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Report to
Damascus Citizens for Sustainability
25 Main Street
Narrowsburg, New York 12764

Baseline Methane Emissions in Town of Delaware, Sullivan County, New York

January 2014

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EXECUTIVE SUMMARY

A baseline data set has been collected for the Town of Delaware, Sullivan County, New York. The data have been compiled, processed, and examined and found to be of high quality. The data indicate relatively low and reasonably consistent methane concentrations throughout the Town. Since no standard criteria for such baselines currently exist, we define for present purposes baseline criteria that could be readily applied by anyone using commonly available spreadsheet software, e.g., Microsoft Excel. For the Town of Delaware this approach showed that 99% of all data in any similar future methane survey should be less than 1.97 ppm, 99.9% should be less than 2.35 ppm. Appropriate methods can be applied to the baseline data set to extract baseline methane levels for any specific location along the surveyed roadways. Other implications of the data, and related data from other locations in the Marcellus Shale region are briefly discussed.

BACKGROUND

A group of residents and property owners of the Town of Delaware (Sullivan County, NY) worked with Damascus Citizens for Sustainability (DCS) to document an environmental baseline for methane in ground-level ambient air. Such a baseline enables early detection of environmental contamination from gas well drilling or other methane sources. Ambient air contamination is most readily detected and quantified if baseline data is collected before any

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contamination occurs. Recently developed technology for measurement of trace gases in the environment offers a useful approach to development of baseline data, early detection of contamination from gas drilling, and verification of actual contamination. Further, this technology in combination with sufficient geological information on faults and fractures could enable pre-drilling identification of lands likely to develop methane migration problems even at considerable distances from the source gas well.

Methane is the lightest, most mobile component of natural gas, and makes up at least 85% of the volume of natural gas, and typically 95% or more of Marcellus Shale gas. Methane is lighter and less viscous than air. Consequently it will move farther and faster than any other contaminant that might be released from shale gas wells. The same properties also cause methane to disperse rapidly once it has reached the open atmosphere. Nevertheless, methane is the first and most rapidly dispersing contaminant likely to be detected from a shale gas well.[3]

The rapid dispersion of methane once it has been released into the open atmosphere implies the need for analytical instrumentation capable of accurately and consistently measuring trace levels of the gas. Previously the potential usefulness of methane as an indicator of environmental contamination from gas wells or other sources was limited by the difficulties involved in effective air sampling and analysis for trace levels of the gas. Measurement of low but environmentally important levels of methane in air required special sample collection work in the field followed by transport to a lab for analysis using sophisticated laboratory instruments. Recent developments in analytical technology, i.e., cavity ring-down laser spectroscopy, have made it possible to measure very low levels of methane in the field continuously with continuous logging of results. The instrumentation is rugged enough for routine field use and capable of measuring methane concentrations consistently to levels of parts per billion (compared to parts per million for most previously used methods). Depending on the instrument configuration, methane measurements are made continuously every 0.2-5 seconds. Typically the instrument is operated in parallel with a GPS unit (internal or external) and tags each methane measurement with location data. Whenever this combination of both the methane measurement and GPS technology is active it will continuously determine and record the time, location, and methane concentration in the air, every 0.2-5 seconds, wherever the instrument has been. This was the instrument combination used to collect the baseline data reported here.

Gas Safety, Inc. (GSI) offers methane measurement services based on this new technology, including environmental methane surveys. DCS, on behalf of the residents and property owners of Delaware Town, engaged GSI to measure and document methane levels in ambient ground level air in the Town of Delaware.

The contracted field data collection work was carried out on 30-31 May 2013. The data was subsequently compiled, processed and analyzed by GSI. The work, data and findings are documented in this report. The digital time, location and methane concentration data are too voluminous for presentation with this report, and have been separately submitted to DCS.

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[3] The single exception to the broad usefulness of methane as an indicator contaminant is during the drilling of the well. Free-flowing methane (natural gas) may or may not be encountered during drilling of the well, i.e., before hydraulic fracturing. When there is no free-flowing methane, other potential contaminants might appear first, e.g., drilling fluids, flowback water. Reports to date suggest free-flowing methane is frequently encountered during the drilling (before hydraulic fracturing) of shale gas wells. Hence, the cases in which methane is not the most likely first contaminant are probably few.

