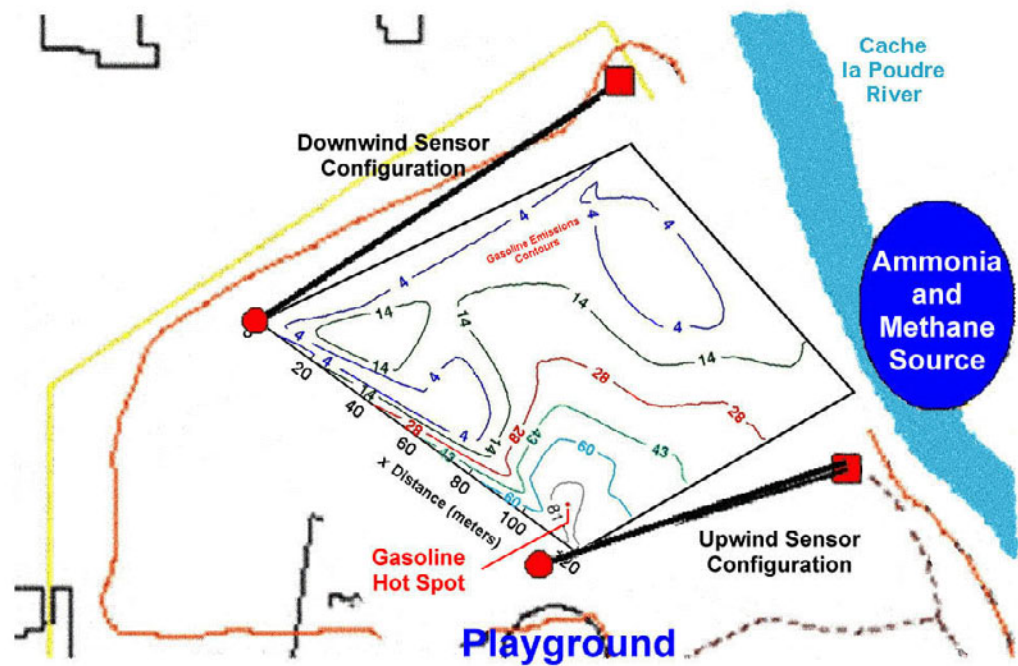


Evaluation of a Former Landfill Site in Fort Collins, Colorado Using Ground-Based Optical Remote Sensing Technology



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Abstract

A former landfill site in Fort Collins, Colorado is being assessed for landfill gas emissions as part of an effort under the city's Brownfields program to support reuse options for the property. Before initiating any additional development at the property, the city requested assistance from the EPA Region 8 Office, and the Office of Superfund Remediation and Technology Innovation, Technology Integration and Information Branch to perform a site assessment to search for the presence of any fugitive gas emissions from the former landfill site. This assessment was necessary due to the potential adverse health effects associated with exposure to landfill gas.

The focus of this study was to evaluate fugitive emissions of methane and VOCs at the site, in support of the reuse objectives, using a scanning open-path Fourier transform infrared spectrometer, open-path tunable diode laser absorption spectroscopy, and an ultra-violet differential optical absorption spectrometer. The study involved a technique developed through research funded by the EPA National Risk Management Research Laboratory that uses ground-based optical remote sensing technology, known as optical remote sensing-radial plume mapping. The horizontal radial plume mapping method was used to map surface concentrations, and the vertical radial plume mapping (VRPM) method was used to measure emissions fluxes downwind of the site.

The study did not detect the presence of any surface methane hot spots at the site. The highest methane concentrations detected at the site were only slightly above ambient background levels. However, the survey detected the presence of a gasoline hot spot (average concentration over 81 ppb, with a maximum concentration of about 100 ppb) located in the vicinity of a recreational building at the site. The VRPM survey of the site detected methane, ammonia, and gasoline along a downwind configuration at the site. The average calculated gasoline flux from the VRPM survey was 0.87 g/s. The measured methane and ammonia concentrations were well-correlated, indicating that the measured concentrations probably came from the same source. Wind data collected indicated that the source of the methane and ammonia detected is located across a river adjacent to the site.

Foreword

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Sally Gutierrez, Acting Director
National Risk Management Research Laboratory

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Acknowledgments

This study was jointly sponsored by the United States Environmental Protection Agency (EPA) Region 8 Office, and the Office of Superfund Remediation and Technology Innovation, Technology Integration and Information Branch under its Monitoring and Measurement for the 21st Century (21M²) initiative. The 21M² initiative is intended to provide EPA staff with resources to apply new approaches to real site problems.

Executive Summary

Background and Site Information

A former landfill site in Fort Collins, Colorado is being assessed for landfill gas emissions as part of an effort under the city's Brownfields program to support reuse options for the property. The city of Fort Collins is interested in developing a larger recreation facility on this property, which is already being used primarily for recreational purposes. Before initiating any additional development at the property, the city requested assistance from EPA to perform a site assessment to search for the presence of any fugitive gas emissions from the former landfill site. This assessment was necessary due to the potential adverse health effects associated with exposure to landfill gas. The EPA Region 8 Office requested assistance with this study through the Monitoring and Measurement for the 21st Century program to utilize innovative approaches for performing an assessment at the site.

The focus of this study was to evaluate emissions of fugitive gases and VOCs at the site, in support of the reuse objectives, using an open-path Fourier transform infrared (OP-FTIR) spectrometer, open-path tunable diode laser absorption spectroscopy (OP-TDLAS), and an ultra-violet differential optical absorption spectrometer (UV-DOAS). The OP-FTIR instrument provided the critical measurements in the current study, and the OP-TDLAS and UV-DOAS provided noncritical, supplemental data. The study involved a technique developed through research funded by the EPA National Risk Management Research Laboratory (NRMRL) that uses ground-based optical remote sensing technology, known as optical remote sensing-radial plume mapping (ORS-RPM) (Hashmonay and Yost, 1999; Hashmonay et al., 1999; Wu et al., 1999; Hashmonay et al., 2001; Hashmonay et al., 2002).

The study consisted of one field campaign performed during September 2003 by ARCADIS and EPA personnel. Figure E-1 presents the overall layout of the site, detailing the geographic location of each horizontal radial plume mapping (HRPM) survey area. Figure E-2 shows the location of the vertical radial plume mapping (VRPM) configurations, which were used to collect data for emission flux calculations.

Testing Procedures

HRPM surveys were done in Areas A, B, C, and D to search for surface emissions hot spots. A VRPM survey was done in Area A to measure emissions of fugitive gases and VOCs upwind and downwind of the area. The OP-TDLAS instrument was deployed in each area of the site to provide additional information on methane concentrations at the site. The UV-DOAS instrument was deployed in Area A to provide information on concentrations of benzene, toluene, and xylenes (BTX) at the site.

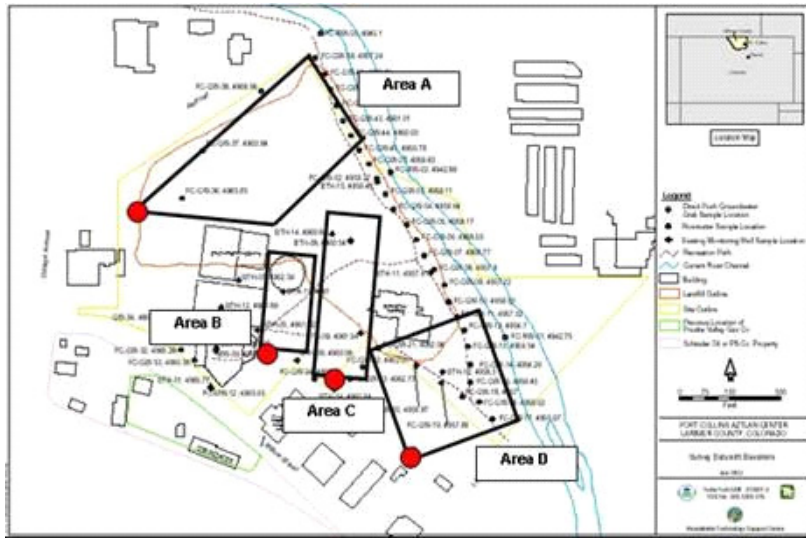


Figure E-1. Map of the Ft. Collins Site Detailing the Location of the HRPM Survey Areas.

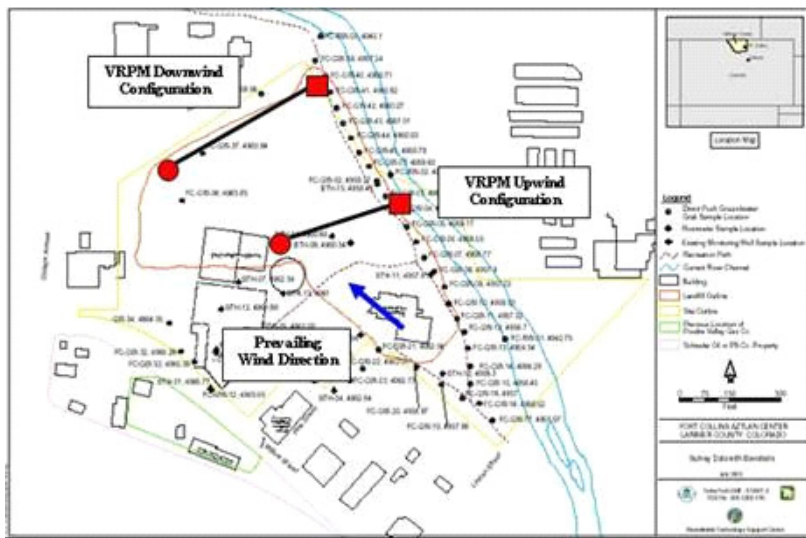


Figure E-2. Map of the Ft. Collins Site Detailing the Location of the VRPM Configurations.

Results and Discussion

Area A

HRPM and VRPM Results

The HRPM survey of Area A did not detect the presence of any methane hot spots. However, the survey detected the presence of a gasoline hot spot (average concentration over 81 ppb, with a maximum concentration of about 100 ppb) located in the southern corner of Area A.

The VRPM survey of the site detected methane, ammonia, and gasoline on the downwind VRPM configuration (see Figure E-2). The average calculated gasoline flux from the VRPM survey was 0.87 g/s. The measured methane and ammonia concentrations were well-correlated, indicating that the measured concentrations probably came from the same source. Wind data collected indicate that the source of the methane and ammonia detected is located outside of Area A, across the river adjacent to the site. This is supported by the fact that methane and ammonia were not detected during the HRPM survey of Area A.

UV-DOAS Results

The UV-DOAS instrument was set up along the surface, approximately parallel to the downwind VRPM configuration in Area A. The UV-DOAS instrument found average concentrations of 2.6 ppb for benzene, 21 ppb for toluene, and 4.9 ppb for p-xylene. The toluene concentrations measured with the UV-DOAS correlated well with the gasoline concentrations measured with the OP-FTIR, indicating that the detected gasoline plume contained BTX compounds.

