Review and Response to "Human Health Risk Evaluation for Hydraulic Fracturing Fluid Additives - Marcellus Shale Formation, New York"

By Gradient Corporation; December 31, 2009

Prepared for:

NYSERDA
17 Columbia Circle
Albany, New York 12203

January 26, 2011

ALPHA GEOSCIENCE

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Geology

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Water Supply

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NYSERDA
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Prepared by:

Alpha Geoscience
679 Plank Road
Clifton Park, New York 12065

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1.0 OVERVIEW

Gradient Corporation (Gradient) prepared a report on behalf of Halliburton Energy Services, Inc. (HESI), to assess the human health risk associated with hydraulic fracturing fluid additives used in the development of natural gas resources in the Marcellus and Utica shales. Gradient assessed the long-term risks to human health resulting from potential contamination of drinking water resources including impacts to ground water resulting from the migration of hydraulic fracturing fluids from the Marcellus shale to overlying drinking water aquifers; impacts to ground water resulting from surface spills or releases of hydraulic fracturing fluids or flowback water; and impacts to surface water resulting from surface spills or releases of hydraulic fracturing fluids or flowback water.

The scenarios that were considered are summarized on the following table.

Release Scenario	Hypothetical Release Volume (gallons)	Estimated Dilution-Attenuation Factor (DAF) at Exposure Point	Comments
Diffuse surface spills/releases to shallow ground water	32,240	1,170 - 3,888	Release volume is cumulative amount released through incidental spills occurring over a one-year period and assumes engineering controls and mitigation measures are not in place.
Diffuse surface spills/releases to surface water	32,240	59,000 - 600,000	Release volume is cumulative amount released through incidental spills occurring over a one-year period and assumes engineering controls and mitigation measures are not in place.
Acute surface leak to shallow ground water	8,500	1,325 - 4,620	Release volume is based on a hypothetical spill resulting from a one-time equipment malfunction and assumes engineering controls and mitigation measures are not in place.
Acute surface leak to surface water	8,500	--	Release scenario is assumed to result in no long-term exposure potential, thus DAF is not quantified.
Well casing leaks to shallow ground water	--	--	Release scenario is considered unlikely based on well drilling and installation practices and established and proposed mitigation measures. Release volume and DAF are not quantified.
Upward migration of fracturing fluid to shallow fresh water aquifers	--	1,650,000 - 8,700,000	Pathway is assumed to be theoretically possible, but highly unlikely based on existing geologic evidence. Regardless, DAF is estimated for comparison purposes.

Gradient presents potential spill scenarios that theoretically might result in impacts to surface water and/or ground water, and the associated long-term risks to human health based on those "worst-case" conditions. The hypothetical releases and scenarios evaluated by Gradient are based on single events or incidents during the specified time periods. Gradient's report concludes that the potential human health risks associated with reported hydraulic fracturing fluid additives and flowback constituents via drinking water and household water use are expected to be insignificant relative to state and federal guidelines.

The analyses presented by Gradient are not intended to represent, and in Alpha's opinion, do not represent, events that could be extrapolated to represent reasonably foreseeable, multiple, cumulative, impacts. Alpha's review of Gradient's report is limited to evaluating the accuracy and completeness of Gradient's conceptual physical, geological and hydrogeological model and release scenarios. It is Alpha's understanding that review of the remaining portions of Gradient's report, including toxicity evaluation and human health risk characterization, will be conducted by others at the request of the NYSDEC.

2.0 COMMENT #1

Sections 3.0 4.1, and 4.2.1 of Gradient's report outline Gradient's conceptual model and their rationale and assumptions used to select potential "uncontrolled" release scenarios that could result in contamination of drinking water sources by hydraulic fracturing fluid additives or flowback water at levels that would exceed health-based standards or guidance. The release scenarios considered are:

- Occasional diffuse surface leaks or spills during hydraulic fracturing fluid or flowback water handling that could result in impacts to surface water and/or ground water resources.
- Acute spills or releases during the injection of hydraulic fracturing fluids, including surface releases by pipe/pump releases and subsurface releases by well casing leaks.
- Potential upward migration of hydraulic fracturing fluid additives that remain in the Marcellus shale after fracturing to overlying shallow aquifers.

The evaluation of release scenarios is the basis for the pathway and exposure analysis presented in subsequent sections of Gradient's report.

