Mid-Atlantic States Section of the Air and Waste Management Association

Wastewater Produced by Natural Shale Gas Production
Some Regulatory and Management Issues

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Wastewater and other waste products produced during oil and gas drilling and production has the potential to negatively impact groundwater and surface water.[1] This paper will focus on unconventional sources of natural gas, defined as sources that use more complex and expensive technologies such as hydraulic fracturing and horizontal drilling, [2] specifically shale gas.

What are the Numbers?

The U.S. Department of Energy's Energy Information Agency (EIA) sets current U.S. consumption at about 23.5 Trillion cubic feet (Tcf) per year. According to a report by the General Accountability Office (GAO), the production of natural gas in the U.S. produces an estimated 56 million barrels of produced water per day, but this is likely underestimated due to incomplete and out of date data (primarily 2007)[3]. For instance, shale gas production has increased significantly since 2007; the GAO reports an average annual growth rate of 48% from 2006 to 2010. Shale gas, according to the EIA, accounts for about 23% of the nation's total gas production.

The amount of wastewater being produced today has sharply increased in the past five years due to the advent of shale gas development. In Pennsylvania, for instance, between 2005 and 2008, there were 251 shale gas well drilling permits issued; from January 1, 2008 to March 21, 2012 10,122 shale gas well permits were issued. From 2005 through to 2008 150 Marcellus Shale gas wells were drilled; from January 1, 2008 to March 21, 2012 there were 5,127 Marcellus Shale wells drilled. The U.S. Environmental Protection Agency (EPA) remarked on the "remarkable speed" of the growth of the natural gas industry in Pennsylvania in a letter dated March 7, 2011.[4]

[1] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water produced during Oil and Gas Production***, GAO-12-56, January 2012.
[2] Ibid.
[3] Ibid.
[4] USEPA letter from Shawn M. Garvin, Regional Administrator to The Honorable Michael Krancer, Acting Secretary, PADEP, 3.7.11.

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Pennsylvania has joined the nine other states that yield 90% of the volume of produced water in the United States[5].

According to the Department of Energy, 100,000 new shale gas wells can be expected nationally.[6] According to state predictions, 50,000 new natural gas wells could be drilled in Pennsylvania[7] and 40,000 in New York. Estimates in the Delaware River watershed alone range up to 32,124 (from the Delaware River Basin Commission) to 64,000 gas wells (National Park Service). Whatever the ultimate number, the expected increase in shale gas development will mean an increase in wastewater volume.

"Produced water" -- water produced from wells during gas and oil exploration and production -- is made up of water that exists in the geologic formations that are disturbed by drilling and extraction processes ("formation water") and can also contain fluids injected to stimulate production. In shale gas processes, the mix of water, chemicals, and proppants that are injected during hydraulic fracturing returns to the surface mixed with formation water as "flowback".

According to PADEP, 31,093,611.51 barrels, or 1,339,951,662 gallons of wastewater was produced by shale gas wells in 2011, according to operator reports.[8] The amount of flowback that initially erupts to the surface in Pennsylvania shale gas wells varies but is estimated to be about 10% of the volume injected; on average, approximately 5 million gallons of water is used to hydraulically fracture the well. Considering the large number of wells involved (PADEP issued 5,728 drilling permits for oil and gas wells in 2011; 2,907 new oil and gas wells were spudded in 2011)[9], significant management challenges are posed by the volume of produced water.

<u>What are the Management Issues?</u>

According to the GAO, produced water is "generally of poor quality, with levels of contaminants varying widely".[10] Treatment is required before the wastewater can be reused or discharged. Hydraulic fracturing methods, using chemicals and proppants under high pressure in deep geologic formations with high levels of naturally occurring contaminants can yield poorer quality produced water than other extraction processes.[11] A previous study from the U.S. Department of Energy concludes that produced water from gas drilling is 10 times more toxic than those from off shore oil drilling.[12]

Contaminants "…can include, but are not limited to: salts (chlorides, bromides, and sulfides of calcium, magnesium, and sodium); metals (including barium, manganese, iron, and strontium); oil, grease, and dissolved organics (including benzene and toluene); naturally occurring radioactive materials; and production chemicals from hydraulic fracturing…Exposure to these contaminants at high levels may pose risks to human health and the environment".[13]

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[5] Ibid.

