Alaska Oil and Gas Association

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Commissioner Cathy P. Foerster, Chair
Alaska Oil & Gas Conservation Commission
333 W. 7th Avenue, Suite 100
Anchorage, AK 99501
Submitted by E-Mail to: jody.colombie@alaska.gov

Re: Comments on Proposed Revisions to 20 AAC 25.005, 20 AAC 25.280, 20 AAC 25.990 and proposed addition of 20 AAC 25.283 – Regulation of Hydraulic Fracturing Operations

Dear Commissioner Foerster:

Thank you for the opportunity to provide the Alaska Oil and Gas Conservation Commission ("AOGCC" or "Commission") with comments and suggestions relating to the proposed hydraulic fracturing regulations in revisions to 20 AAC 25.005—20 AAC 25.990 and the addition of 20 AAC 25.283 ("proposed regulations"). The 15 members of the Alaska Oil and Gas Association ("AOGA") account for the majority of oil and gas exploration, development, production, transportation, refining, and marketing activities in Alaska. As our previous comments and testimony have indicated, AOGA's members remain supportive of reasonable hydraulic fracturing regulations and chemical disclosure and the increased transparency it will provide to Alaskans. Additionally, AOGA appreciates some of the revisions represented in the latest version of the proposed regulations, particularly as it relates to providing trade secret protection. However, as articulated below, AOGA urges the AOGCC to make further revisions to improve the proposed regulations.

As stated previously, AOGCC's proposed regulations come at a time when a number of other States have begun to promulgate new regulations or modify existing regulations relating to hydraulic fracturing. The catalyst for these changes appear to be, in a large part, unsubstantiated public concerns. AOGA believes that a thorough review of relevant scientific studies and analysis should provide the AOGCC with the guidance necessary to create the proper scope and level of regulation. As a result, in addition to providing commentary relating to AOGA's concerns as to the current version of the proposed regulations, AOGA will also take the opportunity to provide a brief discussion regarding the current status of scientific studies and analysis relating to the process of hydraulic fracturing. Absent further changes, the proposed regulations will result in substantial increases in cost to industry that would serve to merely address the misconceptions referenced

above, but would in reality, fail to provide any tangible benefits. Those increased costs could cause some wells, especially those in Cook Inlet, to be adversely affected, and thus frustrating the development of a resource that is important for overall production and vital to providing necessary natural gas for the residents of South-central Alaska. AOGA's specific concerns with AOGCC's proposed regulations echo some of its prior public comments and include issues addressed for the first time in this document.

I. Well Sampling Selection

As it pertains to the former category, AOGA would still propose the following alteration to 20 AAC 25.283(a)(4):

> A plan for water sampling of up to four water wells selected by the operator to reasonably sample in various directions from available wells around and within a vertical quarter mile of the fracture initiation point and also one-quarter mile radius of the proposed wellbore trajectory is required. If there are no water wells located within a vertical quarter mile of the fracture initiation point, and one-quarter mile of the proposed well-bore trajectory, of if property owners do not grant permission for sampling, then this will be documented and submitted in the application, if an application is otherwise required.

These modifications should address the AOGCC and public concerns regarding which hydraulic fracturing operations are subject to these regulations and the manner in which operators will test the applicable wells. As noted in prior submissions and during testimony, the vast majority of fracturing operations in Alaska are conducted in reservoirs located well below any ground water aquifers. By excluding operations from the sampling requirement where the "fractures" are designed to occur more than one-quarter mile below or away from any water source, the AOGCC addresses potential public and health concerns without creating cumbersome and unnecessary burdens on industry. Ultimately, it should be the goal of the AOGCC to promulgate regulations that are narrowly tailored to its goal of protecting fresh water sources. As articulated in more detail below, fractures that occur at depths in excess of a quarter mile below or away from fresh water aquifers pose essentially no threat. Thus, it would be imprudent and unnecessarily cumbersome to attach the proposed sampling requirements to hydraulic fracture operations that occur more than one quarter mile from ground water aquifers.

II. FracFocus Reporting by Treatment

During a previous public hearing, Commissioner Norman inquired during AOGA's oral testimony, whether our members report to FracFocus "by treatment" or "by stage." In previous comments, we have recommended reporting "by treatment." Some operators may base their FracFocus reports on the "job tickets" provided from the service provider; sometimes, the operations reported are single interval treatments and other times, in multi-stage treatments, the job ticket will include several stages reported to FracFocus. AOGA continues to recommend reporting and disclosure "by treatment" as dividing the volumes used in a treatment is arbitrary and is of no benefit.

Furthermore, AOGA reiterates that FracFocus, particularly the updated and improved second iteration, should meet the AOGCC's desire to gather and maintain the relevant information related to hydraulic fracturing operations. The AOGCC's proposed regulations appear to call for dual reporting. Having a separate and redundant State database could result in additional costs and burdens to both industry and the commission, while resulting in little, if any, additional value. FracFocus provides the State, the operator, and the public with a proven method of cataloguing hydraulic fracturing information. AOGA strongly urges the AOGCC to require reporting to FracFocus alone.

III. Surface Owner Participation

AOGA does appreciate AOGCC's alteration in the recently proposed regulations, at 20 AAC 25.283 (4)

> "…. The operator shall detail the well selection process for identifying wells to sample. If surface owners do not grant permission for baseline sampling or disclosure of results, the operator shall document the reasonable and good faith efforts taken to secure such permission. Surface owners that deny permission for pre-fracture sampling or disclosure of results are not required to be included in post fracture water sampling as required by subsection (j)."

The idea that any surface owner can elect to not participate in the program is especially important, and this wording constitutes a crucial addition to the proposed regulations.

IV. Sampling Parameters –Methane Threshold

The AOGCC's proposed regulations relating to the sample parameters [20 AAC 25.283 (a)(4)] are arbitrary, as are the levels triggering notification, and as such, provide no benefit and only serve to unnecessarily alarm those who would be notified. The proposed regulations specify that a "methane concentration greater than of 1.0 mg/l" serves to trigger "gas compositional analysis and stable isotope analysis." However, that concentration standard is within the statistical variation of methane levels in at least some natural gas producing regions even away from active gas wells. AOGA urges the AOGCC to carefully reconsider the prudence of establishing any methane action level without the appropriate study to determine background levels in the areas being regulated. The US Department of the Interior ("DOI") in West Virginia appears to set action levels significantly higher than the 1.0 mg/l level, dictating that "[m]ethane concentrations less than 10mg/l require no action."[1] AOGA recommends against setting such a threshold an order of magnitude lower that the DOI as a state action level. The proposed level falls within the statistical variation for an analytical method, and will inevitably lead to ongoing logistical and analytical

[1] http://pubs.usgs.gov/fs/2006/3011/

issues moving forward.[2] This issue is compounded further since a peer reviewed and Environmental Protection Agency ("EPA") promulgated analytical method is not available that clearly defines scientific expectations and expected range of statistical variation for the analytical test.

Given those issues, AOGA urges the AOGCC to consider relevant scientific literature and studies in order to determine expected methane concentrations and the statistical variation of water sampling concentrations, and to refrain from adopting standards in the absence of the study necessary to develop specific standards. Results at the *Proceedings of the National Academy of Sciences* indicate that water sampling at residential wells not near active gas producing wells show average methane concentrations of 1.9 mg/L +/- 6.3 mg/l in the Catskill group and 1.5 mg/L +/- 3.0 in the Genesee group on samples collected in Pennsylvania and New York. In other words, methane concentrations in a typical fresh water aquifer may possess a statistical range of 0- 8.2 mg/L (1.9 +/-6.3) and this indicates an action level of 1.0 mg/L is excessively low.[3]

V. Sampling Parameters – EPA Approved Methods

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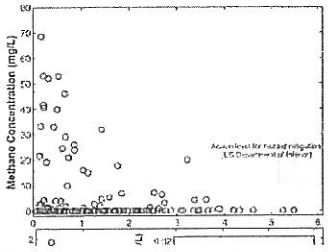
2 

The proposed methane concentration action level, 1.0 mg/L, seems to approach the statistical variation of methane analytical methods. Reviewing actual methane concentrations in this data set of 141 samples may be useful to determine the appropriate action level. These samples were all analyzed at one research quality laboratory and no EPA approved drinking water analytical method is cited or seems to be available. Page 2 does state: "Dissolved methane was detected in the drinking water of 82% of the houses sampled (115 of 141)." This indicates that a number of the data points at the bottom of this graph are likely in the range of 1.0 mg/L. Source of this graph: Proceedings of the National Academy of Sciences, http://www.pnas.org/content/early/2013/06/19/1221635110.full.pdf+html

3 Osborn et. al. as published in Proceedings of the National Academy of Sciences, http://www.pnas.org/content/108/20/8172.long#F3

Table 1. Mean values ± standard deviation of methane concentrations (as milligrams of CH_4 L^{-1}) and carbon isotope composition in methane in shallow groundwater $\delta^{13}C$-CH_4 sorted by aquifers and proximity to gas wells (active vs. nonactive) The variable *n* refers to the number of samples.

Water source, *n*	milligrams CH_4 L^{-1}	$\delta^{13}C$-CH_4, ‰
Nonactive Catskill, 5	1.9 ± 6.3	−52.5 ± 7.5
Active Catskill, 13	26.8 ± 30.3	−33.5 ± 3.5
Nonactive Genesee, 8	1.5 ± 3.0	−57.5 ± 9.5
Active Genesee, 1	0.3	−34.1
Active Lockhaven, 7	50.4 ± 36.1	−40.7 ± 6.7
Total active wells, 21	19.2	−37 ± 7
Total nonactive wells, 13	1.1	−54 ± 11

20 AAC 25.283 (a)(4) requires that "[c]urrent applicable EPA-approved sample custody and collection protocols and analytical methods for drinking water must be used and analyses must be performed by laboratories that maintain nationally accredited programs." However, AOGA believes that at least four of the listed analytical tests mandated by the AOGCC cannot be reconciled with EPA approved methodology. Specifically, AOGA requests that the AOGCC collaborate with or inquire of the EPA regarding approved or promulgated drinking water methods for the following analytes: *bacteria presence* (iron related, sulfate reducing, slime forming); *radium* (measured by radium 226 and 228); *gas compositional analysis and stable isotope analysis of the methane* (carbon and hydrogen-12C, 13C, lH, and 2H); and *Dissolved Methane, Dissolved Ethane, and Dissolved Propane*.

EPA drinking water approved methods will develop reproducible methods to determine analyte concentrations. These promulgated methods have defined levels of expected variability. For instance, an EPA promulgated method will likely state that results within 40% statistical difference are acceptable and meet the requirements of the method and quality guidelines of the laboratory. Other methods, including methods developed through research of a more academic nature may not deliver results that are reproducible and may not have withstood adequate peer review. Of further concern, regulations requiring the utilization of less established methods will frustrate attempts at consistent testing due to the lack of available testing facilities. That, in turn, might lead to samples from the same well resulting in different concentrations or testing results if a common analytical method is not approved and promulgated. AOGA urges the AOGCC not to rely on methods not fully accepted and published.

