Technical Memorandum

To:	Margaret Ash, Peter Gintautas (COGCC)	**4143B**
From:	Susan Wyman, P.E., P.G.	
Date:	October 28, 2008	
Subject:	Technical Review of Methane Mitigation Well Aquifer Testing Report, prepared by Norwest Applied Hydrology Report for Petroglyph Energy, Inc.	

Whetstone Associates has reviewed the "Methane Mitigation Well Aquifer Testing Report" prepared for Petroglyph Energy, Inc. by Norwest Applied Hydrology (Norwest, 2008), and attended Norwest's presentation to the Colorado Oil and Gas Conservation Commission on September 29, 2008. We have prepared the following comments.

Overview

The Methane Mitigation Well Aquifer Testing Report (Norwest, 2008) describes pumping tests performed on three recovery wells and eight injection wells installed to mitigate and prevent the occurrence of methane in domestic water wells. The methane is derived from the upper Vermejo Formation, the source of production from Petroglyph's Little Creek Field, although the methane migration pathways from the Vermejo Formation into water wells completed in the overlying Poison Canyon Formation have not been identified.

The report provides a good description of the mitigation well locations and the pumping tests conducted. Backup information is provided for the pumping tests, including water level measurements, pumping rates, aquifer test analysis, gas flow rates measured during the pumping tests, and the laboratory analytical results for water samples collected near the end of each pumping test. Additional information about mitigation well drilling is available from Petroglyph's monthly reports, which are posted on the COGCC website. Cross sections and/or fence diagrams have not been provided, although Norwest stated that these were being prepared for use in groundwater modeling of the mitigation system.

Overall, the Methane Mitigation Well Aquifer Testing Report (Norwest, 2008) provides sufficient information to determine whether Phase I investigations should continue, and what additional data collection might be useful during the investigation. The next steps in the Phase I investigation include pumping groundwater from the Poison Canyon Formation, separating gas from the water, and injecting the treated water into the same formation, under gravity flow.

Specific Comments

Section 2.1 Geology and Hydrogeology

The report erroneously states that USGS Water-Supply Paper 1805 (McLaughlin, 1966) "discussed the limitations of the Poison Canyon Formation as a water source including the fact that yields from the aquifer were small and the use of the aquifer for water supply would be subject to perennial water shortages." In fact, McLaughlin (1966) stated that all of Huerfano County is subject to perennial water shortages. Taken out of context, McLaughin's words imply that the Poison Canyon Formation is a small and unreliable source of water. Instead, the Poison Canyon Formation is identified as one of the principal aquifers in Huerfano County (Attachment 1). In a county that "is faced with almost perennial water shortages" the principal aquifers should be recognized and protected, not trivialized, in spite of the fact that aquifer yields are variable. In a county plagued by drought, all of the aquifers are significant.

Section 2.3 Investigation and Remediation

The Phase 1 remediation involves creating a hydraulic gradient from the outer ring of injection wells toward the pumping wells. Clearly, groundwater will flow toward the pumping wells in response to the induced hydraulic gradient. Dissolved methane will be transported with groundwater toward the pumping well. How will free methane respond? What percentage of gas is expected to respond to a hydraulic gradient?

Section 3.1 Testing Description

Table 3.1-1 lists the Rec 1 Kittleson well twice. This implies that there were two different wells, when actually there is one well (with two pumping tests conducted). Although the Inj 06 Masters well was tested twice and the Inj 04 Rohr well was tested three times, these wells are not listed multiple times in Table 3.1-1. Please explain the specific reasons for re-testing each well? Why do the two tests conducted on the Rec 1 Kittleson well require it to be listed as two separate wells in Table 3.1-1?

Section 4.0 Testing and Monitoring Procedures

Third paragraph (Page 4-1). The sentence "…long term pumping tests were conducted over a continuous 12-hour time span" should add "in eight of the 11 wells tested," since the Rec 04 Barrett, Inj 07 Walden, and Inj 08 Haeffner were pumped for approximately 5, 6, and 2 hours, respectively.

The second paragraph on Page 4-2 states that water quality samples were collected for "…constituents listed as regulatory standards." The report should list the applicable standards, or the basis for selecting the analytical suite (e.g. EPA Class V Injection parameters). It is not clear from the report whether the applicable standards are based on total or dissolved metals in groundwater.