[6] U.S. Department of Energy Secretary of Energy Advisory Board, ***Shale Gas Production Subcommittee Second Ninety Day Report***, 11.18.2011.

[7] PA Bulletin, Doc_ No_ 10-1572.mht

[8] https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/DataExports/DataExports.aspx

[9] PADEP website, 1.24.12

[10] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.

[11] Ibid.

[12] U.S. Dept. of Energy, Argonne National Laboratory, "A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane", January 2004.

[13] Ibid.

The Marcellus Shale contains radionuclides including uranium-238, thorium-232, and their decay products. Radioactive concentrations in the Marcellus Shale formation are at concentrations 20 to 25 times background, making shale gas wastewater extremely radioactive.[14] The produced water from Marcellus Shale has higher levels of radionuclides than water from Barnett Shale wells, according to the GAO.[15]

Sampling and data-gathering by New York State detected radiological parameters in Marcellus Shale flowback, including Radium-226[16], the longest lived isotope of radium with a half-life of 1600 years. Gross Alpha, Gross Beta, Total Alpha Radium and Radium-228 were also found.[17] This is a significant wastewater management issue because radioactivity poses human health risks.

Radium-226, a decay product of the Uranium-238 decay chain, is taken up like calcium into bone[18] where it concentrates. Radium-226 can cause lymphoma, bone cancer, and diseases that affect the formation of blood, such as leukemia and plastic anemia. The radioactive decay product of radium is radon, which is very dangerous and is the second leading cause of lung cancer in the United States.[19] EPA has set federal air limits, cleanup standards, and a maximum contaminant level for radium 226 and 228 under the Safe Drinking Water Act due to human health hazards.[20] EPA has the authority to regulate all Naturally Occurring Radioactive Materials (NORM), but generally has not done so, leaving a regulatory gap in terms of human health and a lack of data regarding impacts to the natural environment, such as aquatic life.[21] These regulatory and data gaps pose additional management challenges.

In a letter to PADEP in 2011, EPA highlighted the presence of radionuclides, along with other contaminants, as present in wastewater resulting from gas drilling operations and emphasized the importance of investigating the presence of radionuclides in public water supplies and their persistence in wastewater effluent.[22] EPA pointed out that this information is essential to the development of controls to protect public health and aquatic life in receiving water bodies.[23] As a result, testing for radionuclides in Pennsylvania has been required by EPA for water supply facilities and wastewater plants; other measures have been suggested to PADEP and/or have been taken directly by EPA over the past year, including independent EPA inspections, monitoring, data reviews, and compliance determinations. How these actions will shape the management and ultimate fate of gas drilling wastewater remains to be seen.

Other dangerous contaminants in wastewater pose risks to human health and the environment. New York tested flowback from Marcellus Shale gas extraction operations in Pennsylvania and

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[14] Marvin Resnikoff, Ph.D., Radioactive Waste Management Associates, “Comments on Marcellus Shale Development”, October 2011.
[15] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.

[16] Ibid. Table 5.24.
[17] Ibid.
[18] http://www.epa.gov/radiation/radionuclides/radium.html#inbody
[19] Ibid.
[20] Ibid.
[21] Glenn C. Miller, Ph. D., ***Comments to Delaware Riverkeeper Network on the Delaware River Basin Commission's Draft Proposed Natural Gas Development Regulations***, 2011.
[22] USEPA letter from Shawn M. Garvin, Regional Administrator to The Honorable Michael Krancer, Acting Secretary, PADEP, 3.7.11.
[23] Ibid.

West Virginia and found 154 parameters.[24] Many are chemical hazards, many are known to effect human health and the environment.

The GAO highlights some of the health impacts of these chemicals.[25] For instance:

> EPA advises that high levels of barium increase blood pressure.[26]
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> PADEP acknowledges that bromide is a key parameter of concern in the effluent because it can form brominated disinfection by-products (DBP's) in water supplies. These are a drinking water hazard because of the propensity for the brominated DBP's to form trihalomethanes, which can cause cancer.[27]
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> The International Agency for Research on Cancer and the EPA have determined that benzene is carcinogenic to humans; benzene is naturally occurring in the Marcellus shale and is also a hydraulic fracturing additive. The EPA has set the maximum contaminant level of benzene in drinking water at 5 parts benzene per billion parts of water (5 ppb).[28] A very small amount of benzene can contaminate water beyond safe drinking water standards.

