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EPA Science Advisory Board
Hydraulic Fracturing Research Advisory Panel
U.S. Environmental Protection Agency
c/o Mr. Edward Hanlon, Designated Federal Officer
Mail Code: 1400R
1200 Pennsylvania Ave., NW.
Washington, DC 20460

Re: Science Advisory Board Hydraulic Fracturing Research Advisory Panel Request for Comment on New and Emerging Information Related to Hydraulic Fracturing and Drinking Water Resources for its November 20, 2013 Teleconference.

Dear Mr. Hanlon:

Halliburton Energy Services, Inc. ("HESI") hereby submits the following data and scientific literature for the consideration of the U.S. Environmental Protection Agency ("EPA" or "Agency") Science Advisory Board ("SAB") Hydraulic Fracturing Research Advisory Panel. This submission is in response to the Panel's September 10, 2013 publication in the *Federal Register* providing notification of the November 20, 2013 teleconference to receive written and oral comments from the public on new and emerging information related to hydraulic fracturing and drinking water resources. 78 Fed. Reg. 55,253. The data and scientific literature are summarized as follows:

- Flewelling, S. A. and Sharma, M. (2013), Constraints on Upward Migration of Hydraulic Fracturing Fluid and Brine. *Ground Water*. doi: 10.1111/gwat.12095 (open access). This paper discusses the physical constraints on upward fluid migration from black shales such as the Marcellus, Bakken, and Eagle Ford to shallow aquifers, taking into account the potential changes to the subsurface brought about by HF operations. The paper finds that the HF process is unable to create direct hydraulic communication between these shales and shallow aquifers via induced fractures, and that upward migration of HF fluid and brine through the rock layers above the fractures is controlled by pre-existing hydraulic gradients and bedrock permeability. These layers are typically dominated by shales, siltstones, and mudstones that have inherently low permeability, which is further reduced by various mechanisms such as cementation and partial saturation. The paper also finds that the upward head gradients that would be necessary to push fluids toward the surface are found only where the permeabilities of the rock are very low, ensuring that any upward movement will be minimal. Prior analyses (*e.g.*, Myers, "Potential Contaminant

Pathways from Hydraulically Fractured Shale to Aquifers," *Ground Water* (2012); Warner, *et al*., "Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania," *PNAS* (2012)) incorrectly assumed a hydraulic connection between shallow and deep strata without considering the underlying physics that constrain potential upward fluid migration. The paper concludes that rapid upward migration of brine and HF fluid as a result of HF activity does not appear to be physically plausible, and that any fluid migration would occur over very long time periods.

- Flewelling, S. A., M. P. Tymchak, and N. Warpinski (2013), Hydraulic fracture height limits and fault interactions in tight oil and gas formations, *Geophys. Res. Lett.*, 40, 3602–3606, doi:10.1002/grl.50707 (open access). This paper further examines the potential for fluid migration via induced fractures and considers the potential for induced factures to interact with natural faults to provide migration pathways, as some have suggested. The authors conclude that naturally-occurring faults associated with the formations being fractured are normally sealed and that fluids can migrate upward along these faults only when they are opened or induced to slip (otherwise there would be no accumulated oil or gas). The authors developed theoretical limits on fracture height growth as a function of HF fluid volume to determine the potential for upward migration of HF fluid and brine through induced fractures and naturally-occurring faults. They then confirmed the validity of these theoretical limits by reviewing data on over 12,000 HF stimulations mapped with microseismic sensors in approximately 25 U.S. and Canadian sedimentary basins. The tallest observed fracture was about 600 meters, although most were much shorter, while areas of shear displacement (including fault slip that would allow fluid movement) estimated from microseismic data were comparatively small, with radii on the order of 10 meters or less. These findings suggest that fracture heights are ultimately limited by HF fluid volume regardless of whether the fractures interact with faults, although natural mechanisms such as in situ stress contrasts typically keep fractures constrained to the nearby vicinity of the targeted formation. The authors also noted the well-understood tendency of fractures to propagate horizontally rather than vertically as they reach shallower depths. As a result, the shallowest fracture was about 500 meters below ground surface, with most fractures being much deeper. In light of these factors, the paper concludes that it is not physically plausible for induced fractures to create a hydraulic connection between tight formations at depth and overlying drinking water aquifers, even through interaction with naturally-occurring faults.

