2649	42.64	1.68
*BOE = Barrel of Oil Equivalent = 170 m3 = 6,000 ft3)				
**Includes both directional and multilateral wells				

The annual O&G production in the Permian and San Juan Basins has been previously shown in Figure 2 for both the Permian and San Juan Basins. The annual volume of PW generated is shown in Figure 13. The total volume of PW generated in 2019 was 1,203 M bbls/yr and 37 M bbls/yr in the Permian and San Juan Basins, respectively. This corresponds to 155,000 AF and 4,800 AF. In contrast to water used for HF, the volume of PW generated by O&G development in SE NM is of the same order of magnitude as total freshwater diversions. This large volume is relevant for two reasons. First, it presents an enormous wastewater management challenge. Second, the large volume has generated much interest in possible recovery of this water for reuse outside the industry. Both are discussed below.

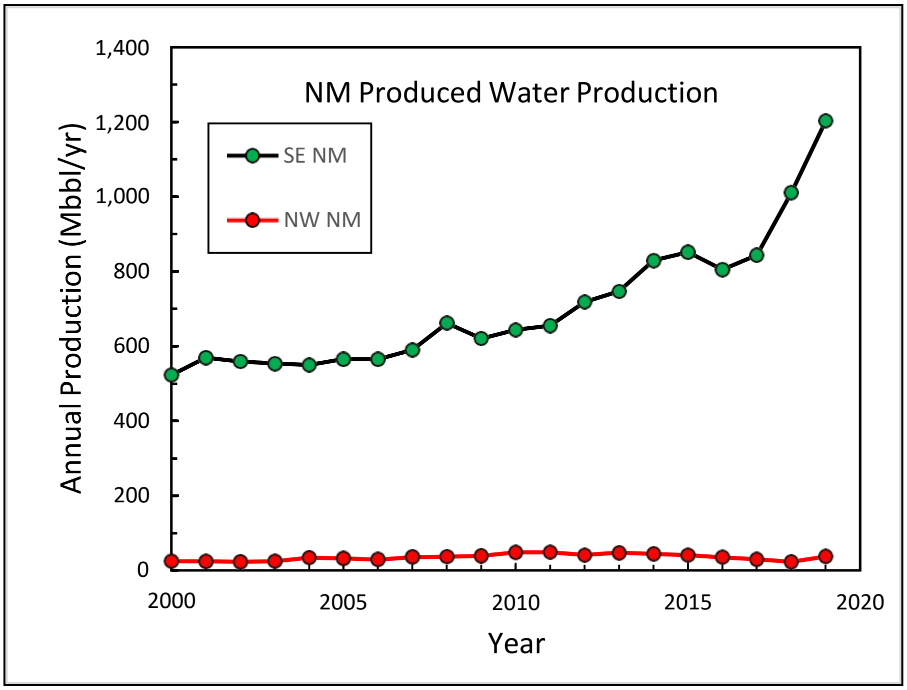


Figure 13. Annual produced water (PW) production from oil and gas wells in the Permian Basin and San Juan Basin in NM (million bbl/yr). Data from the NM Oil Conservation Division (OCD, 2020).

Though its salinity is variable and ranges from total dissolved solids (TDS) concentrations of less than 50,000 mg/L to greater than 300,000 mg/L, the average salinity of PW in the Permian Basin is greater than 100,000 mg/L (Chaudhary et al., 2019; Chaudhary et al., 2016). For comparison, the average TDS of seawater is 35,000 mg/L. The variability in quality, extremely high salinity and complicated water chemistry makes PW very difficult to desalinate. The challenges to desalinating this water include: (1) very high energy costs, (2) very high scale formation potential due to high concentrations of hardness ions (calcium and magnesium), sulfate, and silica, and (3) limited disposal options for the large amounts of waste produced by a desalination process primarily due to risks of induced seismicity caused by deep well injection of large volumes of PW under high pressures (Rinehart et al., 2021; Scanlon et al., 2019). A simple calculation can be done to illustrate this last point. Assuming an average salinity of 100,000 mg/L, desalination of all of the PW generated in SE NM in 2019 (1.2 B bbls/yr) would produce a pile of salt 181 m tall and 580 m in diameter each year (see Figure 14). In a recent paper analyzing these challenges, Scanlon and others (2020) concluded that "quantitative volumetric and water quality issues does not support reuse outside of the energy sector."

Figure 14. Illustration of annual amount of solid waste that would be produced if all produced water on the NM side of the Permian Basin were desalinated.

One of the remarkable recent trends is the remarkable decrease in the ratios of PW-to-oil in the last ten years from greater than 10 bbls PW/bbl oil to 3.1 bbls PW/bbl oil in 2019 in the Permian Basin (Figure 15). This is likely attributable to increased O&G development in low permeability tight sand and shale formations. The PW-to-oil ratio in the San Juan Basin is much smaller and has averaged less than 1.0 in recent years.