VI. Operator Notification

20 AAC 25.283 (A)(4)(a) requires that an "[o]perator must notify the commission and the surface owner within 24 hours if" one of four categories of potential contamination occurs. This particular provision raises several concerns. First, AOGA contends it is more practical to have an operator notify the commission, and then the commission provide notification to the surface owner. This approach is more prudent for a variety of reasons. It is almost certain that once a surface owner and drinking water well owner is notified, that surface owner will want to speak with someone at the commission or other State agency regarding potential ramifications and remedies. Publishing the regulations so that the commission provides surface owner notification would efficiently streamline this process. This modification will also allow for greater transparency, as the commission will have complete autonomy on the substance of the disclosure. Second, if the commission places the onus upon the operator to notify the surface owner, the commission will necessarily need to have someone available 365 days a year to field the inevitable surface owner inquiries that will follow the operator notification. Creating an in-depth protocol detailing the manner in which the commission will be prepared for such situations will be of great benefit to the public. AOGA hopes that all parties are clear that these proposed regulations will increase the staff time at the state agencies involved.

Finally, the proposed regulations describe the first notification trigger as when "the test results indicate thermogenic or a mixture of thermogenic and biogenic gas." AOGA believes that particular "trigger" is ambiguous, and fails to establish the threshold level to prompt notification.

Given the short notification timelines, a definite number or ratio for defining when notification is required is needed, yet, to our knowledge, there are no studies able to provide any indication of what a realistic background concentration is for these analytes. Even test results indicating thermogenic and biogenic gas properties, since they are not clearly defined, make the required 24 hour notice of no benefit to anyone. Ambiguous and undefined 24 hour trigger notifications written in regulations will lead to continuous and contentious problems.

VII. "Privilege log"

In 20 AAC 25.283 (k), the regulations refer to a "privilege log." It is not clear from the entirety of the regulations, what that particular term refers to, or what properties -- legal, institutional, or otherwise -- it may possess. AOGA requests further clarification on the meaning of "privilege log."

For perspective, under the EPA's Freedom of Information Regulations, a request for disclosure of a document labeled as "confidential business information," prompts the EPA to provide the respective company the opportunity to submit written comments addressing several questions, including: (1) measures taken to guard against the undesired disclosure of the information to others; (2) the extent to which the information has been disclosed to others and the precautions taken regarding such disclosure; and (3) description of any harmful effects to the party's competitive position, whether this harm would be substantial, and explanation of the causal relationship between disclosure and such harmful effects.

VIII. Hydraulic Fracturing Studies

Government agencies and respected authorities have conducted a myriad of studies in an attempt to determine whether the practice of hydraulic fracturing poses any environmental threats. To put it simply, those studies have found that hydraulic fracturing, particularly as it is implemented in Alaska, does not pose any harm to the environment. AOGA will focus its comments below on studies conducted by the EPA, the Ground Water Protection Council ("GWPC") and the Interstate Oil & Gas Compact Commission ("IOGCC") as these studies provide a fair cross section, both geographically and temporally, but should hardly be considered exhaustive.

In 2004, the EPA completed an extensive survey of hydraulic fracturing practices and their effect on drinking water. The focus of that particular study was on extremely shallow methane wells, which stand in stark contrast to the depths of hydraulic fracturing in Alaska. The EPA study revealed that several factors (fluid recovery, the small amount of chemicals contained in fracture fluids, their dilution in water, and their absorption by rock formations) serve to mitigate the potential risks associated with hydraulic fracturing. Ultimately, the EPA concurred with the GWPC and the IOGCC in finding that the practice of hydraulic fracturing is environmentally safe. Of particular note, the EPA concluded that hydraulic fracturing does not create pathways for fluids to travel between rock formations to affect fresh water aquifers. In February, 2010, Steve Heare, then director of EPA's Drinking Water Protection division said, "I have no information that states

are not doing a good job already (of protecting water supplies)."[4] Heare also reported that he had not seen any documented cases where hydraulic fracturing was contaminating water supplies.

In May, 2009, the U.S. Department of Energy and Ground Water Protection conducted a study and survey of State regulations relating to the oil industry. The GWPC surveyed relevant state regulatory agencies and were unable to find evidence of even one documented case of contaminated drinking water linked to hydraulic fracturing. The GWPC discussed the process of hydraulic fracturing and noted that critics of that process routinely highlight the theoretical possibility of the exposure of hydraulic fracturing additives while failing to consider the extreme unlikelihood of aquifer contamination. Citing two comparable studies, the GWPC found that depending upon the particular fracturing design and the specific formation dynamics involved, anywhere from 30-70% of fracturing fluids are safely returned to the surface through the well. The unrecovered treatment fluids are typically trapped in the geological formation through a variety of mechanisms, including pore storage and stranding, which result in effective isolation from ground water. The GWPC also noted that the risk of endangerment to ground water is further reduced by other physical factors such as the (1) implementation of state well construction requirements; (2) vertical distance between the fractured zone and ground water; (3) presence of other zones between the fractured zone and the deepest ground water zone that may readily accept fluid; and (4) presence of vertically impermeable formations between the fractured zone and the deepest ground water zone; which act as geologic barriers to fluid migration. Additionally, the utilization of proper surface fluid handling methods significantly decreases the likelihood of environmental harm or human exposure related to hydraulic fracturing fluids.

Furthermore, the GWPC referenced its 1998 survey of twenty-five state oil and gas regulatory agencies, which twenty-four state programs said they had not recorded any complaints of contamination to a underground sources of drinking water ("USDW") that the agency could attribute to hydraulic fracturing of coalbed methane zones, which traditionally occur relatively close proximity to USDW's. In the decade between studies, several citizens brought forth allegations that the practice of hydraulic fracturing had resulted in ground water contamination. The GWPC noted that the majority of those complaints related to hydraulic fracturing of coalbed methane zones. The GWPC observed that CBM wells are typically much shallower when compared to conventional oil and gas wells. The GWPC determined that, in general terms, the amount of vertical separation between an oil and gas producing formation and the deepest ground water zone in many parts of the country can be several thousand feet; while the separation of coalbed methane zones to ground water is sometimes only a few hundred feet or less. In some cases the coalbed methane zones themselves may qualify as USDWs. As noted above, EPAs 2004 study found no confirmed cases of contamination from the relatively shallow hydraulic fracturing of CBM reservoirs. The GWPC found that the risk of fracture fluid intrusion into ground water from the hydraulic fracturing of deeper conventional and unconventional oil and gas zones should be considered very low. Specifically, the GWPC noted that hydraulic fracturing that occurs at more substantial depth poses virtually no threat to ground water, because: (1) there are frequently layers of rock between the fractured zone and ground water zones that are capable of accepting

[4] In May 5, 1995, Carol M. Browner, then an EPA administrator and now energy adviser to President Obama, stated, "There is no evidence that the hydraulic fracturing at issue has resulted in any contamination or endangerment of underground sources of drinking water."

fluid under pressure; which would lower the available fluid that could reach a ground water zone; (2) there are also frequently layers of rock between the fractured zone and ground water zone through which vertical flow is restricted; thus serving as a hydraulic barrier to fluid migration; (3) the use of advanced computer modeling in fracture design has increased the ability to predict the three dimensional geometry of fracturing; which lowers the likelihood of a fracture job extending into an unintended zone.

In 2009, the US House of Representatives tasked the Environmental Protection Agency ("EPA") with conducting scientific research to examine the relationship between hydraulic fracturing and drinking water resources. In December, 2012, the EPA released a "Progress Report" outlining the preliminary findings of that study. The EPA designed the scope of the research around five parts of the hydraulic fracturing water cycle, and associated each cycle with a preliminary research question:

Water acquisition: What are the possible impacts of large volume water withdrawals from ground and surface waters on drinking water resources?

Chemical mixing: What are the possible impacts of hydraulic fracturing fluid surface spills on or near well pads on drinking water resources?

Well injection: What are the possible impacts of the injection and fracturing process on drinking water resources?

Flowback and produced water: What are the possible impacts of flowback and produced water surface spills on or near well pads on drinking water resources?

Wastewater treatment and waste disposal: What are the possible impacts of inadequate treatment of hydraulic fracturing wastewater on drinking water resources?

EPA's "Progress Report" described 18 research projects and was organized according to five different types of research activities: analysis of existing data, scenario evaluations, laboratory studies, toxicity assessments, and case studies. EPA collected data from nine companies that hydraulically fractured a total of 24,925 wells between September 2009 and October 2010, 12,000 well-specific chemical disclosures on FracFocus, and well construction and hydraulic fracturing records provided by well operators for 333 oil and gas wells across the United States. As illustrated in Appendix A, the EPA, during their current analysis of the practice of hydraulic fracturing, has access to a myriad of relevant studies on the practice and utilization of hydraulic fracturing. The results of the EPA study are due to be released in 2014.

On the one hand, AOGA believes that the AOGCC would be prudent to wait for the results of the new EPA study so that both regulators and those within industry can properly determine which concerns, if any, are legitimate, and what regulations may be necessary and beneficial. However, although the results are not yet known, prior studies coupled with the questions posed in the ongoing EPA study should provide adequate guidance for the AOGCC. AOGA still believes in the importance of protecting Alaska's fresh water resources, but believes that any regulations in

that vein should be narrowly tailored to address scientifically supported concerns. Unchanged, the current iteration of the AOGCC's proposed regulations do not meet that standard.

Sincerely,

Kara Moriarty

Kara Moriarty
Alaska Oil & Gas Association
President & CEO

Cc: Commissioner John Norman
Commissioner Dan Seamount
Governor Sean Parnell
Commissioner Joe Balash

Appendix A

Abbott, P. O. 1985. Description of Water-Systems Operations in the Arkansas River Basin, Colorado. Water-Resources Investigations Report 85-4092. US Geological Survey. 79 p. Available athttp://pubs.er.usgs.gov/publication/wri854092. Accessed November 14, 2012.

Abbott, P. O., Geldon, A. L., Cain, D., Hall, A. P. and Edelmann, P. 1983. Hydrology of Area 61, Northern Great Plains and Rocky Mountain Coal Provinces, Colorado and New Mexico.Open-File Report 83-132. US Geological Survey. 105 p. Available at http://pubs.er.usgs.gov/publication/ofr83132. Accessed November 14, 2012.

Toxicity Prediction by Komputer Assisted Technology (TOPKAT) version 3.5. 2012. AccelrysSoftware, Inc., San Diego, California.

ChemFolder version 12.00. 2008. ACD Labs, Toronto, Ontario.

ALL Consulting. 2003. Handbook on Coalbed Methane Produced Water: Management and Beneficial Use Alternatives. ALL Consulting for Ground Water Protection Research Foundation, USDepartment of Energy, and Bureau of Land Management. Available at http://www.allllc.com/publicdownloads/CBM_BU_Screen.pdf. Accessed November 30, 2012.

Ambrose, R. B., Hill, S. I. and Mulkey, L. A. 1983. User's Manual for the Chemical Transport and Fate Model (TOXIWASP), Version 1. EPA 600/3-83-005. US Environmental Protection Agency. 188 p. Available at http://www.epa.gov/nscep/index.html. Accessed November 30, 2012.

Ambrose, R. B. and Wool, T. A. 2009. WASP7 Stream Transport Model Theory and User's Guide. EPA/600/R-09/100. US Environmental Protection Agency. 43 p. Available athttp://www.epa.gov/nscep/index.html. Accessed November 30, 2012.

