Desert Research Institute

Science Environment Solutions

Preliminary Assessment of Hydraulic Fracturing Fluid Concentrations and Hydrologic Conditions in Noble Development Area #2, Upper Humboldt River Basin

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INTRODUCTION

This report describes the hydrologic conditions and concentration analysis for hydraulic fracturing fluids proposed for use in boreholes in the Noble Lease Area #2, located in the upper Humboldt River Basin. The report is the initial step in evaluation of potential for subsurface migration of hydraulic fracturing fluids and a hydrogeologic conceptual model for the Basin.

This report represents the first of three reports that will be developed by the Desert Research Institute (DRI) as part of the Aquifer Quality Assessment Program (AQUA Program). The overarching goal of the AQUA Program is to analyze the potential fate and transport of hydraulic fracturing fluids and consists of three phases:

1. Maximum amount of chemicals to be used in a single stage of stimulation treatment and hydrologic conditions
2. Intermediate phase to document the results of the water quality monitoring
3. Numerical modeling of fracking chemical migration potential following hydraulic fracturing

This report details the results of Phase I. It is important to note that a groundwater flow and transport model will be developed in Phase III. The modeling framework will allow DRI to synthesize all of the subsurface data and create an estimate of the migration potential of hydraulic fracturing fluids. Thus, this report does not represent DRI's interpretations or conclusions regarding migration potential.

Noble Energy is beginning exploration activities in three locations within Elko County, NV (Figure 1). The oil play is expected to be in low permeability shale and will require hydraulic fracturing. The purpose of this first report is twofold:

1. To provide estimates of existing hydrologic conditions in the target zones of the first exploration well, which is anticipated to consist of Tertiary aged strata including the Humboldt and Elko formations.
2. To develop an estimate of chemical mass anticipated to be pumped in a single stage of the stimulation treatment without accounting for liquid recovery during the production phase of the well.

HYDROGEOLOGY

The upper Humboldt River Basin consists of several deep structural basins in which alluvial/fluvial deposits of Tertiary and Quaternary age and volcanic rocks of Tertiary age have accumulated. Figure 2 shows the surficial geology near Noble's Lease Area #2 (Stewart and Carlson, 1978). The key surficial units near Area #2 include the metamorphosed limestone in the Ruby Mountains, the alluvial (basin-fill) and sandstone deposits. The bedrock of each basin and adjacent mountains are composed of carbonate and clastic sedimentary rocks of Paleozoic age, and crystalline rocks of Cambrian, Jurassic, and Tertiary age. Target depths for the exploration wells are in the 6,000 to 12,000 feet below ground surface.