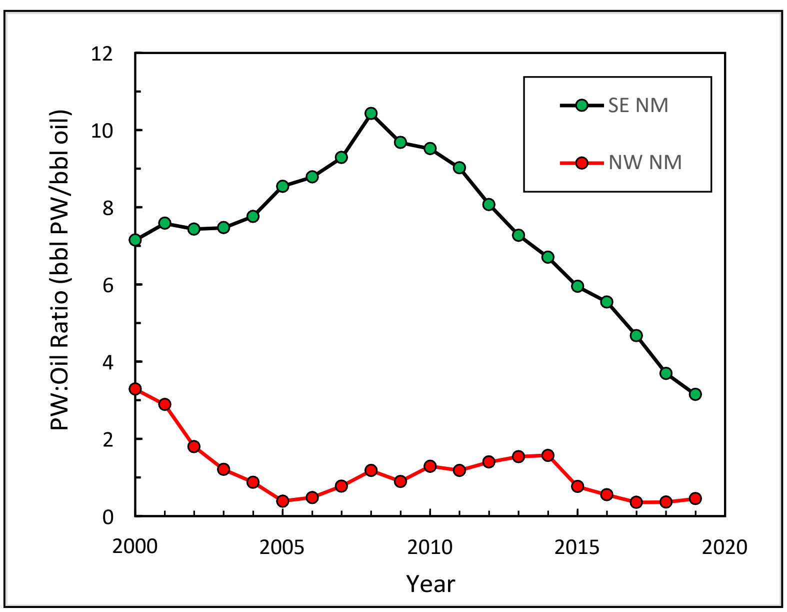


Figure 15. Ratio of PW-to-oil for oil wells in the San Juan and Permian Basins (units of bbl water/bbl oil). Data from the NM Oil Conservation Division (OCD, 2020).

The PW-to-gas ratio is plotted in Figure 16. While the ratio has been fairly constant in the San Juan Basin, there was a six-fold drop from about 0.36 bbl PW/Tcf of gas in 2002 to 0.059 bbl PW/Tcf of gas in 2016. The ratio has steadily increased since then.

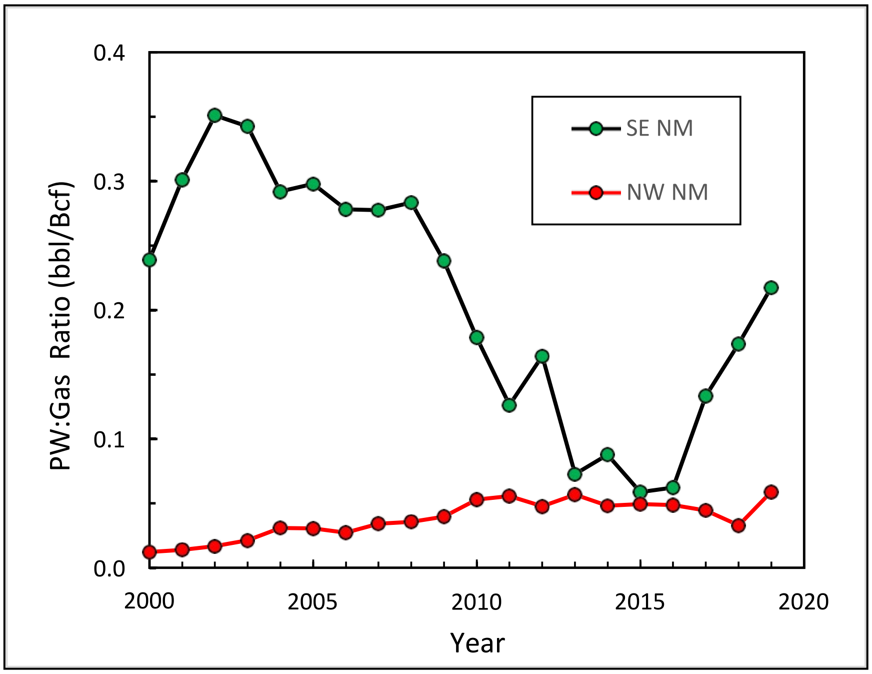


Figure 16. Ratio of PW-to-gas for gas wells in the San Juan and Permian Basins (units of bbl of water/billion ft^3 of gas). Data from the NM Oil Conservation Division (OCD, 2020).

There are two principal methods for managing the large volume of PW generated by O&G development, namely subsurface injection for secondary recovery of oil (SRO) and disposal in salt water disposal (SWD) wells (EPA, 2016). There are a small number of companies offering produced water disposal through use of evaporation ponds but the amount of water disposed in this manner is not reported to the OCD. Furthermore, the volume of water disposed of by evaporation is small compared that disposed of in Class II salt water disposal wells. Figure 17 gives a statewide summary of the annual volume of PW injected for SRO and the volume disposed of in SWD wells.

Although OCD data list PW disposal in 11 counties (Chavez, Colfax, Eddy, Harding, Lea, McKinley, Otero, Roosevelt, Sandoval, San Juan and Union counties) and injection for SRO in 9 counties (injection is not reported for Harding and Union counties because there are no SRO projects in either) nearly all PW is injected or disposed of in Eddy and Lea counties (Table 6), greater than 95% of the water was disposed of or injected in Eddy, Lea or San Juan counties (Figure 18). The OCD database listed over 2,270 SWD or injection wells that received PW in 2017. Summary statistics from the OCD show 3,315 completed injection wells and 863 completed SWD wells.