2.1 Accuracy and Completeness

Diffuse Surface Spills

Gradient provides a rationale and estimates volumes of hypothetical releases to ground water and surface water from diffuse occasional spills that may occur during hydraulic fracturing fluid or flowback water handling. The releases are considered diffuse because the releases are assumed to occur in relatively small quantities anywhere on the drilling pad during an assumed one-year period. Gradient's assumptions generally can be viewed as conservative (i.e., overestimated spill volumes). For example, it is assumed that the well pad will contain eight wells and that no institutional and engineering controls are in place, such as secondary containment and required setbacks; therefore, the assumed conditions may be considered complete but may not be accurate or reasonable.

The estimates may be reasonably conservative (*i.e.* health-protective) for a one-time event at one well pad for the purpose of estimating exposure concentrations for "worst-case" conditions and is not intended to represent typical exposure levels. Extrapolation of the results may grossly overestimate cumulative impacts and may be considered unreasonable for that purpose.

Acute Releases During Fracturing

Gradient discusses two potential acute release scenarios: surface releases resulting from pipe/pump leak during downhole fracturing and subsurface releases resulting from casing failure during fracturing. Gradient concludes that the casing failure scenario is not likely to occur in a properly designed and installed casing; therefore, exposure pathways and risks are not quantified.

Gradient estimates the potential volume of a release to surface water and ground water resulting from a rupture of piping or a pump failure. The estimate is based on conservative assumptions of pumping rates and a lack of institutional and engineering mitigation controls, such as secondary containment. The estimate may be reasonably conservative for a one-time event at one well pad for the purpose of estimating exposure concentrations for "worst-case" conditions and is not intended to represent typical exposure levels. Extrapolation of the results may grossly overestimate cumulative impacts and may be considered unreasonable.

Potential Upward Migration from Marcellus Shale

Gradient assesses the potential for hydraulic fracturing and ambient fluids to migrate from the Marcellus shale through the overlying bedrock and into shallow fresh ground water aquifers. Both the fracturing period and production periods are considered. Gradient concludes that both scenarios are implausible, consistent with ICF (2009) findings (page 30). Gradient acknowledges ICF's conclusion that the migration pathway is implausible, and that ICF's analysis is overly conservative. ICF's simplifying and conservative assumptions include (pages 24 – 25):

- The Marcellus Shale remains under fracturing pressure until pressure within the formation stops changing with time (steady state), which would take an "indefinitely long period of time." "[I]n reality, the HF pressure is only applied for one or two days and 'steady state' is not likely to be achieved."A range of hydraulic conductivities from 10^{-7} to 10^{-9} cm/s when typical values would be in the range of 10^{-7} to 10^{-11} cm/s;
- The complete drawdown of a 1,000-foot well;
- A minimum Marcellus depth of 2,000 feet below ground surface, when the typical depth in the targeted area is from 4,000 to 8,500 feet.;
- Potable aquifer depths up to 1,000 feet deep, which is deeper than the 850 foot reported typical depth in southern NY; and
- Ignored attenuation due to adsorption, dispersion, dilution, and biodegradation.

2.2 Supporting Information

Diffuse Surface Spills

Gradient's estimated diffuse surface release volume is based on an assumed percentage loss of the total flowback volume. The estimated total flowback volume per well is based on a total of 4,030,000 gallons HF fluid per well reportedly anticipated by HESI and an estimated flowback recovery rate of 20%. The total HF fluid volume is less than the 5,000,000 gallons estimated in the dSGEIS (p. 6-56), but within the range reported elsewhere in the dSGEIS (p. 5-92). The flowback recovery rate is based on the range reported in the dSGEIS (p. 5-97) and by the SRBC (2009); therefore, the flowback volumes are a reasonable estimate, based on the available data.

The estimated spill volume (64,480 gallons) is estimated based on an arbitrary 1% of the flowback volume. This may be a reasonable assumption based on the nature of the assumed spills which includes incidental releases from multiple sources such as transfer piping, surface impoundments, and storage tanks. Gradient further assumed that 50% of the 64,480 gallons is released directly to surface water and 50% is released to ground water.

Acute Releases During Fracturing

Gradient concludes that subsurface releases resulting from casing failures during hydraulic fracturing is not reasonably likely to occur. Their conclusion is based on a study conducted by the American Petroleum Institute (API) that estimated the probability of casing failures during the waste disposal operations in properly constructed waste disposal wells is fewer than 1 in 50 million wells.