NOTE: All figures follow the narrative section of this report. This report includes one table that is presented in the section "Basic Statistical Summaries of Data".

FIELD WORK

In order to facilitate as much coverage of the Town in the available time as possible, and to avoid concerns or delays related to private property rights, all measurements were taken driving on public roadways. Figure 1 provides a reference view of the roads driven and general area covered by the methane survey of the Town. The air sample intake was positioned to ride, pointing downward, behind the vehicle ≈12 inches (30 centimeters) above the road surface. Roads were driven at the posted speed limit or slower if necessitated by road conditions. GSI experience has shown this approach is adequate for detection of even relatively weak methane sources under most circumstances. Reasonable efforts were made to run the instrument over every public roadway in the Township at least once during the methane baseline survey field work.

DATA COMPILATION AND PROCESSING

Data is logged by the instruments as data lines in a digital data file. Each line will have several data types, including time, latitude, longitude, methane, and various types of data used by the instrument to monitor and assure proper function. During the Delaware Town baseline work each data line included individual values for 16 active data types. A total of 257,310 data lines were recorded during the survey. The instrument automatically records and starts a new digital data file about every hour to produce data logs as files of sizes (typically 1,000-15,000 lines of data) that are reasonably easy to handle and to reduce risk of data loss. It is not practical or even advisable to turn off the instrument when making necessary vehicle stops, e.g., for turns, traffic, re-fueling, meals, U-turns, navigation, crossing contract area boundaries, etc. Consequently the raw data recorded in the data log is disproportionately weighted in favor of locations where vehicle stops occurred. In order to develop a more geographically balanced data set, the data collected at such stop locations are removed by visual examination and processing with a computer program.[4] Following removal of such data, the amount of data analyzed for the Delaware Town baseline was 173,574 lines.

The processed data were further processed and analyzed using Microsoft Excel (version 12.2.8) for spreadsheet work and Google Earth (version 6.0.3.2197) for mapping and visualization. The distribution of measured methane levels among selected ranges was determined using the FREQUENCY function in Excel (use of some other functions is precluded by the large amount of data or by the time required for calculations for such large amounts of data).

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[4] Code for the program was written for GSI by Xiao Jing Tang of Boston University, and adjusted and debugged by Jacob Lysinger. The program also removes non-essential, instrument function monitoring data in order to facilitate final processing and analysis of the large data files.

RESULTS

Visualization is the most convenient first approach to attempting to understand data sets the size of the methane data files generated during GSI methane survey runs, typically 1,000 to 15,000 methane data points per hour of survey time.

Plots of Survey Data on Remote Imagery

Figures 2.A. and 2.B. present the methane baseline survey data superimposed using Google Earth on aerial/satellite imagery of the Township (and surrounding areas). Comparison of Figure 2.A. to Figure 1 (showing public roads surveyed) provides a visual impression of general patterns of variability in methane levels over the Town. The more intense the yellow color in Figure 2.B., the higher the methane levels. Methane levels are generally higher in an area extending along and to the south of Route 117 for about 5 miles from Callicoon southeast to the junction with 52 then north along and to the east of that road for about 5 miles to Jefferson, covering about one quarter of the Town. Methane levels are generally lower in the remainder of the Town from the Delaware River north of Callicoon to 52 on the east side.

Figure 2.B. provides a lower viewing angle perspective on the image in Figure 2A. This lower angle perspective allows one to see localized "spikes" in methane levels. The generally higher methane area along the southern and eastern sides of the Town is still apparent, and within that area there was a somewhat more elevated methane area between 17A and 97 to the southeast of Callicoon. Some minor peak methane levels occurred in that smaller area. Those elevated methane levels were relatively small and all appeared to be associated with residential properties. Most of the elevated methane levels, and the highest methane levels, occurred in the generally lower methane area covering most of the central, northern and western parts of the Town. Three clusters of less pronounced elevations of methane levels are associated with the vicinities of Callicoon, Jeffersonville, and Kenoza Lake. Interestingly there were relatively few and minor methane level elevations in the vicinities of Hortonville and Kohlertown. There were four distinct spikes in methane concentrations. Three of the 4 are located generally to the northeast of Callicoon, and the fourth to the southwest of Jeffersonville. Field observations and examination of satellite imagery indicated all of these four highest methane levels, and effectively all the other elevated methane levels away from villages occurred near farm operations, a sawmill, or ponds.