Section 5.0 Testing and Monitoring Data Analysis

Section 5.1 Water pressure data. The text uses the term "connection" instead of "response" to describe the effects of pumping on various observations wells and concludes that "…there is no distinct connection during the aquifer tests performed". It is incorrect to assume that because an observation well located 1,000 to 4,000 feet from the pumping well did not respond to a relatively short duration (12-hour) and low flow (0.2- to 27-gpm) pumping test. Although most observation wells showed no hydraulic response, the wells were not pumped hard enough or long enough to demonstrate that there is no connection.

The figure on Page B-4 seems to indicate that observation well Rec 03 PEI responded to pumping from Rec 1 Kittleson. Observation wells commonly exhibit a delayed response to pumping, and the data from Rec 03 PEI should be analyzed using Aqtesolv or other analytical tools. This observation well could provide an aquifer storativity value for use in the groundwater model.

The upper zone of POCI55 demonstrated a trend of increasing water pressure/level throughout the testing. Figure on page B-2 indicates that water pressure (level) increased about 2 psi (4.65 feet) from July 3rd to August 13th, as the tests were conducted. The POCI 55 monitoring well is located relatively close to one of the removal wells. What factors might account for the increasing water level in the POCI55 well during pumping tests at nearby wells?

Section 5.3 Water Quality Analysis. The report states that the water quality sample results will be used to describe the baseline water quality of the Poison Canyon Formation, prior to startup. It should be acknowledged that one sampling event may not be adequate to determine baseline. Typically, eight sampling events are required to provide a statistically valid mean and standard deviation of concentrations in a given well.

The report does not fully describe how the baseline water quality data will be used to determine water quality changes that might occur from the mitigation program. Recognizing that some inherent variability in water quality exists in multiple sampling events, how will normal variability be differentiated from real changes in water quality that may result from operation of the mitigation system? Will a mean plus two standard deviations serve as the level beyond which a change in water quality is assumed? Or will an upper confidence level of the baseline data be determined, and if so, which wells will be used to determine the UCL?

Although the raw laboratory data are provided for three domestic wells and nine mitigation (injection/recovery) wells, no statistical analysis of baseline water quality has been provided. The text states that the water quality was evaluated using AquaChem® software and ExcelStatPro, however, the tabulated statistics are not provided.

The occurrence of organic constituents such as 1,1,2-TCA, benzene, ethylbenzene, chloroform, xylenes, toluene, and naphthalene may indicate that the wells were not fully developed. Similarly, the aquifer pumping test results indicate that several wells were not fully developed at the start of pumping, and development improved over time. Why weren't the wells developed prior to the pumping test, and how do we know the wells are adequately developed now? What are the consequences of starting the injection program in wells that are not adequately developed?

Section 5.3.2.2 Water Quality of the Poison Canyon Aquifer. TDS and electrical conductivity are plotted in Figure 5.3.2.2-1, and wells Barrett, Walden and Gonzales clearly plot on a distinctly different trendline from the remaining six wells. The text attributes the difference in TDS-conductivity ratio and the higher metals concentrations to lower well yields and very small purge volumes. This may be true of the Barrett and Walden wells, which had very low yield and were probably not developed adequately because those low flow rates. The Gonzales well, in contrast, had the fourth highest pumping rate (2.46 gpm). However, the water sample from the Gonzales well had very high total suspended solids (TSS of 122 mg/L) which may indicate problems with well completion. Because total metals were analyzed in the groundwater samples, the high suspended solids could have included clay particles with associated (sorbed) metals. TSS is not listed in Table

5.3.2.1-1, but is shown in the laboratory data sheets. TSS concentrations in the water sample from the Gonzales well was 8- to 40-times the TSS concentrations in other samples, and exceeded the generally acceptable levels for representative samples from monitoring wells. If the high TSS is a result of problems with well completion, the mitigation program should consider whether there may be any negative consequences of injecting water into this well.

Section 5.3.2.3 Injection and Recovery Well Water Quality Comparison. Figure 5.3.2.3 shows the test pumps set below the bottom screen in injection wells Inj 01, Inj 03, and Inj 04. Although higher well yields generally result from greater drawdown, and setting the pump at the bottom of the well allows for maximum drawdown, if the water level in the aquifer is drawn down to the lower screen, then the effective saturated thickness is reduced and the well might actually produce less water and operate less efficiently than if the pump were set above the screen. Also note that the pump must be shrouded if it is set below the screen, so that water can flow across the motor for cooling. This is not to say that recovery pumps must be set above the screen, but that these factors should be taken into consideration when designing the pumping system.

Summary and Recommendations

Methane levels showed a marked decrease in domestic wells during the test pumping, while methane capture in the pumping wells was demonstrated. These results are encouraging, and give reason for moving forward with the mitigation program.