Areas B, C, and D

HRPM surveys did not detect any methane hot spots in Areas B, C, and D. The average surface methane concentrations in these areas were close to ambient background levels. The HRPM survey of Area B detected a small methanol hot spot. The average methanol concentration measured in this area was 20.9 ppb, with a range of 0 to 127 ppb.

OP-TDLAS Measurements

The OP-TDLAS measured methane concentrations in Areas A, B, C, and D. The configurations used by the OP-TDLAS in these areas were often similar to the configurations used with the OP-FTIR instruments. The methane concentrations measured by the OP-TDLAS were only slightly above ambient background levels, reinforcing the findings of the HRPM surveys. The methane concentrations measured with the OP-TDLAS were almost always slightly higher than concentrations measured with the OP-FTIR along similar optical paths.

Chapter 1

Project Description and Objectives

1.1 Background

As part of its Brownfields redevelopment effort, the city of Ft. Collins, Colorado, with assistance from the United States Environmental Protection Agency (EPA) Region 8 Office, is assessing a former landfill site for gas emissions. The property, which is approximately 19 acres in size, is composed of a commercial area, a park, playgrounds, soccer fields, and bike paths. The site is bounded on the northeast by the Cache La Poudre River. The City of Fort Collins is interested in developing a larger recreation facility at the site and is receiving assistance from EPA Region 8 under the Targeted Brownfields Assessment program to perform an assessment at the site. As part of the 21M² (Monitoring and Measurement Technologies for the 21st Century) initiative, the EPA Office of Superfund Remediation and Technology Innovation provided support to EPA Region 8 for this study.

The site encompasses a landfill approximately 5 acres in size. Little information is known about the contents of the landfill, or when the landfill opened. The landfill was operated by the City of Fort Collins and was closed in the early 1960s. After the landfill was closed, the site was covered with a clay cap, ranging in depth from one to three feet. A manufactured gas plant operated adjacent to the site for approximately 30 years. The plant operated until around 1930, and produced gas from coal and, possibly, oil.

The focus of this study was to evaluate emissions of fugitive gases and VOCs at the site using an open-path Fourier transform infrared (OP-FTIR) spectrometer, open-path tunable diode laser absorption spec-

troscopy (OP-TDLAS), and an ultra-violet differential optical absorption spectrometer (UV-DOAS). The OP-FTIR instrument provided the critical measurements in the current study. The OP-TDLAS and UV-DOAS provided noncritical, supplemental data. The study involved a technique developed through research funded by EPA's National Risk Management Research Laboratory (NRMRL) that uses ground-based optical remote sensing technology, known as optical remote sensing-radial plume mapping (ORS-RPM) (Hashmonay and Yost, 1999; Hashmonay et al., 1999; Wu et al., 1999; Hashmonay et al., 2001; Hashmonay et al., 2002). The effort identified emission hot spots (areas of relatively higher emissions), investigated source homogeneity, and calculated an emission flux rate for each compound detected at the site. Concentration maps in the horizontal and downwind vertical planes were generated using the horizontal radial plume mapping (HRPM), and vertical plume mapping (VRPM) methods, respectively.

The study consisted of one field campaign performed during September 2003 by ARCADIS and EPA personnel. The Fort Collins site was divided into four survey areas. Figure 1-1 presents the overall layout of the site, detailing the geographic location of each HRPM survey area. The red dots denote the location of the OP-FTIR used in each configuration. Figure 1-2 shows the location of the VRPM configurations that were used to collect data for emission flux calculations. The red square indicates the location of the scissors jack (vertical structure) used in each VRPM configuration.

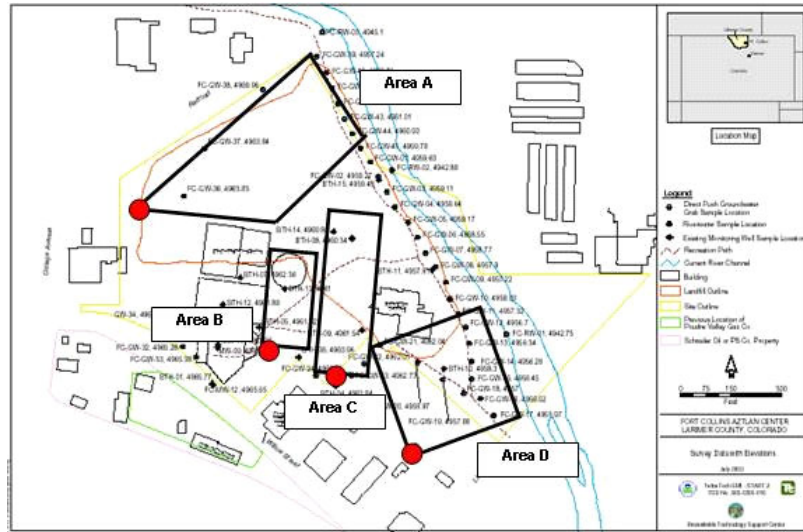


Figure 1-1. Map of the Ft. Collins Site Detailing the Location of the HRP M Survey Areas.

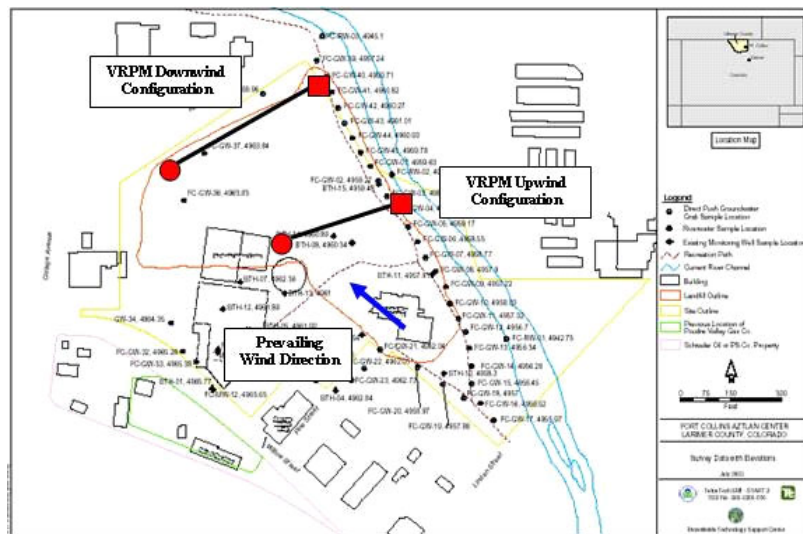


Figure 1-2. Map of the Ft. Collins Site Detailing the Location of the VRPM Configurations.

1.2 Project Description/Purpose

The objectives of the study were to

- Collect OP-FTIR data in order to identify major emissions hot spots at the Ft. Collins, CO landfill by generating surface concentration maps in the horizontal plane,
- Measure emission fluxes of detectable compounds downwind from major hot spots, and
- Demonstrate the operation and function of the various ORS technologies

The ORS techniques used in this study were designed to characterize the emissions of fugitive gases from area sources. Detailed spatial information is obtained from path-integrated ORS measurements by the use of iterative algorithms. The HRPM method involves the use of a configuration of nonoverlapping radial beam geometry to map the concentration distributions in a horizontal plane. This method can also be applied to a vertical plane downwind from an area emission source to map the crosswind and vertical profiles of a plume. By incorporating wind information, the flux through the plane can be calculated, which leads to the emission rate of the upwind area source. An OP-FTIR sensor was chosen as the primary instrument for the study because of its capability of accurately measuring a large number of chemical species that might occur in a plume.

The OP-FTIR Spectrometer combined with the ORS-RPM method is designed for both fence-line monitoring applications, and real-time, on-site, remediation monitoring and source characterization. An infrared light beam, modulated by a Michelson interferometer is transmitted from a single telescope to a retroreflector (mirror) target that is usually 100 to 500 meters from the telescope. The returned light signal is received by the single telescope and directed to a detector. Some of the light is absorbed by the molecules in the beam path as the light propagates to the mirror, and more is absorbed as the light is reflected back to the analyzer. Thus, the round-trip path of the light doubles the chemical absorption signal. One advantage of OP-FTIR monitoring is that the concentrations of a multitude of infrared absorb-

ing gaseous chemicals can be detected and measured simultaneously, with high temporal resolution.

The OP-TDLAS system (Unisearch Associates, Inc.) is a fast, interference-free technique for making continuous concentration measurements of many gases. The OP-TDLAS used in the current study is capable of measuring concentrations of gases such as carbon monoxide (CO), carbon dioxide (CO₂), ammonia (NH₃), and methane (CH₄) in the range of tens of parts per billion over an open path up to 1 km. The laser emits radiation at a particular wavelength when an electrical current is passed through it. The light wavelength depends on the current and therefore allows scanning over an absorption feature and analyzing the target gas concentration using Beer's law. The OP-TDLAS used in this study is a multiple channel TDL instrument that allows fast scanning electronically (few seconds) among many beam-paths (presently 8 beams). The OP-TDLAS utilizes a small 4-inch telescope, which directs the laser beam to a mirror. The laser beam is returned by the mirror to the telescope, which is connected with fiber optics to a control box that houses the laser and a multiple channel detection device. For this particular field campaign, data from the OP-TDLAS were used to provide additional information on methane concentrations at the site. At the time of the field campaign, the OP-TDLAS system had only recently been acquired by EPA. Consequently, standard operating and calibration procedures were still being developed.

The UV-DOAS AR500 instrument (OPSIS, Inc.) has proven to be particularly useful for determining the concentration of unstable species like free radicals or nitrous acid. Additionally, many of the aromatic species can be determined at high sensitivity (Platt, 1994). For the current field campaign, the UV-DOAS instrument was deployed in a bistatic configuration (the UV source and detector on opposite ends of the optical path). This project is the first time the UV-DOAS instrument has been deployed by this group for data collection. For this particular field campaign, data from the UV-DOAS instrument were used to provide additional information on benzene, toluene,

and xylenes (BTX) concentrations. The UV-DOAS instrument was used for BTX measurements because it has a much lower minimum detection limit (MDL) than the OP-FTIR for these compounds. Although the strong, structured UV absorption features of monocyclic aromatic hydrocarbons (i.e., BTX) have been known for a long time, it only recently became possible to use these properties for the reliable, sensitive, and selective measurement of these compounds by UV-DOAS. UV-DOAS measurements of BTX and trace gases can be an extremely valuable complement to more traditional techniques like OP-FTIR.

Table 1-1 presents summary information on the ORS instrumentation used in this study. The table lists the analytes measured by each instrument during the current study and instrument limitations such as weather and interfering species.

Meteorological and survey measurements were also made during the field campaign. A theodolite was used to make the survey measurement of the azimuth and elevation angles and the radial distances to the mirrors, relative to the OP-FTIR sensor.

1.2.1 Horizontal RPM

The HRPM approach provides spatial information to path-integrated measurements acquired in a horizontal plane by an ORS system. This technique yields information on the two-dimensional distribution of the concentrations in the form of chemical concentra-

tion contour maps. This form of output readily identifies chemical “hot spots,” the locations of high emissions. This method can be of great benefit for performing site surveys before, during, and after site remediation activities.