The depth of the shale formation influences the salt and mineral content of the produced water; generally, the deeper the formation, the higher the salt and minerals. Produced water from Marcellus Shale can have salt and mineral levels 20 times higher than coalbed methane wells, for instance.[29] High salt levels (represented as Total Dissolved Solids or TDS), typical of Marcellus Shale gas wastewater, are toxic to the natural environment and can carry significant adverse impacts, including impairment and death of aquatic life. In 2010, DEP stated that "…many of the rivers and streams of Pennsylvania have a very limited ability to assimilate additional TDS, sulfates and chlorides because of elevated levels from historic practices".[30]

As an example, stream contamination due to extremely high TDS and chloride levels led to a cascade of ecosystem changes in Dunkard Creek in 2009, where one of the worst ecological disasters in modern times occurred on this popular fishing stream that winds back and forth across the Pennsylvania and West Virginia border. Over a period of one month, 22,000 fish died and at least 14 species of freshwater mussels were destroyed along with all other aquatic life for 35 miles of stream.[31] Basically, the stream turned from fresh water to salt water, killing everything with gills.

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[24] New York State Department of Environmental Conservation, ***Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and other Low-Permeability Gas Reservoirs***, September 2011, Table 5.9.

[25] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.

[26] Ibid.

[27] PADEP "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.

[28] http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=38&tid=14

[29] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.

[30] PADEP "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.

[31] Adam Federman, "What Killed Dunkard Creek?, Earth Island Journal, Winter 2012. http://www.earthisland.org/journal/index.php/eij/article/what_killed_dunkard_creek

In its Permitting Strategy, DEP goes on to discuss the overload of TDS in the Monongahela River: TDS and sulfates reached historic highs in 2008 (this condition recurred in 2009), exceeding water quality standards at the water facilities that supply water to over 325,000 people in the basin, including Pittsburgh. DEP also lists South Fork Tenmile Creek, the Beaver and Conemaugh Rivers and the West Branch of the Susquehanna River as being overloaded with high TDS concentrations.[32]

PADEP adopted an effluent standard of 500 mg/L as a monthly average for TDS in 2010 but this is based on limited data and not protective of aquatic life, according to recent studies,[33] but is consistent with EPA recommended standards. Pennsylvania also adopted an effluent standard of 250 mg/L of total chlorides as a monthly average and 250 mg/L of total sulfates as a monthly average.

The Philadelphia Water Department commented in support of the chloride standard due to the need to control salinity in the drinking water they provide. The Water Department expressed concern that the elevated salt content of shale wastewater (up to 40,000 mg/L of chloride) and the difficulty in balancing the already high chloride concentration in the City's raw water supply due to proximity to the estuary. High chloride content erodes facility piping and infrastructure and negatively impacts human health for sensitive individuals.[34]

Concern was expressed by the City of Philadelphia about whether these contaminants and others in gas drilling wastewater will make it more difficult for the City as a water supplier to meet Safe Drinking Water Act standards.[35] This concern is magnified statewide considering that there are 349 drinking water suppliers in Pennsylvania that rely on surface water or groundwater directly influenced by surface water.[36]

Arsenic, mercury, and hydrocarbons, as well as many other toxic contaminants in shale gas wastewater are also of concern. For example, in natural gas production in Texas, the arsenic content in wastewater has both a high hazard quotient and a risk factor greater than 10,000, which requires a cleanup of a site; these measurements were not done by New York for the revised draft SGEIS and it is unknown if this is being tracked in Pennsylvania. According to EPA, non-cancer effects of arsenic can include thickening and discoloration of the skin, stomach pain, nausea, vomiting; diarrhea; numbness in hands and feet; partial paralysis; and blindness. Arsenic has been linked to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate. EPA has set the arsenic standard for drinking water at .010 parts per million (10 parts per billion).[37]

Mercury, likewise, is a poison found in gas drilling wastewater[38] that has severe health impacts.[39] EPA has set a safe drinking water limit of 2 ppb, reflecting that tiny amounts can contaminate water supplies and will have direct health effects.

