Hydrology

The domestic wells are completed in the Trinity aquifer. The Edwards-Trinity aquifer system is in Lower Cretaceous rocks that underlie west-central Texas. The aquifer contains predominately terrigenous clastic sediments in the east, fluvial-deltaic (terrestrial) deposits in the west that grade upward into dolomitic and limestone strata. Confining units overly the subcrop of the Edwards aquifer and the Trinity aquifer. Transmissivity values average less than 10,000 feet squared per day over more than 90 percent of the study area, however, fractured and leached rocks in the Balcones fault zone cause transmissivity values to average about 750,000 feet squared per day in the Edwards aquifer (Barker et al.1990).

Data

The data evaluated consisted of chemical compositions, and stable carbon and hydrogen isotopic content of 7 produced gas samples from two gas wells and dissolved gas samples from 32 water wells. As comparison of the casing head and dissolved gas samples from the same well showed no appreciable differences, only the isotopic and compositional data from dissolved gas samples were used with the exception of the DOM1 sampled 12/26/2010, since there was corresponding dissolved gas sample for this well in the December 2010 sampling round. There were 21 samples from water wells with sufficient methane to measure carbon and hydrogen stable isotopes. Gas composition data was available from 32 water wells including the 21 wells with isotopic data. To avoid the potential effects of seasonality, dissolved gas samples taken in December 2010 were used for further analysis, with the exceptions of produced gas from the Butler and Teal wells sampled on 1/6/2011, and the PWS3 and DOM1A wells sampled on 7/6/2011 as these were the only samples available for those locations. Locations for the sampled wells are shown in **Figure 1**.

Figure 1. Locations of sampled wells, source EPA. Tracks of Butler well bores are shown in yellow.

DOM3 and Well 2. Well 2 is approximately 1700 feet from DOM1 and 1A. DOM3 is approximately 750 feet from DOM1 and 1A. DOM3 is also at the approximate end of one of the producing legs of the Teal gas well (see Figure 1). The spatial distribution of intermediate and high methane in water wells suggests multiple sources of elevated methane.

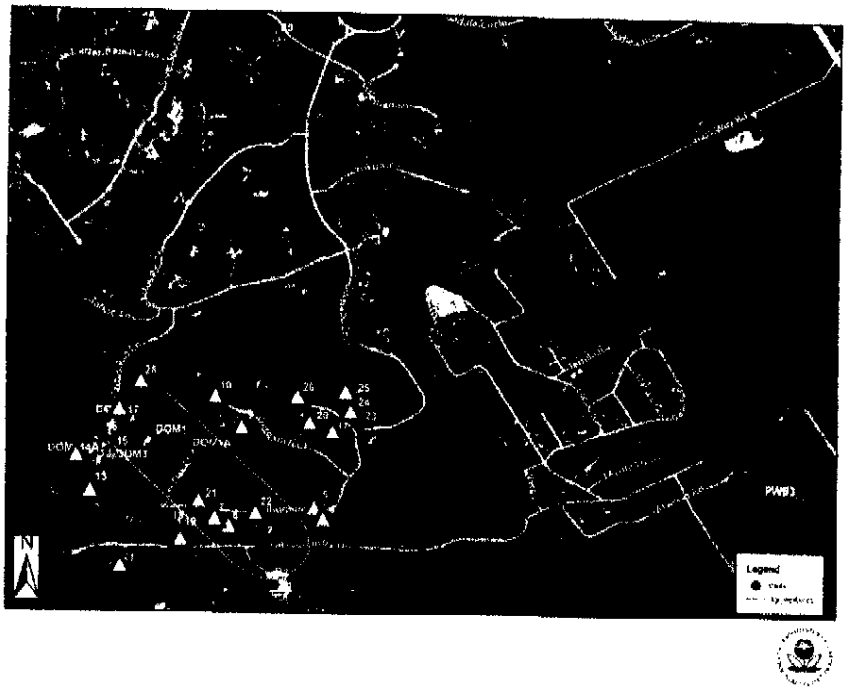

Figure 3. Location of water wells in December 2010 with methane concentration ranges denoted by the color of the triangular symbols. White are <1 ppm, orange are 2.8 to 3.9 ppm and red are 9.5 (DOM1A) to 34.8 ppm (PWS3).