American Petroleum Institute. 2010. Water Management Associated with Hydraulic Fracturing. Available at http://www.api.org/Standards/new/api-hf2.cfm. Accessed January 20, 2011.

Ashley, G. H. and Robinson, J. F. 1922. The Oil and Gas Fields of Pennsylvania. Mineral Resource Report M1. Pennsylvania Bureau of Topographic and Geological Survey, Harrisburg, Pennsylvania.

Agency for Toxic Substances and Disease Registry. 2007. Toxicological Profile for Benzene. Available at http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=40&tid=14. Accessed December 4, 2012.

Bradford County Government. Natural Gas Information. Chart of Permitted Gas Wells. Available athttp://bradfordcountypa.org/Natural-Gas.asp?specifTab=2. Accessed August 16, 2012.

Brathwaite, L. D. 2009. Shale-Deposited Natural Gas: A Review of Potential. Presented at California Energy Commission, Sacramento, California. Available at http://www.energy.ca.gov/2009publications/CEC-200-2009-005/CEC-200-2009-005-SD.PDF. Accessed November 30, 2012.

Brown, D., Bridgeman, J. and West, J. R. 2011. Predicting chlorine decay and THM formation in water supply systems. *Reviews in Environmental Science and Biotechnology* 10 (1): 79-99.

Bruner, K. R. and Smosna, R. 2011. A Comparative Study of the Mississippi Barnett Shale, FortWorth Basin, and Devonian Marcellus Shale, Appalachian Basin. DOE/NETL-2011/1478. URS Corporation for US Department of Energy. Available at http://www.netl.doe.gov/technologies/oil-gas/publications/brochures/DOE-NETL-2011-1478%20MarcellusBarnett.pdf. Accessed December 5, 2012.

Cadmus Group Inc. 2012a. Quality Assurance Project Plan: Modeling the Impact of HydraulicFracturing on Water Resources Based on Water Acquisition Scenarios. Cadmus Group Inc. for US Environmental Protection Agency. Available at http://www.epa.gov/hfstudy/ qapps.html. Accessed November 30, 2012.

Cadmus Group Inc. 2012b. Supplemental Programmatic Quality Assurance Project Plan: National Hydraulic Fracturing Study Evaluation of Existing Production Well File Contents. Cadmus Group Inc. for US Environmental Protection Agency. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed December 4, 2012.

Cao, J., Li, H., Chow, J. C., Watson, J. G., Lee, S., Rong, B., Dong, J. G. and Ho, K. F. 2011. Chemical composition of indoor and outdoor atmospheric particles at Emperor Qin's Terra-cotta Museum. *Aerosol and Air Quality Research* 11 (1): 70-79.

Cappa, F. and Rutqvist, J. 2011a. Impact of CO_2 geological sequestration on the nucleation of earthquakes. *Geophysical Research Letters* 38 (17): L17313.

Cappa, F. and Rutqvist, J. 2011b. Modeling of coupled deformation and permeability evolutionduring fault reactivation induced by deep underground injection of CO_2. *International Journal of Greenhouse Gas Control* 5 (2): 336-346.

Cappa, F. and Rutqvist, J. 2012. Seismic rupture and ground accelerations induced by CO_2 injection in the shallow crust. *Geophysical Journal International* 190 (3): 1784-1789.

Cappa, F., Rutqvist, J. and Yamamoto, K. 2009. Modeling crustal deformation and rupture processes related to upwelling of deep CO_2-rich fluids during the 1965–1967 Matsushiro earthquake swarm in Japan. *Journal of Geophysical Research* 114 (10): B10304.

Carlson, C. G. 1985. Geology of McKenzie County, North Dakota. North Dakota Geological Survey Bulletin 80 Part 1. North Dakota Geological Survey in cooperation with the US Geological Survey, North Dakota State Water Commission, and the McKenzie County WaterManagement District. 54 p. Available at

http://www.swc.state.nd.us/4dlink9/4dcgi/ GetSubContentPDF/PB-285/McKenzie_Part_1.pdf. Accessed December 5, 2012.

Carter, K. M. and Harper, J. A. 2002. Oil and Gas Prospects in Northeastern Pennsylvania. In JD Inners and DD Braun, editors, From Tunkhannock to Starrucca: Bluestone, Glacial Lakes, and Great Bridges in the "Endless Mountains" of Northeastern Pennsylvania. Guidebook for the 67th Annual Field Conference of Pennsylvania Geologists. Field Conference of Pennsylvania Geologists, Tunkhannock, Pennsylvania. pp. 15-31.

CDM and GBSM. 2004. Statewide Water Supply Initiative Report. CDM and GBSM for ColoradoWater Conservation Board. Available at http://cospl.coalliance.org/fedora/repository/ co:3490. Accessed December 3, 2012.

Colorado Department of Public Health and Environment. 2012. Colorado's Section 303(D) List of Impaired Water and Monitoring and Evaluation List. Available at http://www.colorado.gov/cs/Satellite?blobcol=urldata&blobheadername1=ContentDisposition&blobheadername2=ContentType&blobheadervalue1=inline%3B+filename%3D%22Section+303(d)+List+and+Colorado+Monitoring+and+Evaluation+List+(Regulation+%2393).pdf%22&blobheadervalue2=application%2Fpdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1251806966544&ssbinary=true. Accessed November 27, 2012.

Chapman, E. C., Capo, R. C., Stewart, B. W., Kirby, C.S., , Hammack, R. W., Schroeder, K. T. andEdenborn, H. M. 2012. Geochemical and strontium isotope characterization of produced water from Marcellus shale natural gas extraction. *Environmental Science & Technology* 46 (6): 3545-3553.

Molecular Operating Environment (MOE) Linux version 2011.10. 2011. Chemical Computing Group, Montreal, Quebec.

Colorado Oil and Gas Conservation Commission. 2011. Oil and Gas Industry Spills and Releases. Available at http://dnr.state.co.us/SiteCollectionDocuments/SpillsAndReleases.pdf. Accessed December 4, 2012.

Colorado Oil and Gas Conservation Commission. 2012a. Fact Sheet: Water Sources and Demand for the Hydraulic Fracturing of Oil and Gas Wells in Colorado from 2010 through 2015. Available at http://cogcc.state.co.us/Library/Oil_and_Gas_Water_Sources_Fact_Sheet.pdf. Accessed December 12, 2012.

Colorado Oil and Gas Conservation Commission. 2012b. Production Inquiry. Colorado Oil and GasInformation System. Available at http://cogcc.state.co.us. Accessed October 17, 2012.

Colborn, T., Kwiatkowski, C., Schultz, K. and Bachran, M. 2011. Natural Gas Operations from a Public Health Perspective. *Human and Ecological Risk Assessment* 17 (5): 1039-1056.

Coleman, J., Milici, R., Cook, T., Charpentier, R., Kirschbaum, M., Klett, T., Pollastro, R. and Schenk, C. 2011. Assessment of Undiscovered Oil and Gas Resources of the Devonian Marcellus Shale

of the Appalachian Basin Province. National Assessment of Oil and Gas Fact Sheet 20113092. US Geological Survey. 2 p. Available at http://pubs.usgs.gov/fs/2011/3092/. Accessed November 30, 2012.

Cooper, J. R., Crelling, J. C., Rimmer, S. M. and Whittington, A. G. 2007. Coal Metamorphism by Igneous Intrusion in the Raton Basin, Colorado, and New Mexico: Implications forGeneration of Volatiles. *International Journal of Coal Geology* 71 (1): 15-27.

Davies, R. J. 2011. Methane contamination of drinking water caused by hydraulic fracturing remains unproven. *Proceedings of the National Academy of Sciences* 108 (43): E871.

Deng, Z.-Q., Bengtsson, L., Singh, V. P. and Adrian, D. D. 2002. Longitudinal dispersion coefficient insingle-channel streams. *Journal of Hydraulic Engineering* 128 (10): 901-916.

DiToro, D. M., Fitzpatrick, J. J. and Thomann, R. V. 1981. Documentation for Water Quality Analysis Simulation Program (WASP) and Model Verification Program (MVP). EPA 600/3-81-044. USEnvironmental Protection Agency, Duluth, Minnesota.

Dolly, E. D. and Meissner, F. F. 1977. Geology and Gas Exploration Potential, Upper Cretaceous and Lower Tertiary Strata, Northern Raton Basin, Colorado. In H.K. Veal, editors, ExplorationFrontiers of the Central and Southern Rockies: Rocky Mountain Association of Geologists Guidebook. Rocky Mountain Association of Geologists, Denver, Colorado. pp. 247-270.

Donigian Jr., A. S. Bibliography for HSPF and Related References. Available athttp://www.aquaterra.com/resources/hspfsupport/hspfbib.php. Accessed

Donigian Jr., A. S., Bicknell, B. and Bandurraga, M. 2011. Watershed Modeling for the Santa Clara River in Southern California. ASCE EWRI Conference Proceedings on CD-ROM: Bearing Knowledge for Sustainability, World Environmental and Water Resources Congress, PalmSprings, California. Available at http://www.aquaterra.com/resources/pubs/index.php. Accessed November 21, 2012.

Eastern Research Group Inc. 2011. Final Quality Assurance Project Plan for the Evaluation of Information on Hydraulic Fracturing. Eastern Research Group Inc. for US Environmental Protection Agency. Available at http://www.epa.gov/hfstudy/qapps.html. AccessedDecember 11, 2012.

Engelder, T. 2012. Peer review letter for Warner, N.R., Jackson, R.B., Darrah, T.H., Osborn, S.G., Down, A., Zhao, K., White, A., and Vengosh, A. (2012), Geochemical Evidence for Possible Natural Migration of Marcellus Formation Brine to Shallow Aquifers in Pennsylvania. *Proceedings of the National Academy of Sciences* 109 (30): 11961-11966.

ESRI. 2010a. US Counties Shapefile. ESRI Data & Maps Series. ESRI, Redlands, California.

ESRI. 2010b. US States Shapefile. ESRI Data & Maps Series. ESRI, Redlands, California.

ESRI. 2012. US Major Water Shapefile. ESRI Data & Maps Series. ESRI, Redlands, California.

Farhadian, M., Vachelard, C., Duchez, D. and Larroche, C. 2008. In situ bioremediation of monoaromatic pollutants in groundwater: A review. *Bioresource Technology* 99 (13): 5296–5308.

Flores, R. M. 1993. Geologic and geomorphic controls of coal developments in some tertiary rocky-mountain basins, USA. *International Journal of Coal Geology* 23 (1-4): 43-73.

Flores, R. M. and Bader, L. R. 1999. A Summary of Tertiary Coal Resources of the Raton Basin,Colorado and New Mexico. In Resource Assessment of Tertiary Coalbeds and Zones in the Northern Rocky Mountains and Great Plains Region. Professional Paper 1625-A. US Geological Survey. 35 p. Available at http://pubs.usgs.gov/pp/p1625a/. Accessed December 5, 2012.

Freeman, C. M. 2010. Study of Flow Regimes in Multiply-Fractured Horizontal Wells in Tight Gasand Shale Gas Reservoir Systems. MS Thesis. Texas A & M University, College Station, Texas.