Also, it should be noted that while wellbore construction is addressed in the existing GEIS, some enhancements to well construction are proposed in the dSGEIS because of the high pressures exerted during hydraulic fracturing. The amended casing and cementing requirements are outlined in Section 7.1.4.2 (Sufficiency of As-Built Wellbore Construction) of the dSGEIS. These requirements are repeated in Appendix 10 (p. ci), *Proposed Supplemental Permit Conditions for High-Volume Hydraulic Fracturing*. Supplementary permit condition #31 proposes the use of a *Pre-Frac Checklist and Certification* (Appendix 20) which must be received by NYSDEC at least 48 hours before the commencement of high-volume hydraulic fracturing operations. Current *Supplemental Permit Conditions* for wells in primary and principal aquifers are included in dSGEIS Appendix 9. Additionally, Appendix 8 lists *Casing & Cementing Practices Required for All Wells in NY*. It is important to note that these requirements are attached as permit conditions to every well permit issued (Sanford, K.; June 10, 2010; personal communication). NYSDEC's current well permit form requires submission of a casing and cementing plan with every well permit application as follows:

> On attached sheet give details for each proposed casing string and cement job including but not limited to: Bit size, casing size, casing weight and grade, TVD and TMD of casing set, scratchers, centralizers, cement baskets, sacks of cement, cement additives with percentages or pounds per sack, estimated TVD and TMD of top of cement, estimated amount of excess cement and waiting-on-cement time (Sanford, K.; June10, 2010; personal communication).

Additionally, an applicant's proposed casing and cement plan is subject to NYSDEC review before a permit is issued. The purpose of the stringent casing requirements, supplemental permit conditions, and NYSDEC review is, in part, to mitigate the potential for failures during hydraulic fracturing.

Gradient estimates the release volume (17,000 gallons) resulting from a hypothetical aboveground equipment malfunction based on an injection rate of 3,400 gallons per minute (gpm). This is consistent with the 3,000 gpm reported in the dSGEIS (Section 5.9). It is assumed that the leak is detected and shut down within five minutes. Gradient further assumed that 50% of the 17,000 gallons is released directly to surface water and 50% is released to ground water. These assumptions appear reasonable and conservative since liquid surface releases of that magnitude would be highly visible and readily indicated by loss of pressure and/or flow.

Potential Upward Migration from Marcellus Shale

Gradient concludes that upward migration of hydraulic fracturing fluid additives from the Marcellus to overlying fresh water aquifers via rock pores or fractures is highly unlikely. Gradient's conclusion is based on baseline geologic evidence and physical controls on the hydraulic fracturing process and fracture growth.

The baseline geologic evidence that fluid migration to overlying fresh water aquifers cited by Gradient include studies that show that the Marcellus shale has remained isolated from overlying formations for millions of years. This position is consistent with other sources reviewed by Alpha and referenced below. The primary evidence that overlying rock layers of 1000 feet thickness or greater possess such low permeability and create a barrier between the gas producing target zones and ground water aquifers are the facts that these units are "overpressured" and that natural gas and saline water has remained trapped in these formations for millions of years (API, 2009; GEIS p. 5-4; USDOE, 2009). Overpressuring occurs where fluid pressure cannot be transmitted through permeable beds to the surface (Selley, 1998) and can only be maintained if there is no hydraulic connection.

The Devonian shales north of approximately the Pennsylvania-West Virginia border are generally considered over-pressured (Billman, 2008). Reservoir pressure data for the Marcellus in New York is limited. Eight research wells were completed in the Marcellus in 1983, which had reported pressure gradients of 0.46 to 0.51 psia/ft, which is greater than the hydrostatic pressure gradient of 0.433 psia/ft (Hill, et al, 2002). Industry representatives report that the Marcellus shale is slightly to moderately overpressured in northern Pennsylvania and anticipate that similar conditions will be found in New York State (Chesapeake, 2009; East, 2009).

A second pathway considered by Gradient is migration along faults and fractures that intersect the Marcellus or induced fractures that extend beyond the target formation. Physical controls limiting the growth of induced fractures include in-situ stresses exerted by the rock mass, which control the orientation of fractures and the contrast between adjacent rock layers. The extent that the induced fracture will propagate in the vertical direction beyond the target formation is controlled by contrasting physical properties of adjacent stratigraphic units. This contrast will limit the vertical growth of a fracture because it either possesses sufficient strength or elasticity to contain the pressure of the injected fluids (API, 2009). Engineering controls to limit fracture growth are discussed in the dSGEIS (Section 5.8.2).

2.3 Mitigation Measures

Gradient did not propose mitigation measures relative to this comment.

2.4 Proposed SGEIS Revisions

Gradient does not propose revisions to the dSGEIS. HESI, however, states in the cover letter accompanying Gradient's report that the dSGEIS does not sufficiently address the fact that the very low permeability of the many layers of rock and sediment between the Marcellus Shale and any potential freshwater aquifer is the most significant factor limiting the subsurface migration of hydrofracturing fluids from the target formation to overlying aquifers (Baker Botts LLP, 2009). Alpha suggests that the NYSDEC consider including and discussion this information in section 5.11 of the dSGEIS.

