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SCIENCE SUMMARY

OCT 2014

Surface and groundwater contamination associated with modern natural gas development

Peer-Reviewed Literature, 2011 - 2014

Documentation of water contamination associated with modern natural gas development is a complex issue. The list of studies reported here should be seen as conservative and limited reporting of water contamination, as it only contains evidence from peer-reviewed scientific studies and does not include incidences that exist in inspection records. For instance, the Pennsylvania Department of Environmental Protection (PA DEP) released a list of 243 cases where it was determined that private water supplies were impacted by oil and gas activities[1].

Differences in local geologies and hydrologic characteristics, land-use histories, industry practices, and monitored water contaminants can complicate comparisons across studies. Baseline conditions for water quality are often unknown or may have been affected by other activities. **Nonetheless, empirical evidence of surface and groundwater contamination as a result of modern natural gas operations is documented.**

Pennsylvania (*Marcellus*). Several studies indicate degradation of ground and surface waters in dense drilling areas of Pennsylvania. Studies[2,3] found significantly **higher concentrations of thermogenic methane** in private water wells within 1 km of one or more natural gas wells (6 and 17 times on average, respectively; Fig 1).

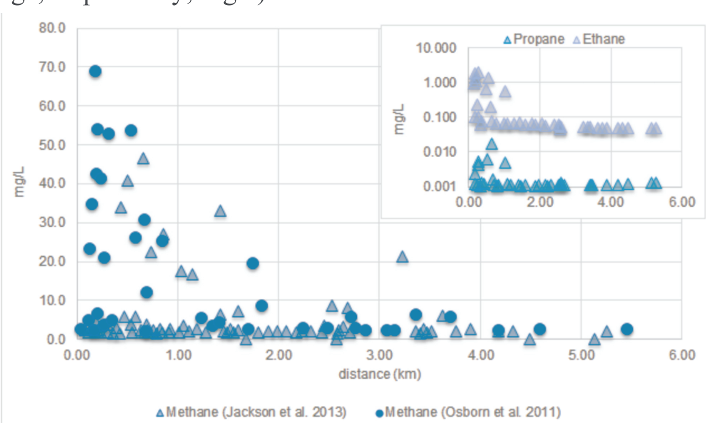

Figure 1. Hydrocarbon concentrations (mg/L) in groundwater by distance to unconventional gas wells. Private water wells within 1 km of shale gas well show higher levels of natural gas constituents (methane, ethane, propane). Isotopic analysis indicates that the hydrocarbons are thermogenic in nature (Source: Osborn et al. 2011; Jackson et al. 2013)

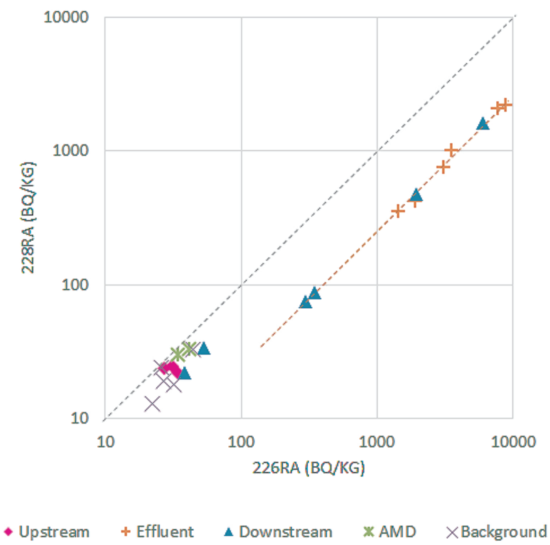

Figure 2. Activities of 228Ra/226Ra in river sediments collected upstream, adjacent, and downstream of a Marcellus shale wastewater discharge site. Despite waste treatment, downstream water quality still reflects the chemical signatures of fluids produced in natural gas extraction, as downstream ratios closely match those of untreated Marcellus brines (orange dashed line; 0.25; Source: Warner et al. 2013).

