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Research article

Water usage for natural gas production through hydraulic fracturing in the United States from 2008 to 2014

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ABSTRACT

Hydraulic fracturing has promoted the exploitation of shale oil and natural gas in the United States (U.S.). However, the large amounts of water used in hydraulic fracturing may constrain oil and natural gas production in the shale plays. This study surveyed the amounts of freshwater and recycled produced water used to fracture wells from 2008 to 2014 in Arkansas, California, Colorado, Kansas, Louisiana, Montana, North Dakota, New Mexico, Ohio, Oklahoma, Pennsylvania, Texas, West Virginia, and Wyoming. Results showed that the annual average water volumes used per well in most of these states ranged between 1000 m^3 and 30,000 m^3. The highest total amount of water was consumed in Texas with 457.42 Mm^3 of water used to fracture 40,521 wells, followed by Pennsylvania with 108.67 Mm^3 of water used to treat 5127 wells. Water usages ranged from 96.85 Mm^3 to 166.10 Mm^3 annually in Texas from 2012 to 2014 with more than 10,000 wells fractured during that time. The percentage of water used for hydraulic fracturing in each state was relatively low compared to water usages for other industries. From 2009 to 2014, 6.55% (median) of the water volume used in hydraulic fracturing contained recycled produced water or recycled hydraulic fracturing wastewater. 10.84% (median) of wells produced by hydraulic fracturing were treated with recycled produced water. The percentage of wells where recycled wastewater was used was lower, except in Ohio and Arkansas, where more than half of the wells were fractured using recycled produced water. The median recycled wastewater volume in produced wells was 7127 m^3 per well, more than half the median value in annual water used per well 11,259 m^3. This indicates that, for wells recycling wastewater, more than half of their water use consisted of recycled wastewater.

1. Introduction

Hydraulic fracturing is used to create fractures in shale formation and has become common practice over the last several years for the production of natural gas in the United States (U.S.). The production of natural gas, especially in various low-permeability shale plays, has increased from 2008 to 2014 due to the use of hydraulic fracturing and horizontal drilling techniques (Jiang et al., 2011; Sakmar, 2011; Vengosh et al., 2014). However, the practice of hydraulic fracturing concerns many environmental groups, policy makers, and scientists due to the potential risks to the environment and human health. Hydraulic fracturing consists of large volumes of hydraulic fracturing fluids, which contain a mixture of 98–99.5% water, proppants, and chemical additives making up the balance (Gregory et al., 2011), being injected into the shale formation under high pressure. Roughly 30–50% of the injected water flows back to the surface after the pressure is released (Stringfellow et al., 2014). The application of hydraulic fracturing requires high volumes of water and therefore has the potential to promote a high demand for freshwater, induce groundwater contamination, and require significant expenses in wastewater disposal (Miller et al., 2013).

Hydraulic fracturing is used to created fractures, or cracks, in the shale formation to facilitate the release of natural gas and oil, while long horizontal laterals drilled by using horizontal drilling increases the contact area between the formations and the hydraulic fracturing fluids (Li et al., 2015). The amount of water used in hydraulic fracturing is not simply related to the well's vertical depth of, but it is also dependent on the shale plays, operators, the lateral lengths, and the number of "fracing" stages

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(Nicot and Scanlon, 2012). A number of factors, including formation geology, product amount, and number of fractured stages, may affect the quantity of water required to fracture a well (Kuwayama et al., 2015). Previous studies have found that the mean water used per well for oil production in the Eagle Ford was twice what was needed to stimulate wells located in the Bakken shale play because of the geological differences and the higher productions, instead of the water-to-oil ratios (Scanlon et al., 2014a), and it has been suggested that there is a strong correlation between water use and gas production in shale gas wells (Nicot and Scanlon 2012). In July 2011, the U.S. Energy Information Administration (2011) reported there was a total of 21.24 trillion m^3 and 3.82 billion m^3 of technically recoverable shale gas and oil in the U.S. 86% of the technically recoverable shale gas reservoirs are located in the Northeast, Gulf Coast, and Southwest regions (U.S. Energy Information Administration, 2011).

When hydraulic fracturing fluids are injected into the formation the public is usually concerned with the potential for these fluids to contaminate groundwater, especially aquifers used as sources of drinking water (Briskin, 2015). Hydraulic fracturing fluids under pressures greater than 68,948 kPa can easily extend the induced fractures into the surrounding areas (Jackson et al., 2015). An adequate vertical separation between hydraulic fracturing operations and aquifers must be maintained for shallow hydraulic fracturing wells, which pose a higher risk of contamination compared to deeper wells (Jackson et al., 2015). The fluids returning back to the surface after releasing well pressure are considered to be oil and gas wastewater, and can consist of flowback (the returning hydraulic fracturing fluids) and produced water (water in the formation) (Gregory et al., 2011; Stringfellow et al., 2014). Another practice used for wastewater management involves chemical treatment prior to reuse. This consists of chemical additives, fresh water, and proppants mixed with the recycle wastewater to make up a fresh hydraulic fracturing fluid for stimulation of new wells (Wang et al., 2014).