Freeman, C. M., Moridis, G. J. and Blasingame, T. A. 2011. A numerical study of microscale flow behavior in tight gas and shale gas reservoir systems. *Transport in Porous Media* 90 (1): 253-268.

Freeman, C. M., Moridis, G. J., Ilk, D. and Blasingame, T. A. 2009a. A Numerical Study of Microscale Flow Behavior in Tight Gas and Shale Gas Reservoir Systems. Proceedings of the 2009 TOUGH Symposium, Berkeley, California. Available at http://www.netl.doe.gov/kmd/RPSEA_Project_Outreach/07122-23%20-%20TOUGH%202009%20Symposium%20-%20914-09.pdf. Accessed November 30, 2012.

Freeman, C. M., Moridis, G. J., Ilk, D. and Blasingame, T. A. 2009b. A Numerical Study of Performance for Tight Gas and Shale Gas Reservoir Systems. Presented at SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana. Available at http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-124961-MS. Accessed November 30, 2012.

Freeman, C. M., Moridis, G. J., Michael, G. E. and Blasingame, T. A. 2012. Measurement, Modeling, and Diagnostics of Flowing Gas Composition Changes in Shale Gas Wells. Presented at SPE LatinAmerican and Caribbean Petroleum Engineering Conference, Mexico City, Mexico. Available at http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-153391-MS. Accessed November 30, 2012.

Gassman, P. W., Reyes, M. R., Green, C. H. and Arnold, J. G. 2007. The soil and water assessment tool:historical development, applications, and future research directions. *Transactions of the American Society of Aricultural and Biological Engineers* 50 (4): 1211-1250.

Greg Lewicki & Associates. 2001. Raton Basin Coal Mine Feature Inventory. Greg Lewicki &Associates for Colorado Oil and Gas Conservation Commission. Available at http://cospl.coalliance.org/fedora/repository/co:3284. Accessed December 3, 2012.

Ground Water Protection Council. 2012a. Disclosures Reported by Month in Frac Focus. Presentation. Ground Water Protection Council, Oklahoma City, Oklahoma.

Ground Water Protection Council. 2012b. FracFocus well records: January 1, 2011, through February 27, 2012. Available at http://www.fracfocus.org/.

Ground Water Protection Council and ALL Consulting. 2009. Modern Shale Gas Development in the US: A Primer. Ground Water Protection Council and ALL Consulting for US Department ofEnergy. Available at http://www.netl.doe.gov/technologies/oilgas/publications/epreports/shale_gas_primer_2009.pdf. Accessed December 12, 2012.

Hairer, E., Norsett, S. P. and Wanner, G. 1991. Solving Ordinary Differential Equations I: NonstiffProblems. Springer-Verlag, Berlin, Germany.

Haritash, A. K. and Kaushik, C. P. 2009. Biodegradation aspects of polycyclic aromatic hydrocarbons (PAHs): A review. *Journal of Hazardous Materials* 169 (1-3): 1-15.

Harrison, S. S. 1983. Evaluating system for ground-water contamination hazards due to gas-welldrilling on the glaciated Appalachian Plateau. *Ground Water* 21 (6): 689-700.

Harrison, S. S. 1985. Contamination of aquifers by overpressurizing the annulus of oil and gas wells. *Ground Water* 23 (7): 317-324.

Hayes, T. 2009. Sampling and Analysis of Water Streams Associated with the Development of Marcellus Shale Gas. Gas Technology Institute for Marcellus Shale Coalition. Available at http://eidmarcellus.org/wp-content/uploads/2012/11/MSCommission-Report.pdf. Accessed November 30, 2012.

Healy, R. W., Bartos, T. T., Rice, C. A., McKinley, M. P. and Smith, B. D. 2011. Groundwater chemistry near an impoundment for produced water, Powder River Basin, Wyoming USA. *Journal of Hydrology* 403 (1-2): 37-48.

Healy, R. W., Rice, C. A., Bartos, T. T. and McKinley, M. P. 2008. Infiltration from an impoundment for coal-bed natural gas, Powder River Basin, Wyoming: Evolution of water and sediment chemistry. *Water Resources Research* 44 (6): W06424.

Holditch, S. A. 1993. Completion methods in coal-seam reservoirs. *Journal of Petroleum Technology* 45 (3): 270-276.

Homer, C., Dewitz, J., Fry, J., Coan, M., Hossain, N., Larson, C., Herold, N., McKerrow, A., VanDriel, J. N. and Wickham, J. 2007. Completion of the 2001 national land cover database for theconterminous United States. *Photogrammetric Engineering & Remote Sensing* 73 (4): 337 341.

Howard, P. H. 1989. Handbook of Environmental Fate and Exposure Data for Organic Chemicals. CRC Press, Syracuse, New York.

Howard, P. H., Boethling, R. S., Jarvis, W. F., Meylan, W. M. and Michalenko, E. M. 1991. Handbook of Environmental Degradation Rates. CRC Press, Boca Raton, Florida.

Ivahnenko, T. and Flynn, J. L. 2010. Estimated Withdrawals and Use of Water in Colorado, 2005. Scientific Investigations Report 2010-5002. US Geological Survey. 61 p. Available at http://pubs.usgs.gov/sir/2010/5002/. Accessed November 30, 2012.

Jackson, R. B., Osborn, S. G., Vengosh, A. and Warner, N. 2011. Reply to Davies: Hydraulic fracturing remains a possible mechanism for observed methane contamination of drinking water. *Proceedings of the National Academy of Sciences* 108 (43): E872.

Jacob, R. 2011. Incident Action Plan, Franchuk 44-20 SWH Incident. Denbury Onshore, LLC, Plano, Texas.

Jeu, S. J., Logan, T. L. and McBane, R. A. 1988. Exploitation of Deeply Buried Coalbed Methane UsingDifferent Hydraulic Fracturing Techniques in the Piceance Basin, Colorado, and San Juan Basin, New Mexico. Presented at SPE Annual Technical Conference and Exhibition, Houston, Texas. Available at http://www.onepetro.org/mslib/app/ Preview.do?paperNumber=00018253&societyCode=SPE. Accessed November 30, 2012.

Jobson, H. E. 1996. Prediction of Traveltime and Longitudinal Dispersion in Rivers and Streams.Water-Resources Investigations Report 96-4013. US Geological Survey. 72 p. Available at http://water.usgs.gov/osw/pubs/wrir964013header.html. Accessed November 30, 2012.

Johnson, N., Gagnolet, T., Ralls, R., Zimmerman, E., Eichelberger, B., Tracey, C., Kreitler, G., Orndorff, S., Tomlinson, J., Bearer, S. and Sargent, S. 2010. Marcellus Shale Natural Gas and Wind. Pennsylvania Energy Impacts Assessment Report 1. The Nature Conservancy. 47 p. Available at http://www.nature.org/media/pa/tnc_energy_analysis.pdf. AccessedNovember 30, 2012.

Johnson, R. C. and Finn, T. M. 2001. Potential for a Basin-Centered Gas Accumulation in the Raton Basin, Colorado and New Mexico. Bulletin 2184-B. US Geological Survey. 18 p. Available athttp://pubs.usgs.gov/bul/b2184-b/b2184-b.pdf. Accessed December 3, 2012.

Johnson, T. E., Butcher, J. B., Parker, A. and Weaver, C. P. 2011. Investigating the sensitivity of U.S. streamflow and water quality to climate change: the U.S. EPA global change research

program's "20 watersheds" project. *Journal of Water Resources Planning and Management* 138 (5): 453-464.

Jurich, A. and Adams, M. A. 1984. Geologic Overview, Coal, and Coalbed Methane Resources of Raton Mesa Region – Colorado and New Mexico. In C.T. Rightmire, G.E. Eddy and J.N. Kirr, editors, Studies in Geology Series 17: Coalbed Methane Resources of the United States. American Association of Petroleum Geologists, Tulsa, Oklahoma. pp. 163–184.

Keighin, C. W. 1995. Raton Basin-Sierra Grande Uplift Province (041). National Assessment of United States Oil and Gas Resources-Results, Methodology, and Supporting Data. Digital Data Series DDS-30. US Geological Survey. 1-7 p. Available athttp://certmapper.cr.usgs.gov/data/noga95/prov41/text/prov41.pdf. Accessed December 3, 2012.

Kenny, J. F., Barter, N. L., Hutson, S. S., Linsey, K. S., Lovelace, J. K. and Maupin, M. A. 2009. Estimated Use of Water in the United States in 2005. Circular 1344. US Geological Survey. p. Available at http://pubs.usgs.gov/circ/1344/. Accessed November 30, 2012.

Kim, J. and Moridis, G. J. 2012a. Analysis of fracture propagation during hydraulic fracturing operations in tight/shale gas systems. In preparation for journal submission. LawrenceBerkeley National Laboratory, Berkeley, California.

Kim, J. and Moridis, G. J. 2012b. Development of the T+M Coupled Flow-Geomechanical Simulator to Describe Fracture Propagation and Coupled Flow-Thermal-Geomechanical Processes inTight/Shale Gas Systems. Proceedings of the 2012 TOUGH Symposium Berkeley, California. Available at http://esd.lbl.gov/files/research/projects/tough/events/symposia/toughsymposium12/Kim_Jihoon-T+M.pdf. Accessed November 30, 2012.

Kim, J. and Moridis, G. J. 2012c. Gas Flow Tightly Coupled to Elastoplastic Geomechanics for Tight and Shale Gas Reservoirs: Material Failure and Enhanced Permeability. Presented at SPE Americas Unconventional Resources Conference, Pittsburgh, Pennsylvania. Available at http://www.onepetro.org/mslib/app/Preview.do?paperNumber=SPE-155640MS&societyCode=SPE. Accessed November 30, 2012.

Kim, J. and Moridis, G. J. 2012d. Numerical Geomechanical Analyses on Hydraulic Fracturing in TightGas and Shale Gas Reservoirs. Presented at 2012 SPE Annual Technical Conference and Exhibition, San Antonio, Texas.

Kim, J. and Moridis, G. J. 2012e. Numerical Studies for Naturally Fractured Shale Gas Reservoirs:Coupled Flow and Geomechanics in Multiple Porosity/Permeability Materials. Presented at 46th U.S. Rock Mechanics/Geomechanics Symposium, Chicago, Illinois.

Kish, L. 1965. Survey Sampling. John Wiley & Sons, New York, New York.

Klausing, R. L. 1979. Ground-Water Resources of Dunn County, North Dakota. US Geological Surveyfor North Dakota State Water Commission and North Dakota Geologic Survey. Available at http://www.swc.state.nd.us/4dlink9/4dcgi/GetSubContentPDF/PB-225/Dunn_Part_3.pdf. Accessed December 3, 2012.

Kuuskraa, V. A. and Ammer, J. 2004. Tight gas sands development–how to dramatically improve recovery efficiency. *GasTIPS* 10 (1): 15-20.

Lawrence Berkeley National Laboratory. 2011. Quality Assurance Project Plan: Analysis of Environmental Hazards Related to Hydrofracturing. Lawrence Berkeley National Laboratory for US Environmental Protection Agency. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed November 27, 2012.