An examination of water chemistry and isoptopic signatures[4] of effluents from a brine treatment facility, stream sediments near the discharge site, and surface waters downstream and upstream of the discharge site showed **elevated levels of chloride and bromide** in downstream waters consistent (combined with isotopic data) with produced waters from Marcellus wastewaters. Radium-228/Radium-226 ratios in downstream waters and near-source sediments also closely matched ratios measured in Marcellus wastewaters (Fig 2). **Radium-226 concentrations** in near-source sediments (544-8759 Bq/kg) were found to be approximately 200 times greater than upstream and background sediments and in excess of U.S. Radioactive waste disposal threshold regulations.

A study using noble gases as tracers in areas overlying the Marcellus shale region and the Barnett shale in TX[5] found four clusters of **fugitive gas contamination** in groundwater. The data suggested the contamination most likely resulted from poor well cement casing that enabled hydrocarbon gas leaks along the well annulus.

Texas (*Barnett*). A study of groundwater quality in the Barnett shale TX[6] revealed significantly **higher levels of heavy metals** (strontium, selenium, arsenic) in private water wells located within 2 km of active gas wells relative to private water wells located further from drilling activity (Fig 3). This study was unique in that it used historical data from the region to create a baseline measure of groundwater quality before the expansion of natural gas operations. Arsenic, strontium, and selenium concentrations were also found to be significantly higher in active drilling areas relative to this historical baseline. Shallower water wells near drilling activity showed the highest levels of contamination. These findings suggest that mechanical disturbance (i.e. subsurface vibrations) of water wells, surface spills and/or faulty well casings/cement as possible causes of contamination.

Kentucky (*Appalachian*). A release of hydraulic fracturing fluids to a Knox County stream resulted in in fish stress and mortality. Water chemistry analysis[7] of the impacted stream revealed **elevated conductivity, lowered pH and alkalinity, and toxic levels of heavy metals**. Fish exposed to the contaminated water exhibited a high incidence of gill lesions consistent with impacts observed in fish exposed to low pH, dissolved heavy metals, or both. Among the species affected was the federally protected Blackside Dace.

Colorado (*Denver-Julesburg and Piceance*). An analysis of reported surface spills (Colorado Oil and Gas Conservation Commission, COGCC) within Weld County (DenverJulesburg) and groundwater monitoring data associated with each spill[8] revealed BTEX (benzene, toulene, ethylbenzene, xylene) contamination of groundwaters. During a one-year period the authors noted 77 reported surface spills impacting groundwater; 62 of these records included BTEX analytical sampling during remediation. A large percent of samples show **BTEX concentrations in excess of federal standards** (Fig 4). Another study of surface and groundwater samples from drilling-dense areas in the Piceance basin[9] showed **higher estrogenic, anti-estrogenic, or ant-androgenic activities** near gas activity relative to reference site with little or no natural gas development.

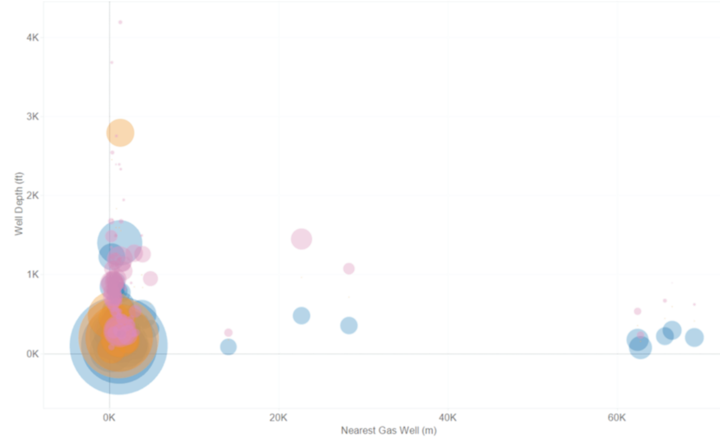

Figure 3. Arsenic (μg/L), strontium (mg/L) and selenium (μg/L) concentrations in groundwater versus distance to nearest active natural gas well and depth of water well. Circle size reflects levels of concentrations with larger circles denoting higher levels of contaminants. Risk of contamination to private water wells appears to increase with proximity to unconventional natural gas wells. Shallower water wells are particularly at risk, suggesting surface spills, mechanical disturbance of water wells, and/or faulty well casings as possible routes to contamination. (Source: Fontenot et al. 2013)