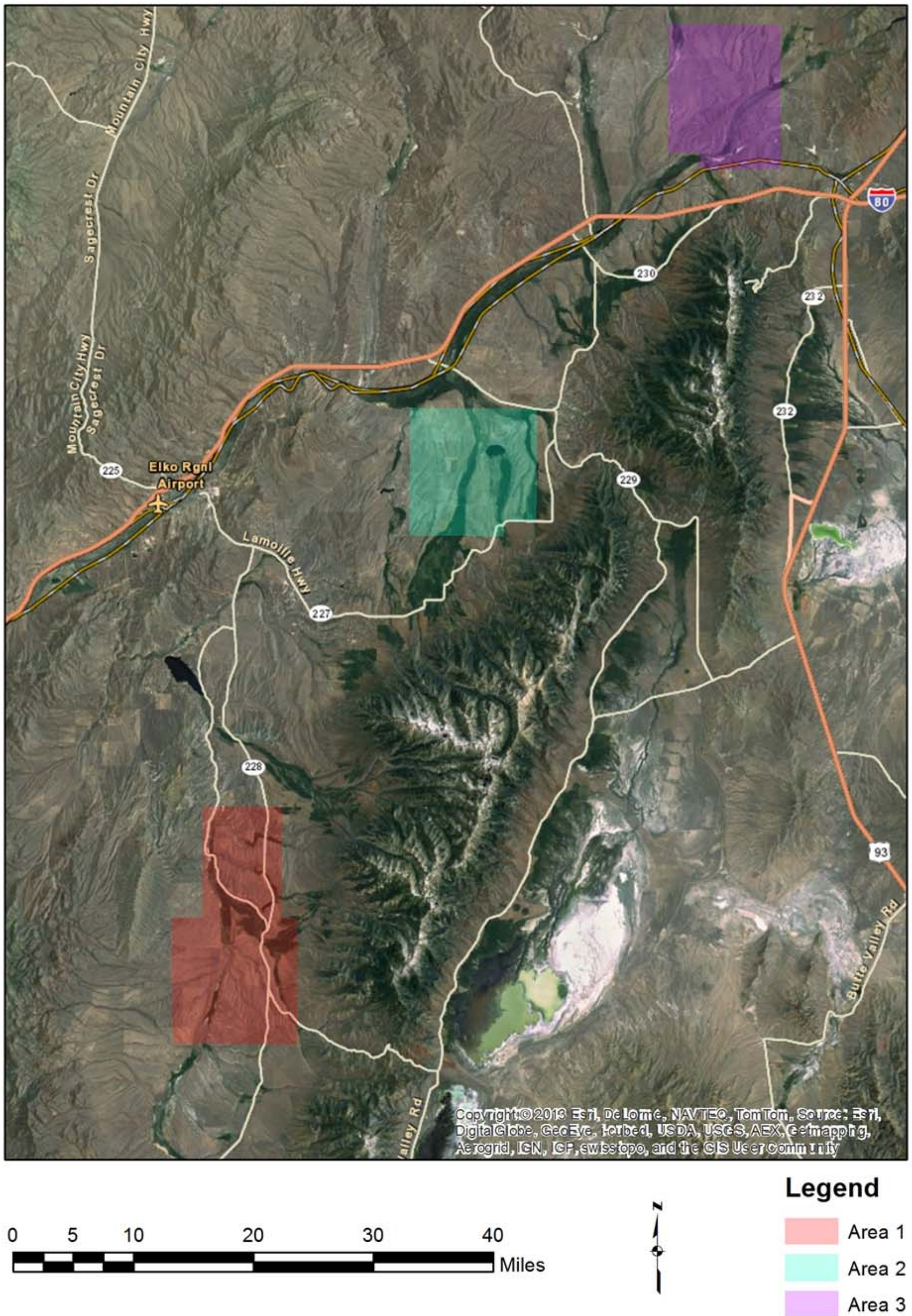

Figure 1. Location of Noble Energy's Humboldt Basin exploration areas.

This region of the Great Basin Province is known to be in an extensional structural environment. The valley is bounded by a listric range front fault to the east of Area 2. Listric faults are common in extensional environments.

Previous investigations have identified three hydrogeologic units of high permeability and three with lower permeability. The low permeability units include (1) clastic sedimentary rocks; (2) crystalline rocks which include granitic intrusives and metamorphic rocks; and (3) volcanic rocks. The high permeability units include (1) carbonate rocks; (2) younger (Quaternary age) basin-fill deposits; and older (Tertiary age) basin-fill deposits. Previous deep oil exploration efforts in the Humboldt River basin suggest that carbonate rocks may be both above and below the resource zone with relatively high permeability (Plume, 2009).

Noble Lease Area #2 is located in hydrographic basin 045. The crystalline rocks within the Ruby Mountains tend to have low permeability and recharge to the groundwater system occurs at the base of the range. The lower permeability is further supported by the numerous perennial streams in the central and northern Ruby Mountains.

Previous hydrogeologic studies for the upper Humboldt River Basin have been limited to hydrogeologic conditions and flow directions in the shallow alluvium (Figure 3; Plume, 2009). The groundwater flow direction is generally to the northwest, away from the mountain front towards the center of the basin and the headwaters of the Humboldt River, a gaining stream along most of its length. Groundwater levels in the basin fluctuate with precipitation. Groundwater levels are relatively shallow (< 100 ft) within the valley.

Recent borehole logging by Noble has provided site-specific lithology, fracture, and porosity data with depth (Figure 4). Alluvium mixed with volcanics was observed in the borehole to more than 5000 feet below the surface with average porosity that declines from up to 0.5 to 0.2 with depth. Porosity fluctuates around 0.2 in the tuff and mixed alluvium/tuff that persists to more than 7500 feet. The shale unit at approximately 8000 feet also has porosity that fluctuates around 0.2. Underlying the shale is a carbonate unit with low (~0.03) porosity. Alluvial and shale units below 10,000 feet have porosity consistently below 0.15.