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[32] PADEP, "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.
[33] Delaware Riverkeeper Network, Comment to PA Environmental Quality Board re. 25 PA Code Ch. 95 Wastewater Treatment Requirements, dated 2.12.2010.
[34] City of Philadelphia Water Department Comments on the Environmental Quality's Board's Proposed Regulation # 7-446 (#2806) to amend 25 Pa. Code Chapter 95, 2.11.2010.
[35] Ibid.
[36] PA Bulletin, DOC No. 10-1572, 25 PA. CODE CH. 95, 8.21.10.
[37] http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/index.cfm
[38] New York State Department of Environmental Conservation, ***Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program, Well Permit***

New York sampling also has found unique contaminants such as acrylonitrile[40], presumably from use as a component of acrylonitrile-butadiene-styrene in-situ polymerization to increase the utility of a propping agent.[41] It is a human health hazard and is "reasonably anticipated" to cause cancer.[42] The composition of shale gas wastewater offers complex and challenging management issues.

Endocrine disrupting chemicals (EDC) used in hydraulic fracturing fluids and found in flowback are of special concern due to the biological effects of these constituents at extremely low concentrations. Scientists and health professionals are beginning to analyze these materials and measure their impacts on human health in a different way, testing these compounds at very low levels in the range of human exposures and at various endpoints.[43] In an effort to protect human health from these very dangerous materials, scientists are concluding that there are no safe doses for endocrine disrupters; the fact that they have biological effects proves that EDC's have biological activity – what the induced effects are is the question.[44]

Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and other Low-Permeability Gas Reservoirs, September 2011, Table 5.9.

[39] **Mercury CAS #: 7439-97-6, How can mercury affect my health?** The nervous system is very sensitive to all forms of mercury. Methylmercury and metallic mercury vapors are more harmful than other forms, because more mercury in these forms reaches the brain. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause effects including lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation. **How likely is mercury to cause cancer?** There are inadequate human cancer data available for all forms of mercury. Mercuric chloride has caused increases in several types of tumors in rats and mice, and methylmercury has caused kidney tumors in male mice. The EPA has determined that mercuric chloride and methylmercury are possible human carcinogens. **How does mercury affect children?** Very young children are more sensitive to mercury than adults. Mercury in the mother's body passes to the fetus and may accumulate there. It can also pass to a nursing infant through breast milk. However, the benefits of breast feeding may be greater than the possible adverse effects of mercury in breast milk. Mercury's harmful effects that may be passed from the mother to the fetus include brain damage, mental retardation, incoordination, blindness, seizures, and inability to speak. Children poisoned by mercury may develop problems of their nervous and digestive systems, and kidney damage. http://www.atsdr.cdc.gov/tfacts46.pdf

[40] New York State Department of Environmental Conservation, ***Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and other Low-Permeability Gas Reservoirs***, September 2011, Table 5.9.

[41] **Acrylonitrile CAS ID #: 107-13-1**, **Affected Organ Systems:** Developmental (effects during periods when organs are developing) , Hematological (Blood Forming), Neurological (Nervous System), Reproductive (Producing Children; **Cancer Effects:** Reasonably Anticipated to be Human Carcinogens; **Chemical Classification:** None; **Summary:** Acrylonitrile is a colorless, liquid, man-made chemical with a sharp, onion- or garlic-like odor. It can be dissolved in water and evaporates quickly. Acrylonitrile is used to make other chemicals such as plastics, synthetic rubber, and acrylic fibers. A mixture of acrylonitrile and carbon tetrachloride was used as a pesticide in the past; however, all pesticide uses have stopped. http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=78

[42] Ibid.

[43] Vandenberg et. al., "Hormones and Endocrine-Disrupting Chemicals: Low-Dose Effects and Nonmonotonic Dose Responses", The Endocrine Society, doi:10.1210/er.2011-1050, 3.14.12.

[44] Laura Vandenberg, Tufts University, "There Are No Safe Doses for Endocrine Disruptors", Environmental Health News, 3.12

Suspected EDC's found in gas drilling wastewater include arsenic and selenium; hydraulic fracturing fluids may contain others such as 2BE, 2-Ethylhexanol, and Crystalline Silica. None of these chemicals are targeted for removal from gas drilling wastewater. The use and/or presence of these chemicals highlights the problem that many of the dangerous constituents of gas drilling wastewater are either unknown or lack testing for human health and natural environment impacts.