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Samples of produced gas (3), injected gas (2), bradenhead gas(2) were compared to dissolved gas samples from domestic wells (21). All samples have values that indicate the origin of the gas is thermogenic with the exception of the bradenhead samples. While the produced and injected gas had identical carbon and hydrogen isotopic values within analytical error, the two bradenhead gas samples had significantly more negative (lighter) carbon isotopic values indicating a biogenic origin, specifically the microbial conversion of carbon dioxide to methane. This type of gas is found in shallower subsurface environments with strongly reducing

Summary

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The carbon and hydrogen isotopic values of the gas wells match the values of samples from water wells DOM1 and DOM1A. The hydrocarbon compositional (relative abundance), of the gas wells is very similar to that of the DOM1 and DOM1A samples. These wells also have much lower nitrogen gas values as do the gas wells. The other water well samples with isotopic and compositional data do not match the Teel or Butler gas wells and have much higher nitrogen values.

The distance between well DOM1 and the Butler gas well is about 2300 feet laterally. Impact from gas wells on shallow aquifers such as elevated methane has been observed between 1500 and 4000 feet laterally from depths greater than 4000 vertical feet (Osborn et al. 2011, URS 2006).

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References

Barker, B., Duffin, G. Flores, R. and T. Lynch, 1990, Evaluation of water resources in part of North-Central Texas, Texas Water Development Board, Austin.

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

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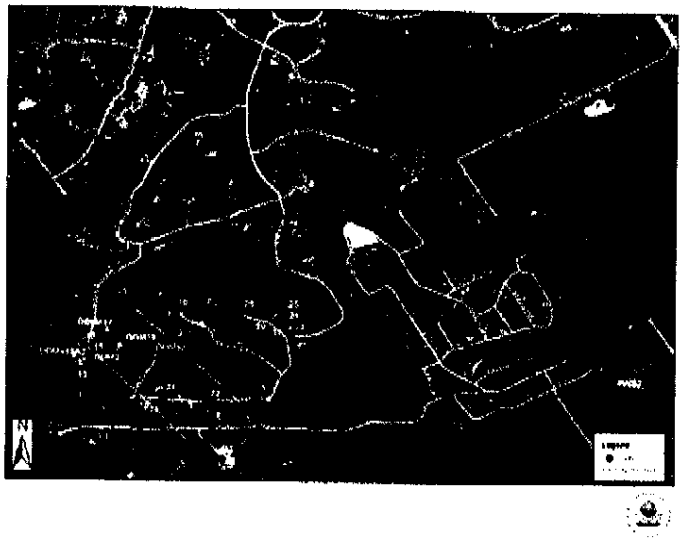

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Spatial Analysis

After removing duplicates, 27 samples with different locations are available from the three-day December 2010 sampling round plus the PWS3 and DOM1A samples from 12/6/2011. These samples are the only ones available from those locations. **Figure 2** shows the concentration of methane for each location. The dissolved methane levels in 22 wells show a distribution of low values near or below analytical resolution (wells 21, 16, 11, 25, 24, 1, 10, 20, 6, 4, 5, 26, 28, 17, 14A, 7, 22, 19, 9, 2, and 13 in order of increasing dissolved methane). These wells are considered natural background. Some wells such as 2, 29 and DOM3 have higher concentrations (2.8-3.9 ppm) greater than background, while three samples (DOM1, PWS3 and DOM1A) have significantly higher concentrations (9.5-34.8 ppm) indicating impact.