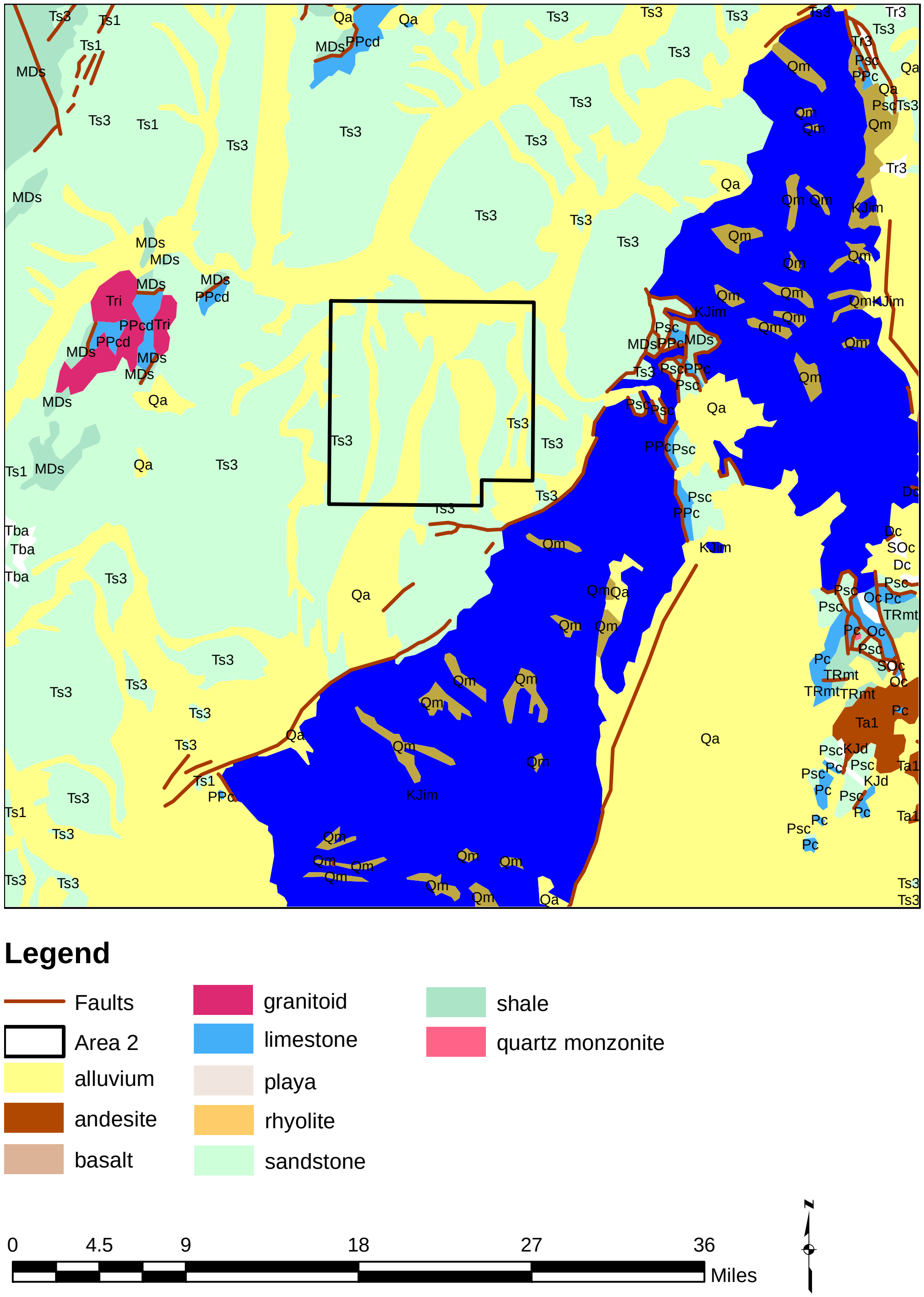

Figure 2. Surficial geology near Area 2 lease.

