ENVIRONMENTAL STUDIES

Comment on "The intensification of the water footprint of hydraulic fracturing"

Daniel Raimi

Kondash *et al*. provide a valuable contribution to our understanding of water consumption and wastewater production from oil and gas production using hydraulic fracturing. Unfortunately, their claim that the water intensity of energy production using hydraulic fracturing has increased in all regions is incorrect. More comprehensive data show that, while the water intensity of production may have increased in regions such as the Permian basin, it has decreased by 74% in the Marcellus and by 19% in the Eagle Ford region. This error likely stems from an improper method for estimating energy production from wells: The authors use the median well to represent regional production, which systematically underestimates aggregate production volumes. Across all regions, aggregate data suggest that the water intensity of oil and natural gas production using hydraulic fracturing has increased by 19%. There also appears to be an error in estimates for water consumption in the Permian basin.

Kondash *et al.* (*1*) demonstrate that both water consumption and wastewater production from oil and gas activities have grown substantially in recent years. The research is quite valuable and provides additional motivation to find inducements for reducing freshwater consumption for hydraulic fracturing and to enhance best management practices for wastewater management.

However, their claim that the water intensity of energy production using hydraulic fracturing has increased in all regions is incorrect.

The authors define water intensity "as the amount of water used for hydraulic fracturing to generate a unit of energy from the produced gas and oil." They gather data on water use for hydraulic fracturing and energy production on a well-by-well basis and then estimate the water intensity of oil and gas production in two steps.

First, they divide the water used to hydraulically fracture the median well in each region by the energy produced from the median well in that same region during its first 12 months of production. The authors focus on these results in the main text. Second, the authors calculate the lifetime oil and gas production from the median well in each region by estimating the well's estimated ultimate recovery (EUR), assuming that 35% of the well's lifetime production occurs in its first year. They divide water used in the median well by its EUR to produce a second estimate of water intensity.

However, using the median well to represent the full distribution systematically underestimates energy production in each region. As shown in figs. S1 and S2, energy production from oil and gas wells in the relevant regions are unevenly distributed with a long right tail. While analysis of production from the median well may be useful for financial analysis, investors in new wells, or others, the mean—rather than the median—better represents aggregate production in a given region.

From 2011 to 2016, the mean well outproduced the median well during its first year of production by 7 to 12% in the Bakken, 24 to 29% in the Eagle Ford, 0 to 6% in the Haynesville, 10 to 25% in the Marcellus, and 13 to 49% in the Permian region (*2*). To make broad conclusions about energy production and the associated water intensity for each region, aggregate regional production data are preferable.

Nonetheless, the authors conclude that "The water-use intensity (that is, normalized to the energy production) increased ubiquitously in all U.S. shale basins." This claim is incorrect, observed most clearly for the Marcellus region.

On the basis of the authors' calculations (table S1), water use per well in 2016 is 0.9% higher than in 2012, while the number of new wells declines by 63%, implying a regional decrease in water use of 62.5% (the authors do not provide well count data for 2011).

The authors also report (table S1) that the first 12 months of natural gas production from the median well in 2016 was 6% lower than in 2012, while the number of new wells was 63% lower, as noted above. If the authors' data were representative of the region, annual natural gas production from new wells in 2016 would be roughly 65% lower than 2012.

However, the U.S. Energy Information Administration (U.S. EIA) reports that new gas production in 2016 from the Appalachian basin (which is primarily composed of production from the Marcellus) was 41% higher than 2012 levels. Indeed, cumulative natural gas production in the region more than doubled from 2012 to 2016 and increased by more than 400% from 2011 to 2016 (*3*). If regional water consumption for new wells declined, as the authors assert, it is not possible that the water intensity of natural gas production could have increased.

For a more careful estimate, I examine the total amount of water consumed for hydraulic fracturing each year (based on the authors' data) and energy produced from those wells at a regional level, based on data from the U.S. EIA (*3*). This regional view does not rely on assumptions about the representativeness of the median well, nor does it rest on assumptions about wells' EUR, which can vary substantially across wells and regions. For a discussion of the differences between the EIA data and Kondash *et al.*'s data, along with a comparison of regional production estimates, see the Supplementary Materials.

These calculations show clearly that—if the authors' data on water use are accurate—the water intensity of energy production using hydraulic fracturing has increased by up to 848% in the Permian, while declining by as much as 74% in the Marcellus. Summing across regions, water intensity of energy production was 19% higher in 2016 than it was in 2012 (Table 1).

Importantly, water consumption data for the Permian region, where Kondash *et al.* report that water intensity has increased the most, appear to include an analytical error. The error is observable in Kondash *et al.*'s tables S1 and S2. In those tables, median water use

Resources for the Future, Washington, DC, USA. Email: raimi@rff.org

Table 1. Water intensity of new-well oil and gas production (liters/gigajoule). Sources and notes: Water volumes and well counts from tables S1 and S2 of Kondash *et al*. (*1*). New natural gas and oil production volumes are based on data from the U.S. Energy Information's Drilling Productivity Report (*3*). The annual water use for hydraulic fracturing is divided by the energy content in the annual sums of new oil and gas production to generate the water intensity of production in each year. See the Supplementary Materials for details.

Year	Haynesville	Marcellus	Permian	Niobrara	Eagle Ford	Bakken	Cumulative
2011						9.1	
2012	8.0	23.3	2.4	11.7	16.7	9.3	12.8
2013	9.4	16.7	3.2	7.8	14.8	9.5	11.5
2014	8.7	10.4	4.5	15.0	12.4	11.3	10.2
2015	10.7	10.5	15.2	17.4	14.2	12.9	13.5
2016	9.7	6.1	22.9	20.5	13.5	16.3	15.3
2016/2012 or 2011 (Bakken only)	+22%	−74%	+848%	+76%	−19%	+79%	+19%

per well is reported over time by region. In table S1, the authors report water consumption for the median "gas" well in the Permian basin, and in table S2, the median "oil" well in the same region.

While the median "gas" well and the median "oil" well differ in terms of lateral length and production volumes in all years, the reported data for water use per well are identical across all years. It is implausible that the median "gas" well and the median "oil" well would have used the identical amount of water for hydraulic fracturing in each of six different years.

The error has important implications for other key findings of the paper, as estimates of future water consumption in the Permian basin—the most productive basin in the United States—are based on this incorrect estimate of water consumption.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/6/8/eaav2110/DC1

Supplementary Materials and Methods

Fig. S1. First 12 months of oil production per well, Permian basin, 2011–2016.

Fig. S2. First 12 months of natural gas production per well, Permian basin, 2011–2016.

Table S1. Haynesville region.

Table S2. Marcellus region.

Table S3. Permian region.

Table S4. Niobrara region.

Table S5. Eagle Ford region.

Table S6. Bakken region.

Table S7. Totals across all regions.

Table S8. Comparison of energy production estimates.

REFERENCES AND NOTES

1. A. J. Kondash, N. E. Lauer, A. Vengosh, The intensification of the water footprint of hydraulic fracturing. *Sci. Adv.* **4**, eaar5982 (2018).
2. DrillingInfo, "DI Desktop Application Query" (Includes all horizontally and vertically drilled wells with first production dates between 1/1/2011 and 12/31/2016. Based on barrels of oil equivalent produced during initial 12 months of production, www.drillinginfo.com [accessed August 2018]).
3. U.S. Energy Information Administration, "Drilling Productivity Report" (Washington, D.C., 2018); https://www.eia.gov/petroleum/drilling/?src=home-b1.

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