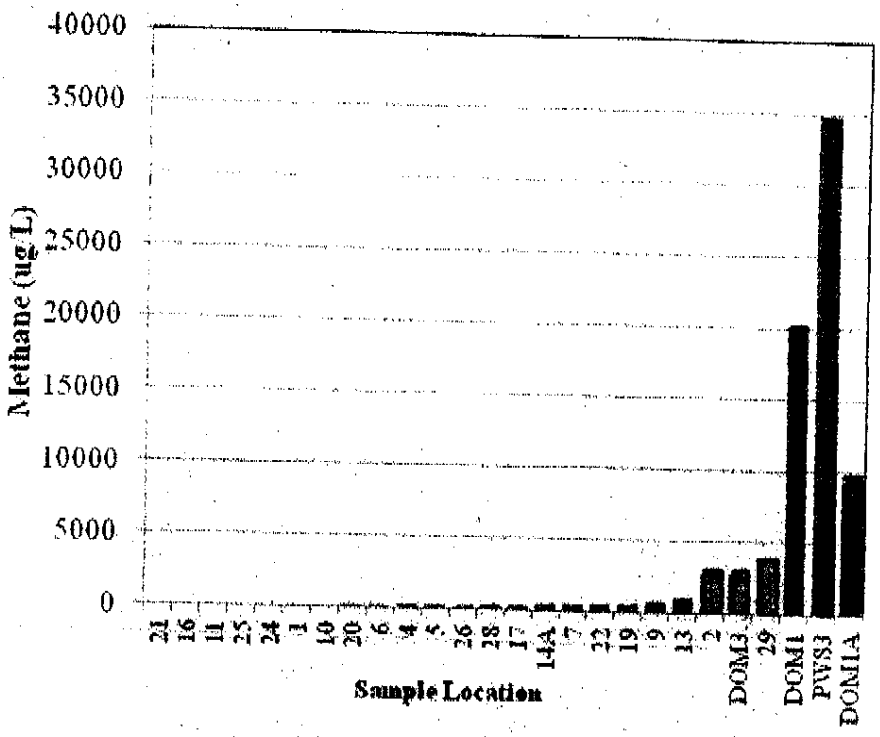

Figure 2. Concentration of dissolved methane for each well sampled in the December 2010 sampling round with additional samples noted in text above.

Figure 3 shows the locations of the wells with the three groups of methane concentrations indicated by the color of the star symbols. The three locations that are clearly impacted are DOM1A, DOM1 and PWS3. DOM1 and DOM1A are very close to each other, but differ in completion depths. The DOM1 and DOM1A wells are approximately 7100 feet from the PWS3 well. In contrast, the area around DOM1 and 1A is heavily sampled with other water wells ranging from 700 to 2000 feet laterally that all show background concentrations except well