- Fisher, K. and Warpinski, N. 2012. Hydraulic-Fracture-Height Growth: Real Data. *SPE Prod. & Oper.* 27 (1): 8-19, SPE-145949-PA. http://dx.doi.org/10.2118/145949-PA. This report examines fracture growth data obtained as a result of microseismic monitoring conducted during thousands of HF treatments in unconventional reservoirs across the country along with the reported aquifer depths in the vicinity of the fractured wells. The paper also examines fracture-growth limiting mechanisms, supported by mapping data, mineback tests and other studies performed to visually examine hydraulic fractures. The paper discusses how the layered structure of typical sedimentary rock has very low vertical permeability that prevents the hydrocarbons from escaping; as the paper points out, otherwise the hydrocarbons would have already escaped and there would be no reservoir to exploit. It is this same low permeability that prevents fracture fluids from migrating to the surface. The paper also explains that, out of the factures mapped, the tallest fractures (those with the most significant fracture-height growth) occur in the deepest wells in a given reservoir, and in general, the shallowest wells in a given reservoir have the least measured fracture height. Importantly, even in areas with the largest measured vertical fracture growth (like the Marcellus Shale), the tops of the induced fractures are still thousands of feet below the deepest aquifer suitable for drinking water, demonstrating that induced fractures are not growing into groundwater aquifers and that fracture treatments themselves are unlikely to contaminate them. The paper concludes that "[f]racture physics, formation mechanical properties, the layered depositional environment, and other factors all conspire to limit hydraulic-fracture-height growth, causing it to remain in the nearby vicinity of the targeted reservoirs." Furthermore, where hydraulic fracturing is conducted at depth, based on observations of the mapping data and the application of basic rock-mechanics principles, "there is no method by which a fracture is going to propagate through the various rock layers and reach the surface."

- Gradient Corp., *National Human Health Risk Evaluation for Hydraulic Fracturing Fluid Additives* (Apr. 2013) (attached). This report evaluates the potential impacts to drinking water associated with the use of HF fluids. The report examines whether it is possible for fluids pumped into a tight formation (such as a shale or tight sand) during the HF process to migrate upward to reach drinking water aquifers and concludes that this is an implausible chemical migration pathway for the reasons discussed in the three papers described above, among others. The report also analyzes the potential human health risks in the event that surface spills of HF fluids or flowback fluid impact either surface water or groundwater. Using a probabilistic analysis, Gradient evaluated surface spills involving a wide range of conditions, determining the concentrations of chemicals that could potentially be found in drinking water resources as a result of spills using a number of conservative

assumptions. Gradient then compared these concentrations to risk-based concentrations developed in accordance with EPA risk assessment guidelines. The report concludes that potential human health risks associated with exposure to drinking water (derived from surface water or groundwater) potentially affected by spills of HF fluids or flowback fluids are expected to be insignificant, as defined by Agency-based risk management guidelines.

- Saiers, J. E. and Barth, E. (2012), Potential Contaminant Pathways from Hydraulically Fractured Shale Aquifers. *Ground Water*, 50: 826–828. doi: 10.1111/j.1745-6584.2012.00990.x. This article provides a critique of the model relied on in Myers' 2012 article. After recognizing that models represent only approximations of reality, the article concludes that "Myers' modeling framework neglects critical hydrologic processes, misrepresents physical conditions that drive groundwater flow, and is underpinned by simplifications that are too severe and unnecessary." The article bases this conclusion on numerous deficiencies in the model, including an incorrect assumption that gas-filled geologic strata are water-saturated, the failure to account for the roles of temperature and salinity variations in groundwater flow, the reliance on unrealistic and unsubstantiated boundary conditions, and the improper representation of the hydrogeologic properties of bedrock above the Marcellus Shale formation.

- Cohen, H. A., Parratt, T. and Andrews, C. B. (2013), Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers. *Ground Water*, 51: 317–319. doi: 10.1111/gwat.12015. This comment follows up on the Saiers & Barth critique of the Myers article (discussed above) to identify additional fundamental issues with the Myers model, including calculation errors associated with effective vertical hydraulic conductivity values and the unsubstantiated assumption that flowback rate is a suitable proxy for hydraulic conductivity of the fractured horizon. After observing the many fundamental issues with the Myers' paper, the comment highlights how "facts" about HF purported to be revealed by the Myers article are no more than restatements of article's original premise, and casts doubt as to whether the Myers article provides any new insights into processes associated with HF.