Due to inadequate regulation and lack of sophisticated study designs that can accurately identify the effects of these contaminants, entire classes of chemicals are not regulated in the environment and so are not captured in the treatment and management effort. As stated by Linda Birnbaum, Director, National Institutes of Health, "It is time to start the conversation between environmental health scientists, toxicologists, and risk assessors to determine how our understanding of low-dose responses influence the way risk assessments are performed for chemicals with endocrine-disrupting activities. Together, we can take appropriate actions to protect human and wildlife populations from these harmful chemicals and facilitate better regulatory decision making".[45]

The GAO points out that a number of options are used to manage produced water, that "most produced water is minimally treated" and that cost is the "primary driver" in decisions about how to manage and treat the wastewater.[46]

<u>How Is Gas Drilling Wastewater Handled Today?</u>

<u>Underground Injection</u>

Most gas and oil wastewater produced in the United States (U.S.) is injected into underground disposal wells. There are 150,855 injection wells that are permitted to inject produced water in the U.S., although not all are in use. About 20% of these are used for disposal, the rest are used for "enhanced recovery", a means of stimulating resource extraction. In Pennsylvania, there are 1,861 injection wells, most all of them used for enhanced recovery; there are only six currently active injection wells for produced water disposal.[47] EPA, who regulates the Underground Injection Control program in Pennsylvania, says there is increased interest from operators for new injection wells in the state.[48] Currently, wastewater that is disposed in injection wells is trucked from Pennsylvania to Ohio and West Virginia.

<u>Surface water discharge</u>

Surface water discharge of produced water accounted for less than 1 percent in 2007 in the U.S. The amounts increased with Marcellus Shale development in Pennsylvania, where surface discharges became "common".[49] However, PADEP officials told EPA that this fell off after the state implemented its stricter Chapter 95 effluent limitations, as discussed above, although surface discharge is not prohibited in the State.[50]

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[45] Linda S. Birnbaum, Director, NIEHS and NTP, National Institutes of Health, U.S. Department of Health and Human Services, "Environmental Chemicals: Evaluating Low-Dose Effects", doi:10.2189/ehp.1205179, Environmental Health Perspectives, Vol. 120, Number 4, April 2012.

[46] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.

[46] PADEP "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.

[47] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.

[48] Ibid.

[49] Ibid.

[50] Ibid.

EPA, in its March 2011 letter, strongly advised PADEP that existing discharge permits for Publicly Owned Treatment Works and centralized waste treatment facilities did not allow the acceptance of gas drilling wastewater without "critical provisions necessary to effective processing and treatment" of the wastewater.[51] EPA has inserted itself into PADEP's review of these facilities for better accountability. Doubtless this interest from EPA has had an effect on surface water discharges there. One new treatment facility has gone into operation under the new effluent standards[52]; several "brine" facilities that were "grandfathered" under the old regulations continue to discharge to surface water, as do some sewage treatment facilities employing pre-treatment.

The issue of how to dispose of sludge and residue from treatment facilities that remove TDS and other contaminants is yet another management challenge. For example, removal of salts from this wastewater will probably require use of membrane systems to recover the majority of the water. However, this will leave large amounts of salty brines for disposal and will require further treatment for safe management/disposal.[53] Other contaminants removed that will be concentrated into residual sludge can also reach highly toxic levels and require special handling. The development of facilities and landfills designed to safely manage this waste is needed. The acceptable treatment and disposal options, including how the residual concentrate will be managed, should be addressed comprehensively on a national level.

Currently, no set of regulations for waste produced during hydraulic fracturing exist. EPA is developing standards for shale gas and coalbed methane wastewater; the rules are expected to be proposed in 2014. This will only address part of the management issues and will leave some critical loopholes in place that pose environmental threats. Because of a 1988 oil and gas industry waste exemption from the Resource Conservation and Recovery Act (RCRA), these regulations will not regulate the wastewater as hazardous, even though there are hazardous constituents in the wastewater.[54] The list of RCRA exempt wastes includes produced water, drilling fluids and muds, drill cuttings, hydrocarbons, hydraulic fracturing fluids, pit sludges, certain gases and hydrocarbons, workover wastes and sediment from the bottom of tanks.[55] The treatment regulations will be proposed by EPA without reclassifying the waste, which will not address the essential problem that hazardous waste is being handled as if it were not hazardous, posing pollution issues. There is also no incentive for companies to minimize hazardous waste since they do not have to meet the high level of management and treatment this hazardous waste requires for all other generators.

