AirWaterGas Sustainability Research Network

Conducting research and providing information on the effects of unconventional oil and gas development in the Rocky Mountain region of the United States

OVERVIEW and GOALS

The United States has experienced an unprecedented boom in oil and gas development during the past decade. The use of horizontal drilling and hydraulic fracturing have allowed withdrawal of oil and gas from previously inaccessible resources like shale and tight sand formations. The increase in oil and gas production has boosted the U.S. economy, reduced U.S dependence on foreign oil, and improved air quality by reducing electric generation from coal. The benefits to our nation have not been without costs. Concern about potential negative impacts to air quality, water quality, water supplies, and public health in oil and gas producing communities has fueled political debates and highlighted the need for cutting-edge research.

AirWaterGas (www.airwatergas.org) is a network of researchers funded by the National Science Foundation to investigate the effects of oil and gas development on the Rocky Mountain region of the United States. This five-year project has brought together more than two dozen researchers from seven universities and three federal research centers. These researchers are using innovative technologies to integrate information about oil and gas across varied disciplines to better understand the potential effects of oil and gas production on our air, water, land, and communities. The AirWaterGas researchers are working together to address a single question: How can we better integrate research about the environment, economic, and social tradeoffs of oil and gas development into policies and regulations governing development?

This summary is an introduction to the research conducted by AirWaterGas through the summer of 2016. For a full listing of all AirWaterGas researcher's journal articles, please see our web site: www.airwatergas.org/publications

Oil and gas development in Colorado's Denver-Julesburg Basin in proximity to a residential area.

AIR QUALITY and CLIMATE CHANGE

- *Is oil and gas development increasing greenhouse gas emissions? How is it affecting air quality?*

AirWaterGas research on the effects of oil and gas development on air quality and climate is led by scientists from the National Oceanic and Atmospheric Administration, University of Colorado Boulder (UCB), and the National Renewable Energy Laboratory. These researchers have added to our understanding of the effects of oil and gas development on ozone formation and the contribution of the oil and gas sector to greenhouse gas emissions.

Oil and gas development is a primary source of the volatile organic compounds (VOCs) and nitrogen oxides that create ground-level ozone. Improved emissions data have helped AirWaterGas researchers and their partners determine the cause of high ozone levels in sparsely populated areas of the Rocky Mountain west.

The occurrence of high ozone levels in Utah's Uinta Basin and in southwest Wyoming was especially surprising to the atmospheric science research community because it occurred in winter, whereas high surface ozone is typically a summertime problem. Field studies have shown that winter temperature inversions in these basins can allow VOCs from the oil and gas industry to build-up and produce ozone when they combine with nitrogen oxides in chemical reactions driven by sunlight reflected from the snow.

As a greenhouse gas, emissions of methane are estimated to be as much as 80 times more potent than carbon dioxide. Reducing methane emissions has therefore become a national priority. Utilizing innovative technology, researchers with AirWaterGas have discovered that the levels of methane, benzene and other oil and gas-related hydrocarbons over the northeast of Colorado's Front Range were several times higher than had been estimated using oil and gas facility inventories (Petron et al., 2014). AirWaterGas research has contributed to a body of measurement studies across the country that found a relatively small number of facilities – "super emitters" – account for a disproportionate amount of methane emissions from the oil and gas sector. Further research is needed to examine the effect of state and federal air quality regulations and new industry practices in reducing these emissions.

AirWaterGas researchers are also modeling different scenarios for future oil and gas production and our nation's energy system in order to understand the trade-offs of the choices we are making. In the Rocky Mountain region the costs of electricity production from wind and natural gas are similar. This means the price of natural gas and any potential fees on greenhouse gas emissions could strongly influence which choice is most economical (McLeod et al., 2014). AirWaterGas researchers are undertaking detailed modeling of emissions from the region's electricity generation and oil and gas production systems to investigate how these choices could affect future air quality.

AirWaterGas researchers are also working to bring low-cost air quality sensors into the hands of communities that are experiencing oil and gas development. These tools are helping educate the public about the benefits and costs of oil and gas development and may one day allow local communities to conduct their own scientific investigations of emissions and exposure.

AirWaterGas researchers monitoring air quality near a gas processing plant in Colorado's Denver-Julesburg Basin.

