



## RESEARCH SUMMARY

# Large-Sample Evidence on the Impact of Unconventional Oil and Gas Development on Surface Waters

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### KEY TAKEAWAYS

1. The application of hydraulic fracturing to develop oil and natural gas has led to a sharp increase in U.S. energy production and generated enormous benefits. As drilling activity has increased, however, a robust debate has begun regarding the pros and cons at a local level. Advocates point to increased economic activity. Opponents point to possible air and water pollution.
2. Several studies have documented instances of ground-water contamination related to hydraulic fracturing wells, but there is limited evidence linking the practice to surface water impacts. This study provides the first evidence that hydraulic fracturing is related to increased salt concentrations in surface waters for several shales across the United States.
3. The study combines surface water measurements with 46,479 hydraulic fracturing wells to examine whether new drilling and development activities are associated with elevated salt concentrations (bromide, chloride, barium and strontium) in 408 U.S. watersheds over an eleven-year period.
4. The authors found a very small but consistent increase in barium, chloride and strontium, but not bromide, in watersheds with new hydraulic fracturing wells. The elevated levels were well below environmental and health advisory levels. The increases in salt levels were largest during the early phases of production when wells generate large amounts of flowback and produced water.
5. The salt concentrations were most pronounced for wells that produced larger amounts of water and for wells located in areas where the deep formations exhibited higher levels of salinity. This evidence ties the elevated salt concentrations more closely to hydraulic fracturing activities.
6. Salt concentrations were highest when observed within a year from drilling, at monitoring stations that were within 15 kilometers and (likely) downstream from a well.

## Introduction

The discovery of hydraulic fracturing is considered by many to be the most important change in the energy sector since the introduction of nuclear generated electricity more than 50 years ago. As a result of its discovery, U.S. production of oil and natural gas has increased to unforeseen levels. This has led to abruptly lower energy prices, stronger energy security and even lower air pollution and carbon dioxide emissions by displacing coal in electricity generation.

As drilling activity has increased, however, a robust debate has begun within communities where development is occurring—and those where it could occur—regarding the pros and cons at a local level. Advocates point to increased economic activity, including tax revenue and jobs. Opponents, on the other hand, point to potential disadvantages such as possible air and water pollution and adverse health effects.

Potential harm to water quality is a key concern because of the unique hydraulic fracturing process, where water mixed with chemical additives and propping agents like sand are injected at a high pressure to create fractures in rocks to allow oil or gas to flow. In addition to concerns surrounding the hydraulic fracturing fluid itself, these wells produce large amounts of wastewater—flowback from the hydraulic fracturing fluid and produced water from the deep formations. The latter is naturally occurring water, into which organic and inorganic constituents from the formation have dissolved, resulting in high salt concentrations.

Some studies have documented groundwater contamination related to hydraulic fracturing, though the results differ across shales. There is even less evidence to date showing a link between hydraulic fracturing and surface water contamination. Prior studies documented localized instances of contamination in surface waters mostly related to known and isolated spills and leaks rather than widespread and systemic contamination. This study provides the first evidence that hydraulic fracturing is related to increased salt concentrations in surface waters across several U.S. shales and many watersheds.

## Research Design

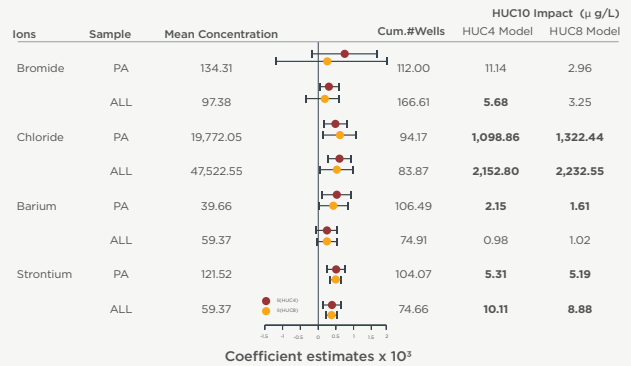
The study investigates the potential impact of hydraulic fracturing on surface water quality. The authors used a geo-coded database that combined surface water measurements with 46,479 hydraulic fracturing wells from 24 shales across 408 watersheds from 2006 to 2016.

They specifically analyzed concentrations of bromide, chloride, barium and strontium because these ions are usually found in high concentrations in flowback and produced water from wells, they do not biodegrade, and they have been found several years after spills. Using a statistical approach, the authors work to identify anomalous changes in ion concentration associated with new wells in the same watersheds. The statistical model explains more than 80 percent, and in many cases more than 90 percent, of the background variation in ion concentrations across watersheds and through time.

## Findings

**In areas where there were new hydraulic fracturing wells there were also elevated salt concentrations in surface waters.** The authors found very small but consistent increases in barium, chloride and strontium concentrations, but not bromide. These elevated levels existed in Pennsylvania—which accounted for almost 41 percent of the sample—and for all U.S. watersheds at comparable magnitude and significance. However, the elevated levels were well below the U.S. Environmental Protection Agency’s limits and advisory levels for what is considered safe.