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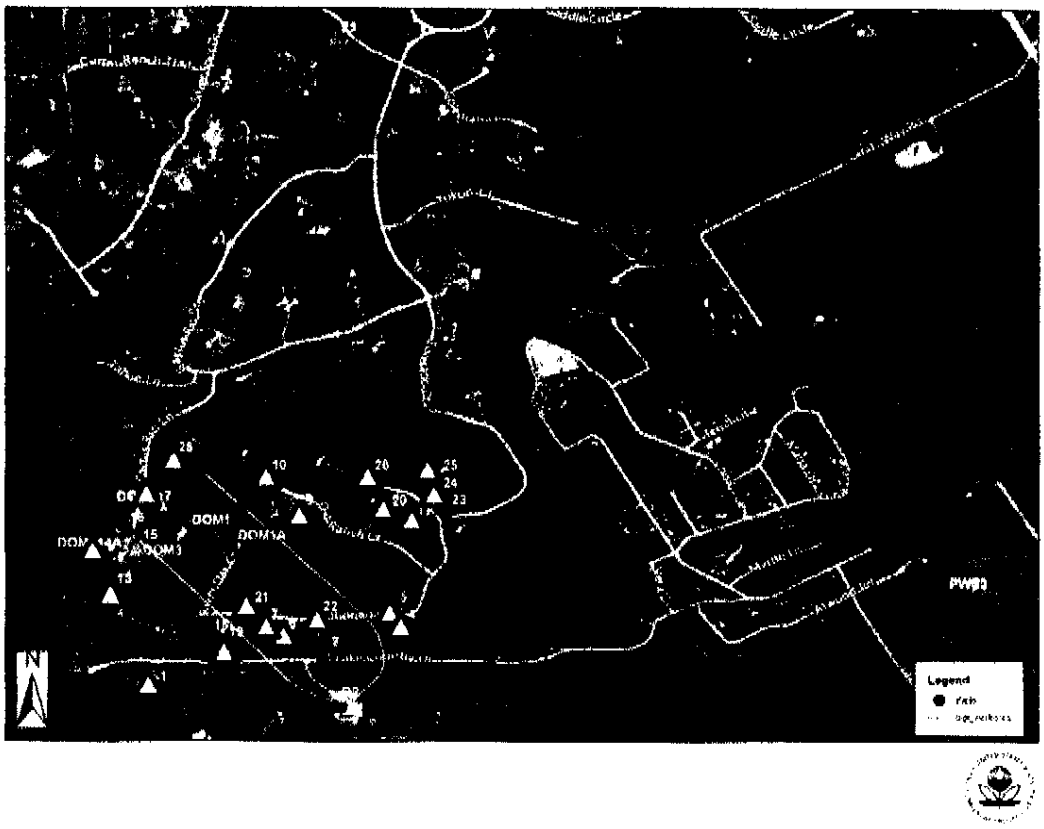

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conditions, but not usually in commercial quantities. The bradenhead samples were excluded from further analysis. **Figure 4** plots the isotopic values for all the samples with the range of values for thermogenic and biogenic methane shown by the labeled shaded areas.

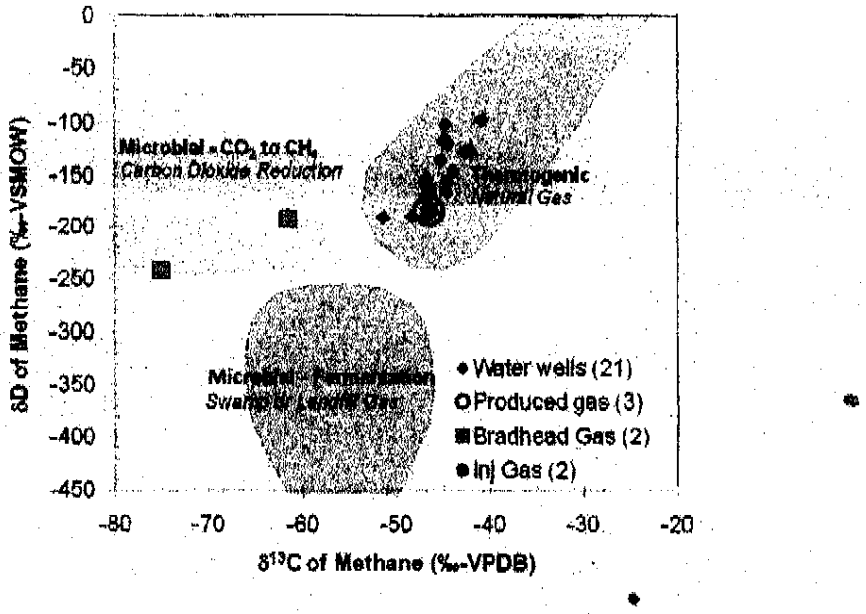


Figure 4. Carbon versus Hydrogen Isotopic values for gas samples in study area.

Five water well samples (DOM1, DOM-1A, #13, #29 and PWS3) have stable isotopic values for methane that are very similar or identical to the produced gas samples. These samples are plotted in **Figure 5**. Of these samples, wells DOM1, DOM1A and PWS3 have elevated concentrations of methane. The isotopic values from water wells DOM1 and DOM-1A and the produced gas are identical within analytical error. Wells 13 and 29 have isotopic values that are similar to the gas wells, but do not display the elevated methane values of the DOM1, DOM1A and PWS3 wells. Well 13 is about 1400 feet from DOM1 and has a methane value at the high end of the background range. Well 29 has a higher methane value than well 13, but is almost 6000 feet from well DOM1. Well PWS3 has the highest dissolved methane value, but is approximately 7200 feet from DOM1.