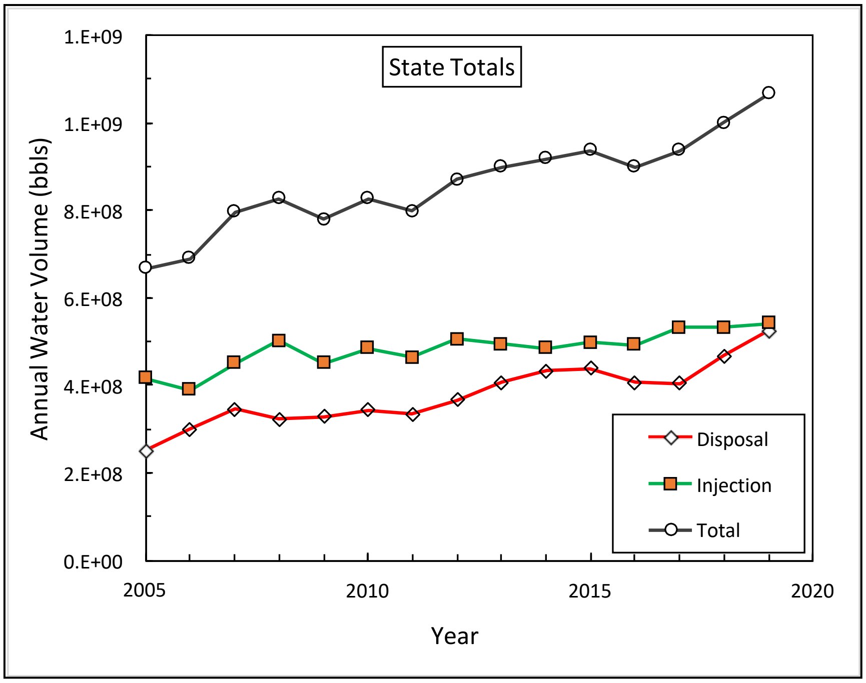
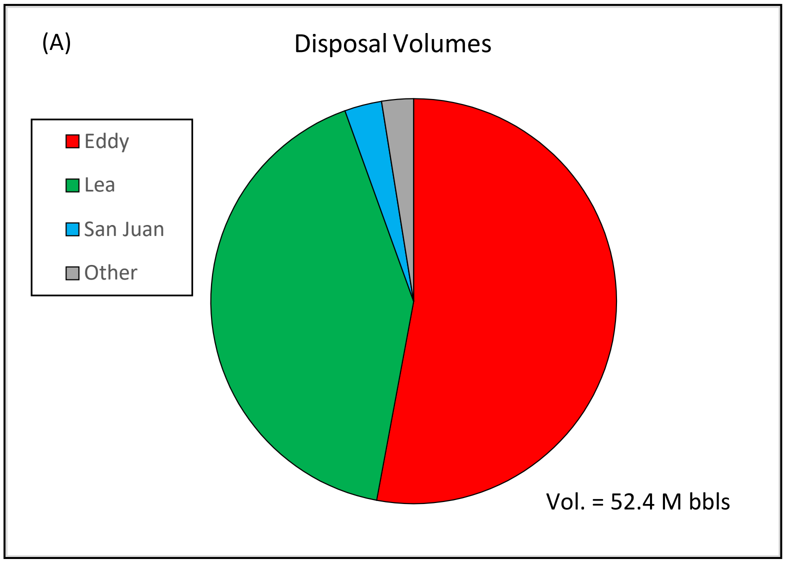


Figure 17. Statewide annual volume of produced water (PW) generated, that was disposed of in salt water disposal (SWD) wells, and that was injected for secondary recovery of oil (SRO). Data from the NM Oil Conservation Division (OCD, 2020).

Table 6. New Mexico counties in which produced water (PW) was disposed of or injected in 2019. Data from the NM Oil Conservation Division (OCD, 2020).

	Volume (bbls)		
County	**Disposal**	**Injection**	**Total**
Chavez	2.14 E+06	2.09 E+05	2.35 e+06
Colfax	5.71 E+06	2.11 E+06	7.83 E+06
Eddy	2.78 E+08	5.99 E+07	3.37 E+08
Harding	2.57 E+05		2.57 E+05
Lea	2.18 E+08	4.70 E+08	6.88 E+08
McKinley	8.23 E+04	3.88 E+04	1.21 E+05
Otero	3.73 E+06	3.34 E+05	4.07 E+06
Roosevelt	1.09 E+06	3.40 E+06	4.49 e+06
Sandoval	7.97 E+04	9.12 E+05	9.91 E+05
San Juan	1.56 E+07	4.32 E+06	1.99 E+07
Union	1.93 E+05		1.93 E+05



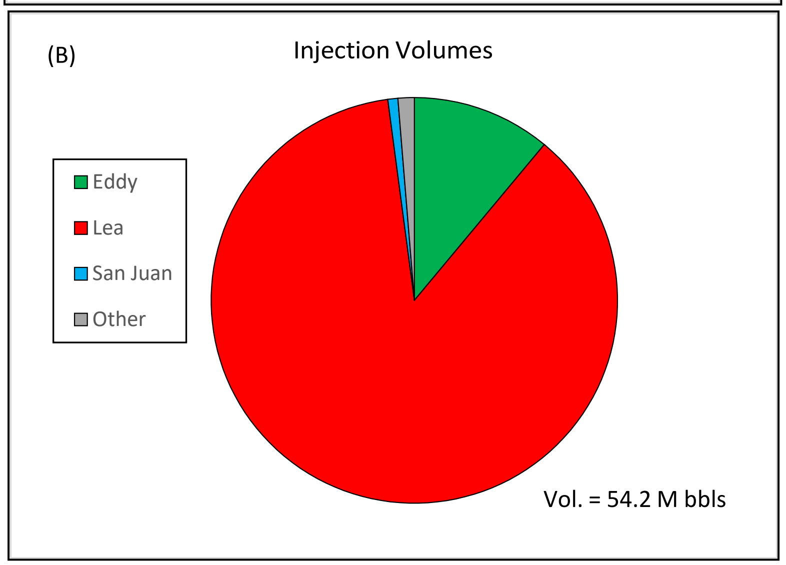


Figure 18. Distribution of NM counties in which PW generated in 2019 was disposed of in SWDwells (A) or injected (B) (units of million barrels). Data from the NM Oil Conservation Division (OCD, 2020).