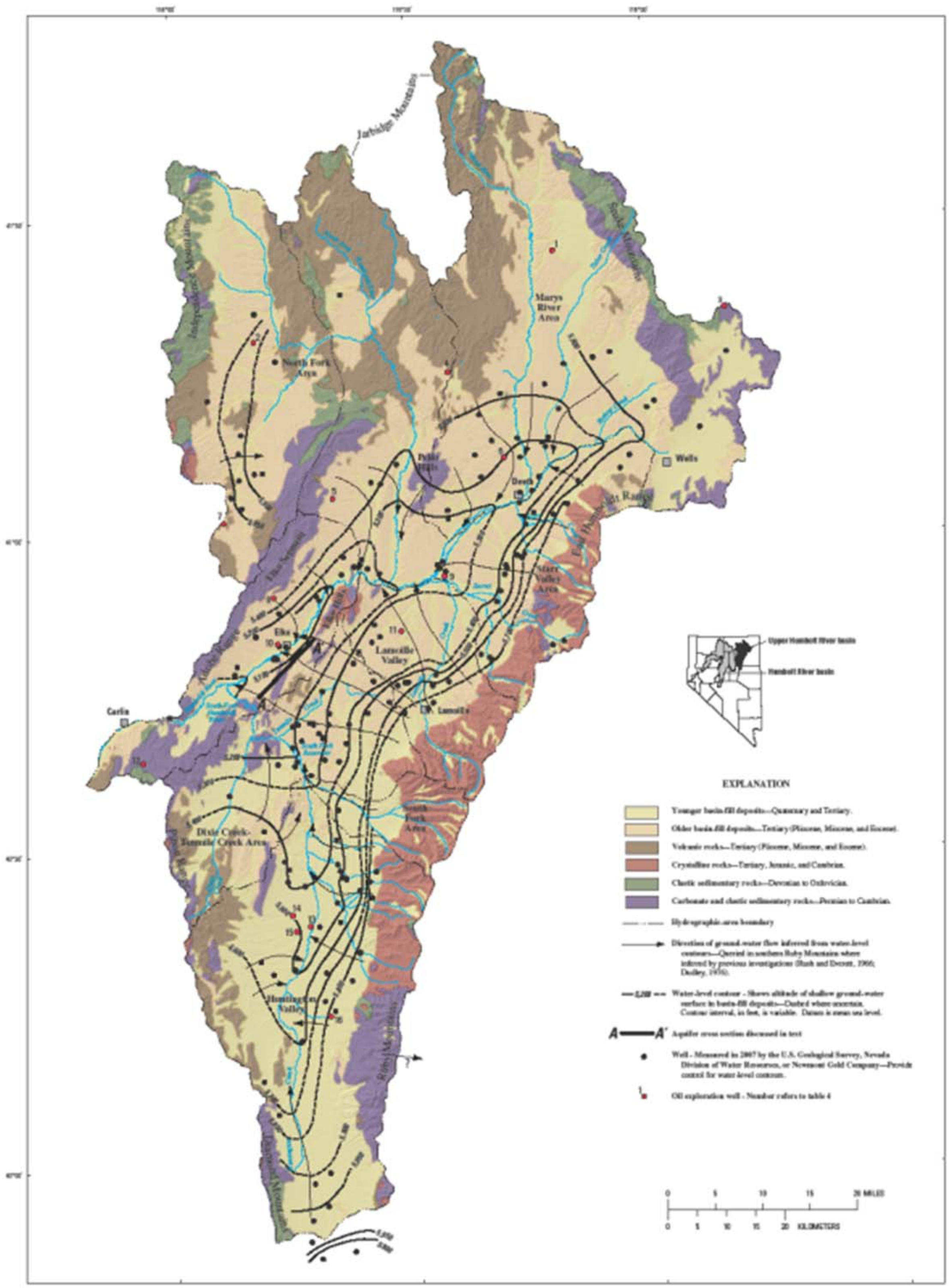

Figure 3. Upper Humboldt River Basin hydrogeologic conditions from Plume, 2009.