**Figure 1 • Hydraulic Fracturing Wells and Water Quality**

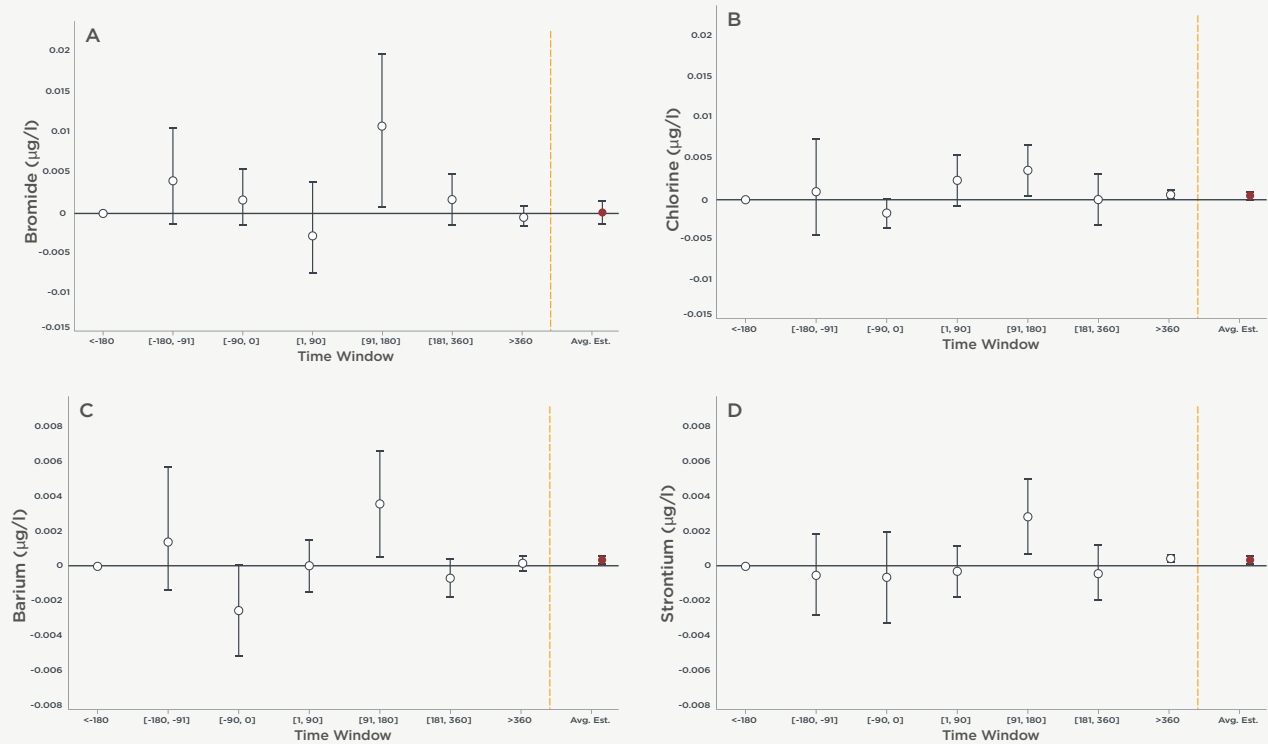


Note: This figure plots OLS coefficients and confidence intervals for the associations between ion concentrations and cumulative HF well counts (#wellsHUC10), estimated using eq. S1 and two different model specifications, HUC4 and HUC8 (Table S4). We report results for treated watersheds (HUC10s) in Pennsylvania (PA) and for all treated U.S. watersheds (ALL). The last two columns report the cumulative impact in the average watershed (HUC10 Impact µg/L) implied by the coefficient estimates, obtained by multiplying the respective coefficient with the sample mean ion concentration and the cumulative number of wells in the average HUC10 over the sample period. Bold impact numbers are based on significant coefficients. The EPA maximum contaminant level (MCL) is 250,000 µg/L for Cl<sup>-</sup> and 2,000 µg/L for Ba. The EPA does not provide a MCL for Br<sup>-</sup> and Sr. Health advisory levels for one-day and lifetime exposure to Sr are 25,000 µg/L and 4,000 µg/L, respectively.

“Our work provides the first large-sample evidence showing that hydraulic fracturing is related to the quality of nearby surface waters for several U.S. shales. Though we estimated very small water impact, one has to consider that most measurements were taken in rivers or streams and that the average fracturing well in our dataset was not particularly close to the monitors in the watershed.”

**CHRISTIAN LEUZ, JOSEPH SONDHEIMER PROFESSOR OF INTERNATIONAL ECONOMICS, FINANCE AND ACCOUNTING AT THE UNIVERSITY OF CHICAGO’S BOOTH SCHOOL OF BUSINESS**

**Figure 2 • Temporal Analysis of Salt Concentrations Around Initial Well Drilling Dates**



Note: Temporal analysis of ion concentrations around well spud dates. (A)  $\text{Br}^-$ , (B)  $\text{Cl}^-$ , (C) Ba, (D) Sr. Panels A to D plot OLS coefficients for well counts calculated over fixed time intervals around the spud dates, together with the 95% confidence interval (see Table S8, Panel B, Columns (1)-(4), for the estimation of these coefficients). For comparison, the red dot marks the coefficient of #wellsHUC10 from Table S4, Panel A, Column (4), and its 95% confidence interval.