Transporting the large volumes of water associated with HF and PW management and disposal is accomplished by trucking, piping through temporary pipes laid on the ground usually along road easements, and through a growing system of permanent pipes constructed by mid-stream companies. The OCD database lists 135 gas transport companies and 159 oil transporting companies in June 2019, and 626 active water haulers in June 2020. It's probably slightly more than a coincidence that the ratio of water-haulers-to-oil-transporters of 3.9 is just slightly larger than the PW-to-oil ratio of 3.1. The challenges of transporting large volumes of water and its impact on roads in the Permian Basin have been described by Collins (2020, 2018). He has coined the phrase “hydrovascularity” to described the transportation networks (Collins, 2020). One large independent O&G company’s strategy for regionalization of its water management challenges has been described by Nichols and others (2017). In addition to the difficulties of treating very poor-quality PW, its management and disposal must also consider logistical problems related to collection, storage, and transport of the water.

Prior to disposal or injection of PW, it must be treated to assure that it does not plug the subsurface formation. Treatment usually consists of removal of hydrocarbons in oil-water separators and filtration to remove particulates. Biocides may be added to prevent microbial growth that can plug formations and enhance corrosion of metals. If a company wants to recycle or reuse PW, drilling fluids, or liquid oil field wastes, it must submit a C-147 form to the NM OCD. Unfortunately, information on these forms is not entered into a searchable database, they are simply scanned and archived as pdf images. A manual search of C-147 forms in OCD files identified 104 facilities permitted to treat PW in 2018 (see Appendix). Information on the treatment capacities and technologies used at most facilities is limited. Furthermore, for most facilities the volume of water treated each month and the source of the water is not presently reported. The OCD is working to address this information gap. Whether the treated water was used for injection or disposed in a SWD well is not reported. No treatment facility was identified in the OCD database that listed desalination equipment.

No information could be found on the volumes of PW transported to or from TX by O&G companies on either side of the border.

New Mexico Produced Water Act

The 2019 NM legislature passed the Produced Water Act, House Bill 546, which became effective July 1, 2019. The Act clarified state agency jurisdiction, along with ownership and liability during transport, storage, treatment, and reuse of produced water. The NM OCD has regulatory responsibility over management and disposal of PW except for that which is used outside of the industry. The company that generates the PW has ownership as well as liability of the water; however, if the water is transferred to another entity, ownership, right to treat and use the water, and liability shall be transferred to the new owner. If the water is to be used outside of the O&G industry, it must meet water quality criteria established by the NM Water Quality Control Commission (WQCC), and this reuse will be administered by the NMED. Currently, PW reuse standards have not been developed so that use of this water outside of the industry is prohibited. A more thorough discussion of this act and other legislation and regulations pertaining to water used by and generated by the O&G industry has been described in a companion report to this one (Russo Baca et al., 2021).

ECONOMIC CONSIDERATIONS

The broad focus on O&G production and the associated PW has, historically, been that of the management of the PW associated with the O&G Industry. Management of produced water has been described as an economic decision, based on the quantity, quality, regulations, and available infrastructure (Shaffer et al., 2013). As such, economic evaluation has mostly been an accounting exercise focusing on the tradeoffs between limited alternatives at a point in time.

Historically, this led to the choice of PW injected for SRO, which does provide a beneficial use through enhanced recovery of hydrocarbons, or disposal. Both incurred similar costs. In NM, with the transition to shale production from horizontal wells, the amount of PW injected has leveled off and, statewide, PW disposal now equals SRO injection amounts (Figure 17). In 2019, about 500 million barrels of PW were injected as part of enhance recovery, with an equal amount going to disposal wells. There are, however, wide variations across counties (Table 6) with Permian Basin counties injecting about two-thirds of PW in 2019. PW injection is for conventional production, as SRO injection in unconventional shale reservoirs is considered infeasible due to the very low permeability of the formations (Du and Nojabaei, 2019). This suggests that, without alternatives, disposal rates may increase over time, depending on the PW-BOE ratios. Costs associated with the disposal of water vary. HIS Markit (2020) terms this portion of the water market "logistics" and breaks it into three categories: hauling, transfer and storage. They estimate the largest cost is hauling, which can be, on average, between $1 and $4 per barrel and up to 25% of total PW management costs. Given the 2015 average NM PW to oil ratio (Table 2), hauling contributes to the per barrel cost of production between slightly over $1 per barrel to slightly less than $9 per barrel. If all produced water were disposed of, the annual hauling costs in NM would be between $1.4 and $9.3 billion.

Water management has become an important, mainstay of the midstream industry. The total costs of disposal are non-trivial, and the cost of capital equipment is substantial. This has resulted in the growth of water disposal companies. While operators may pay a higher total cost per barrel for this disposal service, the capital costs (and risks) are borne by these third-party companies.

The impact of the disposal costs depends on the total costs of production, relative to the price of a barrel of oil. A March 2020 survey conducted by the Dallas Federal Reserve (2020) found that the breakeven oil price for a barrel of oil from a new well varied by location in the greater Permian, ranging from a low of $46 per barrel in the Midland to $52 per barrel in the Delaware. The shut-in price (i.e., the price needed to cover operating costs) for existing wells ranged from a low of $23 per barrel in the Eagle Ford and in the greater Permian Basin it ranged from $26 per barrel (Midland and Delaware) to $32 per barrel in other parts of the Permian. While the Permian remains one of the least expensive basins in the country for production, the disposal costs are not inconsequential. Based on the estimated disposal costs per barrel presented earlier, disposal can be a major portion of the operating cost. While the ratio of barrels of PW to BOE has declined, the overall quantity of PW in the Permian Basin in NM more than doubled between 2000 and 2019 (Figure 13), suggesting an ongoing need to consider economic alternatives to disposal.