WATER QUANTITY

- *Where is the oil and gas industry getting the water used in the hydraulic fracturing process? How much water is used?*

AirWaterGas researchers at Colorado State University are studying current water use trends for oil and gas development throughout Colorado and projecting future water use. Depending on the length of the horizontal wellbore and the basin where the well is located, 2-5 million gallons of water may be needed to hydraulically fracture a well in Colorado. The team determined that annual average water use for oil and gas development from 2011-2013 was about 1% of total water use in Weld County and 2% in Garfield County. While small, these figures exemplify the regional disparity of water delivery and use, particularly since a Colorado oil and gas trade association estimates that the industry's use of water statewide is only 0.13%. In Weld County, most oil and gas companies prefer to lease water from municipalities, private water service companies, and irrigation and reservoir companies. The industry is also drilling wells into non-tributary freshwater aquifer. These water sources are not administered by the state's priority system and have been legally disconnected from the surface water's hydrologic cycle. In Garfield County, gas companies tend to own water rights they obtained during the 1950s, 1960s, and 1970s for oil shale development. The team has recommended adjusting state reporting requirements to better track water consumption in the oil and gas industry (Oikonomou et al., 2016).

Use of water for hydraulic fracturing of gas-producing formations in Colorado's Piceance Basin.

WATER QUALITY

- *What is in hydraulic fracturing fluid?*

More than 20 states require oil and gas developers to report most of the chemicals they use during the hydraulic fracturing process into a national database registry, FracFocus. But the registry had limited utility because inputted data could not be compared across wells. However, AirWaterGas researchers from the University of Colorado Boulder created a program that made all FracFocus data searchable. The increased usability of FracFocus data allowed researchers to screen 659 compounds potentially used in hydraulic fracturing fluids and identify the nine chemicals of most concern used in hydraulic fracturing fluid based on their toxicity, mobility, persistence, and frequency of use. This research and expanded utility of the FracFocus database will provide regulators and the general public with better tools to understand and recommend what chemicals are used to hydraulically fracture nearby wells and what chemicals should be avoided – especially when drilling near domestic drinking water supplies (Rogers et al., 2015).

- *What impact is hydraulic fracturing having on drinking water?*

A primary research question about the hydraulic fracturing process is whether the newly-created fractures could function as a pathway to allow hydraulic fracturing fluid, methane, or salty groundwater located deep underground to flow into and contaminate a drinking water aquifer.

AirWaterGas researchers from the University of Colorado Boulder developed a numerical model of hydraulic fracturing fluid migration underground. The model showed that the combined influence of the hydraulic fracturing fluid being absorbed by the shale (imbibition) and well suction significantly reduce the risk of aquifer contamination because (a) the hydraulic fracturing fluid is sequestered in the underground shale or removed by the well and (b) the flow field is altered such that the hydraulic fracturing fluid remaining in the subsurface will largely be at greater depths, close to the wellbore. Also, most development of oil and gas from shale occurs thousands of feet below a drinking water aquifer and without a permeable pathway the hydraulic fracturing fluid cannot travel far enough to reach an aquifer. However, when developing shale closer to the surface or where the rocks above the deeper shale are highly permeable, then hydraulic fracturing fluid migration to aquifers is expected to be more likely (Birdsell et al., 2015a).

AirWaterGas researchers at the University of Colorado Boulder have shown that large-scale transport of hydraulic fracturing fluid between a deep shale layer and a shallow drinking water aquifer is unlikely through natural geologic pathways, but other work suggests that hydrocarbon transport along faulty oil and gas wells is the primary pathway of concern. Oil and gas wellbores are a system of nested steel casings and cement. If either the cement or steel lose their structural integrity, hydrocarbons from the target formation can escape upwards along the wellbore. In Colorado, where wellheads are sealed at the surface, these fugitive hydrocarbons collect and build a pressure known as surface casing pressure. Oil and gas wells with surface casing pressure have compromised structural integrity and pose a risk for releasing stray gas into the surrounding aquifer or atmosphere. The Colorado Oil and Gas Conservation Commission maintains the only publicly available oil and gas database in the country with surface casing pressure data. To assess the rate at which oil and gas wells in Colorado lose their structural integrity and potentially contaminate groundwater, researchers analyzed surface casing pressure data for 10,365 oil and gas wells in the Wattenberg Field, the most densely drilled region of Colorado. They found that deviated wells (wells drilled at an angle but not fully horizontal), and horizontal wells develop surface casing pressure more frequently than vertical wells. Consequently, since deviated drilling expanded in 2003, the number of wells installed in the Wattenberg Field that developed surface casing pressure has increased. Since 2010, the industry primarily has installed horizontal wells in the Wattenberg, which develop surface casing pressure as frequently as deviated wells. However, the horizontal wells have been consistently built to exceed current regulations, and thus, pose a lower risk of causing a stray gas migration incident than legacy deviated and vertical wells that violate current regulations (Lackey et al., 2016).