HRPM scanning is usually performed with the ORS beams located as close to the ground as is practical. This enhances the ability to detect minor constituents emitted from the ground, since the emitted plumes dilute significantly at higher elevations. The survey area is typically divided into a Cartesian grid of n times m rectangular cells. In some unique cases, the survey area may not be rectangular due to obstructions, and the shape of the cells may be slightly altered accordingly. A mirror is located in each of these cells, and the ORS sensor scans to each of these mirrors, dwelling on each for a set measurement time (30 seconds in the present study). The system scans to the mirrors in the order of either increasing or decreasing azimuth angle. The path-integrated concentrations measured at each mirror are averaged over several scanning cycles to produce maps of time-averaged concentrations. Meteorological measurements are made concurrent to the scanning measurements.

Figure 1-3 represents a typical HRPM configuration. In this particular case, $n = m = 3$. The solid lines represent the nine optical paths, each terminating at a mirror.

Table 1-1. Summary Information on the ORS Instrumentation Used in the Study.

Property	OP-FTIR	OP-TDLAS	UV-DOAS
Wavelength Range	Infrared (2-20 μm)	Near Infrared (approx. 1.5 μm)	Ultraviolet (245-380 nm)
Target Analytes	Methane, ammonia, gasoline, VOCs	Methane	Benzene, toluene, xylene
Detection Limits	Parts per billion	Parts per billion	Parts per billion
Limiting Weather Conditions	Heavy rain	Heavy rain, fog	Heavy rain, fog
Interfering Species	Carbon dioxide, water	None	Oxygen, ozone

Brownfield Landfill in Ft. Collins, Colorado

One OP-FTIR instrument (manufactured by Uni-search Associates) was used to collect Horizontal RPM data during the field campaign.

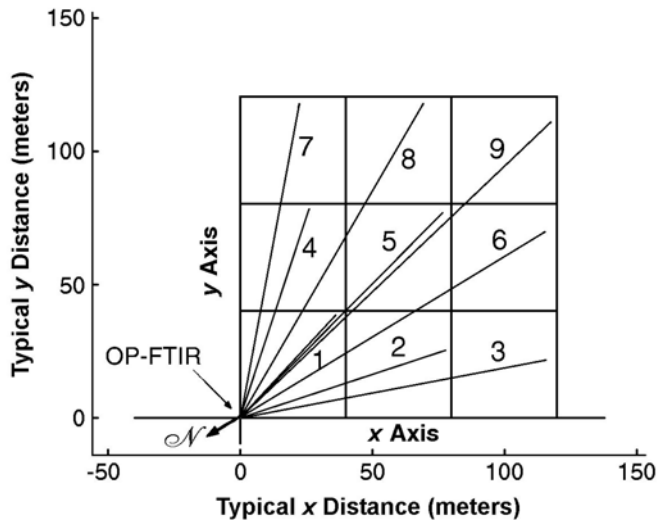


Figure 1-3. Example of a HRPM Configuration.

1.2.2 Vertical RPM

The VRPM method maps the concentrations in the vertical plane by scanning the ORS system in a vertical plane downwind from an area source. One can obtain the plane-integrated concentration from the reconstructed concentration maps. The flux is calculated by multiplying the plane-integrated concentration by the wind speed component perpendicular to the vertical plane. Thus, the VRPM method leads to a direct measurement-based determination of the upwind source emission rate (Hashmonay et al., 1998; Hashmonay and Yost, 1999, Hashmonay et al., 2001).

Figure 1-4 shows a schematic of the experimental setup used for vertical scanning. Several mirrors are placed in various locations on a vertical plane in-line with the scanning OP FTIR. A vertical platform (scissors jack) is used to place two of the mirrors at a predetermined height above the surface. The location of the vertical plane is selected so that it intersects the mean wind direction as close to perpendicular as practical.

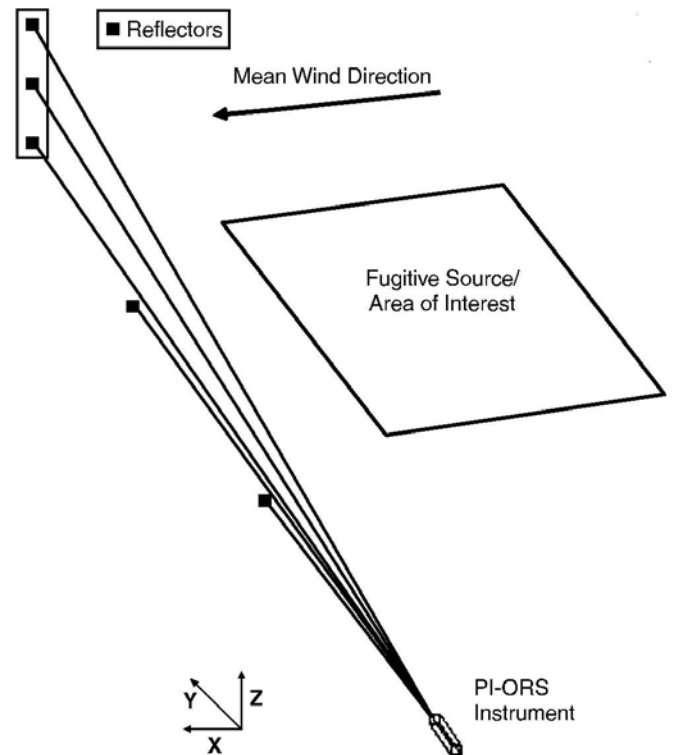


Figure 1-4. Example of a VRPM Configuration.

Two OP-FTIR instruments (manufactured by Uni-search Associates and IMACC, Inc.) were used to create two vertical planes, one upwind and one downwind of the source area. This configuration made it possible to calculate an upwind emission flux from the upwind vertical plane measurements, and a downwind emission flux from the downwind vertical plane measurements. More information on the configurations used in this study can be found in Section 2 of this report.

1.3 Quality Objectives and Criteria

Data quality objectives (DQOs) are qualitative and quantitative statements developed using EPA's DQO Process (EPA 2000) that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions. DQOs

define the performance criteria that limit the probabilities of making decision errors by considering the purpose of collecting the data, defining the appropriate type of data needed, and specifying tolerable probabilities of making decision errors.

Quantitative objectives are established for critical measurements using the data quality indicators of accuracy, precision, and completeness. The acceptance criteria for these data quality indicators (DQIs) are summarized later in Table 5-2 of Section 5 of this report. Accuracy of measurement parameters is determined by comparing a measured value to a known standard, assessed in terms of percent bias. Values must be within the listed tolerance to be considered acceptable.

Precision is evaluated by making replicate measurements of the same parameter and by assessing the variations of the results. Precision is assessed in terms of relative percent difference (RPD), or relative

standard deviation (RSD). Replicate measurements are expected to fall within the tolerances shown in Table 5-2 of Section 5. Completeness is expressed as a percentage of the number of valid measurements compared to the total number of measurements taken.

Estimated minimum detection limits (MDL) of the OP-FTIR instrument, by compound, are given in Table 1-2. It is important to note that the values listed in Table 1-2 should be considered first step approximations, as the MDL is highly variable, and depends on many factors including atmospheric conditions. Actual MDL are calculated in the quantification software for all measurements taken. MDL for each absorbance spectrum are determined by calculating the root mean square (RMS) absorbance noise in the spectral region of the target absorption feature. The MDL is the absorbance signal (of the target compound) that is five times the RMS noise level, using a reference spectrum acquired for a known concentration of the target compound.

Table 1-2. Detection Limits for Target Compounds.

Compound	OP-FTIR Estimated Detection Limit for Path Length = 100m, 1 min Average (ppmv)	AP-42 Value ratioed to an average methane concentration of 50 ppm ^a (ppmv)
1,4-Dichlorobenzene	0.012	0.000021
2-Propanol	0.0060	0.0050
Acetone	0.024	0.00070
Acrylonitrile	0.010	0.00063
Butane	0.0060	0.00050
Chlorobenzene	0.040	0.000025
Chloroform	0.012	0.0000030
Chloromethane	0.012	0.00010
Dichlorodifluoromethane	0.0040	0.0016
Dimethyl sulfide	0.018	0.00078
Ethane	0.010	0.089
Ethanol	0.0060	0.0027
Ethyl benzene	0.060	0.00046
Ethyl chloride	0.0040	0.00013

continued

Brownfield Landfill in Ft. Collins, Colorado

Table 1-2. Detection Limits for Target Compounds (concluded).

Compound	OP-FTIR Estimated Detection Limit for Path Length = 100m, 1 min Average (ppmv)	AP-42 Value ratioed to an average methane concentra- tion of 50 ppm ^a (ppmv)
Ethylene dibromide	0.0060	0.00000010
Ethylene dichloride	0.030	0.000041
Fluorotrichloromethane	0.0040	0.000076
Hexane	0.0060	0.00066
Hydrogen sulfide	6.0	0.0036
Methane	0.024	N/A ^b
Methanol	0.0015	N/A
Methyl ethyl ketone	0.030	0.00071
Methyl isobutyl ketone	0.040	0.00019
Methyl mercaptan	0.060	0.00025
Methylene chloride	0.014	0.0014
Octane	0.0025	N/A
Pentane	0.0080	0.00033
Propane	0.0080	0.0011
Propylene dichloride	0.014	0.000018
Tetrachloroethene	0.0040	0.00037
Trichlorethylene	0.0040	0.00028
Vinyl chloride	0.010	0.00073
Vinylidene chloride	0.014	0.000020
Xylenes	0.030	0.0012

^a The AP-42 values represent an average concentration of different pollutants in the raw landfill gas. This is not comparable to the detection limits for the OP-FTIR which is an average value for a path length of 100 meters across the surface of the area source being evaluated. However, it does provide an indication of the types of pollutants and range of concentrations associated with landfill gas emissions in comparison to the detection limits of the OP-FTIR.

^b N/A = not available.

1.4 Project Schedule

One field campaign was completed for this study

during September 2003. Table 1-3 provides the schedule of ORS work that was performed.

Table 1-3. Schedule of Work Performed at the Site.

Day	Detail of Work Performed
Thursday, September 4 to Saturday, September 6	Travel to site
Sunday, September 7	AM-Set-up PM-HRPM Survey of Areas C and D

continued

Table 1-3. Schedule of Work Performed at the Site (concluded).

Day	Detail of Work Performed
Monday, September 8	AM-HRPM Survey of Area B PM-VRPM Survey
Tuesday, September 9	AM-HRPM Survey of Area A PM-VRPM Survey
Wednesday, September 10	Travel from site

Chapter 2 Test Procedures

The following subsections describe the test procedures used at each of the four survey areas, which are designated as Area A through Area D. Refer to Figure 1-1 for the geographical orientation of each area. The survey areas were chosen to ensure that the study investigated the maximum amount of surface area at the site. Another factor in selecting the survey areas was the location of key areas of interest at the site, including playgrounds and soccer fields. The boundaries of each survey area were determined based on the location of physical barriers such as buildings and trees. HRPM was performed in each area to produce surface concentration maps and to locate any surface hot spots. In addition, VRPM was performed in Area A to obtain an emission flux rate of methane, ammonia, and gasoline from the site. Refer to Figure 1-2 for the geographical orientation of the VRPM configurations. VRPM was not performed in the other areas due to limitations in the size of the areas, and the presence of physical barriers. Each section includes a figure that details the position of the mirrors used in the HRPM surveys. The coordinates of the mirrors used in each configuration are presented in Appendix A of this report.