Figure 10 shows that the average amount of water used for completions has increased. While water consumptions for HF's remain a relatively small portion of water withdrawals, the increased use of water for HF suggests PW as a substitute for fresh water in completions may be a viable beneficial use. Specific to NM, the amount of PW used for completions is sparse. In information reported by Veil (2020), less than 1% of PW in NM was re-used in the oil fields in 2017, compared to slightly over 1% nationally. In addition, another 1% of the total PW in the US reported a beneficial re-use outside of the oil fields. The majority of this was in CA, where 10% of PW was used either for aquifer recharge or irrigation in 2017 (Veil, 2020). This is feasible because PW in CA has much lower TDS than almost any other major O&G producing region. Preliminary data resulting from reporting requirements under 19.16.15.21 NMAC promulgated in October 2020 show that approximately 40% of water used for fracking in the Permian Basin is PW and 47% is brackish water, which substantiates the trend toward use of low-quality water and reduced demand for fresh water (Table 4).

In order to increase the use of PW and brackish water for fracking in NM, the water quality must be compatible with that needed for fracking, and the cost to treat and deliver this water to the site must be competitive with the cost of fresh water delivered. This suggests that either the current cost of PW, the PW quality, or lack of capital equipment makes this an unviable alternative.

While ongoing research (Rodriguez, et al., 2020) provides potential pathways for increased re-use in the oil fields, the problem of capital expenditure remains.

The choices made by private enterprise in the oil fields are driven by economic considerations. This has been borne out by the response to the current recession that was exacerbated by the coronavirus, and is illustrated by the decrease in the numbers of wells drilled following collapse of O&G prices in 2008-2009 and 2015-2016 (see Figure 3). Most remarkable is the precipitous decline in the number of gas wells drilled after 2008 due to a sharp drop in gas prices that have never recovered. Figure 19 shows the average monthly rig count for New Mexico as reported by Baker Hughes for 2019 and 2020 (2020), as well as the average spot price for a barrel of West Texas Intermediate (WTI) crude oil. While there is a lag in terms of rig count to price, we can see the reaction in 2019 of higher first quarter oil prices in the increase in rig count in the 3rd and 4th quarters of 2019. The decline in price in the first four months of 2020, coupled with COVID-19 restrictions continues to impact the industry. While prices have rebounded, somewhat, the current price is well below that of the beginning of the year. Future PW volumes, costs, and the mid-stream water management company choices will be, in part, dictated by new drilling activity, which depends on market conditions.

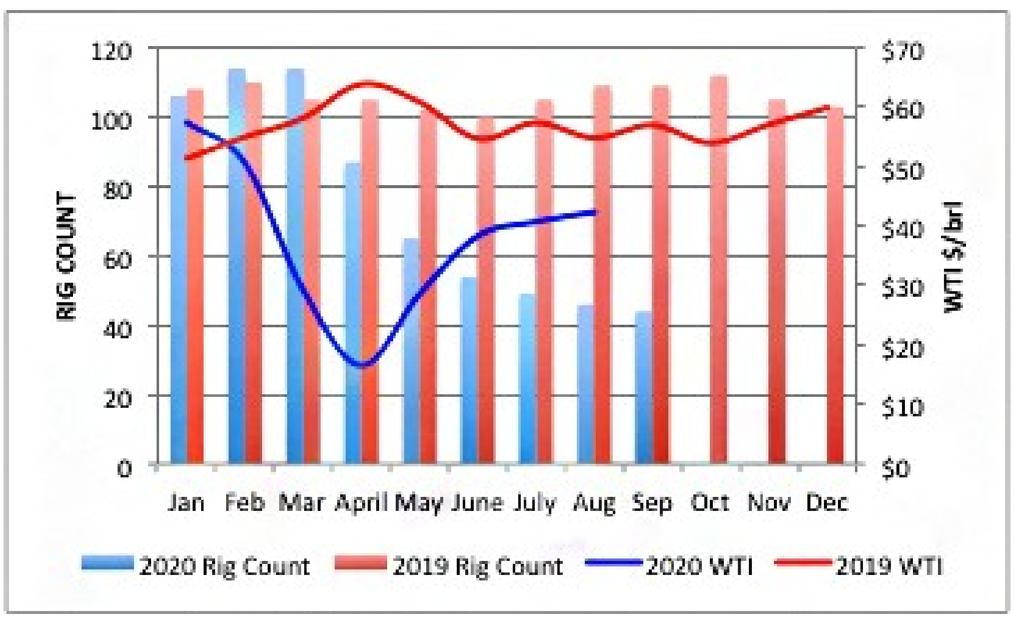


Figure 19. Active Average Monthly Rig Count in New Mexico and WTI Spot Price (Baker Hughes, 2020 and US EIA, 2020).

The above discussion suggests the current economic management practices for PW at a private market level will continue to provide challenges as operators choose to find the least costly solution in order to maximize profits and the economic viability of new wells. Further, the selected choices are mainly reactive to the situation and the analysis is a basic static analysis. The 2019 Produced Water Act is described by NMED Cabinet Secretary Kenney as having the goal to "*create regulations that are protective of human health and the environment, reduce industry reliance on fresh water and encourage science-based and innovative solutions*." In order for that to happen, improved information concerning the economics of PW and its production is needed as well as a dynamic analysis of the industry overall, providing insights for proactive solutions.