The existing ground water pathway and migration analysis by ICF generally assumes more conservative conditions, as listed in Section 2.1 above. Impacts to surface water and ground water resources from hydraulic fracturing fluid additives or flow back water via surface spills, drilling and fracture procedures, and migration from the target formation are already discussed in dSGEIS Sections 6.1.3 (surface spills and releases at the well pad), 6.1.4 (ground water impacts from well drilling and construction), and 6.1.5 (hydraulic fracturing procedure). The corresponding mitigation measures are presented in Sections 7.1.3 (surface spills), 7.1.4 (ground water impacts), and 7.1.5 (hydraulic fracturing).

3.0 COMMENT #2

Gradient report Sections 4.2.2 through 4.2.6 outline the quantification of dilution that would theoretically occur under "worst-case" conditions favoring migration of fluids from the target fracture zone to overlying fresh water aquifers. Gradient deems this exposure scenario as implausible. Regardless, Gradient estimates dilution and attenuation factors to place potential risks to human health in perspective.

Gradient concludes that:

- Fluids in the Marcellus shale are hydraulically isolated from overlying formations under ambient conditions and do not migrate to fresh water aquifers.
- Hydraulic fracturing is not expected to result in the creation of a hydraulic connection between the target fracture zone and fresh water aquifers.
- Hydraulic fracturing fluids left behind in the formation after the stimulation phase are expected to either migrate towards the well or remain trapped in the hydraulically isolated Marcellus.
- Even if the above conclusions do not hold, dilution and attenuation would sufficiently reduce concentrations to below health-based standards.

3.1 Accuracy and Completeness

The approach used by Gradient to estimate dilution and attenuation factors (DAFs) is consistent with the approach used by ICF to evaluate seepage of hydraulic fracturing fluids and deep formation water into overlying fresh water aquifers. The two approaches differ in the assumptions used to estimate parameters used in the calculations.

The assumptions used by Gradient include:

- There is a direct hydraulic connection between the Marcellus and the overlying aquifers.
- Hydraulic conductivity of 10^{-9} cm/s for units between the Marcellus and the fresh water aquifers.
- The head in the Marcellus is equal to reservoir pressure estimated to be 1,200 psi at 2,000 feet below the ground surface.
- Chemical retardation of hydraulic fracturing fluid additives is not considered.

Gradient's approach considers only the situation where a gas well is drilled to the minimum allowable depth of 2,000 feet (i.e., the minimum separation of 1000 feet between an overlying aquifer), unless a site-specific environmental assessment is performed (dSGEIS Section 3.2.3. This condition represents a worst-case scenario. The depth to the Marcellus can be more than 6,000 feet in southern New York and the Utica shale is up to 10,000 feet (dSGEIS Chapter 4); therefore, Gradient's conceptual model represents only a fraction of the actual conditions in New York State where the separation between the Marcellus shale and fresh water aquifers will be greater than 1,000 feet. The assumption that hydraulic conductivity in the overlying units is the same as that estimated for the Marcellus (10^{-9} cm/s) may underestimate the effective hydraulic conductivity of the variable bedrock units. The assumed conditions for this scenario may be considered complete but may not be accurate, but an assumption was necessary to estimate DAFs. Freeze and Cherry (1979) report that the median hydraulic conductivity for shale is 10^{-9} cm/s. Gradient used this number as an estimation of the effective hydraulic conductivity of the variable bedrock units. Gradient is very conservative with all other aspects of its representation of the subsurface between the Marcellus Shale and overlying aquifers. The conclusions are considered valid based on the overall conservative nature of the scenario representation.

3.2 Supporting Information

The support for Gradient's conclusion that the Marcellus shale is hydraulically isolated from overlying aquifers is discussed above in Section 2.2 of this review. It was necessary for Gradient to make assumptions to calculate estimated dilution attenuation factors. Gradient's estimated dilution attenuation factors are based on an assumed hydraulic conductivity of 10^{-9} cm/s, which is four orders-of-magnitude less than the maximum hydraulic conductivity used by ICF (10^{-5} cm/s) (dSGEIS Appendix 11). Gradient's value is based on the median of the reported range for typical shales of 10^{-7} cm/s to 10^{-11} cm/s reported by Hornberger et al. (1998). The value used by ICF considers a range of values from 10^{-8} cm/s to 10^{-5} cm/s that is supported by the fact that the rocks overlying the Marcellus include alternating layers of shale, sandstone, and limestone so that the average hydraulic conductivity of the intervening layers will be influenced by varying hydraulic properties of the rocks that are present. For this reason, Gradient's DAF estimate may overestimate dilution under this "worst-case" scenario and be less conservative than that assumed by ICF. This does not affect the validity of any conclusions, because the scenario representation is extremely conservative overall. ICF also concluded that a migration pathway of fracture fluid additives from the Marcellus to overlying aquifers is implausible.