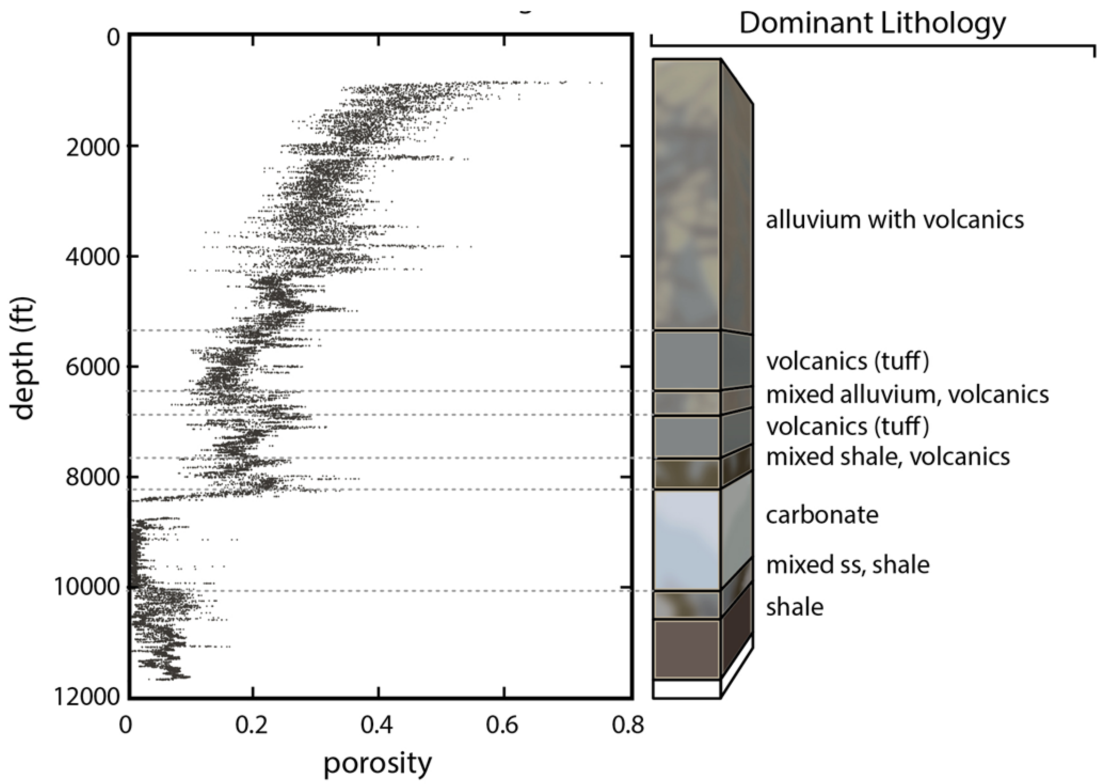

Figure 4. Dominant lithology and porosity with depth in a Noble borehole from Lease Area 2.

ANALYSES

Chemical mass and fluid volumes were supplied by Noble Energy as estimated from previous hydraulic fracturing operations (Table 1).

Overall migration potential for subsurface solutes is a function of subsurface physical characteristics such as the hydraulic gradient, hydraulic conductivity, and matrix porosity; however, migration potential for individual constituents will vary based on likelihood of 1) degradation and 2) sorption. Degradation potential for each constituent was determined through a literature review. Of the proposed constituents listed in Table 1, ammonium persulfate, 2,2-Dibromo-3-nitrilopropionamide, and formic acid are known to have the potential to degrade in the subsurface. Sorption potential was determined through review of known octanol-water partition coefficients (log K_{ow}- Table 1), a parameter related to a chemical's tendency to sorb to the organic fraction of the aquifer matrix. Log K_{ow} can range from -3 (low sorption potential) to 7 (high sorption potential). Sorption potential is not understood for many of the constituents in Table 1. Citric acid, 2,2-dibromo-3-nitrilopropionamide, triisopropanolamine, glycerin, and formic acid have low sorption potential, while the naphthalene portion of petroleum distillates is known to have moderate sorption potential.

Estimates of aquifer hydraulic and transport parameters are given in Table 2. Effective porosities for various depths were obtained from the nuclear magnetic resonance borehole tool collected for one of the Noble wells as summarized in Figure 4. Dispersion and hydraulic conductivity values were taken from the literature as appropriate for the hydrogeologic conditions that exist. Currently, the hydraulic gradient below the alluvium is unknown. Groundwater velocities were estimated using Darcy's Law

$$v = \frac{-K}{n} \nabla h, \tag{1}$$

where v is the average linear velocity, K is hydraulic conductivity, n is porosity, and ∇h is the hydraulic gradient. Velocity calculations incorporated formation-specific values and the shallow regional hydraulic gradient as defined by Plume (2009). Transport calculations should be based on both the average linear velocity and dispersion.