**The elevated salt concentrations occur after well completion and during the early phases of production, when large amounts of flowback and produced water are collected.** The study found the greatest increases in salt concentrations 91-180 days after drilling began, though they were still small in magnitude. The 91-180-day period marks a time after the drilling is complete and during the early phases of production when large amounts of flowback and produced water are collected. This timing suggests a link between elevated concentrations and the unconventional oil and gas development process. Additionally, any impact likely declines over time.

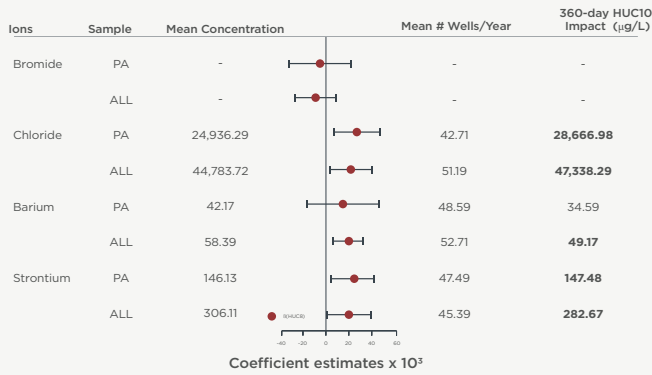
**The salt concentrations were most pronounced for wells with larger amounts of produced water, further drawing the tie between elevated salt concentrations and hydraulic fracturing activities.** The authors analyzed wells with both above-average and below-average amounts of produced water. They found that in the watersheds with wells that produced more water, salt concentrations were higher—though still below EPA's limits and health advisory levels. This evidence ties the elevated salt concentrations more closely to hydraulic fracturing activities.

**Increases in salt concentrations were more pronounced for wells located in areas where the deep formations exhibited higher levels of salinity.** The authors explored whether the associations between elevated salt concentrations and hydraulic fracturing were stronger in areas where wells were expected to produce water with higher salinity, given the variation in regional geochemistry and

the salinity of deep formations. They found that the association is indeed more pronounced in sub-basins where deep formations exhibit higher levels of salinity. This suggests that produced water is likely part of the explanation for the elevated salt concentrations.

**The high salt concentrations were most pronounced at monitoring stations located closer to wells and at stations likely located downstream from wells.** The authors also explored whether the associations between wells and salt concentrations were more pronounced when wells and monitors were closer together and wells were likely upstream from water monitors. They found that the highest salt concentrations were observed within a year from drilling at monitoring stations assigned as downstream from a well and within 15 kilometers from a well. Although the concentrations were an order of magnitude larger than the long-run increases (mentioned above/ Fig. 2), they were still well below the EPA maximum contaminant and health advisory levels.

**Figure 3** • Hydraulic Fracturing Wells and Water Quality Using Time, Distance and Well Position



Note: This figure plots WLS coefficients and confidence intervals for the associations between ion concentrations and an indicator for a new HF well, estimated using eq. S2 (Table S12, Panel C). For this analysis, we pair wells and monitors in a watershed. For each pair, we determine that well and monitor are within 15km and that the well is assigned as likely upstream of the monitor, and we only use water measurements taken up to 360 days after the spud date. We report results for treated watersheds (HUC10s) in Pennsylvania (PA) and for all treated U.S. watersheds (ALL). The last column reports the 360-day impact on the average watershed (HUC10 Impact µg/L) implied by the coefficient estimates, obtained by multiplying the respective coefficient with the sample mean ion concentration and the average number of new wells per year in the average HUC10. We computed the 360-day impact only for positive coefficients. For this reason, we do not report the mean ion concentration and average number of wells per year for Br<sup>-</sup>. Bold impact numbers are based on significant coefficients. See Fig. 1 for EPA maximum contaminant and other health advisory levels.

## Policy Implications

While the study suggests that hydraulic fracturing had a small impact on surface water quality, it is important to recognize that not all wells are close to surface water and not all monitors are in locations where they could detect an effect (e.g., the closest monitor could be upstream). Thus, the estimated impact could be small due to distance from the well to the water.

In addition, the study was hampered by the availability and measurement frequency of water quality data. Hydraulic fracturing fluids contain chemical substances that are potentially more dangerous than salts. But the authors were not able to look for these chemicals because they are not widely covered by public databases. Further, more frequent measurement closer to wells and around the time of new drillings would allow for more granular analyses. Thus, an important policy implication of this study is that better and more frequent water measurement is needed to fully understand the surface water impact of unconventional oil and gas development. For instance, federal and state environmental agencies could consider placing monitoring stations in a more targeted fashion to better track potential water quality impacts. More extensive water measurement for a broader array of substances also requires adequate funding for these agencies.

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