OP-FTIR data were collected as interferograms. All data were archived to CD-ROMs. After archiving, interferograms were transferred to ARCADIS personnel who performed the transformations to absorbance spectra and then calculated concentrations using Non-Lin (Spectrosoft) quantification software. This analysis was done after completion of the field campaign. Concentration data were then matched with the appropriate mirror locations, wind speed, and wind direction. The ARCADIS RPM software was used to process the data into horizontal plane concen-

tration maps or vertical plane plume visualizations, as appropriate.

Meteorological data including wind direction, wind speed, temperature, relative humidity, and barometric pressure were continuously collected during the measurement campaign with a Climatronics model 101990-G1 instrument. The Climatronics instrument is automated. It collects real-time data from its sensors and records time-stamped data as one-minute averages to the computer used for data collection. Wind direction and speed-sensing heads were used to collect data at the surface during the HRPM surveys, and at heights of 2 and 10 meters during the VRPM survey. The 10 meter sensor was placed on top of the scissors jack. The sensing heads for wind direction incorporate an auto-north function (automatically adjusts to magnetic north) that eliminates the errors associated with subjective field alignment to a compass heading. After collection, a linear interpolation between the two sets of data is done to estimate wind velocity as a function of height.

Once the concentrations maps and wind information are processed, the concentration values are integrated incorporating the wind speed component normal to the plane at each height level to compute the flux through the vertical plane. In this stage, the concentration values are converted from parts per million by volume to grams per cubic meter considering the molecular weight of the target gas and ambient temperature. This enables the direct calculation of the flux in grams per second using wind speed data in meters per second.

In reporting the average calculated flux, a moving

average is used in the calculation of the average flux values to show temporal variability in the measurements. A moving average involves averaging flux values calculated from several different consecutive cycles, which are defined as data collected when scanning one time through all the mirrors in the configuration. For example, a data set taken from 5 cycles may be reported using a moving average of 4, where values from cycles 1 to 4, and 2 to 5 are averaged together to show any variability in the flux values.

Section 3 of the report contains a figure depicting the reconstructed gasoline plume map and calculated gasoline flux generated from the collected data using the VRPM method. It should be noted that the shape of the plume maps generated by this method is used to give information on the homogeneity of the plume and do not affect the calculated flux values. The shape of the maps generated represents the best fit of the limited data to a symmetric Gaussian function, and this fit may drive the plume shape outside of the configuration.

2.1 Area A

Area A was located in the northwestern section of the site. The area was bounded on the north by the Cache La Poudre River, on the west by a set of railroad tracks, and on the south by a recreational building at the site. Figure 2-1 shows a schematic of the HRP configuration used in Area A, and Figure 2-2 shows a partial picture of the configuration. The area was divided into nine cells, and the OP-FTIR/scanner was placed in the southwestern corner of the area.

2.2 Area B

Area B was located in a central location at the site. The area consisted primarily of a large playground and land directly adjacent to the playground. The area was bounded on the west by a large parking lot and recreation building and on the east by another parking lot. Figure 2-3 shows a partial picture of the HRP configuration used in the area. The area was divided into eight cells, and the OP-FTIR/scanner was placed along the southern boundary of the area.

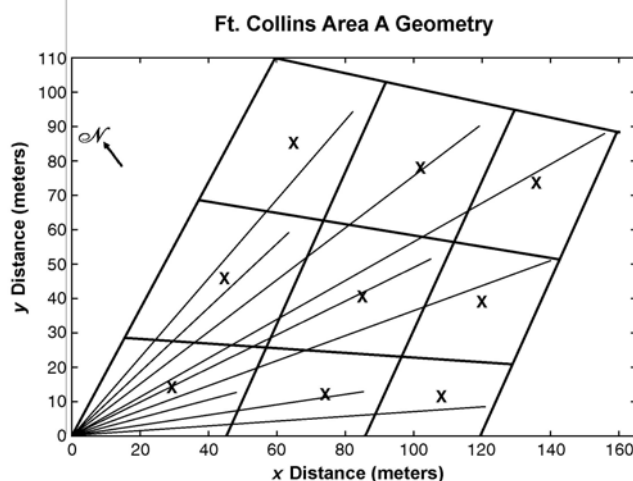


Figure 2-1. Schematic of the HRP Configuration Used in Area A.



Figure 2-2. Partial Picture of the HRP Configuration Used in Area A.

2.3 Area C

Area C was located in a central location at the site. The area was bounded on the west by the large playground in Area B, on the east by the United Way building at the site, and on the north by the Cache La Poudre River. A small ravine running north to south bisected the area. Figure 2-4 shows a partial picture of the HRP configuration used in the area. The area was divided into eight cells, and the OP-FTIR/scanner was located along the southern boundary of



Figure 2-3. Partial Picture of the HRP Configuration Used in Area B.



Figure 2-4. Partial Picture of the HRP Configuration Used in Area C.

the area.

2.4 Area D

Area D was located in the southeastern corner of the site. The area was bounded on the east by the Cache La Poudre River, on the west by an industrial area, and on the north by a playground on the southern side of the United Way Building. Figure 2-5 shows a partial picture of the HRP configuration used in the area. The area was divided into eight cells, and the



Figure 2-5. Partial Picture of the HRP Configuration Used in Area D.

OP-FTIR/scanner was set up along the southwestern boundary of the area.

2.5 VRPM Measurements

The VRPM survey was conducted in Area A using two monostatic OP-FTIR instruments and two scissors jacks. The configuration formed two vertical planes, one upwind and one downwind. The upwind plane was located near the eastern boundary of Area A, and the downwind plane was located along the western boundary of the site (Figure 1-2). Each plane consisted of three mirrors placed along the surface and two mirrors placed on the scissors jack. Figure 2-6 shows a partial picture of the VRPM configuration used in the study.

2.6 OP-TDLAS Measurements

The OP-TDLAS system was deployed during each day of the field campaign to provide additional information on methane concentrations at the site. The OP-TDLAS is a more cost-effective instrument for collecting measurements of specific target compounds, such as methane. The methane measurements from the OP-TDLAS served as a validation of methane measurements taken with the OP-FTIR. Figure 2 7 shows a picture of the OP-TDLAS system. The OP-TDLAS collected data along the surface in Areas C and D on September 7 and in Areas A and B on September 8. On September 9, the instrument was



Figure 2-6. Partial Picture of the VRPM Configuration Used at the Site.



Figure 2-8. UV-DOAS Instrument.



Figure 2-7. OP-TDLAS System.

set up in Area A and collected data using surface and vertical beam paths. In most cases, the optical configurations used with the OP-TDLAS were very similar to the configurations used with the OP-FTIR instrument. The distance of the path lengths used in each OP-TDLAS configuration are presented in Appendix

B of this report.

2.7 UV-DOAS Measurements

The UV-DOAS instrument was deployed at the site by a representative of OPSIS, Inc. to provide supplemental data on BTX concentrations at the site. The instrument collects continuous measurements and reports one-minute, path-averaged concentrations. Figure 2-8 shows a picture of the UV-DOAS instrument.

On September 9, the instrument was set up along the western boundary of Area A. The UV-DOAS configuration in Area A was approximately parallel to the path of mirror 3 from the VRPM survey done in this area with the OP-FTIR instrument. The UV-DOAS instrument collected data on this day for approximately three hours.

Chapter 3 Results and Discussion

The results from the ORS-RPM data collected at the site are presented in the following subsections. The HRPm results from Areas B, C, and D are not presented because no significant hot spots of methane or VOC were detected in these areas. Data from the VRPM surveys were collected only in Area A. VRPM surveys in Areas B, C, or D were not necessary because the HRPm surveys in these areas indicated that there were no significant methane or VOC hot spots to contribute to a significant emissions flux. Moreover, physical and geographical barriers in Areas B, C, and D would have precluded VRPM measurements. It should be noted that the concentration values reported in the following sections have not been corrected to standard atmospheric conditions.

3.1 Area A

Data from HRPm and VRPM surveys using the OP-FTIR instrument were collected for Area A. In addition, the OP-TDLAS collected methane emission data to validate the OP-FTIR measurements, and the UV-DOAS collected supplemental BTX data.

3.1.1 HRPm Results

A HRPm survey was performed in Area A to identify possible hot spots of methane and VOCs. Table 3-1 presents the average methane concentrations detected along each beam path in the configuration. The locations of the mirrors used in this configuration are presented in Appendix A of this report.

Table 3-1. Average Methane Concentrations Measured During the HRPm Survey of Area A.

Loop	Methane Concentrations (ppm)								
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8	Mirror 9
1	1.81	1.83	1.81	1.81	1.81	1.81	1.86	1.83	1.83
2	1.81	1.83	1.81	1.81	1.82	1.80	1.84	1.81	1.82
3	1.80	1.82	1.78	1.79	1.80	1.79	1.83	1.80	1.79
4	1.79	1.82	1.80	1.80	1.80	1.78	1.83	1.80	1.80
5	1.79	1.81	1.78	1.79	1.79	1.78	1.83	1.79	1.78
6	1.79	1.81	1.78	1.76	1.79	1.77	1.83	1.79	1.78
7	1.78	1.80	1.78	1.77	1.79	1.77	1.82	1.78	1.79
8	1.78	1.80	1.78	1.77	1.78	1.71	1.82	1.78	1.78
9	1.80	1.79	1.78	1.77	1.77	1.76	1.82	1.78	1.78
10	1.77	1.79	1.77	1.77	1.78	1.76	1.83	1.78	1.78

continued

Table 3-1. Average Methane Concentrations Measured During the HRPM Survey of Area A (concluded).

Loop	Methane Concentrations (ppm)								
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8	Mirror 9
11	1.77	1.79	1.78	1.78	1.80	1.77	1.81	1.78	1.78
12	1.78	1.80	1.78	1.78	1.79	1.77	1.83	1.80	1.79
13	1.78	1.79	1.77	1.78	1.78	1.77	1.81	1.79	1.77
14	1.78	1.80	1.77	1.78	1.79	1.77	1.82	1.78	1.77
15	1.77	1.79	1.78	1.78	1.78	1.76	1.81	1.78	1.78
Mean	1.79	1.80	1.78	1.78	1.79	1.77	1.83	1.79	1.79
Std. Dev.	0.014	0.015	0.013	0.014	0.013	0.022	0.012	0.014	0.016

The survey did not detect the presence of any methane hot spots along the surface in Area A. This is supported by the relatively small standard deviations of measured methane concentrations for each beam path in the configuration (Table 3-1). Average methane concentrations measured along each beam path were very close to ambient background levels.

(primarily octane) in Area A. Figure 3-1 presents the reconstructed map of surface gasoline concentrations (in parts per billion) measured in Area A. The figure shows the presence of one hot spot with an average concentration over 81 ppb and a maximum concentration of about 100 ppb located in the southern corner of Area A. The MDL of the OP-FTIR instrument is 15 ppb for gasoline.