Gradient acknowledges that hydraulic head and gradient data for Marcellus shale in New York is not available and relies on estimates of a reservoir pressure gradient of 0.6 psi/ft, which is reported in the dSGEIS. This assumption may overestimate the actual reservoir pressure, calculated hydraulic gradient, and DAF because their analysis assumes the same pressure conditions exist throughout the overlying strata to the surface.

The exclusion of a chemical retardation factor in Gradient's estimate is consistent with the approach used by ICF. This conservative approach underestimates the DAF, because dissolved contaminants tend to migrate slower than the ground water due to various chemical and physical factors such as dispersion and interaction with the rock matrices.

3.3 Mitigation Measures

Gradient did not propose mitigation measures relative to this comment.

3.4 Proposed SGEIS Revisions

Gradient does not propose revisions to the dSGEIS.

Alpha proposes no revisions to the dSGEIS based on this comment. The existing analysis by ICF generally assumes more conservative conditions, as listed above in Section 2.1 of this narrative. Impacts to ground water resources from hydraulic fracturing fluid additives resulting from migration from the target formation already are assessed in the dSGEIS (Section 6.1.4 and Appendix 11). Mitigation measures are included in Sections 7.1.4.

4.0 COMMENT #3

Gradient estimates DAFs for diffuse and acute surface releases to shallow ground water using an established fate and transport approach. The two scenarios differ only in the volume of the release and the area over which the release is distributed. Both scenarios result in a zone of soil contamination that could leach to shallow ground water.

4.1 Accuracy and Completeness

Gradient states their approach to fate and transport is consistent with the approach that is generally accepted by scientists and regulatory agencies. The two-step process considers vertical migration from the release point through the unsaturated soils to the water table and horizontal transport from the water table to a water supply well. Chemical-specific pore water dilution is calculated, which accounts for fractionization between pore water and adsorption to soil during the leaching phase. Gradient calculates separate DAFs for the vertical leaching component (18 to 222) and horizontal ground water migration component (15 to 132). The resulting combined, overall, DAFs range from 1,170 to 4,620.

4.2 Supporting Information

No specific references are made other than to readily available USEPA published data for recharge rates, hydraulic conductivity, and gradient. Gradient's derivations of the variables used to estimate advection-dispersion through the unsaturated zone are included as Appendix A of their report. The values and equations used are reasonable and calculations are accurate, based on the supporting published information.

4.3 Mitigation Measures

Gradient did not propose mitigation measures relative to this comment.

4.4 Proposed SGEIS Revisions

Gradient does not propose revisions to the dSGEIS.

Alpha proposes no revisions to the dSGEIS based on this comment. The existing analysis by ICF generally assumes more conservative conditions, as listed in Section 2.1 above. Impacts to surface water from spills and releases at the well pad are already included in the dSGEIS in Section 6.1.3. Mitigation measures are included in Sections 7.1.3.

5.0 COMMENT #4

Gradient estimates DAFs for surface water exposure pathways in Section 4.4. The acute spill scenario is not quantified because Gradient assumes the effects of an acute spill on surface water quality are short-lived, while their risk-based evaluation to human health is based on long-term exposure. Surface water DAFs for the chronic spill scenario were estimated between 59,000 and 600,000.

5.1 Accuracy and Completeness

Gradient considers the case of diffuse surface releases that may impact surface water quality. The approach assumes that engineering controls and mitigation measures outlined in the dSGEIS are not employed. This approach conservatively overestimates exposure concentrations.

5.2 Supporting Information

Section 4.1.1 of Gradient's report quantifies a diffuse release volume of 32,240 gallons over one year, which is discussed in Section 2.0 of this review. The surface water flows used by Gradient were estimated based on available data from the USGS National Water Information System Website (NWIS).

5.3 Mitigation Measures

Gradient did not propose mitigation measures relative to this comment.

5.4 Proposed SGEIS Revisions

Gradient does not propose revisions to the dSGEIS.

Alpha proposes no revisions to the dSGEIS based on this comment. Impacts to surface water from spills and releases at the well pad are discussed the dSGEIS Section 6.1.3. Mitigation measures are presented in Section 7.1.3.

6.0 LIST OF REFERENCES

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