Reuse for hydraulic fracturing

Some produced water is reused to hydraulically fracture additional wells. Reuse is attractive to an operator because it can reduce the amount of newly withdrawn water required, although the amount recovered as flowback is relatively small, about 10% of the injected volume in Pennsylvania. It can greatly reduce the costs of disposal, primarily because transportation of

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[51] USEPA letter from Shawn M. Garvin, Regional Administrator to The Honorable Michael Krancer, Acting Secretary, PADEP, 3.7.11, p.2.

[52] Eureka Resources, Williamsport, PA, http://www.eureka-resources.com/

[53] Glenn C. Miller, Ph. D., ***Comments to Delaware Riverkeeper Network on the Delaware River Basin Commission's Draft Proposed Natural Gas Development Regulations***, 2011, p.3.

[54] Oil and Gas operations are exempt from portions of major federal environmental laws including: Clean Air Act; Clean Water Act; Safe Drinking Water Act; Resource Conservation and Recovery Act, Comprehensive Environmental Response, Compensation and Liability Act (the Superfund Law); and Emergency Planning and Community Right-to-Know Act. Amy Mall, et. al., Natural Resources Defense Council, ***Drilling Down***, October 2001, p.iv.

[55] U.S. Environmental Protection Agency, "Exemption of Oland Gas Exploration and Production Wastes from Federal Hazardous Waste Regulations," p. 10-11, http://epa.gov/osw/nonhaz/industrial/special/oil/oil-gas.pdf

wastewater to injection wells or treatment facilities adds substantial expense. Low cost on-site treatment technologies would need to be developed if reuse for hydraulic fracturing is to be widespread.[56]

Presently, there are no water quality standards set by government for produced water or flowback that is reused, posing a water quality problem. Operators reported to the GAO that they "treat the water to meet their own operating requirements" and that "…they had previously treated the water to a very high quality before reusing it for hydraulic fracturing, they are currently experimenting with lower levels of treatment."[57] For example, one operator reported that they used to remove the salt but no longer go to that expense to reduce operating costs and are considering eliminating other treatment if the reused wastewater can still meet their individual operating needs.[58]

One problem caused by reuse is the resulting concentration of certain contaminants. Reuse of this produced water will generally increase the contaminant load in the produced water in the subsequent well, both from additives and formation contaminants because there will be no dilution of the contaminants. If a leak occurs in the top few hundred feet in the well being fractured, the leak will contain very contaminated water under high pressure, and even a small leak can release large amounts of contaminants that can pollute aquifers and usable domestic water.[59]

Likewise, concentrated contaminants in flowback stored in open basins, as is allowed in most states, including Pennsylvania, provides the opportunity for highly toxic materials to leak, spill, or volatilize to the air. Also, when pits are closed after use is discontinued, it is legal under certain conditions in Pennsylvania to bury some pit waste on the well site. Also, the transport of these concentrated fluids for reuse between well pads in Pennsylvania is typically by plastic pipe over ground and even along and across streams, increasing the opportunity and likelihood for a release of pollutants to the environment. Leak detection of well bores, open pits, pipelines, and other critical junctures, including post-closure monitoring of well sites is not required in most states, including Pennsylvania. This presents a management problem in terms of avoiding pollution releases from natural gas wastewater and waste products.

The radioactive component is particularly challenging, since interstitial or formation water (the brine in the shale formation) can be highly radioactive (as concentrated as 15,000 pCi/L), so each time the water is reused, the radium is concentrated. This will result in TENORM, or technologically enhanced radium,[60] which is extremely toxic.

This problem magnifies as the radioactivity concentrates in wet rock cuttings that are produced by drilling, producing a waste with proportionally higher radioactivity. The cuttings, separated from the drilling fluid by screens, is more like a sand or dust and may contain up to 20% radioactive liquid.[61] These cuttings are typically disposed of in municipal landfills; some are buried on the well site. Testing for radioactivity should be required to properly manage this waste product and standards set for a maximum allowable level, based on natural background levels. The cuttings

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[56] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.
[57] Ibid.
[58] Ibid.
[59] Glenn C. Miller, Ph. D., ***Comments to Delaware Riverkeeper Network on the Delaware River Basin Commission's Draft Proposed Natural Gas Development Regulations***, 2011.
[60] Marvin Resnikoff, Ph.D., Radioactive Waste Management Associates, "Comments on Marcellus Shale Development", October 2011.
[61] Ibid.

should be dewatered and the radioactive components removed. The radioactive waste should then be sent to a licensed disposal facility that is designed to handle radioactive wastes.[62]

Pollution Incidents are Multiplying

Current wastewater management practices are not adequate to protect the environment or the public. The dangerous constituents involved in the waste, the lack of adequate treatment technologies, the expensive and complex management issues presented, coupled with poor government oversight and lack of comprehensive regulation elevates this issue to one of national urgency.