Plots of Survey Data

Another visual approach to understanding such a volume of data is to look at plots of distributions of the data with respect to a parameter of interest. One type of such plots is shown in Figures 3.A and 3.B., which show the cumulative number of methane data points compared to methane concentrations. Figures 3.A. and B. show plots of the same data but with different scales on the horizontal axis. Figure 3.A. shows how consistent the methane levels are in the Town and how exceptional the most elevated methane levels were. The high values for the highest four methane levels (discussed previously) are all within the fraction of data between the two highest, and farthest right points on the graph in Figure 3.A. The second point from the right in Figure 3.A. indicates the methane concentration below which 99.9% of the data occurred. 95% of the measurements were below 1.86 ppm and 99% were below 1.97 ppm.

Basic Statistical Summaries of Data

Another approach to examining the quality of and understanding the baseline methane data is to consider some basic statistical summary information. Table 1 shows the summary data for the Town of Delaware survey. Most of the statistical data in Table 1 are included in the data plotted in Figures 3.A. and 3.B.

Table 1. Basic statistical summaries of the Town of Delaware methane baseline survey data.

Total Measurements	173,574
Maximum	4.83 ppm
99.9% less than	2.35 ppm
99% less than	1.97 ppm
95% less than	1.86 ppm
90% less than	1.84 ppm
Median	1.789 ppm
Average	1.798 ppm
Minimum	1.715 ppm

The descriptive statistical summary data in Table 1 indicate the methane measurements collected during the survey were consistently low, 99% being less than 1.97 ppm. Only one data point in a thousand exceeded 2.35 ppm and all of those were associated with the four highest methane areas near farm operations. The data also provide a means by which to define and select appropriate baselines for methane in ground level air in the Town of Delaware.

RECOMMENDED BASELINES

GSI suggests two broad types of baselines, a general broad area baseline and location specific baselines

The General Area Baseline

The general Town broad area baseline is to be regarded as the normal methane condition in ground level air in the Township. It is based on conditions that can be considered normal or typical in the Township generally regardless of location. A general baseline value is important for assessing future changes in broad area methane levels, e.g., for evaluating whether or not the results of a future methane survey indicate new or unusual sources of methane have

developed in the Town. The baseline should be conservative, i.e., favor high values in order to avoid false alarms regarding possible future methane contamination sources. The recommended baseline should be based on statistical criteria that are readily obtainable for large methane data sets. The percentiles based on frequency distributions provide such readily obtainable statistical summary. For the present, GSI recommends the following values listed in the table above be defined as the broad area baseline measures. The recommended general area Town methane baseline measures for similarly run surveys are then as follows:

95% of all methane data should be less than 1.86 ppm
99% of all methane data should be less than 1.97 ppm
99.9% of all methane data should be less than 2.35 ppm
Any area with a methane level above 5 ppm should be considered a matter of concern meriting further investigation, especially if not clearly associated with an agricultural operation, or other facility or water body or wetland not already identified as a prominent methane source in the Town.

Specific Location Baselines

Baseline criteria for specific locations within the Town survey area should be extracted from the full baseline data set. As a result of this methane baseline survey, there are now methane data covering to our knowledge all of the public roadways in the Town. It is, however, important to recognize that the survey vehicle is moving constantly over the road near most specific locations. A short time is required for the sampled air to travel from the sample intake through the sample tube into the laser chamber. That sample tube transit time causes the methane data for a given location to be offset in data plots from the actual location, in proportion to the speed of the vehicle. This offset is not important for general area baseline studies, but it is for evaluation of methane concentrations at specific locations. Further, the baseline data for a given location should not be regarded as the value of the single methane measurement nearest the location of interest, even if the vehicle speed offset has been accounted for. An array of data points surrounding the location of interest should be selected from each survey run, and appropriate statistical tests applied to establish a confidence level regarding whether a given methane result is consistent with previous methane baseline data for the location. It should be noted that methane levels at almost all locations in the Town of Delaware were at local baseline levels, i.e., less than 1.86 ppm for 99% of the surveyed locations. For such locations, the location specific baseline will be the measured local baseline, which can be directly extracted from the original data.