Another AirWaterGas study found that insufficient casing or cementing of a wellbore in the Denver-Julesburg Basin of Colorado was the main cause of methane migration from oil and gas wells into water wells. Using publicly-available data from the Colorado Oil and Gas Conservation Commission (COGCC), AirWaterGas researchers identified 42 drinking water wells in Colorado that contained thermogenic stray gas originating from underlying oil and gas producing formations. The incidence rate was about two cases per year over the past 15 years. The COGCC determined the cause for roughly one-third of the occurrences of thermogenic methane was improper casing of nearby oil and gas wells. None of the water wells with thermogenic stray gas could be specifically attributed to recent horizontal well drilling or hydraulic fracturing. Therefore, an assessment of the risk of thermogenic methane release should address the full history and life cycle of both conventional vertical well and unconventional oil and gas operations (Sherwood et al., 2016).

Drilling for natural gas in Colorado's Piceance Basin.

WATER TREATMENT

- *What happens to the millions of gallons of water used in the hydraulic fracturing process to develop an oil and gas well?*

During the hydraulic fracturing process, some 2-5 million gallons of water-based solution will be forced down the borehole. Roughly 20-40% of the water injected into the well will return to the surface. This is known as flowback water, and will flow for roughly two weeks. Produced water is another term used to describe water that flows to the surface through the borehole. Produced water is naturally-occurring water found in the shale formation, and it will typically flow for the entire lifespan of the well. The transition between flowback and produced water is not readily identifiable, but will probably have a different chemical composition and flowrate. Both flowback and produced water typically have high levels of total dissolved solids, which makes them extremely salty.

AirWaterGas researchers at the Colorado School of Mines and the University of Colorado Boulder are developing on-site techniques for treatment of hydraulic fracturing flowback and produced water because the current practice of injecting the wastewater into deep wells may not be sustainable. There is also a growing body of research that shows that injecting wastewater into deep wells may cause earthquakes (induced seismicity). The research task requires examination and optimization of physical/chemical, biological-based, and membrane-based treatment technologies. Using results from the development of treatment technology, researchers are developing a decision support tool that will allow industry to select sustainable processes for the treatment and beneficial reuse of reclaimed water from the oil and gas industry.

In order to assure proper treatment, reuse, or disposal of produced water and flowback wastewater, the contaminants in the water need to be accurately characterized and quantified. AirWaterGas researchers conducted a multi-laboratory, round-robin comparison testing five different methods to characterize the chemical composition of different types of flowback water– raw fracturing flowback, treated fracturing flowback, raw produced water, and treated produced water. A follow up round-robin test will be conducted focusing on organic matter and hydrocarbons in the wastewater.

OIL and GAS INFRASTRUCTURE

- *Are oil and gas wells being constructed in a way that prevents release of potential contaminants to groundwater used for drinking water?*

AirWaterGas researchers from the Colorado School of Mines analyzed data from 17,948 wells drilled in the Wattenberg Field, Colorado between 1970-2013 for possible barrier failures that would allow migration of hydrocarbons or hydraulic fracturing fluid into an aquifer. The researchers determined that three independent events must occur for migration of hydrocarbons into an aquifer: failure of the cemented surface casing, failure of the cemented production casing, and failure of the annular hydrostatic pressure. An additional two independent events must occur for contamination of an aquifer during the hydraulic fracturing process: failure of the stimulation pressure monitoring and failure of the annular pressure monitoring. No evidence of aquifer contamination by hydraulic fracturing operations through wellbores was discovered in the Wattenberg Field. However, a total of 10 wells in the study area exhibited signs of hydrocarbon migration to freshwater aquifers. These events were found to only be associated with older wells, with surface casing which was not extended through the entire series of fresh water aquifers in the study area.

Oil and gas drilling near a residential area in Colorado's Denver-Julesburg Basin.

PUBLIC HEALTH EFFECTS

- *How is oil and gas development affecting the health and welfare of nearby communities?*

Oil and gas development results in emissions of pollutants and other hazards that can affect the health of residents living near oil and gas development. A team from the Colorado School of Public Health is focusing on human health impacts stemming from exposure to contaminants in air and water, as well as nonchemical stressors that affect residents, such as noise, traffic, fires, and explosions.

AirWaterGas researchers conducted a review of published studies to evaluate risks to public health from chemical and nonchemical stressors associated with oil and gas development. The review describes likely exposure pathways and potential health effects, and identifies major uncertainties to address with future research (Adgate et al., 2014). The review found no comprehensive population-based studies of the public health effects of oil and gas development exists in the peer-reviewed scientific literature and notes that comprehensive health studies will take many years and millions of dollars to conduct.

