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Evolving water management practices in shale oil & gas development

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ABSTRACT

Advances in horizontal drilling coupled with hydraulic fracturing have unlocked trillions of cubic feet (billions of cubic meters) of natural gas and billions of barrels (millions of cubic meters) of petroleum in shale plays across the United States. There are over 72,000 unconventional well sites in the United States, with anywhere from 2 to 13 million gallons (7500–49,000 cubic meters) of water used per unconventional well. While unconventional wells produce approximately 35% less waste water per unit of gas than conventional wells, the sheer number of wells and amount of oil and gas being produced means that water use has increased by as much as 500% in some areas. Such large water demands give rise to questions about water management, including acquisition, transportation, storage, treatment, and disposal. While these issues vary by play, some key concerns include competition for drinking water sources, impacts of fresh and wastewater transportation, the extent of wastewater recycling, contamination, and the effects of various treatment and disposal methods on communities and watersheds. These concerns have not been fully resolved, yet there is a noticeable, and largely quantifiable, evolution of management practices toward operating more sustainably and with smaller regional impacts. Here we explore water management issues as they arise throughout the unconventional drilling process, particularly focusing on how practices have changed since the beginning of the shale boom and how these issues vary by play.

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Introduction

The oil and gas industry has been working with shales, horizontal wells, and hydraulic fracturing for a long time. The first shale gas well was hand-dug in 1821 in New York, the first horizontal well was drilled in the 1930s, and the first hydraulic fracture was performed in 1947 (King, 2012). However, initial drilling and fracturing methods were not advanced enough to economically produce shale plays on a large scale (Horton, 1981). Greater research into shales and hydraulic fracturing was spurred by Department of Energy funding during the energy crises of the 1970s (e.g. Komar et al., 1976; Vortman, 1976; McCann and Schuster, 1977; Nuckols, 1979). Then, in 1997, Mitchell Energy began successfully producing gas from the Barnett Shale in the Fort Worth Basin of Texas using horizontal drilling and staged hydraulic fracturing

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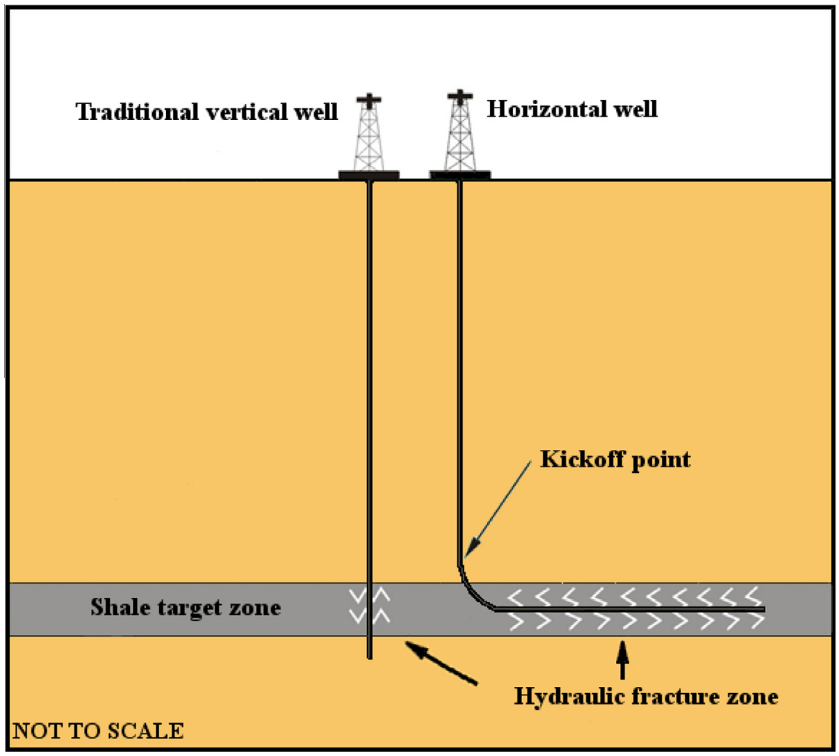

Fig. 1. Illustration showing a traditional, vertical, hydraulically fractured well next to a modern well that combines directional drilling and hydraulic fracturing for production from shales. Modified from Soeder and Kappel (2009).