Leadscope version 3.0.6-3. 2012. Leadscope Inc., Columbus, Ohio.

Lee, J. J. 2011. Hydraulic Fracturing and Safe Drinking Water. Proceedings of the US Environmental Protection Agency Technical Workshops for the Hydraulic Fracturing Study: Water Resources Management, Arlington, Virginia. Available at http://epa.gov/hfstudy/waterworkshop.html. Accessed November 30, 2012.

Leonard, B. P. 2002. Stability of explicit advection schemes. The balance point location rule. *International Journal for Numerical Methods in Fluids* 38 (5): 471-514.

Lide, D. R. 2008. CRC Handbook of Chemistry and Physics. 89th Edition. CRC Press, Boca Raton,Florida.

Macartney, H. 2011. Hydraulic Fracturing in Coalbed Methane Development, Raton Basin, Southern Colorado. Presented at US Environmental Protection Agency Technical Workshop for the Hydraulic Fracturing Study: Well Construction and Operations, Arlington, Virginia. Available at http://www.epa.gov/hfstudy/wellconstructworkshop.html. Accessed December 5, 2012.

Marcellus Center for Outreach and Research. 2012a. Depth of Marcellus Shale Base. PennsylvaniaState University. Available at http://www.marcellus.psu.edu/images/Marcellus_Depth.gif. Accessed December 6, 2012.

Marcellus Center for Outreach and Research. 2012b. Extent and Thickness of Marcellus Shale. Pennsylvania State University. Available at http://www.marcellus.psu.edu/images/Marcellus_thickness.gif. Accessed December 6, 2012.

MarcellusGas.Org. 2012a. Estimated Anticipated Water Usage (for Hydraulic Fracturing) forPermitted Horizontal Wells, by Township, for Washington County, Pennsylvania. Available at http://www.marcellusgas.org/graphs/PA-Washington#waterstat. Accessed September 27, 2012.

MarcellusGas.Org. 2012b. Marcellus Well Permits, by Year, for Washington County, Pennsylvania. Available at http://www.marcellusgas.org/graphs/PA-Washington#pyear. Accessed September 25, 2012.

MarcellusGas.Org. 2012c. Marcellus Well Starts, by Year, for Washington County, Pennsylvania. Available at http://www.marcellusgas.org/graphs/PA-Washington#wstarts. Accessed September 25, 2012.

Material Safety Data Sheets. (a) Encana/Halliburton Energy Services, Inc.: Duncan, Oklahoma. Provided by Halliburton Energy Services during an onsite visit by the EPA on May 10, 2010; (b) Encana Oil and Gas (USA), Inc.: Denver, Colorado. Provided to US EPA Region 8.

Mazzoldi, A., Rinaldi, A. P., Borgia, A. and Rutqvist, J. 2012. Induced seismicity within geological carbon sequestration projects: Maximum earthquake magnitude and leakage potential from undetected faults. *International Journal of Greenhouse Gas Control* 10 (1): 434-442.

McCarthy. 2009. Travel Times, Streamflow Velocities, and Dispersion Rates in the Yellowstone River, Montana. Scientific Investigations Report 2009-5261. US Geological Survey. 25 p. Available at http://pubs.usgs.gov/sir/2009/5261/. Accessed November 30, 2012.

McGonigal, K. H. 2005. Nutrients and Suspended Sediment Transported in the Susquehanna River Basin, 2004, and Trends, January 1985 Through December 2004. Publication 241. Susquehanna River Basin Commission. 61 p. Available at http://www.srbc.net/ pubinfo/techdocs/Publication_241/NutrientReport.pdf. Accessed November 30, 2012.

Milici, R. C. and Swezey, C. S. 2006. Assessment of Appalachian Basin Oil and Gas Resources:Devonian Shale–Middle and Upper Paleozoic Total Petroleum System. Open-File Report Series 2006-1237. US Geological Survey. 70 p. Available at http://pubs.usgs.gov/of/2006/1237/of2006-1237.pdf. Accessed December 4, 2012.

Montgomery, J. H. 2000. Groundwater Chemicals Desk Reference. 3rd Edition. CRC Press, Boca Raton, Florida.

Moridis, F. and Webb, F. 2012. The RealGas and RealGasH2O Options of the TOUGH+ Code for the Simulation of Coupled Fluid and Heat Flow in Tight/Shale Gas Systems Proceedings of the 2012 TOUGH Symposium, Berkeley, California. Available at http://esd.lbl.gov/files/research/projects/tough/events/symposia/toughsymposium12/ Moridis_GeorgeRealgasH2O.pdf. Accessed November 30, 2012.

Moridis, G. J., Blasingame, T. and Freeman, C. M. 2010. Analysis of Mechanisms of Flow in Fractured Tight-Gas and Shale-Gas Reservoirs. Presented at 2010 SPE Latin American & CaribbeanPetroleum Engineering Conference, Lima, Peru. Available at http://www.onepetro.org/ mslib/servlet/onepetropreview?id=SPE-139250-MS. Accessed November 30, 2012.

Moridis, G. J. and Freeman, C. M. 2012. The RGasH2OCont module of the TOUGH+ code for simulation of coupled fluid and heat flow, and contaminant transport, in tight/shale gas systems. In preparation for journal submission. Lawrence Berkeley National Laboratory, Berkely, California.

Moridis, G. J., Kowalsky, M. B. and Pruess, K. 2008. TOUGH+HYDRATE v1.0 User Manual: A Code for the Simulation of System Behavior in Hydrate-Bearing Geologic Media. Report 149E. Lawrence Berkley National Laboratory. 279 p. Available at http://esd.lbl.gov/files/research/projects/tough/documentation/TplusH_Manual_v1.pdf. Accessed November 30, 2012.

Murphy, E. C. 2001. Geology of Dunn County. Bulletin 68 Part 1. North Dakota Geological Survey. 43 p. Available at http://www.swc.state.nd.us/4dlink9/4dcgi/GetSubContentPDF/PB221/Dunn_Part_1.pdf. Accessed December 4, 2012.

Myers, T. 2012a. Author's Reply. *Ground Water* 50 (6): 828-830.

Myers, T. 2012b. Potential contaminant pathways from hydraulically fractured shale to aquifers. *Ground Water* 50 (6): 872-882.

National Academy of Sciences. 2012. Induced Seismicity Potential in Energy Technologies. Available at http://dels.nas.edu/besr. Accessed November 30, 2012.

North Dakota Industrial Commission. 2003. January 2003 Oil and Gas Production Report. Availableat https://www.dmr.nd.gov/oilgas/mpr/2003_01.pdf. Accessed November 27, 2012.

North Dakota Industrial Commission. 2012a. North Dakota Monthly Bakken Oil Production Statistics Available at https://www.dmr.nd.gov/oilgas/stats/historicalbakkenoilstats.pdf. Accessed November 27, 2012.

North Dakota Industrial Commission. 2012b. Oil and Gas Production Report. Available at https://www.dmr.nd.gov/oilgas/mpr/2012_07.pdf. Accessed December 5, 2012.

Newport, T. G. 1973. Summary Ground-Water Resources of Washington County, Pennsylvania.Water Resource Report 38. Pennsylvania Geological Survey. 32 p. Available at http://www.dcnr.state.pa.us/topogeo/pub/water/pdfs/w038_text.pdf. Accessed December4, 2012.

Nicot, J., Hebel, A., Ritter, S., Walden, S., Baier, R., Galusky, P., Beach, J., Kyle, R., Symank, L. and Breton, C. 2011. Current and Projected Water Use in the Texas Mining and Oil and GasIndustry. The University of Texas at Austin Bureau of Economic Geology for Texas Water Development Board. Available at http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/0904830939_MiningWaterUse.pdf. Accessed November 10, 2012.

Noorishad, J. and Tsang, C.-F. 1997. Coupled Thermohydroelasticity Phenomena in VariablySaturated Fractured Porous Rocks -Formulation and Numerical Solution. In O. Stephanson,

L. Jing and C.-F. Tsang, editors, Coupled Thermo-Hydro-Mechanical Processes in FracturedMedia: Mathematical and Experimental Studies. Elsevier Science B.V., Amsterdam, The Netherlands. pp. 575.

Nordeng, SH. 2010. The Bakken Source System: Emphasis on the Three Forks Formation. NorthDakota Geological Survey. Available at http://www.ndoil.org/image/cache/Stephan_Nordeng_-_NDGS.pdf. Accessed December 5, 2012.

Nordin, C. F. and Sabol, G. V. 1974. Empirical Data on Longitudinal Dispersion in Rivers. Water-Resources Investigations 20-74. US Geological Survey, p. 332.

Nordstrom, P. L. 1982. Occurrence, Availiability and Chemical Quality of Ground Water in the Cretaceous Aquifers of North-Central Texas. Volume 1. Report 269. Texas Department of Water Resources. 66 p. Available at http://www.twdb.state.tx.us/publications/reports/numbered_reports/doc/R269/R269v1/R269v1.pdf. Accessed December 3, 2012.

New York State Department of Environmental Conservation. 2011. Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program(Revised Draft). Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs.Available at http://www.dec.ny.gov/energy/75370.html. Accessed September 1, 2011.

Olorode, O. M. 2011. Numerical modeling of fractured shale-gas and tight-gas reservoirs using unstructured grids. MS Degree. Texas A&M University, College Station, Texas.

Osborn, S. G., Vengosh, A., Warner, N. R. and Jackson, R. B. 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences* 108 (20): 8172-8176.

Pennsylvania Department of Environmental Protection. 2010. Chemicals Used by Hydraulic Fracturing Companies in Pennsylvania for Surface and Hydraulic Fracturing Activities.Available at http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/MarcellusShale/Frac%20list%206-30-2010.pdf. Accessed November 27, 2012.

Pennsylvania Department of the Environment. 2011. Letter from Pennsylvania Department of the Environment to US EPA Region 3 Administrator Shawn Garvin. Available at http://www.epa.gov/region3/marcellus_shale?#inforeqsbypadep. Accessed April 6, 2011.

Pennsylvania Department of Environmental Protection. 2012. State Water Plan Digital Water Atlas. Available at http://www.pawaterplan.dep.state.pa.us/statewaterplan/DWA/DWAMain.aspx?theme=6&cacheId=227881113. Accessed August 13, 2012.

Palmer, I. D., Fryar, R. T., Tumino, K. A. and Puri, R. 1991. Water fracs outperform gel fracs in coalbed pilot. *Oil & Gas Journal* 89 (32): 71-76.

Palmer, I. D., Lambert, S. W. and Spitler, J. L. 1993. Coalbed Methane Well Completions and Stimulations: Chapter 14. In Ben E. Law and Dudley D. Rice, editors, SG 38: Hydrocarbons from Coal. American Association of Petroleum Geologists, Tulsa, Oklahoma. pp. 303-341.

Pancras, J. P., Vedantham, R., Landis, M. S., Norris, G. A. and Ondov, J. M. 2011. Application of EPA unmix and non-parametric wind regression on high time resolution trace elements and speciated mercury in Tampa, Florida, aerosol. *Environmental Science & Technology* 45 (8): 3511-3518.