According to Vengosh et al. (2014), the estimated volumes of wastewater per shale gas well were 3500 m^3 in Marcellus Shale, Pennsylvania (PA) (2012), and 4000 m^3 in Niobrara, Colorado (CO) (2012); however, Stringfellow et al. (2014) estimated the volume of flowback per well to be between 1900–9000 m^3. With the large volumes of water being used and returning to the surface as wastewater, recycling or reusing the water from hydraulic fracturing is considered to be a management strategy for oil and gas operations (Mauter and Palmer, 2014; Warner et al., 2013). Recycling oil and gas wastewater can reduce, not only water consumption in hydraulic fracturing (Gregory et al., 2011), but also the amount of water transported to wastewater treatment plants (WWTPs) or injected into Class II deep wells. Compared with other applications (e.g. irrigation), wastewater can reach the requirements set for recycling into hydraulic fracturing after relatively simple treatment (Lester et al., 2015). Increasing the amount of brackish groundwater and produced water used can alleviate the limitations on the future development of shale gas and oil production (Scanlon et al., 2014b), while decreasing the amount of freshwater usage. The large amounts of water needed for hydraulic fracturing may also contribute to the contamination of drinking water or groundwater due to inappropriate management operations (Llewellyn et al., 2015). These concerns would be more critical for the shale plays located in water scarcity regions (Kargbo et al., 2010; Nicot and Scanlon, 2012). The objective of this study was used to investigate the volume of water used in hydraulic fracturing and the vertical depth of hydraulic fracturing wells in recent years, as well as, to evaluate the use of recycled produced water by the oil and gas industry. Since most studies on hydraulic fracturing water use were focused on the Marcellus and Barnett shale plays, the objective of this study was to examine the water usage for the 14 states where the most of the hydraulic fracturing operations took place.

2. Database and tools

The data for this study was obtained from www.FracFocus.org (FracFocus, 2015). The website is managed by the Groundwater Protection Council and Interstate Oil and Gas Compact Commission. Natural gas and oil companies use the website to disclose data for each well that is put into production through hydraulic fracturing. The database includes wells that recover oil and natural gas. A total of 80,968 portable document format (PDF) files from 14 states were downloaded from FracFocus between January 5, 2015 and March 18, 2015.

MATLAB version R2014b (The MathWorks, Natick, MA) was used to import the data from 80,968 PDF files into an Excel spreadsheet (Microsoft Office 2013, Microsoft Corporation, Redmond,WA). The database consisted of 20 variables including: Fracturing Date, State, County, API Number, Operator Name, Well Name and Number, Longitude, Latitude, Long/Lat Project, Production Type, True Vertical Depth (ft.), Total Water Volume (gal), Trade Name, Suppler, Purpose, Ingredients, CAS Number, Max Additive Concentration (%), Max Concentration In Hydraulic Fracturing Fluids (%), and Comments. The wells were identified by: Fracturing Date, State, County, American Petroleum Institute (API) Number, Operator Name, Well Name and Number, Longitude, Latitude, and Long/Lat Project (used for the GIS software).

A summary of the database is available in Table S1 found in the supplementary information. Although 80,968 Excel files were imported, the database used to organize the information had a total of 80,164 wells. This was due to the fact that some wells were determined to be duplicates based on the previously mentioned identifiers. Of the 80,164 wells, 80,047 were fractured between 2008 and 2014, which are listed in Table S2 (in the supplementary information) while the others were fractured either before 2008 or in the beginning of 2015. Only 79,840 of 80,047 wells reported the total water volume (illustrated in Fig. 1), while 73,633 of 80,047 wells presented the vertical depth. For the True Vertical Depth, four wells (two wells in Texas (TX), one well in Pennsylvania, and one well in West Virginia (WV)) with the vertical depths larger than 3.05 Mm and three wells in Texas with vertical depths smaller than 3.05 m were considered as outliners and were not included when analyzing the vertical depth. For the Total Water Volume, two wells in Texas and one well in Oklahoma (OK) with water volumes greater than 3.79 Mm^3 or less than 0.038 m^3 were considered as outliners and were not used in the calculations to determine the amount of water used.

The wells fractured between 2008 and 2014 were analyzed in this study by MATLAB with a Statistics Toolbox. Origin 9.1 (OriginLab Corporation, Northampton, MA) was used to develop the graphs, while ArcGIS 10.2 (ESRI, Redlands, CA) was used to plot the location of wells on the Geographic Information System (GIS) map according to their Longitude, Latitude, and Long/Lat Project. Three data coordination systems were used in the database and include the North American Datum of 1927 (NAD27), the North American Datum of 1983 (NAD83), and World Geodetic System of 1984 (WGS84). Before the GIS plotting, the data was converted into NAD83. The different data were used because of the assumptions and measurements utilized by the coordination systems, which can make locations with identical latitude and longitude appear to be in different positions on the earth.