EPA, the U.S. Department of Energy and other agencies are studying the issues involved.[63] The recent EPA investigation of groundwater contamination near Pavilion Wyoming[64] supports the finding of upward contaminant migration of non-naturally occurring gas field chemicals caused by natural gas extraction operations[65]; ongoing EPA analysis will attempt to pinpoint the mechanism involved but the report may help shed light on how drilling materials, hydraulic fracturing fluids, and formation water can migrate into fresh water aquifers. This issue is key to understanding how to manage and regulate these fluids.

The incidents of pollution are the subject of much public attention and continue to emerge.[66] Communities where drilling is occurring are experiencing water and air pollution, as well as other adverse impacts. Some of these are caused by poor performance by operators where violations of environmental permits by drillers have reached about 11 per day in Pennsylvania. [67] Some are caused by inadequate regulation and oversight of gas drilling, hydraulic fracturing, and well site and wastewater handling practices such as water, air and soil pollution being investigated in Washington County, Dimock, Beaver County, Butler County, Bradford County, Susquehanna County and other areas in Pennsylvania.[68] Some are due to deficiencies in the processes used to extract and produce shale gas, such as the overloading of Pennsylvania's streams with TDS[69] and the discharge of radioactive materials to waterways there.[70]

Conclusion

The management and regulation of wastewater produced during natural gas exploration and extraction is one of the most complex and challenging issues related to shale gas development. Regulation is a hodge-podge of state rules without an established federal regulatory floor.

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[62] Ibid.

[63] EPA is studying hydraulic fracturing impacts on drinking water; a final report is due in 2014, an interim report in 2012. http://www.epa.gov/hfstudy/ The Dept. of Energy is has issued several reports and research is ongoing. US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012, p.29-34.

[64] http://www.epa.gov/region8/superfund/wy/pavillion/EPA_ReportOnPavillion_Dec-8-2011.pdf

[65] Paul Rubin, HydroQuest, "Review of EPA Investigation of Groundwater Contamination near Pavillion Wyoming", March 9. 2012, p.1.

[66] http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html

[67] http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/OG_Compliance

[68] http://thetimes-tribune.com/news/dep-asks-gas-driller-to-help-remedy-franklin-twp-methane-spike-1.1287791#axzz1plWELhB8; http://www.propublica.org/article/so-is-dimocks-water-really-safe-to-drink ; http://shale.sites.post-gazette.com/index.php/news/daily-headlines/24402-3202012-another-nepa-methane-spike-new-well-sites-in-beaver; http://shale.sites.post-gazette.com/index.php/news/archives/24313-dep-fines-chesapeake-over-multiple-incidents; http://shale.sites.post-gazette.com/

[69] PADEP, "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.

[70] http://www.nytimes.com/interactive/2011/02/27/us/natural-gas-documents-1-intro.html

Environmental impacts are not fully understood and yet mounting evidence of water contamination, air quality degradation, and community impacts is coming to light. The federal government is trying to play catch up in terms of policy, technical issues, and regulation while exemptions from major environmental laws remain in place and while shale gas development speeds ahead. A lack of ready-to-use comprehensive studies of the environmental and public health impacts allows critical issues regarding gas drilling wastewater management to go unaddressed while millions of gallons of wastewater are being produced every day, billions every year.

The industry is a major force in driving the direction of management today, well illustrated in regard to on-site treatment and reuse of wastewater for hydraulic fracturing where operators are making management decisions to meet their own economic needs. It is not reasonable to expect industrial interests to make decisions that provide protection to the public and the environment. The culture of gas and oil development is one that relies on exemptions from environmental laws, which allows a disconnect from corporate accountability and on large gaps in independent oversight, which provide favoritism to the industry at the expense of everything else. The conventional assumption is that without those props, the economic viability of these operations could falter.

Protection of public health and environmental resources is the job of government and is carried out in the regulatory structures we apply to activities such as resource extraction. Until a comprehensive approach to waste management is developed with federal standards that will prevent pollution and avoid degradation, shale gas drilling wastewater management issues will continue to pose unmet challenges.