The remaining 16 dissolved gas water well samples (see Figure 4) have somewhat heavier (less negative) carbon and hydrogen isotopic values that can be attributed to the microbial oxidation of the produced gas. This pattern is associated dissolved gas that is gradually consumed by microbial metabolism causing the carbon and hydrogen isotopic values of the remaining methane to become progressively more positive (heavier).

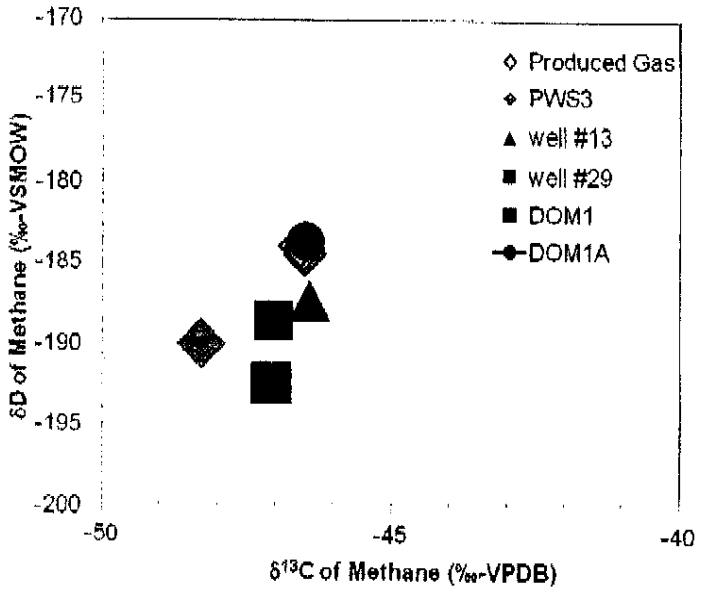


Figure 5. Stable isotopic values for selected dissolved gas samples and produced gas samples. Symbol size is equivalent to range of analytical precision.

Gas Composition Data

The relative abundances of selected gas components are plotted in **Figure 6**. The figure shows the relative abundance of each component plotted on a log scale to highlight similarities. Patterns of relative abundances can be used to identify different sources. The majority of the water wells had detectable methane, but little or no C2 to C6+ components. The presence of C2-C6 hydrocarbons indicates a nearby source since there has not been significant degradation of the hydrocarbons. The absence of the higher homologues (C2-C6) in most samples is consistent with thermogenic gas altered by microbial degradation.

The composition of the produced gas from the Butler and Teal wells is identical within analytical precision. The gas is dominantly methane (71-77%) with lesser amounts of C2-C6 gases; ethane (12-13%), propane (4.0-4.6%), butane (1.7-1.9%), pentane (0.5-0.7%) and C6+ (0.2-0.6%). This gas is classified as 'wet' due to the presence of appreciable amounts of the higher carbon number (C2-C6) gases, which is typical of thermogenic gas. The thermogenic gas also has low nitrogen content of about 1%. The nitrogen content of all the water well samples is generally very high, approximately 75-90% indicating equilibrium with the atmosphere. The exceptions are the samples from wells DOM1, DOM1A, 29 and PWS3. These wells have much lower nitrogen values between 4 and 31%.