- Carter, *et al.*, "Technical Rebuttal to Article Claiming a Link between Hydraulic Fracturing and Groundwater Contamination" (2013) (attached). This peer-reviewed document prepared by representatives of the Pennsylvania Council of Professional Geologists and the Pennsylvania Geological Survey provides a technical rebuttal to the purported results of Myers' modeling. The rebuttal illustrates weaknesses and shortcomings of the Myers article, including the selective use of modeling parameters, the inappropriate use of technical references to support the modeling scenario, and the omission of key data and widely accepted principles regarding subsurface geology and fluid

flow through porous media to conclude that Myers lacks objectivity and an understanding of how to develop a credible hydrogeological conceptual site model.

- R. D. Vidic, S. L. Brantley, J. M. Vandenbossche, D. Yoxtheimer, and J. D. Abad (May 17, 2013) Impact of Shale Gas Development on Regional Water Quality. *Science*: 340 (6134), 1235009, doi:10.1126/science.1235009. This paper reviews the current understanding of potential environmental issues associated with unconventional gas extraction, including gas migration, contaminant transport through induced and natural fractures, wastewater discharge, and accidental spills. Through its review of available data from drinking water wells in the shale gas region of rural Pennsylvania, as well as prior reports and studies addressing the potential link between HF fluids and groundwater contamination, the article observes that contamination of groundwater by HF fluids has not been reported. The article identifies the need to establish flow models that take into account realistic hydraulic conductivities and HF conditions. The article also describes the numerous simplifications that compromise the conclusions of the Myers article, including that the article is based on the assumption of hydraulic conductivity that reflects water-filled voids in the geologic formation, despite the fact that may of the shale and overburden formations are not water-saturated. In addition, the article's assumption of preexisting 1500-m long vertical fractures is hypothetical and not based on geologic formation.

- Molofsky, L. J., Connor, J. A., Wylie, A. S., Wagner, T. and Farhat, S. K. (2013), Evaluation of Methane Sources in Groundwater in Northeastern Pennsylvania. Ground Water, 51: 333–349. doi: 10.1111/gwat.12056. This study evaluated the prevalence and distribution of methane concentrations in groundwater to test the hypothesis that elevated methane concentrations in water wells are the result of regional impacts from shale-gas extraction activities. The authors collected and reviewed studies on aquifer dynamics and geochemical characteristics, historical documentation on the presence of gases in the subsurface, and regional geologic data, including data from 1,701 water wells in Susquehanna County, Pennsylvania, and 15 water wells that were part of the natural gas investigation in Dimock Township. The study concluded that on a regional scale, methane concentrations are best correlated to topographic and hydrogeologic features, rather than shale gas extraction, and suggested that the methane concentrations in Susquehanna County water wells can be explained without the migration of Marcellus shale gas through fractures.

- Neuzil, C. E. (2013), Can Shale Safely Host U.S. Nuclear Waste?, EOS Trans. AGU, 94(30), 261. This article, supported by the U.S. Geological Survey, proposes the use of argillaceous formations, including shales, to host

repositories for spent nuclear fuel and high-level nuclear waste. In explaining how these geologic formations could be effective geologic barriers to migration from a nuclear waste repository, the article describes how the presence of pressure anomalies signals formation-scale permeabilities small enough to rule out water-conducting fractures. For the same reasons that argillaceous formations would provide an effective barrier to nuclear waste migration, these formations also provide an effective barrier to the migration of HF fluids to shallow aquifers.

- Kresse, *et al.*, *Shallow Groundwater Quality and Geochemistry in the Fayetteville Shale Gas-Production Area, North-Central Arkansas, U.S. Geological Survey Scientific Investigations Report 2012-5273* (Jan. 2013) (attached). In this study, the USGS analyzed water samples from 127 drinking water wells in the western third of the Fayetteville shale for methane and major ions and trace metals, with a subset analyzed for methane and carbon isotopes. Out of the 127 wells sampled, seven samples were detected with higher methane concentrations, all of which were determined to be the result of natural processes and evolution of groundwater chemistry through rock-water interaction and redox processes. The study used two comparative analysis methods to identify potential impacts to water quality from gas-production activities and found no evidence of migration of gas-production fluids into shallow groundwater based on the wells sampled in the study. The USGS concluded that there were no apparent effects on well water quality from gas production activities in the portion of the Fayetteville shale covered by the study.