Table 1. Characteristics of chemicals proposed for Humboldt hydraulic fracturing operations.

Trade Name	Ingredient	Purpose	Mass (kg) chemical per 110,800 gal water	Maximum Concentration in hydraulic fracturing fluid (% by mass)*	log K_{oc}	Notes	Source of log Koc and Notes
GW-45LF	Petroleum Distillate (C10-C14 naphthenes, iso- and n-paraffin)	Gelling agent	254	0.50000%	3.1 (napth)		2
Hig Perm CRB	Ammonium Persulfate	Breaker	1793	0.25000%	unknown	Decomposed by moisture to form oxygen and ozone	3
HCL- 10.1-15%	Hydrochloric Acid	Acidizing	2698	0.10000%	unknown		
Inorganic Salt	Lithium Bromide	Chemical tracer	2.3	0.01000%	unknown		
Ferrotrol 300L	Citric Acid	Iron control	151	0.03600%	-1.2		
	Potassium Chloride	Clay Stabilizer	4082	1.00000%	unknown	stable	4
Frac-Cide 1000	2,2-Dibromo-3-nitrilopropionamide	Biocide	1837	0.00200%	1.81	Observed half-life in soil 4-24 hours through biotic and abiotic degradation.	5
XLW-22C	Triisopropanolamine	Crosslinker	1105	0.22500%	1	mixed results from degradation studies	6
BF-9L	Potassium carbonate	Buffer	307	0.05000%	unknown		
NE-945W	Glycerin	Non-emulsifier	454	0.10000%	0		6
CI-31	Formic Acid	Corrosion Inhibitor	2	0.00034%	Adsorption nominal	May be anaerobically degraded by microorganisms to form hydrogen, nitrogen, hydrogen sulfide, carbon dioxide and methane	1

1 Montgomery, J, 2007, Groundwater Chemicals Desk Reference, Taylor & Francis Group, LLC.
2 http://www.cdc.gov/niosh/ipcsneng/neng1379.html
3 http://hazard.com/msds/mf/baker/baker/files/a6096.htm
4 http://www.chemicalbook.com/ProductChemicalPropertiesCB9137176_EN.htm
5 PubChem Compound. USA: National Center for Biotechnology Information.
6 Hazardous Substances Data Bank; US National Library of Medicine

Table 2. Aquifer hydraulic and transport parameters

Aquifer Parameters	Value	Source
Shallow alluvium		
Hydraulic Conductivity	10^{-4} -10^{-2} cm/s	Representative of basin fill conductivities from Middle Humboldt Basin – Prudic, 2007
Porosity	0.35-0.45	Representative value from Noble borehole data
Hydraulic Gradient	0.004	Plume, 2009 - Humboldt River Floodplain
Longitudinal Dispersivity	1.5-3 m	Gelhar, 1986
Average Linear Velocity	0.4-40 m/yr	Darcy's Law
Volcanics overlying shale		
Hydraulic Conductivity	10^{-9} -10^{-5} cm/s	Domenico and Schwartz, 1990; Yucca Flat Phase I tuff parameter estimates
Porosity	0.2	Representative value from Noble borehole data
Hydraulic Gradient	<0.004	Expert judgment
Longitudinal Dispersivity	1.5-3 m	Gelhar, 1986
Average Linear Velocity	10^{-5} -10^{-1} m/yr	Darcy's Law
Shale		
Hydraulic Conductivity	10^{-12}-10^{-9} cm/s	Domenico and Schwartz, 1990
Porosity	0.2	Representative value from Noble borehole data
Hydraulic Gradient	<0.004	Expert judgment
Longitudinal Dispersivity	1.5-3 m	Gelhar, 1986
Average Linear Velocity	10^{-8}-10^{-5} m/yr	Darcy's Law
Carbonate		
Hydraulic Conductivity	10^{-6}-10^{-2} cm/s	Dettinger, et al., 1995, representative of K in Lower Carbonate Aquifers in Death Valley and NTS regional flow models
Porosity	0.03	Representative value from Noble borehole data
Hydraulic Gradient	<0.004	Expert judgment
Longitudinal Dispersivity	1.5-3 m	Gelhar, 1986
Average Linear Velocity	0.04-400 m/yr	Darcy's Law