(Montgomery et al., 2005). Their methodology was soon applied to other organic-rich shales such as the Haynesville in Louisiana, the Fayetteville in Arkansas, and the Bakken in North Dakota. In 2004, Range Resources completed the first Marcellus well as a fallback after deeper formations failed to show promise (Carter et al., 2011); they subsequently modified techniques from the Barnett to complete over 400 Marcellus wells in Pennsylvania (GWPC, 2014). The Marcellus Shale has since been identified by the Energy Information Administration as the largest natural gas resource in the United States (USEIA, 2014).

One major contributor to today's success with shale plays is the advancement of horizontal, or directional, drilling. The contact area between a vertical well and a shale formation is limited by the vertical thickness of the rock. In contrast, a directional well can be drilled along the horizontal extent of the target formation, meaning the well is effectively only limited by the length of lateral that can be drilled. A comparison of vertical and directional wells is shown in Fig. 1. Having a larger contact area between wellbore and target formation is of particular importance in shales, as their permeability is so low that large volumes of rock must be intersected to produce economic volumes of hydrocarbons.

The other major component of success in shale plays is the development of hydraulic fracturing techniques. Hydraulic fracturing is used to address the low permeability of shale formations and involves pumping water into the target formation at pressures high enough to fracture the rock. This water also contains a proppant, usually sand, that flows into the fractures then props them open once water pressure has been lowered. Other additives can include friction reducers, thickeners, corrosion and scale inhibitors, acids (to clean perforations), and antibacterial agents (GWPC, 2014). The fracturing process creates high-permeability flow paths into the shale, allowing more gas to flow out of the rock and into the wellbore. Hydraulic fracturing in horizontal shale wells proceeds in stages, wherein a segment of the lateral is blocked off, the production casing (tubing that lines the lateral segment of the well) is perforated, and the rock around that section of the well is fractured. This process is repeated along the length of the lateral (Fig. 1). After the rock has been fractured, pressure is lowered and the water that was initially injected flows back up the well for up to a few weeks; this water is known as flowback water. Flowback water is chemically nearly identical to the fracturing fluid that was injected. After flowback water has been recovered, briny water will continue to be produced over the lifetime of the well; this water is known as produced water. Produced water is much saltier than fracturing fluid and generally contains salts from the fractured rock formation. However, the term "produced water" is sometimes used as an all-inclusive term to describe any water that flows into the well.

Combined horizontal drilling and staged hydraulic fracturing has opened up huge reserves of shale oil and gas throughout the United States that were formerly thought to be unrecoverable (Fig. 2). Although the cost of drilling a horizontal shale well is approximately 2–3 times higher than that of a vertical well, the initial gas production can be 3–4 times greater (Engelder and Lash, 2008). The economic development of shale resources has brought along an unprecedented energy boom, unlocking trillions of cubic feet (billions of cubic meters) of natural gas and billions of barrels (millions of cubic meters) of petroleum (USEIA, 2013). It has also made the United States the largest producer of natural gas in the world, with domestic crude oil production recently exceeding foreign oil imports for the first time in decades (USEIA, 2014).

The explosion of shale oil and gas exploration and production has led to a number of environmental concerns. Many of these involve water, as 2–13 million gallons (7500–49,000 cubic meters) of water can be required to complete an unconventional shale well, and there are over 72,000 well sites in the United States (GWPC, 2014). Although unconventional wells produce about 35% less waste per unit of gas than conventional wells, the increased number of wells and amount of production has meant a 500% increase in water use for some regions (Lutz et al., 2013). Furthermore, 47%