Plewa, M. J., Muellner, M. G., Richardson, S. D., Fasano, F., Buettner, K. M., Woo, Y.-T., McKague, B. and Wagner, E. D. 2008. Occurrence, synthesis and mammalian cell cytotoxicity and genotoxicityof haloacetamides: an emerging class of nitrogenous drinking water disinfection byproducts. *Environmental Science & Technology* 42 (3): 955-961.

Plewa, M. J. and Wagner, E. D. 2009. Quantitative Comparative Mammalian Cell Cytotoxicity andGenotoxicity of Selected Classes of Drinking Water Disinfection By-Products. Presented at Water Research Foundation, Denver, Colorado. Available at http://prod2010.waterrf.org/ ExecutiveSummaryLibrary/91249_3089_profile.pdf. Accessed November 30, 2012.

Plewa, M. J., Wagner, E. D., Jazwierska, P., Richardson, S. D., Chen, P. H. and McKague, A. B. 2004.Chemical and biological characterization of newly discovered iodoacid drinking water disinfection byproducts. *Environmental Science & Technology* 38 (18): 4713-4722.

Puder, M. and Veil, J. 2006. Offsite Commercial Disposal of Oil and Gas Exploration and ProductionWaste: Availability, Options, and Costs. ANL/EVS/R-06/5. Argonne National Laboratory for US Department of Energy. Available at http://www.evs.anl.gov/pub/doc/ANL-EVS-R-065.pdf. Accessed October 18, 2012.

Reed, L. A. and Stuckey, M. A. 2002. Prediction of Velocities for a Range of Streamflow Conditions in Pennsylvania. Water-Resources Investigations Report 01-4214. US Geological Survey. 13 p. Available at http://pubs.er.usgs.gov/publication/wri014214. Accessed November 21, 2012.

Reutter, D. C. and Dunn, D. D. 2000. Water-Quality Assessment of the Trinity River Basin, Texas: Ground-Water Quality of the Trinity, Carrizo-Wilcox, and Gulf Coast Aquifers, February-August 1994. Water-Resources Investigations Report 99-4233. US Geological Survey. 64 p. Available at http://pubs.usgs.gov/wri/wri99-4233/. Accessed December 5, 2012.

Richardson, S. 2003. Disinfection by-products and other emerging contaminants in drinking water. *Trends in Analytical Chemistry* 22 (10): 666-684.

Richardson, S. D., Plewa, M. J., Wagner, E. D., Schoeny, R. and DeMarini, D. M. 2007. Occurrence, genotoxicity, and carcinogenicity of regulated and emerging disinfection by-products indrinking water: a review and roadmap for research. *Mutatation Research* 636 (1-3): 178
242.

Richenderfer, J. 2011. Natural Gas Industry Effects on Water Consumption and Management. Susquehanna River Basin Commission. 40 p. Available at http://www.mde.state.md.us/programs/Land/mining/marcellus/Pages/surfacewater.aspx. Accessed November 30, 2012.

Rogers, S. W., Ong, S. K., Kjartanson, B. H., Golchin, J. and Stenback, G. A. 2002. Natural attenuation of polycyclic aromatic hydrocarbon-contaminated sites: review. *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management* 6 (3): 141-155.

Rossenfoss, S. 2011. From flowback to fracturing: water recycling grows in the marcellus shale. *Journal of Petroleum Technology* 63 (7): 48-51.

Railroad Commission of Texas. 2012. Barnett Shale Information. Available at http://www.rrc.state.tx.us/barnettshale/index.php. Accessed December 5, 2012.

Rupp, B., Appel, K. E. and Gundert-Remy, U. 2010. Chronic oral LOAEL prediction by using a commercially available computational QSAR tool. *Archives of Toxicology* 84 (9): 681-688.

Rutqvist, J. 2012. The geomechanics of CO_2 storage in deep sedimentary formations. *Geotechnical and Geological Engineering* 30 (3): 525-551.

Rutqvist, J., Birkholzer, J., Cappa, F. and Tsang, C.-F. 2007. Estimating maximum sustainableinjection pressure during geological sequestration of CO2 using coupled flow and geomechanical fault-slip analysis. *Energy Conversion and Management* 48 (6): 1798-1807.

Rutqvist, J., Borgesson, L., Chijimatsu, M., Kobayashi, A., Jing, L., Nguyen, T. S., Noorishad, J. andTsang, C.-F. 2001. Thermohydromechanics of partially saturated geological media: governing equations and formulation of four finite element models. *International Journal of Rock Mechanics and Mining Sciences* 38 (1): 105-127.

Rutqvist, J., Rinaldi, A. P., Cappa, F. and Moridis, G. J. 2012. Modeling of fault reactivation and induced seismicity during hydraulic fracturing of shale-gas reservoirs. In preparation forjournal submission. Lawrence Berkeley National Laboratory, Berkeley, California.

Papadopulos & Associates Inc. 2008. Coalbed Methane Stream Depletion Assessment Study – Raton Basin, Colorado. S.S. Papadopulos & Associates Inc. prepared in conjunction with the Colorado Geological Survey for Colorado Department of Natural Resources and the Colorado Oil and Gas Conservation Commission. Available at http://geosurvey.state.co.us/water/CBM%20Water%20Depletion/Documents/RatonCBMdepletion_FINAL.pdf. Accessed December 3, 2012.

Papadopulos & Associates Inc. 2007a. Coalbed Methane Stream Depletion Assessment Study – Piceance Basin, Colorado. S.S. Papadopulos & Associates Inc. for Prepared in conjunctionwith the Colorado Geological Survey for the State of Colorado Department of Natural Resources and the Colorado Oil and Gas Conservation Commission. Available at http://water.state.co.us/groundwater/GWAdmin/NontribGW/Archive/Pages/CBMStream DepletionStudies.aspx. Accessed November 30, 2012.

Papadopulos & Associates Inc. 2007b. Coalbed Methane Stream Depletion Assessment Study –Raton Basin, Colorado, Draft Final Report. S.S. Papadopulos & Associates Inc. for Prepared in conjunction with the Colorado Geological Survey for the State of Colorado Department of Natural Resources and the Colorado Oil and Gas Conservation Commission. Available at http://water.state.co.us/groundwater/GWAdmin/NontribGW/Archive/Pages/CBMStream DepletionStudies.aspx. Accessed November 30, 2012.

SAIC Energy Environment & Infrastructure LLC and Groundwater & Environmental Services Inc.2011. ATGAS Investigation Initial Site Characterization and Response, April 19, 2011 to May 2, 2011, ATGAS2H Well Pad, Permit No. 37-015-21237, Leroy Township, Bradford County, PA. SAIC and GES for Chesapeake Appalachia, LLC. Available at http://www.chk.com/news/ articles/documents/atgas_initial_site_characterization_report_final_08292011.pdf. Accessed December 4, 2012.

Satterfield, J., Kathol, D., Mantell, M., Hiebert, F., Lee, R. and Patterson, K. 2008. Managing Water Resource Challenges in Select Natural Gas Shale Plays. Presented at Ground Water Protection Council Annual Forum, Oklahoma City, Oklahoma.

Schiesser, W. E. 1991. The Numerical Method-of-Lines: Integration of Partial Differential Equations. Academic Press, San Diego, California.

Qikprop version 3.4. 2012. Schrodinger, LLC, New York, New York.

Schwarzenbach, R. P., Gschwend, P. M. and Imboden, D. M. 2002. Environmental Organic Chemistry. 2nd Edition. John Wiley & Sons, Inc, Hoboken, New Jersey.

Scott, G. and Armstrong, J. M. 1932. The Geology of Wise County, Texas. The University of TexasBulletin No. 3224. The University of Texas. 80 p. Available at http://www.lib.utexas.edu/books/landscapes/publications/txu-oclc-983185/txu-oclc-983185.pdf. Accessed December 5, 2012.

Scott, M. J. and Jones, M. N. 2000. The biodegradation of surfactants in the environment. *Biochimica et Biophysica Acta* 1508 (1-2): 235-251.

Seagren, E. A. and Becker, J. G. 2002. Review of natural attenuation of BTEX and MTBE in groundwater. *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management* 6 (3): 156-172.

Seo, J. S., Keum, Y. S. and Qing, X. L. 2009. Bacterial degradation of aromatic compounds. *International Journal Environmental Research and Public Health* 6 (1): 278-309.

Sharma, V. K., Anquandah, G. A. K., Yngard, R. A., Kim, H., Fekete J., Bouzek, K., Ray, A. K. and Golovko, D. 2009. Nonylphenol, octylphenol, and bisphenol-A in the aquatic environment: a review on occurrence, fate, and treatment. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering* 44 (5): 423-442.

Shultz, C. H. 1999. The Geology of Pennsylvania. Pennsylvania Geological Survey and Pittsburgh Geological Society, Harrisburg, Pennsylvania.

Soares A., Guieysse, B., Jeffereson, B., Cartmell, E. and J.N., L. 2008. Nonylphenol in the environment:a critical review on occurrence, fate, toxicity and treatment in wastewaters. *Environment International* 34 (7): 1033-1049.

Soonthornnonda, P. and Christensen, E. 2008. Source apportionment of pollutants and flows of combined sewer wastewater. *Water Research* 42 (8-9): 1989-1998

Spahr, N. E., Apodaca, L. E., Deacon, J. R., Bails, J. B., Bauch, N. J., Smiath, C. M. and Driver, N. E. 2000. Water Quality in the Upper Colorado River Basin, Colorado, 1996-98. Circular 1214. US Geological Survey. 33 p. Available at http://pubs.water.usgs.gov/circ1214/. AccessedNovember 30, 2012.

Susquehanna River Basin Commission. Susquehanna River Basin Commission Information Sheet. Available at http://www.srbc.net/pubinfo/docs/Susq%20River%20Basin%20General%20%2811_06%29.PDF. Accessed November 27, 2012.

Susquehanna River Basin Commission. 2012. Flowback and Produced Water Volume. Data Providedto EPA Upon Request. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

Stangroom, S. J., Collins C.D. and Lester, J. N. 2010. Abiotic behavior of organic micropollutants in soils and the aquatic environment. A review: II. Transformations. *Environmental Technology* 21 (8): 865-882.

Staples, C. A., Williams, J. B., Craig, G. R. and Roberts., K. M. 2001. Fate, effects and potential environmental risks of ethylene glycol: a review. *Chemosphere* 43 (3): 377-383.

Talmage, S. S. 1994. Environmental and Human Safety of Major Surfactants—Alcohol Ethoxylates and Alkylphenol Ethoxylates. CRC Press, Boca Raton, Florida.

Taylor, L. E. 1984. Groundwater Resources of the Upper Susquehanna River Basin, Pennsylvania. Pennsylvania Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania.

Topper, R., Scott, K. and Watterson, N. 2011. Geologic Model of the Purgatoire River Watershed within the Raton Basin, Colorado. Colorado Geological Survey for Colorado WaterConservation Board. Available at http://geosurvey.state.co.us/water/CBM%20Water%20Depletion/Documents/Raton%20Geology_CGS%20final%20report.pdf. Accessed December 3, 2012.

Tremain, C. M. 1980. The Coalbed Methane Potential of the Raton Basin, Colorado. Presented at SPE Unconventional Gas Recovery Symposium, Pittsburgh, Pennsylvania. Available athttp://www.onepetro.org/mslib/servlet/onepetropreview?id=00008927. Accessed December 3, 2012.