- Cardno Entrix, *Hydraulic Fracturing Study: PXP Inglewood Oil Field* (Oct. 2012) (attached). This peer-reviewed study was performed as a result of a settlement between the Baldwin Hills Community Standards District and plaintiffs that brought a lawsuit challenging the validity of a supplemental district created to improve the compatibility of oil production with adjacent urban land use. After observing two high-volume HF (HVHF) jobs at separate wells in the field, the study concluded that: (1) microseismic monitoring indicated that proppant-filled fractures were confined within the deep shale formations, separated from the designated base of fresh water by 7,700 feet; (2) before-and-after monitoring of groundwater quality in monitor wells did not show impacts from HVHF; (3) before-and-after tests showed no effects on the integrity of the steel and cement casings; (4) there was no indication of methane impacts from HVHF; (5) before-and-after studies showed no detectable effect on ground movement or subsidence; (6) before-and-after measurements indicated that the HVHF had no detectable effects on vibration and did not induce seismicity; (7) noise and vibration associated with HVHF were within applicable limits; (8) emissions associated with HVHF were within regional air quality standards; and (9) a community health

assessment found no statistical difference between the health of the local community and that of Los Angeles County as a whole.

- Halliburton Energy Services, Inc., *Inglewood Oil Field Hydraulic Fracturing Report* (July 2012) (attached). This report gives a description and analysis of the HF treatments that were performed as part of the Inglewood Oil Field HF study described above. HESI used pressure history matching to determine the vertical distances between the top of the HF treatments in the study wells and the discontinuous groundwater bodies near the surface. HESI found that the actual distances from the tops of the created hydraulic fractures, after completing the well treatments, to the discontinuous groundwater bodies was approximately 7,700 feet. The report concludes that the fracture height growth in the Inglewood field is limited by the physical properties of the multiple layered formations. In addition, microseismic monitoring observed hundreds of microseismic events during the fracturing treatment, finding that all of these events occurred within 20 feet of the top of the shale. The results of microseismic monitoring of the HF treatments showed that the seismic events were much smaller than the magnitude which can be felt on the surface. The appendices to the report can be at the following website: http://www.inglewoodoilfield.com/res/docs/102012study/Halliburton Inglewood Field HF Report Appendices.pdf (last accessed Nov. 13, 2013).

- Gradient Corp., *Evaluation of Potential Impacts of Flowback Fluid Constituents from Hydraulic Fracturing on Treatment Processes in Publicly-Owned Treatment Works (POTWs)* (Jan. 2012) (attached). This report evaluates the potential for flowback water recovered from the HF process in the Marcellus Shale to upset the treatment process at a POTW, finding that the treatment of the organic constituents in flowback water from HF activities at POTWs is not expected to upset biological wastewater treatment processes at these facilities.

- Gradient Corp., *Human Health Risk Evaluation for Hydraulic Fracturing Fluid Additives* (Jan. 2012) (attached). This report evaluates the potential human health impacts of HF fluid leaks or spills that could occur during well development activities in the Marcellus Shale, including the potential for such spills to impact groundwater or surface water and the human health implications of exposure to HF constituents if such water is then used for household drinking purposes. The report concludes that potential human health risks associated with exposure to drinking water (derived from surface water or groundwater) potentially affected by spills of typical HESI HF fluids are expected to be insignificant, as defined by Agency-based risk management guidelines. The report also discusses the conclusion that upward migration of HF constituents from the Marcellus Shale formation to shallow aquifers is not a realistic migration pathway.

- MIT Energy Initiative, *The Future of Natural Gas: An Interdisciplinary MIT Study* (June 2011) (attached). This study examined the potential risks of HF to groundwater aquifers and found that no incidents of direct invasion of shallow water zones by fracture fluids during the fracturing process have been recorded. The study also examined recorded fracture lengths and found that in all cases several thousand feet existed between the longest fractures recorded and the groundwater aquifer.

- Jin, *et al.*, Alabama Geological Survey, *Application of discrete fracture network models to coalbed methane reservoirs of the Black Warrior basin*, University of Alabama College of Continuing Studies, 2003 International Coalbed Methane Symposium Proceedings, Paper 0321 (2003) (attached). This paper assesses the risks that coalbed methane operations may pose to shallow groundwater resources through the use of discrete fracture network models to quantify and model the degree of interconnection between coalbed methane reservoirs and shallow supplies of domestic groundwater. The paper concludes that the likelihood of significant hydraulic communication between reservoir coal beds and shallow aquifers is minimal and the chance of contamination of water wells through hydraulic fracturing of coalbed methane reservoirs appears remote. In addition, even though cross-formational flow is facilitated by fault zones, compartmentalization analysis indicates that the formation is extremely heterogeneous and that flow paths are highly tortuous.