The HRPM survey detected the presence of gasoline

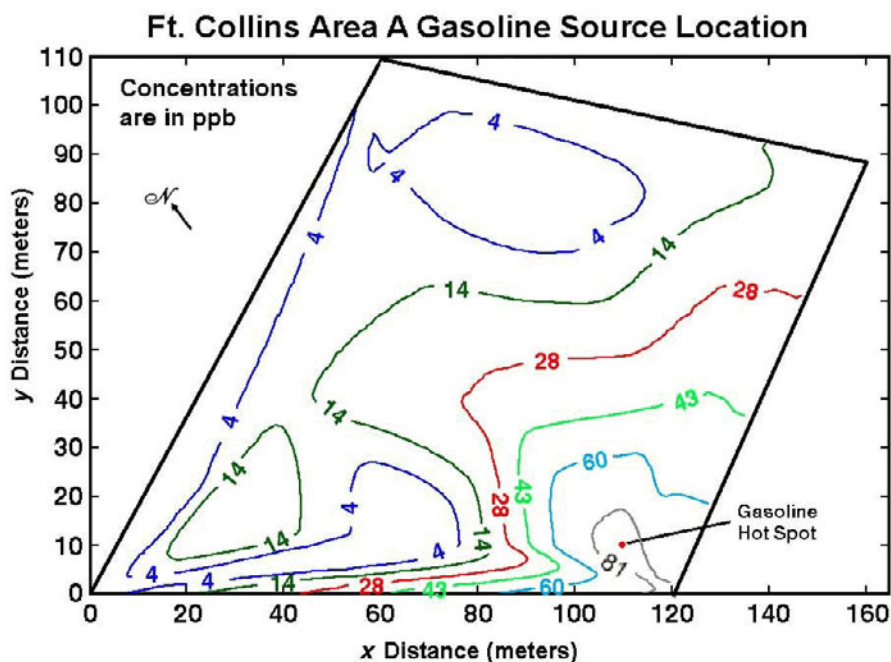


Figure 3-1. Reconstructed Gasoline Surface Concentrations in Area A.

3.1.2 VRPM Results

The VRPM survey of the site detected methane, ammonia, and gasoline on the downwind VRPM configuration (Figure 1-2). Figure 3-2 shows a time series of methane and ammonia concentrations measured along beam path #5 of the VRPM downwind survey (which extended from the OP-FTIR instrument to the mirror placed at the top of the scissors jack), and observed wind direction during the period of data collection. The methane and ammonia concentrations are well-correlated, indicating that the measured concentrations probably came from the same source. The peak concentrations of methane and ammonia occur during periods that the wind direction is around -20° from normal to the plane of the configuration (approximately 123° from due north). Since methane and ammonia hot spots were not detected during the HRPm survey of Area A, and methane and ammonia were detected on the downwind VRPM configuration when the winds shifted to a more

easterly direction, it is likely that the source of the methane and ammonia detected is located outside of Area A across the river.

Figure 3-3 is a vertical map of the reconstructed gasoline plume from the downwind VRPM survey showing contours of gasoline concentrations in parts per million. The average calculated gasoline flux from this survey was 0.87 g/s. The reconstruction shows that the shape of the plume is very broad both horizontally and vertically, indicating that the source of the plume is relatively far from the configuration. This is consistent with the location of the gasoline hot spot found in the HRPm survey of this area. No vertical gasoline plume was detected on the upwind VRPM configuration, but low levels of gasoline were detected on the surface beam paths of the upwind VRPM configuration. This is probably due to the gasoline hot spot located close to the axis of the upwind VRPM configuration (Figures 1-1 and 1-2).

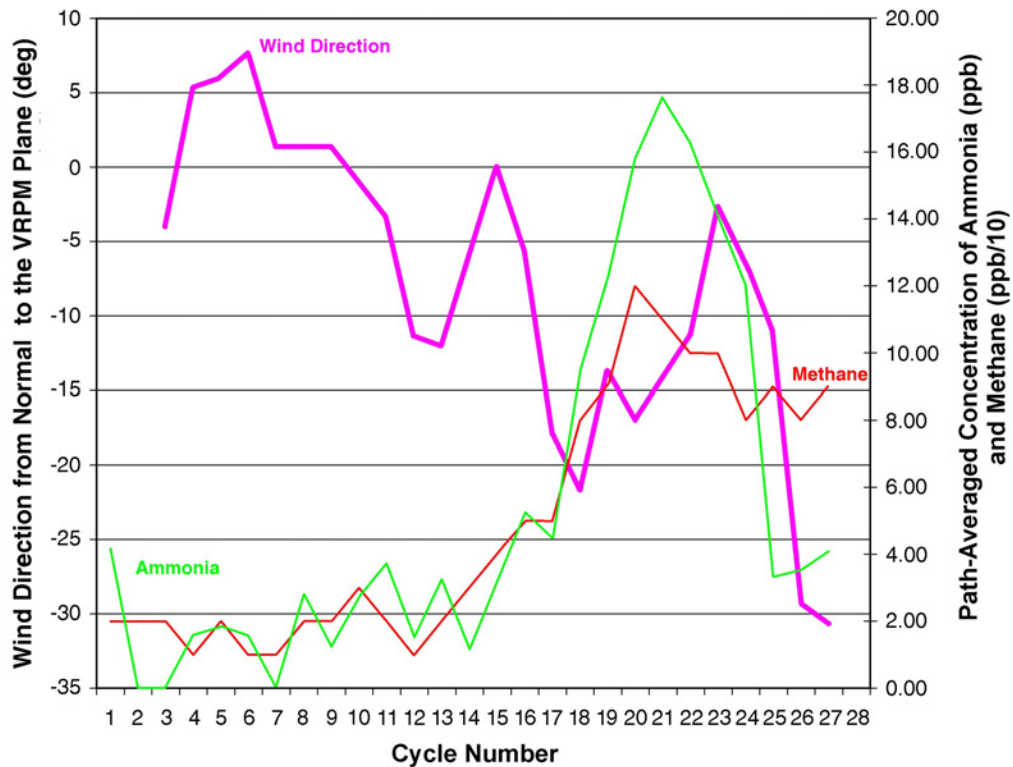


Figure 3-2. Time Series of Wind Direction and Concentrations of Methane and Ammonia Measured on Beam Path #5 of the VRPM Downwind Survey.

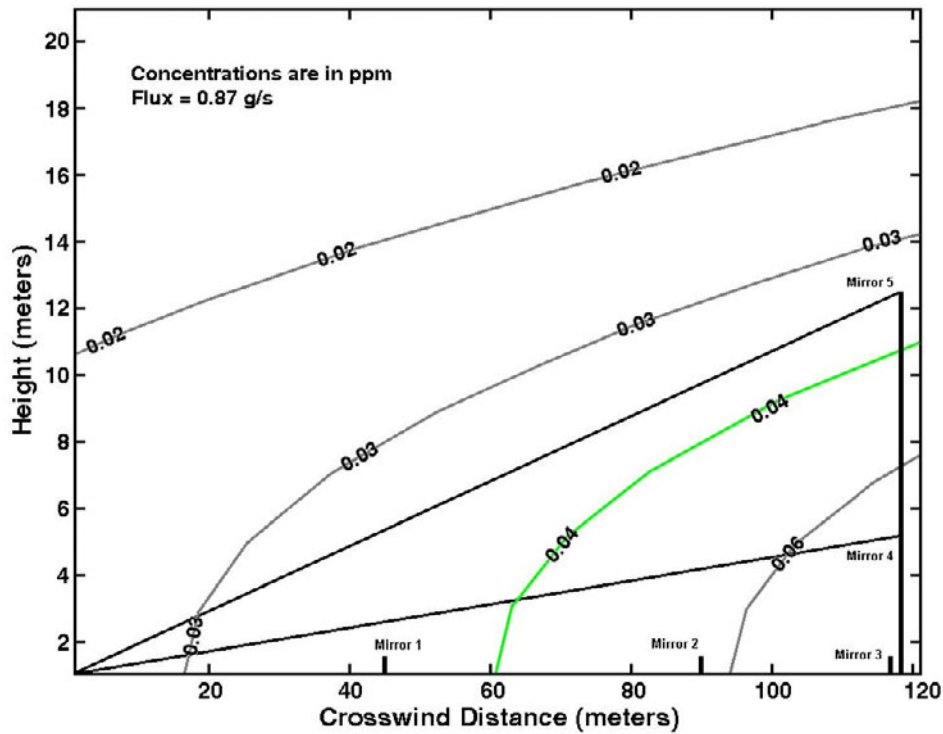


Figure 3-3. Reconstructed Gasoline Plume Map from the Downwind VRPM Survey.

Figure 3-4 presents a time series of gasoline, methane, and ammonia fluxes measured during the downwind VRPM survey. The average flux values were calculated using a moving average of 4 cycles. The well-correlated methane and ammonia fluxes appeared during the second half of the survey when wind shifted slightly to the east. These flux values are probably a significant underestimation of the emission rate of the methane and ammonia source because only a small portion of the plume was captured by the measurement configuration. However, the gasoline flux values are significant throughout the measurement period. The gasoline flux values are probably a slight underestimation of the source emission rate since the detected hot spot is located approximately 100 meters away from the downwind VRPM configuration. The highest gasoline flux values occurred during periods when the observed wind direction was close to perpendicular to the downwind VRPM configuration (see Figure 3-2 for a time series of observed wind directions during this period).

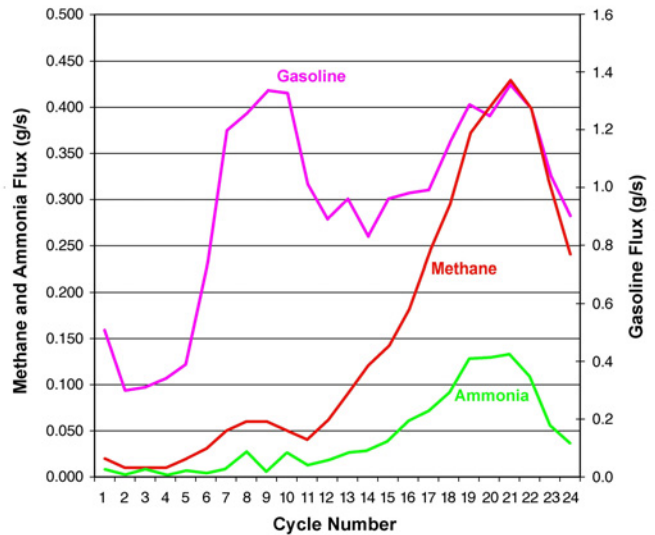


Figure 3-4. Gasoline, Methane, and Ammonia Fluxes Measured during the Downwind VRPM Survey.