Tyler, R. 1995. Geologic and Hydrologic Assessment of Natural Gas from Coal: Greater Green River, Piceance, Powder River, and Raton Bains, Western United States. The University of Texas atAustin, Bureau of Economic Geology, Austin, Texas.

Tyler, R. and McMurry, R. G. 1995. Genetic Stratigraphy, Coal Occurrence, and Regional Cross Section of the Williams Fork Formation. Open File Report 95-2. Colorado Geological Survey.42 p. Available at http://geosurveystore.state.co.us/p-764-genetic-stratigraphy-coaloccurrence-and-regional-cross-section-of-the-coal-bearing-williams-fork-formation.aspx. Accessed November 30, 2012.

US Energy Information Administration. 2011a. Annual Energy Review 2010. Available at http://www.eia.gov/aer. Accessed September 26, 2012.

US Energy Information Administration. 2011b. Distribution and Production of Oil and Gas Wells by State, 1995 to 2009. Available at http://www.eia.gov/pub/oil_gas/petrosystem/petrosysog.html. Accessed November 27, 2012.

US Energy Information Administration. 2011c. Shale Gas and Oil Plays, Lower 48 States. Available at http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm. Accessed December 12, 2012.

US Energy Information Administration. 2011d. Shapefiles for Basin boundaries. Data for the US Shale Plays Map. May 9, 2011. US Energy Information Administration, Washington, DC. Available at http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm. Accessed November 30, 2012.

US Energy Information Administration. 2011e. Shapefiles for Play Boundaries. Data for the US Shale Plays Map. May 9, 2011. US Energy Information Administration, Washington, DC. Available at http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm. Accessed November 30, 2012.

US Energy Information Administration. 2012. Annual Energy Outlook 2012. Available at http://www.eia.gov/forecasts/aeo/index.cfm. Accessed November 27, 2012.

US Environmental Protection Agency. 1995. Guidance for Methods Development and MethodsValidation for the Resource Conservation and Recovery Act (RCRA) Program. Available at http://www.epa.gov/sw-846/pdfs/methdev.pdf. Accessed December 12, 2012.

US Environmental Protection Agency. 2000a. EPA Quality Manual for Environmental Programs. Available at http://www.epa.gov/irmpoli8/policies/2105P010.pdf. Accessed December 3, 2012.

US Environmental Protection Agency. 2000b. Guidance on Technical Audits and RelatedAssessments for Environmental Data Operations. Available at http://www.epa.gov/ quality/qa_docs.html. Accessed December 3, 2012.

US Environmental Protection Agency. 2000c. Policy and Program Requirements for the MandatoryAgency-Wide Quality System. Available at http://www.epa.gov/irmpoli8/policies/ 21050.pdf. Accessed December 3, 2012.

US Environmental Protection Agency. 2002. Guidelines for Ensuring and Maximizing the Quality,Objectivity, Utility, and Integrity of Information Disseminated by EPA. US Environmental Protection Agency, Washington, DC.

US Environmental Protection Agency. 2003a. A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information. Available athttp://www.epa.gov/spc/pdfs/assess2.pdf. Accessed November 27, 2012.

US Environmental Protection Agency. 2003b. Toxic Substances Control Act (TSCA) Confidential Business Information (CBI) Protection Manual. Available at http://www.epa.gov/oppt/pubs/tsca-cbi-protection-manual.pdf. Accessed November 27, 2012.

US Environmental Protection Agency. 2004a. Assuring the Competency of Environmental Protection Agency Laboratories. Available at http://epa.gov/osa/fem/pdfs/labdirective.pdf. Accessed December 3, 2012.

US Environmental Protection Agency, Office of Water. 2004b. Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed MethaneReservoirs. EPA 816-R-04-003. Available at http://water.epa.gov/type/groundwater/uic/ class2/hydraulicfracturing/wells_coalbedmethanestudy.cfm. Accessed November 27, 2012.

US Environmental Protection Agency. 2006. Office of Research and Development Policies andProcedures Manual. US Environmental Protection Agency, Washington, D.C.

US Environmental Protection Agency. 2007. U.S. EPA Reach File 1 (RF1) for the Conterminous United States. Better Assessment Science Integrating point & Non-point Sources (BASINS). Washington, DC. Available at http://water.epa.gov/scitech/datait/models/basins/b3webdwn.cfm. Accessed 6/11/2007.

US Environmental Protection Agency. 2008. EPA Procedure for Quality Policy. Available at http://www.epa.gov/irmpoli8/policies/2106p01.pdf. Accessed December 3, 2012.

US Environmental Protection Agency. Chesapeake Bay Phase 5.3 Community Watershed Model. Available at http://www.chesapeakebay.net/about/programs/modeling/53/. Accessed November 27, 2012.

US Environmental Protection Agency. 2010b. Hydraulic Fracturing Study Consultation with TribalGovernments, August 5 and 30, 2010. Available at http://www.epa.gov/hfstudy/publicoutreach.html. Accessed September 5, 2012.

US Environmental Protection Agency. 2010c. Integrated Climate and Land-Use Scenarios (ICLUS)version 1.3 User's Manual: ArcGIS Tools and Datasets for Modeling US Housing Density Growth. Available at http://www.epa.gov/ncea/global/iclus/. Accessed September 2010.

US Environmental Protection Agency. 2010d. Summary of Public Comments, Binghamton, NewYork, September 13 and 15, 2010. Hydraulic Fracturing Public Informational Meeting. Available at http://www.epa.gov/hfstudy/publicoutreach.html. Accessed September 5, 2012.

US Environmental Protection Agency. 2010e. Summary of Public Comments, Canonsburg, Pennsylvania, July 22, 2010. Hydraulic Fracturing Public Informational Meeting. Available at http://www.epa.gov/hfstudy/publicoutreach.html. Accessed September 5, 2012.

US Environmental Protection Agency. 2010f. Summary of Public Comments, Denver, Colorado, July13, 2010. Hydraulic Fracturing Public Informational Meeting. Available at http://www.epa.gov/hfstudy/publicoutreach.html. Accessed September 5, 2012.

US Environmental Protection Agency. 2010g. Summary of Public Comments, Fort Worth, Texas, July8, 2010. Hydraulic Fracturing Public Information Meeting. Available at http://www.epa.gov/hfstudy/publicoutreach.html. Accessed September 5, 2012.

US Environmental Protection Agency. 2010h. Technical Basis for the Lowest ConcentrationMinimum Reporting Level (LCMRL) Calculator. EPA 815-R-11-001. Available at http://water.epa.gov/scitech/drinkingwater/labcert/upload/LCMRLTechRpt.pdf. AccessedNovember 27, 2012.

US Environmental Protection Agency. 2011a. Counties with Oil and Gas Production Wells Hydraulically Fractured from September 2009 through October 2010 Shapefile. Data received from nine hydraulic fracturing service companies. US Environmental ProtectionAgency, Washington, DC.

US Environmental Protection Agency. 2011b. Data Received from Hydraulic Fracturing Service Companies. Non-confidential business information is available athttp://www.regulations.gov/#!docketDetail;rpp=100;so=DESC;sb=docId;po=0;D=EPA-HQORD-2010-0674. Accessed November 27, 2012.

US Environmental Protection Agency. 2011c. EPA Records Schedule 501. Applied and Directed Scientific Research. Available at http://www.epa.gov/records/policy/schedule/sched/501.htm. Accessed November 27, 2012.

US Environmental Protection Agency. 2011d. Location of Oil and Gas Production Wells Selected for Review Shapefile. US Environmental Protection Agency, Washington, DC.

US Environmental Protection Agency. 2011e. Plan to Study the Potential Impacts of HydraulicFracturing on Drinking Water Resources. EPA/600/R-11/122. Available at http://www.epa.gov/hfstudy/. Accessed November 27, 2012.

US Environmental Protection Agency. 2011f. Proceedings of the US Environmental ProtectionAgency Technical Workshops for the Hydraulic Fracturing Study: Water Resources Management, Arlington, Virginia. Available at http://www.epa.gov/hfstudy/waterworkshop.html. Accessed August 24, 2012.

US Environmental Protection Agency. 2011g. Quality Assurance Project Plan: Chemical Characterization of Select Constituents Relevant to Hydraulic Fracturing. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed November 27, 2012.

US Environmental Protection Agency. 2011h. Quality Assurance Project Plan: Formation of Disinfection By-products from Hydraulic Fracturing Fluid Constituents. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed November 27, 2012.

US Environmental Protection Agency. 2011i. Quality Assurance Project Plan: Hydraulic FracturingRetrospective Case Study, Bakken Shale, Killdeer and Dunn County, North Dakota. Available at http://www.epa.gov/hfstudy/bakken-qapp.pdf. Accessed November 27, 2012.

US Environmental Protection Agency. 2011j. Safe Drinking Water Information System. USEnvironmental Protection Agency, Washington, DC.

US Environmental Protection Agency. 2011k. Sampling Data for Flowback and Produced Water Provided to EPA by Nine Oil and Gas Well Operators (Non-Confidential Business Information). Available at http://www.regulations.gov/ #!docketDetail;rpp=100;so=DESC;sb=docId;po=0;D=EPA-HQ-ORD-2010-0674. AccessedNovember 27, 2012.

Estimation Programs Interface Suite for Microsoft® Windows (EPI Suite) version 4.10. 2012a. US Environmental Protection Agency, Washington DC.

US Environmental Protection Agency. 2012b. Exposure Assessment Tools and Models: Estimation Program Interface (EPI) Suite. Available at http://www.epa.gov/oppt/exposure/pubs/ episuite.htm. Accessed November 21, 2012.

US Environmental Protection Agency. 2012c. Interim EJSCREEN Common User Guidelines. Draft for Environmental Justice Committee Presentation. US Environmental Protection Agency, Washington, DC.

US Environmental Protection Agency. Key Documents About Mid-Atlantic Oil and Gas Extraction. Available at http://www.epa.gov/region3/marcellus_shale/. Accessed December 5, 2012.

US Environmental Protection Agency. 2012e. Peer Review Handbook. 3rd Edition. Available athttp://www.epa.gov/peerreview/pdfs/peer_review_handbook_2012.pdf. Accessed December 3, 2012.

US Environmental Protection Agency. 2012f. Quality Assurance Project Plan: Data and Literature Evaluation for the EPA's *Study of the Potential Impacts of Hydraulic Fracturing (HF) on Drinking Water Resources*. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed December 4, 2012.

US Environmental Protection Agency. 2012g. Quality Assurance Project Plan: Analysis of Data Extracted from FracFocus. Available at http://www.epa.gov/hfstudy/qapps.html. AccessedDecember 4, 2012.

US Environmental Protection Agency. 2012h. Quality Assurance Project Plan: Analysis of Data Received from Nine Hydraulic Fracturing (HF) Service Companies. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed December 4, 2012.

US Environmental Protection Agency. 2012i. Quality Assurance Project Plan: Chemical Information Quality Review and Physicochemical Property Calculations for Hydraulic Fracturing Chemical Lists. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed November30, 2012.