HESI is also submitting copies of papers prepared for it that review and critique the results of EPA's December 2011 draft study entitled "Investigation of Ground Water Contamination near Pavillion, Wyoming." EPA has stated that it does not intend to rely on the results of the Pavillion draft study report to inform the Agency's Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources,[1] a decision which HESI believes is appropriate given that the Pavillion draft study was not subject to peer review and because the study design and implementation has been criticized as being technically flawed (as discussed below). Nonetheless, HESI is aware that some have urged the panel to recommend to EPA that the Agency in fact take the draft Pavillion report into account in its Study. Accordingly, HESI believes it is important for the panel members to understand the basis for HESI's view that EPA is entirely correct in declining to consider the draft Pavillion report further.

- Gradient Corp. and Environmental Resources Management, *Review of US EPA's "Draft Investigation of Ground Water Contamination near Pavillion, Wyoming"* (June 2012) (attached). This paper is a critique of EPA's Pavillion draft study. The paper finds that the study design was flawed, the study implementation (*i.e.*, field work and data quality evaluation) was very poor,

[1] *See* Press Release, EPA, *Wyoming to Lead Further Investigation of Water Quality Concerns Outside of Pavillion with Support of EPA* (June 20, 2013), http://yosemite.epa.gov/opa/admpress.nsf/20ed1dfa1751192c8525735900400c30/dc7dcdb471dcfe1785257b90007377bf!OpenDocument (last visited Oct. 28, 2013).

and the analysis of the data was not based on sound science. First, given the extremely limited number of monitoring wells installed for the study (two) and the arrangement and depths of those wells, the study was not designed to determine local or regional hydraulic gradients or whether gas production wells had impacted domestic wells in the study area, critical flaws that rendered the study incapable of addressing its stated objective of differentiating between potential source areas. Second, EPA's implementation of the study did not follow Agency guidance or the project work plan for groundwater sample collection. In addition, EPA failed to install and develop the deep monitoring wells properly, which compromised the groundwater quality data and resulted in faulty interpretations of groundwater chemistry. Third, the "multiple lines of reasoning" used by EPA for the basis for its conclusions rely on poor quality and unreliable data, do not take account of the scientific literature, and do not adequately consider the available data. For example, the study's conclusions are premised on the existence of an upward hydraulic gradient to convey HF fluids from the formations being fractured to the shallower formations in which the monitoring wells were screened; however, the available data demonstrate that the hydraulic gradient in the area is actually downward. In addition, the study's assertion that elevated pH levels at the site are the result of HF activities cannot be reconciled with the reality that most of the HF stimulations in Pavillion used HF fluids with an acidic pH (*i.e.*, <7) and not the high (caustic) pH values observed in the deep monitoring wells. Consequently, EPA's methods and data do not support the conclusion reached in the report that constituents associated with HF have contaminated groundwater at and below the depth used for domestic water supply.

- Gradient Corp., *Review of US EPA and USGS Groundwater Sampling Data Reports* (Aug. 2013) (attached). This paper provides a supplemental critique of EPA's Pavillion draft study based upon the resampling of the two deep monitoring wells by EPA and the United States Geological Survey using more rigorous quality assurance and quality control measures, which was initiated by EPA in response to concerns regarding the poor quality of the analytical results reported by EPA in the Pavillion draft study. The paper finds that the additional data from the resampling corroborate earlier conclusions that EPA's study implementation (*i.e.*, field work and data quality evaluation) was very poor and the analysis of the data was not based on sound science. Specifically, these additional findings further confirm that the two deep monitoring wells were poorly installed and developed by EPA, groundwater chemistry at these wells for certain analytes continues to be affected by poor well installation techniques and is hence unreliable, and the hydrocarbon-related compounds detected in the monitoring wells are consistent with the geochemistry of a natural gas-rich area.

HESI respectfully requests that these summaries and the attached data and scientific literature be included in the record for the November 20, 2013 Public Teleconference of the SAB Hydraulic Fracturing Research Advisory Panel. HESI appreciates the opportunity to provide these materials to inform the SAB on new and emerging information related to hydraulic fracturing and drinking water resources.

Respectfully submitted,

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Attachments