AirWaterGas researchers studied Colorado's population living in oil and gas development areas. They estimated that at least 378,000 people in Colorado live within one mile of an oil and gas well and that the population living within a mile of oil and gas wells is growing at a faster rate than the overall population. They found that the growing population around the wells appears to be a result of homes being built near the wells in some areas and wells being drilled near homes in other areas. In populations living nearest to the wells, they found possible environmental injustices with regards to income, distribution of risks and benefits resulting from oil and gas development, and participation decision making processes concerning oil and gas development.

In parallel with their AirWaterGas-funded research, the Colorado School of Public Health team has been conducting epidemiological studies on associations between oil and gas development and health outcomes. One recent study by the Colorado School of Public Health researchers considered the incidence prevalence of birth defects and the proximity of the mother's residence to natural gas development in rural Colorado (McKenzie et al., 2014). Researchers found a positive association between greater density and proximity of natural gas wells within a 10-mile radius of maternal the mother's residence and greater prevalence of congenital heart defects and possibly neural tube defects. While not conclusive, this research speaks to the need for additional study on the potential health effects associated with oil and gas development in and near homes and schools.

Oil and gas drilling in Colorado's Denver-Julesburg Basin.

ECONOMIC EFFECTS

- *How can the economic value and market and non-market costs of oil and gas development be quantified to provide a cost-benefit accounting?*

Conversations about oil and gas economics are often cast solely in terms of jobs, tax revenue, and cost of energy. Colorado State University economists are working to quantify the economic value of market and non-market costs such as the economic cost of impacts on public health, air quality, and water quality. The goal is to enable comprehensive conversations about regulations of oil and gas development rather than just having an economy versus public health and environment debate. This cost-benefit accounting research will be used to build a framework for a model that will assess the total costs and benefits of an oil and gas policy (such as setbacks from homes). The model will consider the direct economic effects of oil and gas regulations (access to resources, employment, oil and gas revenue) as well as the non-market economic effects (air quality, water quality, public health, habitat fragmentation, greenhouse gases).

AirWaterGas researchers from Colorado State University conducted a study examining the effects of hydraulically fractured oil and gas wells on house prices in Weld County, Colorado, a county with prior oil and gas activity. Active drilling within a half mile of a well during the time a buyer was deciding about a purchase reduced the price of the house by 1% per well. This price effect was found in the city of Greeley, but not in rural areas of the county. Also, once active drilling finished, there was no statistically significant negative effect on house prices. Employment in the oil and gas industry has a statistically significant but very small positive effect on house prices of less than 1% of the purchase price (Bennett and Loomis, 2015).

POLITICAL and SOCIAL EFFECTS

- *What are the changing beliefs, resources, and strategies of policy actors – officials from all levels of government, industry, nonprofit organizations, engaged citizens, scientists, journalists – involved in hydraulic fracturing issues in Colorado?*

AirWaterGas researchers at University of Colorado Denver's School of Public Affairs studied policy actors within Colorado involved or knowledgeable about oil and gas development. Researchers conducted interviews, administered surveys, and analyzed of news articles. The researchers found divergent views on the risks and benefits and positions related to oil and gas development. On average, respondents reported the political debate worsening over the past two years despite acknowledging a greater availability of scientific and technical information. Respondents stated that their strategic relationships with those they disagree with are somewhat collegial, and their relationships with those they agree with are slightly more collegial, on average. Respondents overall cited interactions with state government as a valuable resource for achieving their goals (Heikkila and C. Weible, 2015).

Oil and gas drilling in Colorado's Denver-Julesburg Basin.

PRACTICES and REGULATIONS

- *How can statutes, regulations, and non-regulatory agreements governing oil and gas development be made more accessible to the public?*

The AirWaterGas practices and regulations team has created several web-based tools to share information on air, water, and other resources impacted by oil and gas development. These tools include a searchable best management practices database (www.oilandgasbmps.org) for the Intermountain region and the LawAtlas comparative air quality, water quality, and water quantity law databases (http://lawatlas.org/oilandgas), which cover 17 states and four federal agencies. Researchers have recently added non-regulatory, voluntary negotiated agreements, known as memoranda of understanding (MOU) between local governments and operators to the BMP database. MOUs allow operators and local governments to negotiate siting and operations of oil and gas development despite the fact that Colorado has preempted local governments from directly regulating most aspects of oil and gas development. The MOU project has also conducted a stakeholder assessment regarding the use and potential use of MOUs to address oil and gas development within Colorado's regulatory framework.