CONCLUSIONS

A baseline data set has been collected for the Town of Delaware, Sullivan County, New York. The data have been compiled, processed, and examined and found to be of high quality. Most of the elevated methane levels, and all of the four highest, appeared to be associated with agricultural operations. The data indicate low and consistent methane concentrations throughout most of the Town, leading to a set of baseline recommendations including that 99% of all data in any similar future methane survey should be less than 1.96 ppm, 99.9% should be less than 2.35 ppm, and maxima should not exceed 5 ppm. Appropriate methods can be applied to the baseline data set to extract baseline methane levels for any specific location along the surveyed roadways.

Figure 1. Ground Level Ambient Air Methane Survey of the Town of Delaware, Sullivan County, New York. 1-3 June 2013. Yellow lines indicate roadways travelled and tracks of methane measurements during the survey.

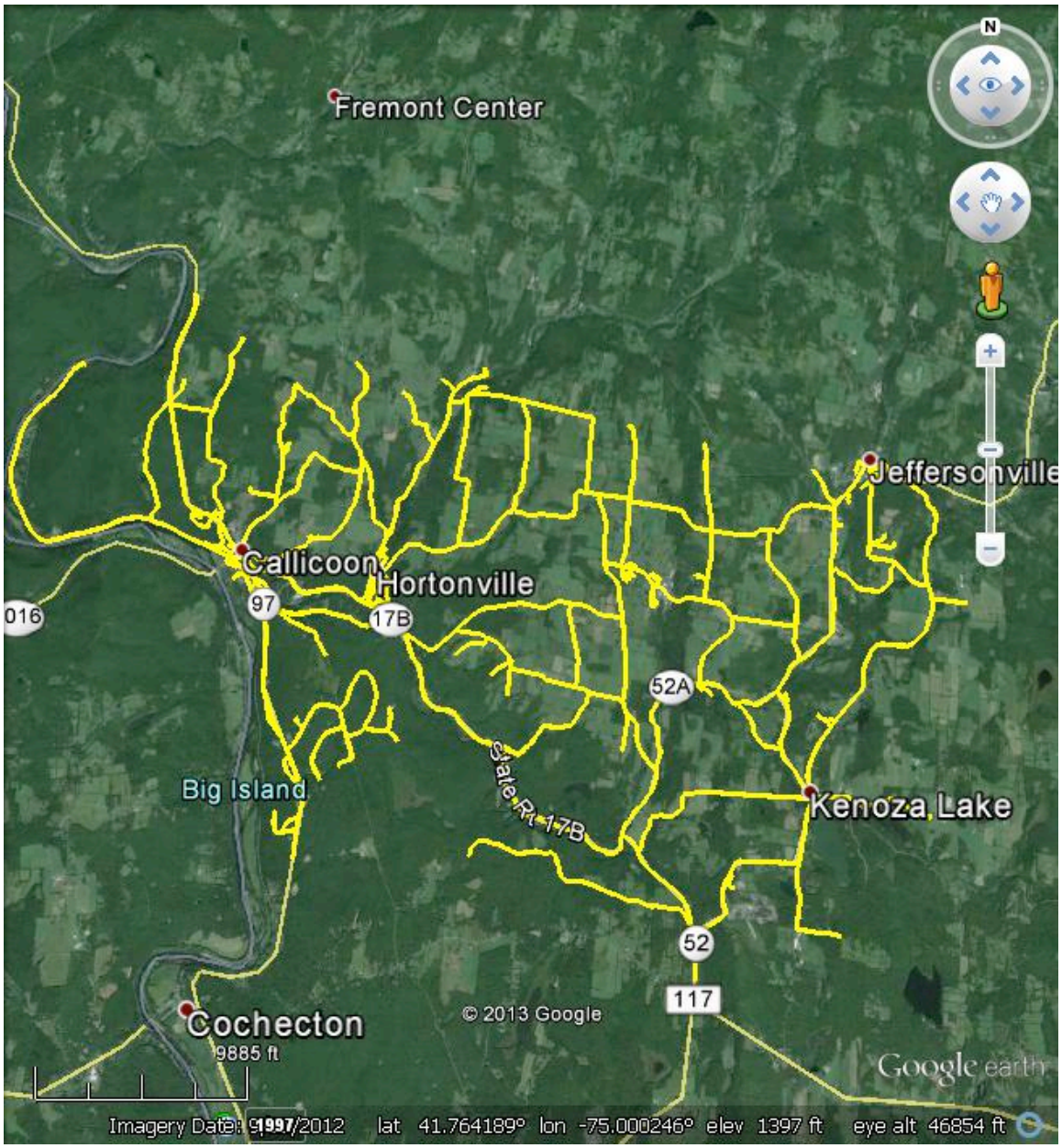

Figure 2.A. Ground Level Ambient Air Methane Survey of the Town of Delaware, Sullivan County, New York. 1-3 June 2013. Yellow lines indicate roadways travelled and tracks of methane measurements during the survey. Intensity of yellow color indicates relative intensity of measured methane levels.

