Risks of shale gas exploration and hydraulic fracturing to water resources in the United States

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Exploration of unconventional natural gas reservoirs such as low-permeability organic shale formations through horizontal drilling and hydraulic fracturing has changed the energy landscape in the Unites States, providing a vast new energy source. Since the mid-2000s, drilling and production of natural gas has accelerated, also triggering a public debate over the safety and environmental impacts of these operations (1). This paper provides an overview of one critical set of possible environmental effects: the potential short- and long-term risks to water resources.

We highlight two key issues related to shorter-term risks. The first is stray gas contamination – the occurrence of elevated levels of methane and other gases in some shallow drinking water wells, which can pose a potential flammability or explosion hazard to homes near shale gas drilling sites. Evidence for stray gas contamination has been suggested in northeastern Pennsylvania overlying the Marcellus Shale (2). In these areas, elevated methane levels in shallow groundwater less than 1 km from shale gas wells were characterized by a thermogenic carbon isotope fingerprint, distinctive hydrocarbon ratios with presence of ethane, and noble gas geochemical fingerprints (2,3). Combined, these studies suggest stray gas contamination results from the leaking of natural gas along the well annulus from the shale production formations or shallower formations and/or the release of natural gas from the target formation through poorly constructed or failing well casings. In contrast, shallow groundwater associated with the Fayetteville Shale in north-central Arkansas showed no evidence for methane contamination (4,5), indicating that the local geology and/or drilling practices may play a role in stray gas contamination.

The second short-term risk is the disposal and/or accidental release (spill) of the flowback and produced waters that are generated during well completion, hydraulic fracturing, and gas production from unconventional wells (6,7). Shale gas wastewater is often highly saline and toxic and can contain high levels of naturally occurring radioactivity (8-13). In spite of treatment, discharge of shale gas wastewater to surface waters causes direct contamination of the river systems (12-14). The magnitude of contamination depends on the volume of the disposed wastewater and the local hydrological system (i.e., flow rate and dilution). Disposal of treated wastewater originated from shale gas can also generate bromide levels above baseline levels (13) that can trigger formation of brominated trihalomethanes compounds (e.g., bromodichloromethane) in downstream drinking waters upon water chlorination (15).

As for long-term risks, we have identified four key issues. The first is potential water shortage in areas where water scarcity induces competition over limited or diminishing water availability. In spite of the overall low volume of water that is needed for drilling and hydraulic fracturing relative to other water utilization (16), large-scale unconventional development in water-scare areas such as the Eagle Ford play in Texas could require additional groundwater exploitation and depletion of aquifers that are being utilized for agricultural and domestic uses. Over-exploitation of these aquifers is often associated with water quality deterioration.

The second risk is the potential for natural pathways and hydraulic connection between deep underlying formations and shallow drinking water aquifers, such as faults and/or the natural fracture network, in which pressurized gas and brine can flow to shallow aquifers (17). In spite of thick geological barriers between shallow and deep formations, evidence for possible pathways has been shown in the northeastern Appalachian Basin where shallow groundwater had high salinity combined with geochemical and isotopic fingerprints similar to waters produced from the Marcellus formation during drilling and production (18).

The third potential risk is associated with abandoned oil and gas wells in close proximity to areas targeted for unconventional energy development. Abandoned wells in some cases could provide conduits for vertical fluid flow of saline formation waters to shallow drinking water aquifers (19). The legacy of hundreds to thousands of abandoned and improperly sealed conventional oil and gas wells, superimposed with the installation of new shale gas wells, could in principle lead to contamination of overlying water resources. Areas of high occurrence of conventional oil and gas wells in the Appalachian Basin, with a well density of up to 20 wells per square kilometer, are of higher risks of groundwater contamination.

The fourth risk is the accumulation of residual contaminants in areas of oil and gas wastewater disposal, spills, and leaks. Field evidence shows that long-term disposal of treated wastewater originating from shale gas production can cause reactive radioactive elements (radium and daughter isotopes) to accumulate in the river sediments downstream of disposal sites (13). Likewise, treatment of shale gas wastewater generates solid waste with potentially high levels of radioactivity (13). Improper disposal of these solid wastes to unregulated landfills could in some cases contaminate associated water resources.

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