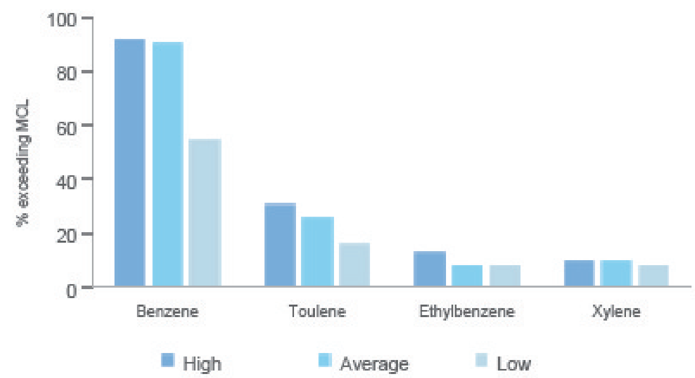

Figure 4. Percent of groundwater samples exceeding federal maximum contaminant levels (MCL) for BTEX species. Samples were taken at different stages of remediation following reported surface spills related to natural gas development. While many of the spills were effectively mitigated, >50% of samples still exceeded benzene MCLs after remediation; 16% of samples exceeded toulene MCLs post-remediation, and 8% of samples exceeded MCLs for both ethylbenzene and xylene. (Source: Gross et al. 2013)

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CU-Boulder researchers confirm leaks from Front Range oil and gas operations

May 7, 2014 •

Natural Sciences, Institutes, Cooperative Institute for Research in Environmental Science (CIRES)

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During two days of intensive airborne measurements, oil and gas operations in Colorado's Front Range leaked nearly three times as much methane, a greenhouse gas, as predicted based on inventory estimates, and seven times as much benzene, a regulated air toxic. Emissions of other chemicals that contribute to summertime ozone pollution were about twice as high as estimates, according to the new paper, accepted for publication in the American Geophysical Union's *Journal of Geophysical Research: Atmospheres*.

"These discrepancies are substantial," said lead author Gabrielle Petron, an atmospheric scientist with the Cooperative Institute for Research in Environmental Sciences, a joint institute of the University of Colorado Boulder and the National Oceanic and Atmospheric Administration. "Emission estimates or 'inventories' are the primary tool that policy makers and regulators use to evaluate air quality and climate impacts of various sources, including oil and gas sources. If they're off, it's important to know."

The new paper provides independent confirmation of findings from research performed from 2008-2010, also by Petron and her colleagues, on the magnitude of air pollutant emissions from oil and gas activities in northeastern Colorado. In the earlier study, the team used a mobile laboratory—sophisticated chemical detection instruments packed into a car—and an instrumented NOAA tall tower near Erie, Colorado, to measure atmospheric concentrations of several chemicals downwind of various sources, including oil and gas equipment, landfills and animal feedlots.

Back then, the scientists determined that methane emissions from oil and gas activities in the region were likely about twice as high as estimates from state and federal agencies, and benzene emissions were several times higher. In 2008, northeastern Colorado's Weld County had about 14,000 operating oil and gas wells, all located in a geological formation called the Denver-Julesburg Basin.

In May 2012, when measurements for the new analysis were collected, there were about 24,000 active oil and gas wells in Weld County. The new work relied on a different technique, too, called mass-balance. In 2012, Petron and her colleagues contracted with a small aircraft to measure the concentrations of methane and other chemicals in the air downwind and upwind of the Denver-Julesburg Basin. On the ground, NOAA wind profilers near Platteville and Greeley tracked around-the-clock wind speed and wind direction.