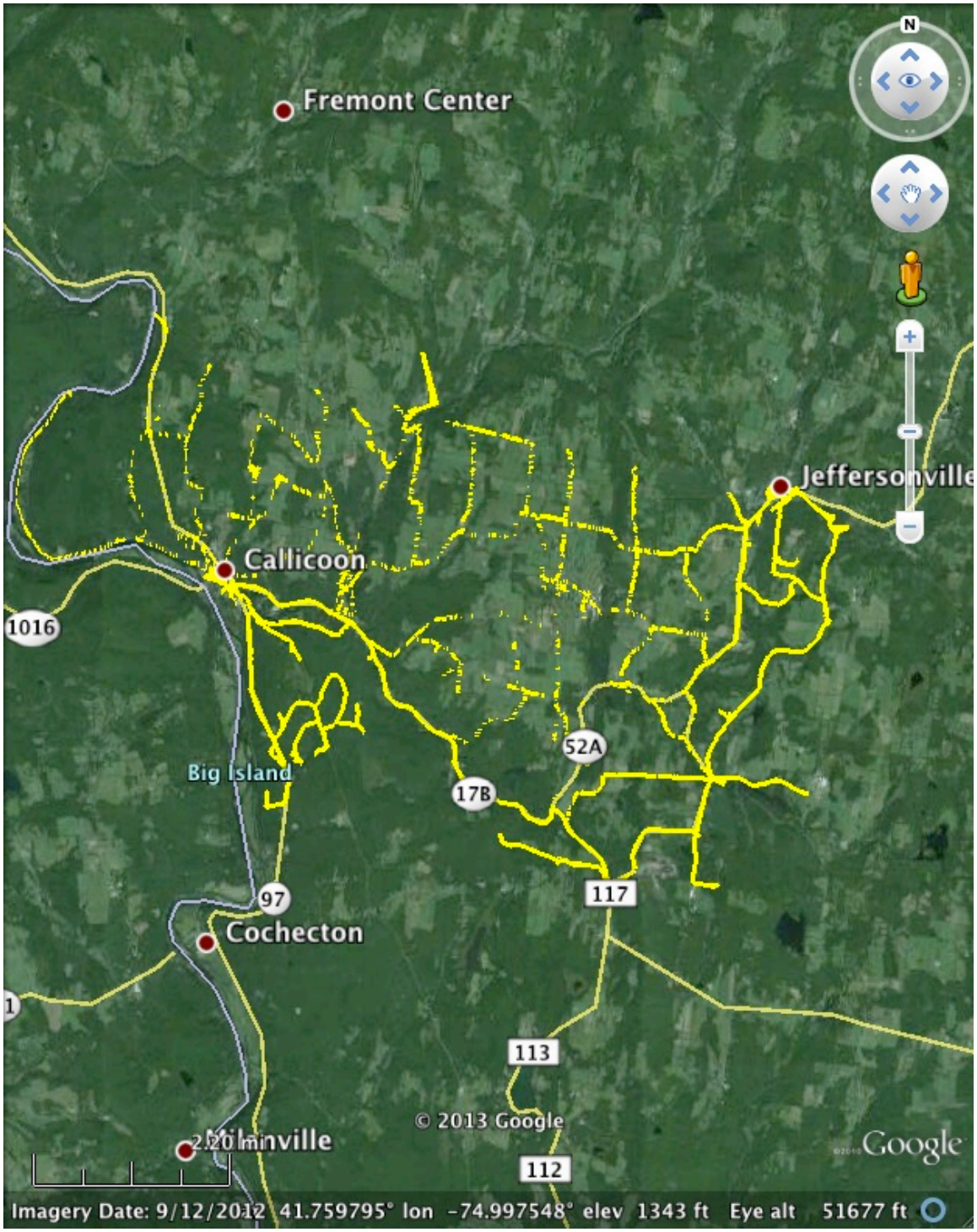

Figure 2.B. Ground Level Ambient Air Methane Survey of the Town of Delaware, Sullivan County, New York. 1-3 June 2013. Oblique, eastward view. Yellow lines indicate roadways travelled and tracks of methane measurements during the survey, intensity of yellow color and spikes along yellow lines indicate intensity of measured methane levels.