3.1.3 UV-DOAS Results

The UV-DOAS instrument was set up along the

Brownfield Landfill in Ft. Collins, Colorado

surface approximately parallel to the downwind VRPM configuration on September 9. Table 3-2 presents the average concentrations of benzene, toluene, and p-xylene (in parts per billion) measured by the UV-DOAS instrument during the same time period as the VRPM run. The MDL of the UV-DOAS instrument was 1 ppb for benzene, toluene, and p-xylene.

Table 3-2. Average Concentration of BTX Compounds Measured by the UV-DOAS Instrument.

Compound	Concentration (ppb)		
	Average	Range	Std. Dev.
benzene	2.6	0.91 to 7.2	1.8
toluene	21	5.6 to 27	5.8
p-xylene	4.9	3.8 to 7.6	0.95

Figure 3-5 presents a time series of gasoline concentrations (in parts per billion) collected with the OP-FTIR instrument along beam path #3 (which extended along the surface from the OP-FTIR instrument to the base of the scissors jack), and BTX concentrations (in parts per billion) collected with the UV-DOAS instrument. The time period depicted in the figure represents times that the two instruments were concurrently collecting data. The figure shows that the concentrations of toluene and gasoline correlate well although they were collected with different instruments, indicating that the detected gasoline plume contains BTX compounds below the detection levels of the OP-FTIR (MDL of 90 ppb for benzene, 40 ppb for toluene, and 37 ppb for p-xylene).

3.1.4 Summary of Results from Area A

Figure 3-6 presents a summary of the results of the gasoline surface concentration map from the HRPm survey in Area A showing a hot spot in the southern corner of the area. The figure also shows the suspected location of the source of methane and ammonia measured on the VRPM downwind plane. The location of this source is based on wind data and the fact that methane and ammonia plumes were not

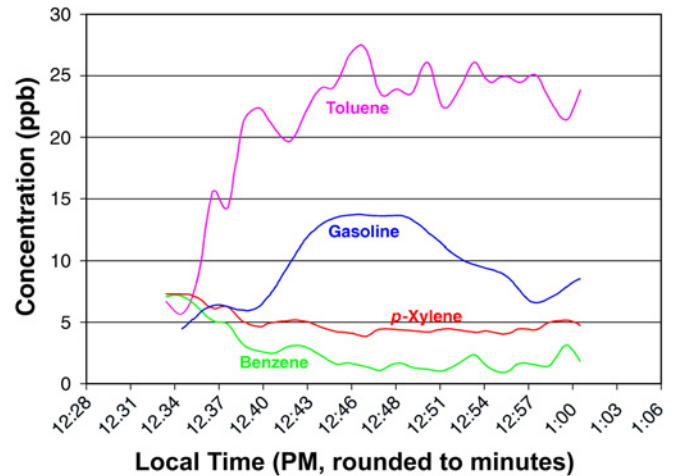


Figure 3-5. Time Series of Path-Averaged Concentrations of Benzene, Toluene, and p-Xylene Measured with the UV-DOAS Instrument and Gasoline Measured with the OP-FTIR in Area A.

detected during the HRPm survey or the upwind VRPM configuration.

3.2 Areas B, C, and D

HRPM surveys were completed in Areas B, C, and D, and these surveys did not detect any methane hot spots. Table 3-3 presents the average methane concentrations (in parts per million) found during the HRPm survey of Areas B, C, and D. The location of the mirrors used in each configuration are presented in Appendix A. The table shows that the average surface methane concentrations measured in each area were close to ambient background levels. The fact that the standard deviations of the methane concentrations are small relative to the mean measured concentration in each area supports the finding that methane hot spots were not present.

The data collected from the HRPm surveys of Areas B, C, and D were also analyzed for the presence of VOCs. Methanol was detected along beam path #3 in Area B, indicating a small hot spot south of the playground. The average methanol concentration measured was 20.9 ppb, with a range from not detected (at the OP-FTIR MDL of 14 ppb) to 127 ppb.

Figure 3-7 presents a time series of measured methanol concentrations.

3.3 OP-TDLAS Measurements

The OP-TDLAS measured methane concentrations in Areas A, B, C, and D. As mentioned previously, the configurations used by the OP-TDLAS were often similar to the configurations used with the OP-FTIR instruments. Data from the survey of Area C were unavailable due to a software malfunction. Table 3-4 presents the average methane concentrations (in parts per million) measured at the site by the OP-TDLAS system. The table also includes information on the average methane concentrations measured by the

OP-FTIR instrument for cases that the OP-FTIR beam paths were similar to those of the OP-TDLAS.

The methane concentrations measured by the OP-TDLAS did not show much variability between areas. In fact, most of the measured concentrations were only slightly above ambient methane levels, reinforcing the findings of the HRPM surveys. Concentrations measured with the OP-TDLAS ranged from 1.83 to 2.09 ppm. The methane concentrations measured with the OP-TDLAS system were almost always slightly higher than concentrations measured with the OP-FTIR instrument along similar optical paths.

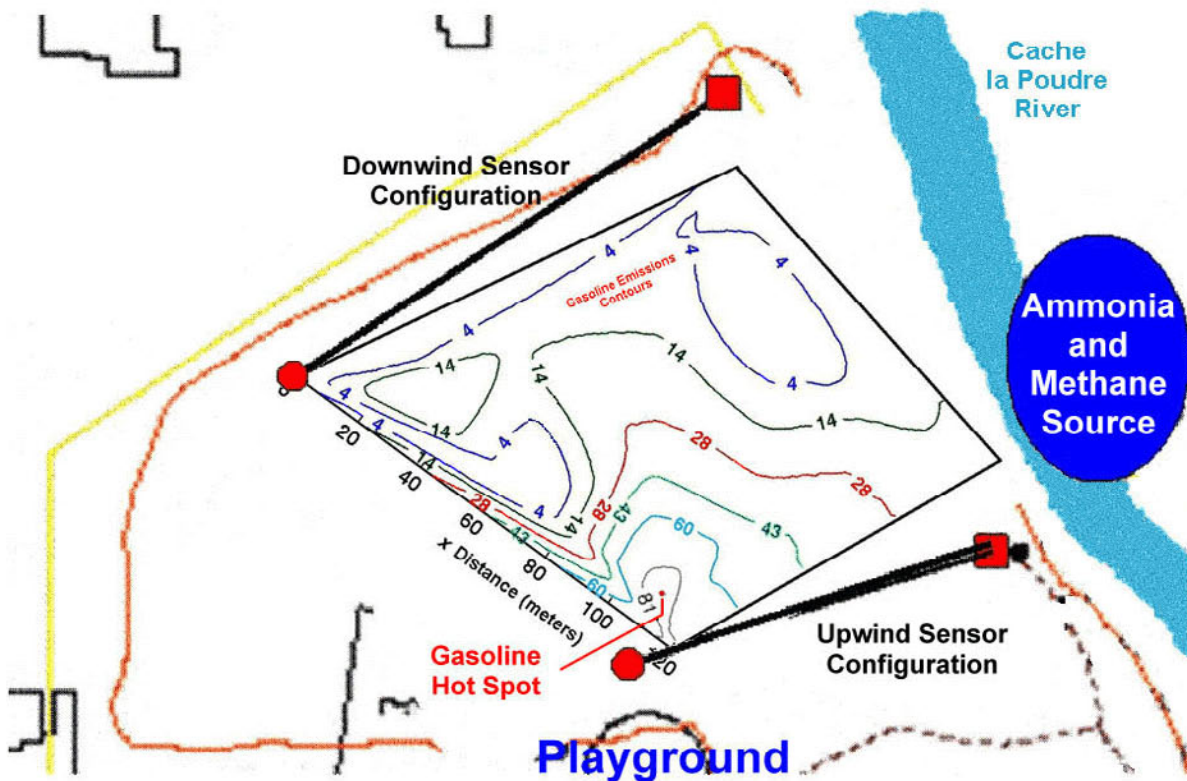


Figure 3-6. Results Summary Map from Area A Measurements.

Brownfield Landfill in Ft. Collins, Colorado

Table 3-3. Average Methane Concentrations Found during the HRPM Surveys of Areas B, C, and D.

Area	Concentration (ppm)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
A	1.89±0.027	1.81±0.008	1.89±0.012	1.81±0.009	1.92±0.012	1.82±0.005	1.81±0.009	1.89±0.009
B	1.80±0.011	1.76±0.011	1.75±0.012	1.73±0.010	1.73±0.011	1.74±0.011	1.74±0.010	1.78±0.011
C	1.80±0.020	1.75±0.020	1.73±0.017	1.77±0.018	1.73±0.018	1.75±0.018	1.72±0.017	1.71±0.017

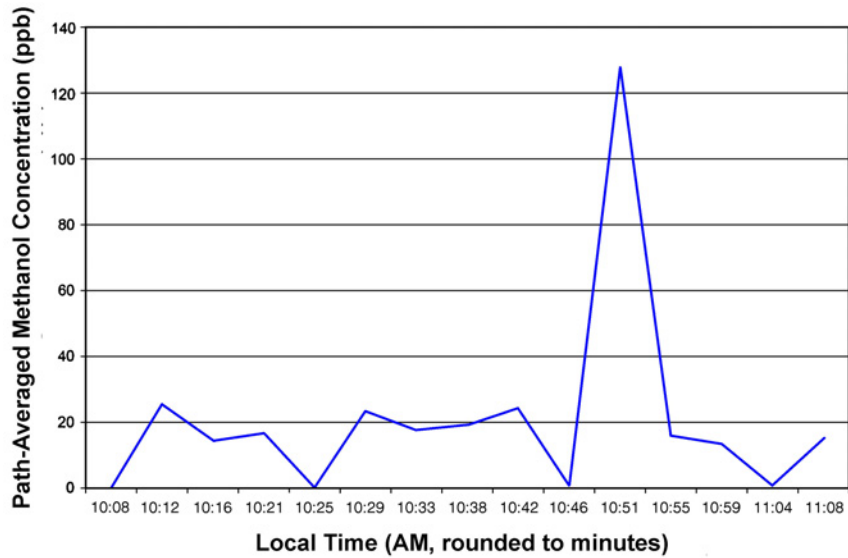


Figure 3-7. Time Series of Methanol Concentrations Measured along Beam Path #3 of the Area B HRPM Survey.

Table 3-4. Comparison of Methane Concentrations Measured with the OP-TDLAS and OP-FTIR Instruments.