US Environmental Protection Agency. 2012j. Quality Assurance Project Plan: Evaluation of Existing Production Well File Contents. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed January 4, 2012.

US Environmental Protection Agency. 2012k. Quality Assurance Project Plan: Health and Toxicity Theme Hydraulic Fracturing Study. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed November 30, 2012.

US Environmental Protection Agency. 2012l. Quality Assurance Project Plan: Hydraulic Fracturing (HF) Surface Spills Data Analysis. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed December 4, 2012.

US Environmental Protection Agency. 2012m. Quality Assurance Project Plan: Hydraulic Fracturing Retrospective Case Study, Bradford-Susquehanna Counties, Pennsylvania. Available at http://www.epa.gov/hfstudy/pdfs/bradford-review-casestudy.pdf. Accessed November 27,2012.

US Environmental Protection Agency. 2012n. Quality Assurance Project Plan: Hydraulic Fracturing Retrospective Case Study, Marcellus Shale, Washington County, Pennsylvania. Available athttp://www.epa.gov/hfstudy/washingtonco-qapp.pdf. Accessed November 27, 2012.

US Environmental Protection Agency. 2012o. Quality Assurance Project Plan: Hydraulic Fracturing Retrospective Case Study, Raton Basin, Colorado. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed November 27, 2012.

US Environmental Protection Agency. 2012p. Quality Assurance Project Plan: Hydraulic Fracturing Retrospective Case Study, Wise, Texas. Available at http://www.epa.gov/hfstudy/barnettqapp.pdf. Accessed November 27, 2012.

US Environmental Protection Agency. 2012q. Quality Assurance Project Plan: Hydraulic Fracturing Wastewater Source Apportionment. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed November 27, 2012.

US Environmental Protection Agency. 2012r. Quality Assurance Project Plan: Inter-Laboratory Verification and Validation of Diethylene Glycol, Triethylene Glycol, Tetraethylene Glycol, 2Butoxyethanol and 2-Methoxyethanol in Ground and Surface Waters by Liquid Chromatography/Tandem Mass Spectrometry. Available at http://www.epa.gov/hfstudy/ qapps.html. Accessed November 27, 2012.

US Environmental Protection Agency. 2012s. Quality Assurance Project Plan: Surface WaterTransport of Hydraulic Fracturing-Derived Waste Water. Available at http://www.epa.gov/ hfstudy/qapps.html. Accessed November 27, 2012.

US Environmental Protection Agency. 2012t. Quality Management Plan: Plan to Study the Impactsof Hydraulic Fracturing on Drinking Water Resources. Available at http://www.epa.gov/ hfstudy/qapps.html. Accessed December 3, 2012.

US Environmental Protection Agency. 2012u. Request for Information to Inform HydraulicFracturing Research Related to Drinking Water Resources. *Federal Register* 77:218 p. 67361.

US Environmental Protection Agency. 2012v. Science Advisory Board Staff Office Request forNominations of Experts for the SAB Hydraulic Fracturing Advisory Panel. *Federal Register*
77:162. p. 50505.

US Environmental Protection Agency. 2012w. Unconventional Gas Drilling Projections for the US:2011-2040 AEO2012 Reference Case. National Energy Modeling System. US Environmental Protection Agency, Washington, DC.

US Fish and Wildlife Service. 2008. Programmatic Biological Opinion for Water Depletions Associated with Bureau of Land Management's Fluid Mineral Program within the

UpperColorado River Basin in Colorado. Memorandum. US Fish and Wildlife Service, Grand Junction, Colorado.

US Government Accountability Office. 2012. Information on the Quantity, Quality, and Managementof Water Produced during Oil and Gas Production. Energy-Water Nexus GAO-12-156. Available at http://www.gao.gov/products/GAO-12-156. Accessed December 12, 2012.

US Office of Management and Budget. 2004. Final Information Quality Bulletin for Peer Review. Available at http://www.whitehouse.gov/sites/default/files/omb/assets/omb/memoranda/fy2005/m05-03.pdf. Accessed August 23, 2012.

US Census Bureau. 2010a. Bradford County, Pennsylvania. State and County QuickFacts. Available at http://quickfacts.census.gov/qfd/states/42/42015.html. Accessed November 27, 2012.

US Census Bureau. 2010b. Dunn County, North Dakota. State and County QuickFacts. Available athttp://quickfacts.census.gov/qfd/states/38/38025.html. Accessed November 27, 2012.

US Census Bureau. 2010c. Huerfano County, Colorado. State and County QuickFacts. Available at http://quickfacts.census.gov/qfd/states/08/08055.html. Accessed November 27, 2012.

US Census Bureau. 2010d. Las Animas County, Colorado. State and County QuickFacts. Available athttp://quickfacts.census.gov/qfd/states/08/08071.html. Accessed November 27, 2012.

US Census Bureau. 2010e. Washington County, Pennsylvania. State and County Quick Facts. US Census Bureau, Available at http://quickfacts.census.gov/qfd/states/42/42125.html. Accessed December 5, 2012.

US Census Bureau. 2010f. Wise County, Texas. State and County QuickFacts. Available at http://quickfacts.census.gov/qfd/states/48/48497.html. Accessed November 27, 2012.

US Census Bureau. 2012a. Counties (and Equivalent) Shapefile. 2010 TIGER/Line Shapefiles. USCensus Bureau, Washington, DC. Available at http://www.census.gov/cgibin/geo/shapefiles2010/main. Accessed December 4, 2012.

US Census Bureau. 2012b. Places Shapefile. 2010 TIGER/Line Shapefiles. US Census Bureau, Washington, DC. Available at http://www.census.gov/cgi-bin/geo/shapefiles2010/main. Accessed December 5, 2012.

US Census Bureau. 2012c. States (and Equivalent) Shapefile. 2010 TIGER/Line Shapefiles. USCensus Bureau, Washington, DC. Available at http://www.census.gov/cgibin/geo/shapefiles2010/main. Accessed December 4, 2012.

US Department of Agriculture. 2012. Information on Hydrologic Units and the Watershed Boundary Dataset. Available at http://www.ncgc.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/dma/?cid=nrcs143_0216_16. Accessed November 27, 2012.

US Geological Survey. 2003. Petroleum Systems and Geologic Assessment of Oil and Gas in the Uinta-Piceance Province, Utah and Colorado. Digital Data Series DDS-69-B. Available athttp://pubs.usgs.gov/dds/dds-069/dds-069-b/chapters.html. Accessed November 30, 2012.

US Geological Survey. 2011a. Allegheny River at Franklin, Pennsylvania (03025500). Surface-WaterMonthly Statistics for the Nation. May 2006-September 2011. Available at http://waterdata.usgs.gov/nwis/inventory/?site_no=03025500&agency_cd=USGS&amp. Accessed October 10, 2012.

US Geological Survey. 2011b. Blacklick Creek at Josephine, Pennsylvania (03042000). Surface-Water Monthly Statistics for the Nation. May 2006-September 2011. Available at http://waterdata.usgs.gov/nwis/inventory/?site_no=03042000. Accessed November 27, 2012.

US Geological Survey. 2011c. Information Relevant to the U.S. Geological Survey Assessment of the Middle Devonian Shale of the Appalacian Basin Province. Open-File Report 2011-1298. US Geological Survey. 22 p. Available at http://pubs.usgs.gov/of/2011/1298/. Accessed

US Geological Survey. 2012a. Allegheny River at Franklin, Pennsylvania (03025500). Current Conditions for Selected Sites (Provisional). Available at http://nwis.waterdata.usgs.gov/nwis/uv?site_no=03025500. Accessed November 27, 2012.

US Geological Survey. 2012b. Blacklick Creek at Josephine, Pennsylvania (03042000). Current Conditions for Selected Sites (Provisional). US Geological Survey, Available at http://nwis.waterdata.usgs.gov/nwis/uv?site_no=03042000. Accessed November 27, 2012.

US House of Representatives. 2009. Appropriations Committee Report for the Department of the Interior, Environment, and Related Agencies Appropriations Bill, HR 2996. Available at http://www.gpo.gov/fdsys/pkg/CRPT-111hrpt180/pdf/CRPT-111hrpt180.pdf. AccessedDecember 6, 2012.

US House of Representatives 2011. Chemicals Used in Hydraulic Fracturing. Available at http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf. Accessed November 27, 2012.

Van Ginkel, C. G. 1996. Complete degradation of xenobiotic surfactants by consortia of aerobic microorganisms. *Biodegradation* 7 (2): 151-164.

Van Schie, P. M. and Young L.Y. 2000. Biodegradation of phenol: mechanisms and applications. *Bioremediation Journal* 4 (1): 1-18.

Wallis, S. 2007. The numerical solution of the advection-dispersion equation: a review of some basic principles. *Acta Geophysica* 55 (1): 85-94.

Warner, N. R., Jackson, R. B., Darrah, T. H., Osborn, S. G., Down, A., Zhao, K., White, A. and Vengosh, A.2012. Geochemical evidence for possible natural migration of marcellus formation brine to shallow aquifers in Pennsylvania. *Proceedings of the National Academy of Sciences of the United States of America* 109 (30): 11961-11966.

Watts, K. R. 2006a. Hydrostratigraphic Framework of the Raton, Vermejo, and Trinidad Aquifers in the Raton Basin, Las Animas County, Colorado. Scientific Investigations Report 2006-5129. US Geological Survey 37 p. Available at http://pubs.usgs.gov/sir/2006/5129/pdf/SIR065129_508.pdf. Accessed December 3, 2012.

Watts, K. R. 2006b. A Preliminary Evaluation of Vertical Separation between Production Intervals of Coalbed-Methane Wells and Water-Supply Wells in the Raton Basin, Huerfano and LasAnimas Counties, Colorado, 1999-2004. Scientific Investigations Report 2006-5109. US Geological Survey. 15 p. Available at http://pubs.usgs.gov/sir/2006/5109/pdf/sir2006_5109.pdf. Accessed December 3, 2012.

Westat. 2011. Quality Assurance Project Plan v. 1.1 for Hydraulic Fracturing. Westat for US Environmental Protection Agency. Available at http://www.epa.gov/hfstudy/qapps.html. Accessed December 11, 2012.

Williams, D. R., Felbinger, J. K. and Squillace, P. J. 1993. Water Resources and the Hydrologic Effects of Coal Mining in Washington County, Pennsylvania. Open-File Report 89-620. US Geological Survey, Lemoyne, Pennsylvania.

Williams, J. E., Taylor, L. E. and Low, D. J. 1998. Hydrogeology and Groundwater Quality of the Glaciated Valleys of Bradford, Tioga, and Potter Counties, Pennsylvania. Water Resources Report 68. US Geological Survey and Pennsylvania Geological Survey. 98 p. Available athttp://eidmarcellus.org/wp-content/uploads/2011/06/USGS-Bradford-Report.pdf. Accessed December 5, 2012.

Ziemkiewicz, P. 2011. Wastewater from Gas Development: Chemical Signatures in the Monongahela River Basin. Proceedings of the US Environmental Protection Agency Technical Workshops for the Hydraulic Fracturing Study: Water Resources Management, Arlington, Virginia. Available at http://epa.gov/hfstudy/waterworkshop.html. Accessed November 30, 2012.