AirWaterGas research assistants sampling a water well near gas development in Colorado's Piceance Basin.

EDUCATION and OUTREACH

- *How can researchers help bring good science to the public debate about oil and gas development?*

The education and outreach team seeks to develop evidence-based resources to create more productive and substantive education and conversations about unconventional oil and gas development. The AirWaterGas researchers are working with K-12 educators and interested citizens through several programs including a rural classroom air quality inquiry project-based learning program and a community small grant program. They also conducted two teacher professional development programs for Colorado secondary science teachers, including a year-long program with a curriculum development component and a second online course highlighting curriculum developed in the first program Each program gives the public access to scientists in different settings such as the classroom, online learning, in-person workshops, and community lectures. By building and fostering mutually beneficial partnerships that bridge the gap between scientists and the public, AirWaterGas researchers will continue to look for new ways and new opportunities to bring scientific information about the costs and benefits of oil and gas development to the public at large.

Learn more about AirWaterGas

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REFERENCES

Adgate, J.L., B.D. Goldstein, L.M. McKenzie (2014) Potential public health hazards, exposures and health effects from unconventional natural gas development. *Environmental Science & Technology* **48**(15), 8307-8320; doi: 10.1021/es404621d.

Bennett, A. and J. Loomis (2015) Are housing prices pulled down or pushed up by fracked oil and gas wells? *Society & Natural Resources* **28**(11), 1168-1186; doi:10.1080/08941920.2015.1024810

Birdsell, D.T., H. Rajaram, and G. Lackey (2015), Imbibition of hydraulic fracturing fluids into partially saturated shale. *Water Resources Research* **51**(8), 6787-6796; doi:10.1002/2015WR017621.

Birdsell, D.T., H. Rajaram, D. Dempsey, and H.S. Viswanathan (2015), Hydraulic fracturing fluid migration in the subsurface: A review and expanded modeling results. *Water Resources Research* **51**(9), 7159-7188; doi:10.1002/2015WR017810.

Heikkila, T. and C. Weible (2015) A Summary Report Of A 2015 Survey of the Politics of Oil And Gas Development that Uses Hydraulic Fracturing in Colorado. Published July 24, 2015, School of Public Affairs, University of Colorado Denver.

McKenzie, L.M., R. Guo, R.Z. Witter, D.A. Savitz, L.S. Newman, and J.L. Adgate (2014) Birth outcomes and maternal residential proximity to natural gas development in rural Colorado. *Environmental Health Perspectives* **122**(4), 412-417; doi:

10.1289/ehp.1306722.

McLeod, J.D., G.L. Brinkman, J.B. Milford (2014) Emissions implications of future natural gas production and use in the U.S. and in the Rocky Mountain region. *Environmental Science & Technology* **48**(22)13036-13044; doi:10.1021/es5029537.

Oikonomou, P.D., J.A. Kallenberger, R.M. Waskom, K.K. Boone, E.N. Plombon, and J.N. Ryan (2016) Water acquisition and use during unconventional oil and gas development and the existing data challenges: Weld and Garfield counties, CO. *Journal of Environmental Management* **181**, 36-47; doi:10.1016/j.jenvman.2016.06.008.

Pétron, G., A. Karion, C. Sweeney, B.R. Miller, S.A. Montzka, G.J. Frost, M. Trainer, P. Tans, A. Andrews, J. Kofler, D. Helmig, D. Guenther, E. Dlugokencky, P. Lang, T. Newberger, S. Wolter, B. Hall, P. Novelli, A. Brewer, S. Conley, M. Hardesty, R. Banta, A. White, D. Noone, D. Wolfe, and R. Schnell (2014), A new look at methane and nonmethane hydrocarbon emissions from oil and natural gas operations in the Colorado Denver-Julesburg Basin. *Journal of Geophysical Research Atmospheres* **119**(11), 6836–6852; doi:10.1002/2013/JD021272.

Rogers, J.D., T.L. Burke, S.G. Osborn, and J.N. Ryan (2015) A framework for identifying organic compounds of concern in hydraulic fracturing fluid based on their mobility and persistence in groundwater. *Environmental Science and Technology Letters* **2**(6), 158-164; doi:10.1021/acs.estlett.5b00090.

Sherwood, O.A., J.D. Rogers, G. Lackey, T.L. Burke, S.G. Osborn, and J.N. Ryan (2016) Groundwater methane in relation to oil and gas development and shallow coal seams in the Denver-Julesburg Basin of Colorado. *Proceedings of the National Academy of Sciences* **113**(30), 8391-8396; doi:10.1073/pnas.1523267113.