CONCLUSIONS

The relationship between O&G production, water supply, and wastewater management in NM is intricate and complicated. Large volumes of water, estimated at 311 M bbls (40,000 AF) in 2019, are used in the development of O&G resources for HF. However, this volume constitutes a small fraction of the total water withdrawn in the O&G producing regions of SE and NW NM; a much greater volume of water is withdrawn for agriculture. For comparison 2.2 B bbls 285,000 AF) of water was withdrawn for agricultural use in Eddy and Lea counties in 2015 (Magnuson et al., 2019).

Produced water constitutes a much greater volume of water compared to the water used in O&G development and presents a very difficult management challenge. In 2019, approximately 1.2 B bbls (155,000 AF) of PW was generated by the O&G industry (OCD, 2020) in the Permian Basin and 37 M bbls (48,000 AF) was produced in the San Juan Basin. This water is extremely salty, with an average salinity roughly three times that of seawater. In contrast to seawater, PW has very high concentrations of calcium, magnesium, and sulfate that make it very difficult to desalinate. Because it cannot be economically treated for reuse, half of the PW generated in NM is disposed of by injection into deep SWD wells, and the remainder is injected into O&G formations for secondary recovery of oil (SRO). In recent years, the fraction reused within the industry has declined while that sent to SWD wells has increased. Due to the low permeability of unconventional oil and gas formations the fraction that must be disposed of appears likely to continue to increase. Developing safe and cost-effective methods for managing and disposing of PW is arguably the biggest environmental challenge facing the O&G industry, both in NM and elsewhere.

A much better and more quantitative understanding of the relationship between oil, gas, and water has been developed in recent years. However, the accuracy of both fresh water use and PW generation is uncertain due to a variety of technical and administrative challenges. In addition, the quality of PW is highly variable and data on its bulk and trace chemistry is limited.

The challenges of managing fresh and produced water in NM are recognized by regulators and acknowledged by the industry. Addressing these challenges will require cooperation in research as well as extensive and honest public outreach.

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APPENDIX

OCD Administrative Orders in 2018 pertaining to permitting of produced water treatment facilities. Information obtained from OCD for C-147.

Order Number	County	Order Date	Entity	Operator
1RF-440	Lea			TAP ROCK OPERATING, LLC
1RF-439	Lea			COG Operating LLC
1RF-438	Lea			TAP ROCK OPERATING, LLC
1RF-437	Lea			Legacy Reserves Operating, LP
1RF-436	Lea			EOG Resources Inc.
1RF-435	Lea	11/4/2018		OXY USA INC
1RF-434	Lea	11/4/2018		OXY USA INC
1RF-433	Lea	11/4/2018		OXY USA INC
1RF-432	Lea			TAP ROCK OPERATING, LLC
1RF-431	Lea			EOG Resources Inc.
1RF-430	Lea			DEVON ENERGY PRODUCTION COMPANY, LP
1RF-32	Lea	8/10/2018	EOG Hearns Recycling facility and containment	EOG RESOURCES INC
1RF-31	Lea	8/7/2018	EOG Condor Recycling facility and containment	EOG RESOURCES INC
1RF-30	Lea	6/5/2018	Cimarex Vaca Draw SWD Recycling Facility	CIMAREX ENERGY CO.
1RF-29	Lea	3/12/2018	Advance Energy Merchant RF & RC	ADVANCE ENERGY PARTNERS HAT MESA, LLC
1RF-28	Lea	3/12/2018	EOG Streetcar Recycling facility & containment	EOG RESOURCES INC
1RF-27	Lea	3/12/2018	EOG Lomas RF & RC	EOG RESOURCES INC
1RF-26	Lea	2/19/2018	EOG Chili Pepper Recycling facility & containment	EOG RESOURCES INC
1RF-25	Lea	1/18/2018	EOG Galaxy Recycling Facility and Containment	EOG RESOURCES INC
1RF-24	Lea	1/18/2018	3 Bears Energy Libby RF	3BEAR FIELD SERVICES, LLC
1RF-23	Lea	10/10/2017	OWL Fulfer Recycling Facility and Containment	OWL SWD OPERATING, LLC
1RF-22	Lea	10/4/2017	Devon Rattlesnake RF	DEVON ENERGY PRODUCTION COMPANY, LP
1RF-21	Lea	7/28/2017	Mewbourne Red Hills Recycling Facility	MEWBOURNE OIL CO