Although the report provides permeability values for wells, it does not discuss the planned pumping and injection rates. Will those rates be estimated from the modeling, or determined through “trial and error”? The total pumping rate from the three recovery wells is approximately 27 gpm, which the injection wells will be capable of receiving, given the relatively high injection heads resulting from gravity flow. How will the re-injection water be distributed among the injection wells?

The spatial (vertical and horizontal) distribution of sand lenses and high permeability zones are not well understood. With this in mind, the mitigation program should include careful monitoring of water levels and water quality in potentially affected wells. In particular, the southern portion of the injection well ring (near Inj 05 Rhor and Inj 06 Masters) had higher methane concentrations during pumping. Domestic wells in this area should be monitored to ensure that the injection system does not drive methane to the south.

References

Hem, John D., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water, Third Edition, U.S. Geological Survey Water Supply Paper 2254. 263 pp.

McLaughlin, Thad G., 1966. Ground Water in Huerfano County, U.S. Geological Survey Water-Supply Paper 1805, 91 pp plus plates.

Norwest Applied Hydrology, 2008. Methane Mitigation Well Aquifer Testing Report, consultants' report prepared for Petroglyph Energy, Inc. September 24, 2008.

ATTACHMENT 1

DESCRIPTION OF POISON CANYON FORMATION

(McLaughlin, 1966. USGS Water-Supply Paper 1805) the Vermejo and Raton outcrop area should be available from either the sandstone within the two formations or the underlying Trinidad Sandstone. If larger supplies are needed, they may be available locally from properly constructed deeper large-diameter wells. The yield of Niggerhead shaft, which reportedly was 3,000 gpm before the shaft was abandoned, indicates that moderate to large supplies may be available from wells penetrating most or all of the sandstone. The water from such wells probably would be highly mineralized, however, and would have only limited use. For a discussion of the quality of water in these formations, see the section on mine water (p. 38).

POISON CANYON AND CUCHARA FORMATIONS

The Poison Canyon and Cuchara Formations have similar water-supply characteristics in Huerfano County and are discussed as a unit in this section. The Poison Canyon consists of 0–2,500 feet of buff to red massive sandstone and conglomerate with thin beds of shale and siltstone. The Cuchara consists of 0–5,000 feet of red, pink, and white massive sandstone and red to tan shale. The sandstone of the two formations is commonly medium to coarse grained, is friable in places, and is generally lenticular. It crops out in a broad area through central Huerfano County from the coal basin in the southeast to Huerfano Park on the northwest (pl. 1).

In places the outcrop areas are well dissected, and numerous small springs and seeps issue from the beds of sandstone. These natural discharges supply most of the domestic and stock needs of the area, although wells and stock ponds have been constructed to supplement the supply. Most of the wells in the area are shallow dug wells tapping thin alluvial deposits or the uppermost part of the two bedrock formations, or both. The wells generally yield a dependable supply of water that is hard but is satisfactory for domestic and stock use. Some of the water has a high sodium content and is soft.

Athough water can generally be obtained from the sandstone within a depth of 200 feet in the outcrop areas of the Poison Canyon and Cuchara, the formations may be dry to a depth of several hundred feet where the area is highly dissected—as in the vicinity of the Spanish Peaks. In developing ground-water supplies in the outcrop areas, preliminary testing of the alluvial deposits may be advantageous if the desired location is near a draw or arroyo, particularly if the area is high above the major streams. If this effort is not successful, then the sandstone in the Poison Canyon and Cuchara can be tested. In most of the outcrop areas, water can probably be obtained within a reasonable drilling depth. As the Poison Canyon contains thicker, more permeable, and more numerous sandstone beds and generally is in a lower topographic position, its area of outcrop is a more fruitful area to drill for water than is that of the Cuchara. The Cuchara areas, on the other hand, are more deeply dissected and, hence, are more adequately watered by springs and seeps.