On two days in May 2012, conditions were ideal for mass-balance work. Petron and her team calculated that 26 metric tons of methane were emitted hourly in a region centered on Weld County. To estimate the fraction from oil and gas activities, the authors subtracted inventory estimates of methane emissions from other sources, including animal feedlots, landfills and wastewater treatment plants. Petron and her team found that during those two days, oil and gas operations in the Denver-Julesburg Basin emitted about 19 metric tons of methane per hour, 75 percent of the total methane emissions. That's about three times as large as an hourly average estimate for oil and gas operations based on Environmental Protection Agency's (EPA's) Greenhouse Gas Reporting Program (itself based on industry-reported emissions).

Petron and her colleagues combined information from the mass-balance technique and detailed chemical analysis of air samples in the laboratory to come up with emissions estimates for volatile organic compounds, a class of chemicals that contributes to ozone pollution; and benzene, an air toxic.

Benzene emissions from oil and gas activities reported in the paper are significantly higher than state estimates: about 380 pounds (173 kilograms) per hour, compared with a state estimate of about 50 pounds (25 kilograms) per hour. Car and truck tailpipes are a known source of the toxic chemical; the new results suggest that oil and gas operations may also be a significant source.

Oil-and-gas-related emissions for a subset of volatile organic compounds (VOCs), which can contribute to ground-level ozone pollution, were about 25 metric tons per hour, compared to the state inventory, which amounts to 13.1 tons. Ozone at high levels can harm people's lungs and damage crops and other plants; the northern Front Range of Colorado has been out of compliance with federal health-based 8-hour ozone standards since 2007, according to the EPA. Another CIRES- and NOAA-led paper published last year showed that oil and natural gas activities were responsible for about half of the contributions of VOCs to ozone formation in northeastern Colorado.

This summer, dozens of atmospheric scientists from NASA, the National Center for Atmospheric Research, NOAA, CIRES and other will gather in the Front Range, to participate in an intensive study of the region's atmosphere, said NCAR scientist Gabriele Pfister. With research aircraft, balloon-borne measurements, mobile laboratories and other ground-based equipment, the scientists plan to further characterize the emissions of many possible sources, including motor vehicles, power plants, industrial activities, agriculture, wildfires and transported pollution.

"This summer's field experiment will provide us the information we need to understand all the key processes that contribute to air pollution in the Front Range," Pfister said.

##

CIRES is a partnership of NOAA and CU-Boulder.

Authors of "A new look at methane and non-methane hydrocarbon emissions from oil and natural gas operations in the Colorado Denver-Julesburg Basin," include 26 scientists from CIRES; NOAA's Earth System Research Laboratory; the Institute for Arctic and Alpine Research at CU-Boulder; the University of California, Davis; and the University of Colorado Boulder. Funding for the work, which is published in the *Journal of Geophysical Research: Atmospheres,* came from the Environmental Defense Fund, NOAA (the Office of Oceanic and Atmospheric Research and the Climate Program Office) and the National Science Foundation.

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Graphics:
High-resolution images are available for download on CIRES' Flickr account, News Release album:

- Pilot and scientist Steve Conley prepares to take off in a Mooney TLS research aircraft.
- Drilling rig and associated equipment near a neighborhood in Weld County, Colo.
- Sunset and a drilling rig in northeastern Colorado.
- more

Atmospheric scientist and pilot Stephen Conley (University of California Davis and Scientific Aviation) prepares to take off from Boulder Municipal Airport in a single-engine Mooney TLS aircraft, retrofitted for atmospheric research, in May 2012. During two days of measurements that month, researchers found oil and gas activities in northeastern Colorado released more methane, ozone pollution precursors and benzene than estimated by regulators. Credit: Will von Dauster, NOAA

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