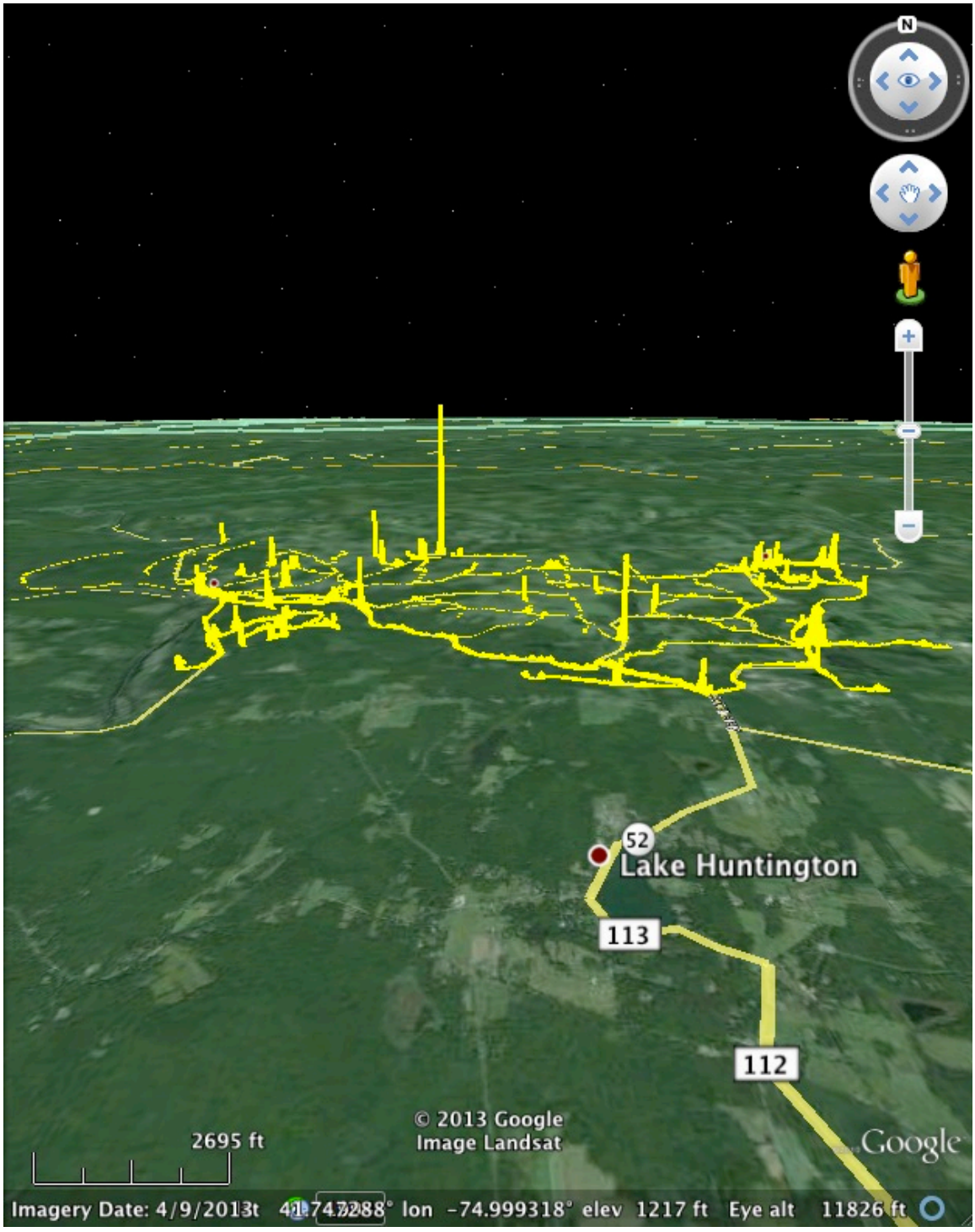

Figure 3.A.