1RF-20	Lea	7/28/2017	Mewbourne Red Hills Recycling Facility	MEWBOURNE OIL CO
1RF-19	Lea	7/28/2017	Mewbourne Red Hills Recycling Facility	MEWBOURNE OIL CO
1RF-18	Lea	7/28/2017	Mewbourne Salado Draw Recycling Facility	MEWBOURNE OIL CO
1RF-17	Lea	7/28/2017	Mewbourne Salado Draw Recycling Facility	MEWBOURNE OIL CO
1RF-16	Lea	7/28/2017	Mewbourne Salado Draw Recycling Facility	MEWBOURNE OIL CO
1RF-15	Lea	7/27/2017	Oxy Mesa Verde West recycling containment #2	OXY USA INC
1RF-14	Lea	6/15/2017	Oxy Mesa Verde West recycling containment #3	OXY USA INC
1RF-13	Lea		Chevron Salado Draw 13	Chevron USA INC
1RF-12	Lea		EOG South Red Hills	EOG RESOURCES INC
1RF-11	Lea		SALADO DRAW; DELAWARE, NORTHEAST	Chevron USA INC
1RF-10	Lea		Seely	MCELVAIN ENERGY, INC
1RF-9	Lea	10/3/2016	Slash Z Recycling Facility/Containment	Wyatt Permian, LLC
1RF-7	Lea	9/2/2016	Ursala Produced Water Recycling Facility	DEVON ENERGY PRODUCTION COMPANY, LP
1RF-6	Lea	10/6/2015	North Gaucho Containment and Recycling Facility	DEVON ENERGY PRODUCTION COMPANY, LP
1RF-4	Lea		Rattlesnake 2	DEVON ENERGY PRODUCTION COMPANY, LP
1RF-3	Lea		Big XL Containment and Recycling. Facility	DEVON ENERGY PRODUCTION COMPANY, LP
1RF-2	Lea		Rat Camp Booster Station	DEVON ENERGY PRODUCTION COMPANY, LP
2RF-133	Eddy	8/15/2018	Riverbend 12013 Fed Com CTB	CIMAREX ENERGY CO.
2RF-132	Eddy	8/15/2018	DaVinci 7 L8 Federal Battery	CIMAREX ENERGY CO.
2RF-131	Eddy	8/15/2018	Crawford Fee 27/26 Battery	CIMAREX ENERGY CO.
2RF-130	Eddy	8/13/2018	Willow 17 State SWD #1	COG Operating LLC
2RF-128	Eddy	4/18/2018	Cottonwood Recycling Facility	3BEAR FIELD SERVICES, LLC
2RF-126	Eddy	2/28/2018	Remuda Recycling Facility	XTO ENERGY, INC
2RF-124	Eddy	2/28/2018	PLU Central 2 Recycling Facility	BOPCO, LP
2RF-123	Eddy	2/28/2018	PLU Central 1 Recycling Facility	BOPCO, LP
2RF-122	Eddy	2/27/2018	PLU South Recycling Facility	BOPCO, LP
2RF-121	Eddy	2/27/2018	PLU North Recycling Facility	BOPCO, LP
2RF-119	Eddy	2/14/2018	Corral Fly Recycling and Containment	OXY USA INC
2RF-117	Eddy	2/20/2017	RDX Section 16 Aboveground Storage Tank	WPX Energy Permian, LLC
2RF-114	Eddy	10/2/2017	Todd 2 Water Treatment Facility	DEVON ENERGY PRODUCTION COMPANY, LP

2RF-113	Eddy	10/2/2017	Bebop Containment East	MEWBOURNE OIL CO
2RF-112	Eddy	10/2/2017	Bebop Containment West &Recycling Facility	MEWBOURNE OIL CO
2RF-111	Eddy	8/21/2017	OXY Turkey Track South	OXY USA INC
2RF-108	Eddy	1/23/2018	Bullwhip Water Recycling Facility 1	BULLWHIP WATER SOLUTIONS, LLC
2RF-107	Eddy	1/12/2017	Hayhurst Recycling Facility	Chevron USA INC
2RF-106	Eddy	7/8/2016	Tiger Recycling Facilities	MATADOR PRODUCTION COMPANY
2RF-105	Eddy	9/22/2015	Hackberry Containment and Recycling Facility	DEVON ENERGY PRODUCTION COMPANY, LP
2RF-104	Eddy	9/18/2015	Terrapin Containment and Recycling Facility	DEVON ENERGY PRODUCTION COMPANY, LP
2RF-103	Eddy	9/18/2015	Trionyx Containment and Recycling Facility	DEVON ENERGY PRODUCTION COMPANY, LP
2RF-102	Eddy	6/1/2015	Hackberry 16 Containment and Recycling Facility	DEVON ENERGY PRODUCTION COMPANY, LP
2RF-101	Eddy	5/21/2015	WILLOW 17 State swd No. 001, Willow State SWD #1	COG Operating LLC
2RF-100	Eddy	5/20/2015	Cotton Draw, Bone Spring, SOUTH, Cotton Draw PW Storage #1	RAGING BULL OILFIELD SERVICES
3RF-41	San Juan	11/26/2018	W LYBROOK UNIT No.758H, W LYBROOK UNIT No.757H, W LYBROOK UNIT No.756H, W LYBROOK UNIT No.724H, W LYBROOK UNIT No.722H, W LYBROOK UNIT No.720H	ENDURING RESOURCES, LLC
3RF-40	San Juan	11/27/2018	W LYBROOK UNIT No.761H, W LYBROOK UNIT No.760H, W LYBROOK UNIT No.759H, W LYBROOK UNIT No.729H, W LYBROOK UNIT No.728H, W LYBROOK UNIT No.726H	ENDURING RESOURCES, LLC
3RF-39	San Juan		KWU 2309-30D	ENDURING RESOURCES, LLC
3RF-38	San Juan		RINCON 2706-32F	ENDURING RESOURCES, LLC
3RF-37	Sandoval	11/2/2018	N ESCAVADA UNIT No.329H, N ESCAVADA UNIT No.328H, N ESCAVADA UNIT No.314H, N ESCAVADA UNIT No.313H	ENDURING RESOURCES, LLC
3RF-36	Sandoval	11/1/2018	W ESCAVADA UNIT No.304H, W ESCAVADA UNIT No.303H, W ESCAVADA UNIT No.302H	ENDURING RESOURCES, LLC
3RF-35	Sandoval	11/1/2018	N ESCAVADA UNIT No.318H, N ESCAVADA UNIT No.317H	ENDURING RESOURCES, LLC
3RF-34	San Juan	10/31/2018	ATHENA 2308 14L No.002H, ATHENA 2308 14L No.001H	LOGOS OPERATING, LLC
3RF-33	Rio Arriba	10/31/2018	FEDERAL 2307 07P COM No.003H, FEDERAL 2307 07P COM No.002H, FEDERAL 2307 07P COM No.001H	LOGOS OPERATING, LLC