SUMMARY

1. While many of the constituents listed in Table 1 are suspected to be irritants or toxic to humans and the environment, no environmental regulatory standards currently exist for their maximum acceptable levels in drinking water.
2. Based on Noble Energy estimates of injectate volume and chemical mass, the maximum concentration of injectate fluid is less than 1.0 percent. A literature review suggests that ammonium persulfate, 2,2-Dibromo-3-nitrilopropionamide, and formic acid will degrade in the subsurface with time. The characteristics and fate of their daughter products is not known. Studies on the degradation potential of triisopropanolamine have produced mixed results. Napthalenes, found in petroleum distillates, are known to have moderate sorption characteristics in the presence of dissolved organic carbon. The remainder of proposed hydraulic fracturing constituents has either unknown or very low sorption potential and is considered conservative for transport estimates.
3. The shallow hydraulic gradient in the Upper Humboldt Basin was previously observed to be approximately 0.004. Hydraulic head and gradients at target depths in the basin are currently unknown but are unlikely to exceed the shallow gradient. Estimates of porosity were obtained from Noble geophysical data, while representative values of hydraulic conductivity were taken from the literature. Based on these estimates of hydrologic variables, average linear velocities are estimated to be:

    - alluvium: 0.4-40 m/yr
    - volcanics: 10^{-5} -10^{-1} m/yr
    - shale: 10^{-8}-10^{-5} m/yr
    - carbonate: 0.04-400 m/yr.

    Given the large uncertainty expected for the transport parameters this analysis is not meant to be predictive but rather to inform general hydrologic conditions. Transport calculations should be based on both the average linear velocity and dispersion.

REFERENCES

Alpha Environmental Consultants, I. (2009), Technical consulting reports prepared in support of the draft supplemental generic environmental impact statement for natural gas production in New York state, Report, New York State Energy Research and Development Authority, Albany, N. Y. Environmental Protection Agency, 2013. Drinking Water Contaminants, Accessed April 12, 2013, http://water.epa.gov/drink/contaminants/index.cfm.

Belcher, W.R., and Sweetkind, D.S., eds., (2010), Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model: U.S. Geological Survey Professional Paper 1711, 398 pp.

Domenico, P. A., and F. W. Schwartz (1997), Physical and Chemical Hydrogeology, 2nd ed., 528 pp., Wiley.

Dettinger, M.D., J.R. Harrill, D.L. Schmidt, and J.W.Hess (1995), Distribution of carbonate-rock aquifers and the potential for their development, Southern Nevada, and adjacent parts of California, Arizona, and Utah: U.S. Geological Survey Water Resources Investigations Report 91-4146, 100 pp.

Fetter, C. W. (1994), Applied Hydrogeology, 691 pp., Prentice-Hall, Englewood Cliffs, NJ.

Frac Focus, 2013. What Chemicals are Used, Accessed April 12, 2013, http://fracfocus.org/chemical-use/what-chemicals-are-used.

Gelhar, L.W., 1986. Field –measured values of longitudinal dispersivity as a function of the scale of measurement. *Water Resources Research*, 22, 9: 135S—145S.

Plume, R.W., 2009. Hydrogeologic Framework and Occurrence and Movement of Ground Water in the Upper Humboldt River Basin, Northeastern Nevada, U.S. Geological Survey Scientific Investigations Report 2009-5014.

Prudic, D.E., 2007. Evaluating Cumulative Effects of Ground-Water Withdrawals on Streamflow. PhD Dissertation, University of Nevada, Reno.

Stewart, J.H., and J.E. Carlson, 1978. Geologic Map of Nevada (Scale 1:500,000), U.S. Geological Survey, Reston, Virginia.

Stoller-Navarro (2006), Phase I Hydrologic data for the groundwater flow and contaminant transport model of corrective action unit 97: Yucca Flat/Climax Mine, Nevada Test Site, Nye County, Nevada, 643 pp.