Mirror No.		Methane Concentration (ppm)									
		Area A						Area B		Area D	
		09/08/03			09/09/03			OP-TDLAS	OP-FTIR	OP-TDLAS	OP-FTIR
		OP-TDLAS	OP-FTIR	OP-TDLAS	OP-FTIR	OP-TDLAS	OP-FTIR				
1	Avg.	1.91	1.92	1.94		1.96	1.74	2.01	1.81	2.03	1.80
	Std. Dev.	0.02	0.03	0.02		0.05	0.04	0.04	0.01	0.12	0.02
2	Avg.	1.99	1.88	1.96	1.78	1.83	1.88	2.03		1.93	1.77
	Std. Dev.	0.08	0.03	0.01	0.01	0.12	0.04	0.05		0.18	0.02
3	Avg.	2.08	1.84	1.98	1.78	2.03	1.86	2.06	1.81	1.90	1.75
	Std. Dev.	0.05	0.02	0.01	0.01	0.05	0.04	0.05	0.02	0.24	0.02
4	Avg.	2.05	1.85	1.95	1.77	2.03	1.88	2.03		1.98	1.75
	Std. Dev.	0.04	0.03	0.02	0.02	0.05	0.05	0.04		0.12	0.02
5	Avg.	2.06	1.84	1.98	1.79	2.03	1.87	1.98	1.82	1.94	1.73
	Std. Dev.	0.05	0.02	0.03	0.02	0.04	0.04	0.03	0.02	0.12	0.02
6	Avg.	2.09		1.99		2.07		2.05		1.95	1.72
	Std. Dev.	0.03		0.02		0.06		0.02		0.15	0.02
7	Avg.	2.09		2.01		2.04		2.02	1.81	1.99	1.73
	Std. Dev.	0.02		0.02		0.05		0.02	0.02	0.13	0.02
8	Avg.	2.06		1.96		2.04		2.07		1.97	1.71
	Std. Dev.	0.02		0.02		0.04		0.02		0.15	0.02

Chapter 4 Conclusion

This report presents the results from a field campaign conducted in September 2003 at a former landfill site in Fort Collins, Colorado. The study used measurements from several ground-based ORS instruments and the ORS-RPM method to characterize fugitive emissions of methane, ammonia, and VOCs from the site.

HRPM surveys of the site did not detect the presence of any methane hot spots, and methane surface concentrations at the site were essentially at ambient background levels. The HRPM survey of Area A detected a gasoline hot spot (average concentration over 81 ppb, maximum concentration about 100 ppb) in the southern corner of Area A (north of the large playground adjacent to the gymnasium). The HRPM survey of Area B detected the presence of methanol along beam path #3, indicating a small hot spot south of the large playground, within the fence line of the property. The average methanol concentration measured during the survey was 21 ppb.

A VRPM survey was done in Area A to measure fluxes of fugitive emissions. The VRPM survey detected methane, ammonia, and gasoline in the downwind configuration, along the fence line of the site. The measured concentrations of methane and ammonia correlated well temporally, suggesting the source of the methane and ammonia emissions may be the same. Looking at data on wind direction and the lack of methane and ammonia concentrations measured during the HRPM survey, it is concluded that this source of ammonia and methane was located

outside of Area A, northeast of the survey area (across the river). The calculated gasoline flux of 0.87 g/s was from the gasoline hot spot detected during the HRPM survey of Area A. Since the location of this hot spot is approximately 100 meters upwind of the VRPM measurement configuration, it is concluded that this flux is a slight underestimation of the actual emission rate from the source because a small portion of the plume may not have been captured by the measurement configuration. The above conclusions are confirmed by the fact that the VRPM survey did not detect any methane, ammonia, or gasoline plumes along the upwind configuration.

The UV-DOAS instrument was deployed in Area A to collect data concurrently with the OP-FTIR instrument. The UV-DOAS detected the presence benzene, toluene, and p-Xylene. The average measured concentrations of benzene, toluene, and p-Xylene were 2.6 ppb, 21 ppb, and 4.9 ppb, respectively. The concentrations of toluene measured with the UV-DOAS instrument correlated well with gasoline concentrations measured with the OP-FTIR instrument during the same time period, indicating that the gasoline plume contains BTX compounds at levels lower than the MDL of the OP-FTIR.

The OP-TDLAS system collected information on methane concentrations in Areas A, B, C, and D. The methane concentrations measured with the OP-TDLAS were generally slightly higher (less than 10%) than concentrations measured with the OP-FTIR instrument along similar optical paths.

Chapter 5 Quality Assurance/Quality Control

5.1 Equipment Calibration

As stated in the ECPD Optical Remote Sensing Facility Manual (U.S. EPA, 2004), all equipment is calibrated annually or cal-checked as part of standard operating procedures. Certificates of calibration are kept on file. Maintenance records are kept for any equipment adjustments or repairs in bound project notebooks that include the data and description of maintenance performed. Instrument calibration procedures and frequency are listed in Table 5-1 and further described in the text.

As part of the preparation for this project, a Category III Quality Assurance Project Plan (QAPP) was prepared and approved for each separate field campaign. In addition, standard operating procedures were in place during the field campaign.

5.2 Assessment of DQI Goals

The critical measurements associated with this project and the established data quality indicator (DQI) goals in terms of accuracy, precision, and completeness are listed in Table 5-2. More information on the procedures used to assess DQI goals can be found in Section 10 of the ECPD Optical Remote Sensing Facility Manual (U.S. EPA, 2004).

5.2.1 DQI Check for Analyte PIC Measurement

The precision and accuracy of the analyte path-integrated concentration (PIC) measurements was assessed by analyzing the measured nitrous oxide concentrations in the atmosphere. A typical background atmospheric concentration for nitrous oxide is about 315 ppb, but this value may fluctuate due to

Table 5-1. Instrumentation Calibration Frequency and Description.

Instrument	Measurement	Calibration Date	Calibration Detail
Climatronics Model 101990-G1 meteorological heads	Wind speed in miles/hour	22 April 2003	APPCD Metrology Lab calibration records on file
Climatronics Model 101990-G1 meteorological heads	Wind direction in degrees from north	22 April 2003	APPCD Metrology Lab calibration records on file
Topcon Model GTS-211D theodolite	Distance measurement	1 May 2003	Calibration of distance measurement: Actual distance=50 ft. Measured distance=50.6 ft. and 50.5 ft.
Topcon Model GTS-211D theodolite	Angle measurement	21 May 2003	Calibration of angle measurement: Actual angle= 360° Measured angle= 359°41'18", and 359°59'55"

Table 5-2. DQI Goals for Instrumentation.

Measurement Parameter	Analysis Method	Accuracy	Precision	Detection Limit	Completeness
Analyte PIC	OP-FTIR: Nitrous Oxide Concentrations	±25%/15%/10% ^a	±10%	See Table 1-2	90%
Ambient Wind Speed	Climatronics heads met side-by-side comparison in the field	±1 m/s	±1 m/s	N/A	90%
Ambient Wind Direction	Climatronics heads met side-by-side comparison in the field	±10°	±10°	N/A	90%
Distance Measurement	Theodolite- Topcon	±1m	±1m	0.1m	100%

^a The accuracy acceptance criterion of ±25% is for pathlengths of less than 50 m, ±15% is for pathlengths between 50 and 100 m, and ±10% is for pathlengths greater than 100 m.

seasonal variations in nitrous oxide concentrations or elevation of the site. The elevation of the site surveyed in this field campaign is approximately 5,000 ft above sea level. At this elevation, the optical density of a nitrous oxide concentration of 315 ppb would be equivalent to a lower concentration of nitrous oxide at sea level, due to the decreased air density. To correct the background nitrous oxide level for the effects of elevation, the measured temperature and atmospheric pressure were ratioed to standard temperature and pressure values. The corrected background nitrous oxide concentration is approximately 265 ppb.

The precision of the analyte PIC measurements was evaluated by calculating the relative standard deviation of each data subset. A subset is defined as the data collected along one particular path length during one particular survey in one survey sub-area. The number of data points in a data subset depends on the number of loops used in a particular survey.

The accuracy of the analyte PIC measurements was evaluated by comparing the calculated nitrous oxide concentrations from each data subsets to the corrected background concentration of 265 ppb. The number of calculated nitrous oxide concentrations

that failed to meet the DQI accuracy criterion in each data subset was recorded.

Overall, 61 data subsets were analyzed from this field campaign. Based on the DQI criterion set forth for precision of ±10%, each of the 61 data subsets were found to be acceptable. The range of calculated relative standard deviations for the data subsets from this field campaign was 0.57 to 11.7 ppb, which represents 0.22% to 4.4% RSD.

Each data point (calculated nitrous oxide concentration) in the 61 data subsets were analyzed to assess whether or not it met the DQI criterion for accuracy of ±25% (265 ± 66 ppb) for path lengths less than 50 meters, ±15% (265 ± 40 ppb) for path lengths between 50 and 100 meters, and ±10% (265 ± 27 ppb) for path lengths greater than 100 meters. All the 1136 data points that were analyzed met the DQI criteria for accuracy. Based on the DQI criterion set forth for accuracy and precision, all data points were found to be acceptable, for a total completeness of 100%.

5.2.2 DQI Checks for Ambient Wind Speed and Wind Direction Measurements

Section 10 of the ECPD Optical Remote Sensing Facility Manual (U.S. EPA, 2004) states that the DQI

goals for precision and accuracy of the Climatronics meteorological heads are assessed by collecting meteorological data for 10 minutes with the two heads set up side-by-side. This was not done prior to the current field campaign because this DQI procedure had not been implemented at the time of the study. However, the Climatronics heads were calibrated in April 2003 by the APPCD Metrology Lab (see Table 5 2). Additionally, checks for agreement of the wind speed and wind direction measured from the two heads (2 m and 10 m) were done in the field during data collection. Although it is true that some variability in the parameters measured at different levels should be expected, this is a good first-step check for assessing the performance of the instruments. Another check is done in the field by comparing the measured wind direction to the forecasted wind direction for that particular day.

5.2.3 DQI Check for Precision and Accuracy of Theodolite Measurements

Although this instrument was not calibrated immediately prior to the current field campaign, the theodolite was originally calibrated by the manufacturer prior to being received by the U.S. EPA. Additionally, there are several internal checks in the theodolite software that prevent data collection from occurring if the instrument is not properly aligned on the object being measured or if the instrument has not been balanced correctly. When this occurs, it is necessary to reinitialize the instrument to collect data.

The following DQI checks were performed on the theodolite prior to the current field campaign. These checks were performed during May 2003 at a field site near Chapel Hill, NC. The calibration of distance measurement was done using a tape measure to compare the actual distance to the measured distance. This check was duplicated to test the precision of this measurement. The actual distance measured was 15.2m. The measured distance during the first test was 15.4m, and the measured distance during the second test was 15.4m. The results indicate the accuracy (1.3% bias for test one and two) and precision (0% RSD) of the distance measurement fell well

within the DQI goals.

The check to test the precision and accuracy of the angle measurement was done by placing two mirror targets approximately 180 degrees apart. The theodolite was placed in the middle of the imaginary circle formed by the two mirrors. The actual angle was 360°. The angle measured during the first test was 359°41'18", and the angle measured during the second test was 359°59'55". The results indicate the accuracy and precision of the angle measurement fall well within the DQI goals.

5.3 QC Checks of OP-FTIR Instrument Performance

Several checks should be performed on the OP-FTIR instrumentation prior to deployment to the field and during the field campaign. More information on these checks can be found in MOP 6802 and 6807 of the ECPD Optical Remote Sensing Facility Manual. At the time of the current field campaign, the procedures and schedule of QC checks were still being developed. Consequently, QC checks were performed only in the field on the Unisearch OP-FTIR.

On the first day of the field campaign (September 7), the single beam ratio, electronic noise, saturation, linearity, baseline stability, and random baseline noise tests were performed. The results of the saturation test indicated that some saturation was occurring in the detector of the instrument. In response to this, the instrument detector response was adjusted slightly to correct this problem. The results of the other tests indicated that the instrument was operating within the acceptable criteria range.