The sandstone beds of the Poison Canyon and Cuchara Formations are potential sources of larger water supplies for irrigation or other uses, but they are largely untapped. Enough water for current domestic or stock needs is generally obtained within 100 feet of the land surface; therefore, few wells have been extended deeper, and the great thickness of relatively porous sandstone and conglomerate remains inadequately tested. The Poison Canyon and Cuchara section might yield moderate to large supplies of water to properly constructed deep wells. Some deep tests have been drilled, but generally with little success. Most of the deeper tests have been in the higher land around the Spanish Peaks, where the sandstone of the Cuchara is largely drained. In attempting to develop large-capacity wells, the testing could be tried in topographically low areas, preferably in the larger valleys, such as Cucharas, Bear Creek, and Santa Clara, where the chances are greater that the underlying sandstone is saturated with water. Figure 22 illustrates the position of saturated sandstone in relation to a major valley. Sandstones A and B are largely drained north of the Cucharas River beneath the high pediment surface, but they are saturated with water toward the west, where they are lower than the level of the flood plain and thus have an opportunity to be recharged with water from the alluvial deposits beneath the flood plain. In figure 22, well 1 would probably fail to obtain enough water even for stock use, either in the alluvial deposits beneath the pediment surface or in sandstones A and B. Well 2, if drilled deeper, would probably obtain water from sandstone C. The water would be under artesian pressure and would rise to a level about equal to that of the flood plain of the Cucharas Valley. The static water level would be so great, however, that large-scale pumping for irrigation might be too costly. Wells 3 and 4, in the Cucharas Valley, would probably penetrate several beds of saturated sandstone, have shallow static water levels, and yield large amounts of water with comparatively small pumping lifts.

So little is known of the hydrology of the Poison Canyon and Cuchara Formations that their potential can only be conjectured. First attempts at developing larger supplies would be most fruitful in the flood plains of the larger valleys. If these are successful, additional tests could be made in areas outside the valleys where the artesian heads may possibly be sufficient to raise the water in the wells to within economical pumping lifts.

If large-capacity wells can be developed in the Poison Canyon and Cuchara Formations, some care must be taken if the water is to be

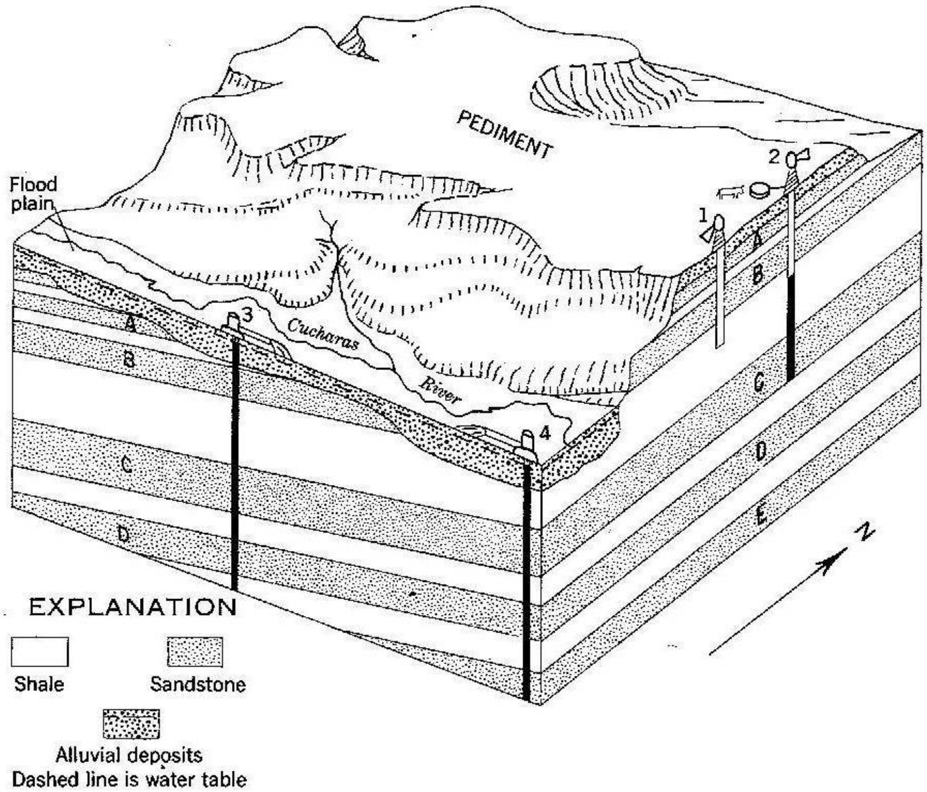

FIGURE 22.—Idealized relation of topographic position to water supply in the Poison Canyon and Cuchara Formations. Shaded areas indicate saturated sandstone.

used for irrigation. Seven samples of water from wells tapping these formations were analyzed as a part of this investigation. Five of the samples had a low sodium hazard and medium salinity hazard, one had medium sodium hazard and high salinity hazard, and one had low sodium hazard and very high salinity hazard (fig. 19). For details of the limitations on the use of such water for irrigation, the reader is referred to p. 40. If proper care is exercised, much of this water could probably be used successfully for irrigation.