3RF-32	Sandoval	10/31/2018	N ESCAVADA UNIT No.331H, N ESCAVADA UNIT No.330H, N ESCAVADA UNIT No.316H, N ESCAVADA UNIT No.315H	ENDURING RESOURCES, LLC
3RF-31	San Juan			INDUSTRIAL ECOSYSTEMS, INC.
3RF-30	Sandoval			INDUSTRIAL ECOSYSTEMS, INC.
3RF-29	San Juan	10/15/2018	WLU 2309-24N	ENDURING RESOURCES, LLC
3RF-28	San Juan	9/20/2018	NEU 2207-16B WATER RECYCLING FACILITY	ENDURING RESOURCES, LLC
3RF-27	San Juan	9/10/2018	TSAH TAH SWD No.011	JUNIPER RESOURCES EXPLORATION COMPANY, LLC
3RF-26	San Juan	8/28/2018	PINON UNIT No.306H	JUNIPER RESOURCES EXPLORATION COMPANY, LLC
3RF-25	San Juan	7/19/2018	ATHENA 2308 14L No.003H	LOGOS OPERATING, LLC
3RF-24	San Juan	7/19/2018	HEROS 2308 09L COM No.005H, HEROS 2308 09L COM No.004H, HEROS 2308 09L COM No.003H, HEROS 2308 09L COM No.002H	LOGOS OPERATING, LLC
3RF-23	San Juan	3/26/2018	ATHENA 2308 14L No.002H, ATHENA 2308 14L No.001H	LOGOS OPERATING, LLC
3RF-22	San Juan	1/26/2018	N ESCAVADA UNIT No.312H, N ESCAVADA UNIT No.311H	WPX ENERGY PRODUCTION, LLC
3RF-21	San Juan	7/11/2017	STATE 2207 36D No.193H	WPX ENERGY PRODUCTION, LLC
3RF-20	San Juan	7/11/2017	N ESCAVADA UNIT No.328H, N ESCAVADA UNIT No.314H, N ESCAVADA UNIT No.313H	WPX ENERGY PRODUCTION, LLC
3RF-19	San Juan	2/1/2017	W LYBROOK UNIT No.702H, W LYBROOK UNIT No.701H	WPX ENERGY PRODUCTION, LLC
3RF-18	San Juan	2/1/2017		WPX ENERGY PRODUCTION, LLC
3RF-17	San Juan	2/1/2017		WPX ENERGY PRODUCTION, LLC
3RF-16	San Juan	2/1/2017	W LYBROOK UNIT No.744H, W LYBROOK UNIT No.743H, W LYBROOK UNIT No.713H, W LYBROOK UNIT No.711H, W LYBROOK UNIT No.704H, W LYBROOK UNIT No.703H	WPX ENERGY PRODUCTION, LLC
3RF-15	Sandoval	12/29/2016	CHACO 2206 16A No.221H	WPX ENERGY PRODUCTION, LLC
3RF-14	San Juan	12/29/2016	LOGOS No.005	WPX ENERGY PRODUCTION, LLC
3RF-13	Sandoval	7/6/2016	N ESCAVADA UNIT No.329H	WPX ENERGY PRODUCTION, LLC
3RF-12	San Juan	7/6/2016	KIMBETO WASH UNIT No.771H	WPX ENERGY PRODUCTION, LLC
3RF-11	San Juan	7/6/2016	W LYBROOK UNIT No.767H, W LYBROOK UNIT No.735H, LYBROOK 2309 34B No.765	WPX ENERGY PRODUCTION, LLC

3RF-10	San Juan		W LYBROOK UNIT No.749H, W LYBROOK UNIT No.747H, W LYBROOK UNIT No.709H, W LYBROOK UNIT No.708H, W LYBROOK UNIT No.707H	WPX ENERGY PRODUCTION, LLC
3RF-9	Rio Arriba	2/8/2016	MC 6 COM No.918H, MC 6 COM No.160H	WPX ENERGY PRODUCTION, LLC
3RF-8	Rio Arriba	2/2/2016	MC 8 COM No.410H, MC 8 COM No.409H	WPX ENERGY PRODUCTION, LLC
3RF-7	Rio Arriba	12/14/2015	ROSA UNIT No.649H, ROSA UNIT No.648H, ROSA UNIT No.647H, ROSA UNIT No.646H, ROSA UNIT No.645H, ROSA UNIT No.644H, ROSA UNIT No.643H, ROSA UNIT No.642H, ROSA UNIT No.641H, ROSA UNIT No.640H	WPX ENERGY PRODUCTION, LLC
3RF-6	Rio Arriba	12/7/2015	NE CHACO COM No.912H, NE CHACO COM No.902H	WPX ENERGY PRODUCTION, LLC
3RF-5	Rio Arriba	10/20/2015	NE CHACO COM No.903H	WPX ENERGY PRODUCTION, LLC
3RF-4	San Juan	10/20/2015	MC 5 COM No.906H, MC 5 COM No.119H, MC 5 COM No.113H, MC 5 COM No.112H	WPX ENERGY PRODUCTION, LLC
3RF-3	Rio Arriba	8/19/2015	Section 30 Containment and Recycling Facility	lOGOS OPERATING, LLC, but LOGOS on main website?
3RF-2	Rio Arriba		Basin Disposal Inc. dbA Basin Water Recycling	BASIN DISPOSAL INC
3RF-1	Sandoval	5/8/2015	MC 4 COM No.285H	WPX ENERGY PRODUCTION, LLC