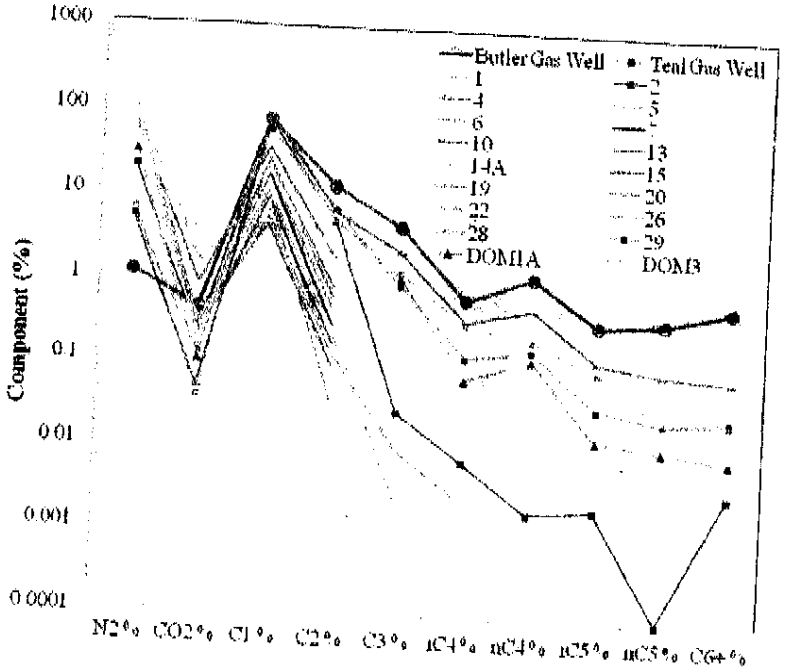
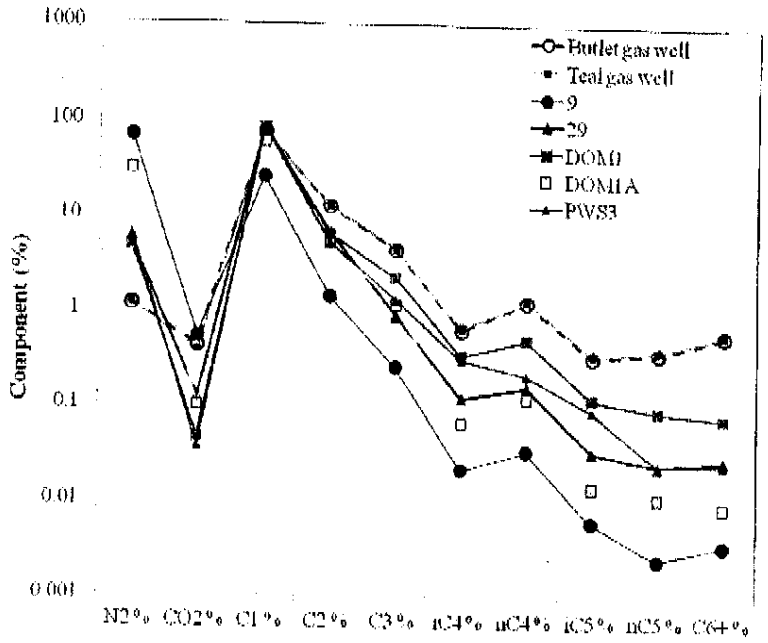


Figure 6. Gas content for carbon dioxide and C1 to C6 alkanes in produced gas samples and dissolved gas samples from the water wells.

The data from water wells (DOM1, DOM1A, 9, 29 and PWS3) with similar hydrocarbon relative abundances to the gas wells are plotted in **Figure 7**. While well 9 does has a similar relative abundance pattern, the concentrations of hydrocarbons are much lower. The well is about 700 feet from the DOM wells with a background methane value (0.76 ppm). The sample from well 29 shows a similar relative abundance pattern to DOM1 and DOM1A . The sample from well PWS3 is somewhat different as well indicating that the source of gas in well PWS3 is probably different than the other wells. The hydrocarbon relative abundance patterns for the DOM1 and DOM1A wells are very similar to the gas wells. There are small differences, specifically nitrogen content is somewhat higher and C5-C6 abundances show a declining trend rather than increasing trend. The change in C5-C6 could be due to those higher-chain hydrocarbons being most prone to degradation.



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