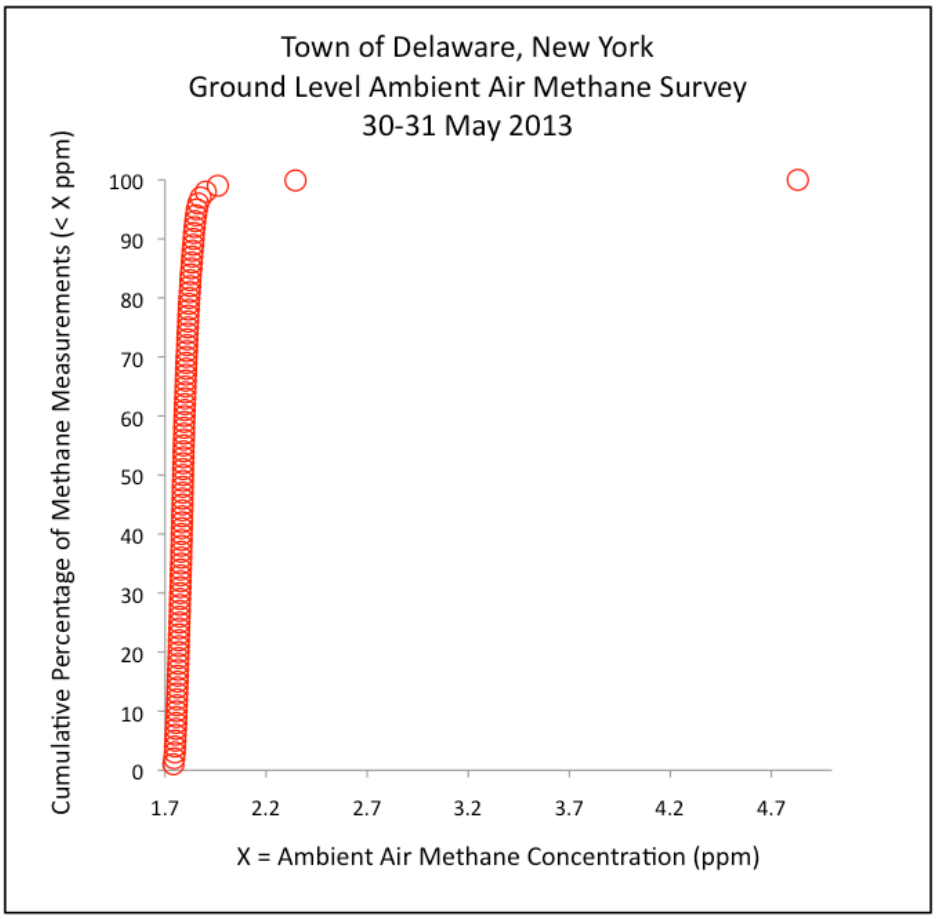

Figure 3.B.