On September 8, the signal-to-noise, and single beam ratio tests were performed on the Unisearch OP-FTIR. The results of these tests indicated that the instrument was operating within the acceptable criteria range.

In addition to the QC checks performed on the OP-FTIR, the quality of the instrument signal (interferogram) is checked constantly during the field

campaign. This is done by ensuring that the intensity of the signal is at least five times the intensity of the stray light signal (the stray light signal is collected as background data prior to actual data collection and measures internal stray light from the instrument itself). In addition to checking the strength of the signal, checks are done constantly in the field to ensure that the data are being collected and stored to the data collection computer. During the campaign, a member of the field team constantly monitors the data collection computer to make sure these checks are completed.

5.4 Validation of Concentration Data Collected with the OP-FTIR

During the analysis of the OP-FTIR data, a validation procedure was performed to aid in identifying the presence of gasoline and ammonia in the dataset. This validation procedure involves visually comparing an example of the measured spectra to a laboratory-measured reference spectrum.

Figure 5-1 shows an example of a validation done using a spectrum collected at the site. Gasoline was detected in this particular spectrum. The reference spectrum used to quantify gasoline concentrations is an actual laboratory-measured spectrum of Exxon 87-octane gasoline. The gasoline features can be seen in the measured field spectrum (green trace). Classical Least Squares (CLS) analysis performed on this spectrum resulted in determinations of 55.1 ± 3.0 ppb of gasoline. The uncertainty value is equal to three times the standard error in the regression fit of the measured spectrum to a calibrated reference spectrum, propagated to the concentration determination.

Figure 5-2 shows a validation done for an ammonia spectrum collected at the site. The ammonia features can be clearly seen in the measured field spectrum (blue trace). Classical Least Squares (CLS) analysis performed on this spectrum resulted in determinations of 17.4 ± 0.97 ppb of ammonia.

5.5 Internal Audit of Data Input Files

An internal audit was performed by the ARCADIS

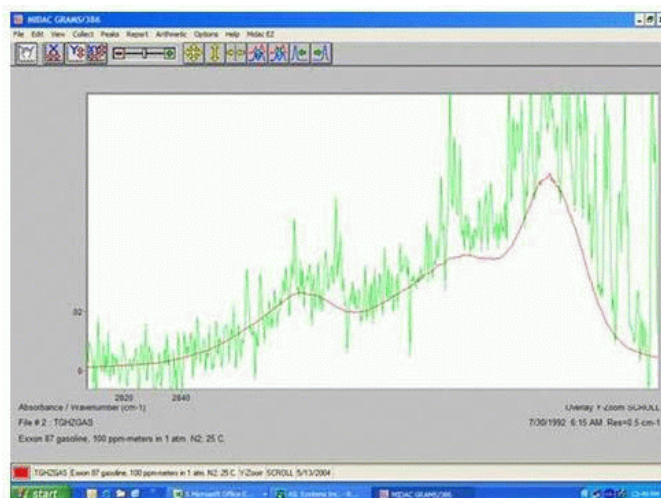


Figure 5-1. Comparison of a Gasoline Spectrum Measured at the Site (Green Trace) to Reference Spectra of Gasoline (Red Trace).

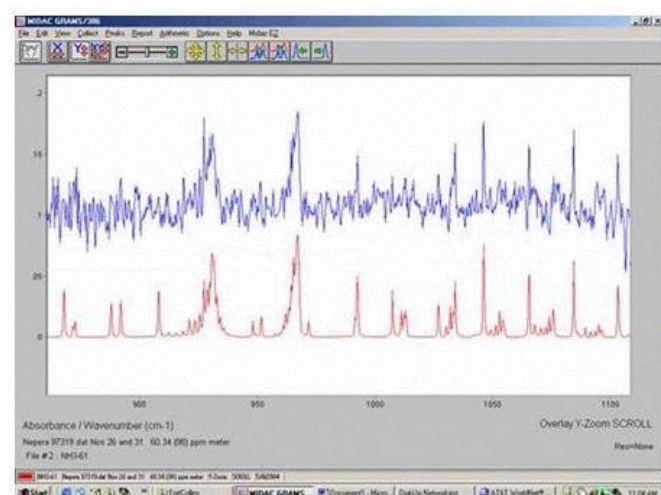


Figure 5-2. Comparison of an Ammonia Spectrum Measured at the Site (Blue Trace) to Reference Spectra of Ammonia (Red Trace).

Field Team Leader on a sample of approximately 10% of the data from the field campaign. The audit investigated the accuracy of the input files used in running the radial plume mapping (RPM) programs. The input files contain analyzed concentration data, mirror path lengths, and wind data. The results of this audit found no problems with the accuracy of the input files created.

5.6 OP-TDLAS Instrument

At the time of the field campaign, the OP-TDLAS system had only recently been acquired by EPA. Consequently, standard operating and calibration procedures were still being developed. Many improvements have been made to the QA process since this field campaign. Some of these improvements include the development of calibration cells and the development of a standard operating procedure for collecting emissions measurements with the OP-TDLAS (see MOP 6811 of the ECPD Optical Remote Sensing Facility Manual).

The comparison of methane concentrations measured with the OP-TDLAS system to methane concentrations measured with the OP-FTIR is a good validation of the OP-TDLAS. Table 3-4 shows that there is reasonable agreement between the concentrations measured with the two instruments, although the methane concentrations measured with the OP-TDLAS system were generally slightly higher (within 10%) than concentrations measured with the OP-FTIR instrument along similar optical paths. The data from Table 3-4 also indicates that the precision of the data collected with the OP-FTIR is better than the precision of the OP-TDLAS data. This is especially true of data collected in Area D, where the standard deviation of the OP-TDLAS data is as high as 0.24 ppm.

An experiment performed in January 2004 compared methane concentrations measured with the OP-TDLAS system and the IMACC OP-FTIR. The experiment collected methane measurements at a wide range of concentrations. Figure 5-3 shows the results of this experiment. The results show that there is very good agreement in methane concentrations measured with both instruments. However, a closer inspection of this dataset found that the precision of the OP-TDLAS data was not favorable at methane concentrations close to ambient background levels. This is consistent with the findings of the current study.

Despite the issue of precision of the OP-TDLAS

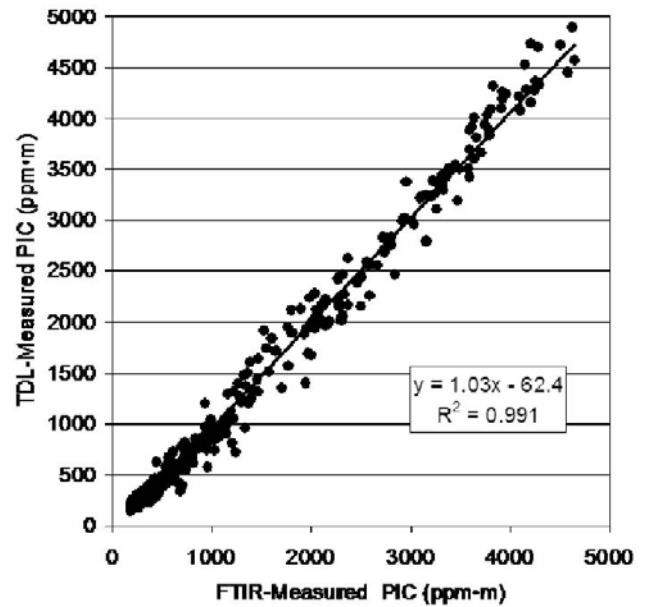


Figure 5-3. Post-Fort Collins Comparison of Methane Concentrations Measured with the OP-TDLAS and OP FTIR Instruments.

instrument at low concentrations, it is apparent from the data presented in Figure 5-3 that methane concentrations measured with the OP-TDLAS and OP-FTIR instruments are comparable for area emissions monitoring when a wide range of concentrations are measured.

5.7 UV-DOAS Instrument

Data from the UV-DOAS instrument were collected and analyzed by a representative of OPSIS, Inc. The following QC summary was created using information provided to ARCADIS by OPSIS, Inc.

- The UV-DOAS AR500 emitter and receiver were placed on a stable foundation in order to provide a high and stable light signal input to the spectrometer.
- The AR500 provides a system check function that performed a complete check of the integrity of the spectrometer.
- A zero and span calibration check was performed for all gases involved when the system was installed at the site.
- Monitored data, including the stored concentra-

tion, deviation, and light level values, were reviewed. Data that was sampled with light level values below minimum threshold were invalidated. A few of the data points collected were invalidated due to loss of light signal.

- Spectral validation of the detected compounds (similar to validation provided for the OP-FTIR data in Section 5.4) was not provided. This is recommended for future studies using the UV-DOAS instrument.
- In the application of BTX measurements using the standard resolution spectrometer, the effect of

oxygen in the monitoring path was compensated for. This was done in the oxygen reference calibration procedure. This procedure was performed for each specific optical path length that the system operated on. Some of the data were corrected in offset levels. The origin of offset concentration was due to the fact that only one oxygen reference was performed during the project.

- The MDL for benzene, toluene, and p-xylene was 1 ppb. The precision and accuracy of the measurements is 1%, as reported by OPSIS, Inc.

Chapter 6

List of References

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Appendix A OP-FTIR Mirror Coordinates

Table A-1. Standard Distance and Horizontal Coordinates of Mirrors Used in the HRPM Survey of Area A.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (degrees)
1	125	76
2	87.3	82
3	149	88
4	179	97
5	117	99
6	149	105
7	49.8	110
8	86.2	116
9	121	120

Table A-3. Standard Distance and Horizontal Coordinates of Mirrors Used in the HRPM Survey of Area C.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (degrees)
1	50.0	68
2	69.7	62
3	93.2	61
4	139	59
5	129.1	40
6	92.7	30
7	68.3	29
8	37.9	20

Table A-2. Standard Distance and Horizontal Coordinates of Mirrors Used in the HRPM Survey of Area B.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (degrees)
1	42.4	353
2	83.7	1
3	37.9	10
4	79.1	15
5	38.2	25
6	77.2	29
7	82.8	50
8	45.2	54

Table A-4. Standard Distance and Horizontal Coordinates of Mirrors Used in the HRPM Survey of Area D.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (degrees)
1	52.2	286
2	84.9	290
3	107	292
4	52.5	309
5	87.5	310
6	50.0	341
7	88.2	335
8	126	329

Table A-5. Standard Distance and Horizontal Coordinates of Mirrors Used in the VRPM Survey.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (degrees)	Vertical Angle^a (degrees)
Upwind			
1	36.9	65	0
2	68.7	70	0
3	110	70	0
4	113	70 ^b	1
5	113	69 ^b	5
Downwind			
1	44.9	48	0
2	89.9	51	0
3	117	53	0
4	118	53	2
5	118	53	6

^a Vertical angle shown is the angle from horizontal (positive values indicate elevation from the horizontal, negative values indicate descent from the horizontal).

^b Although Mirrors 4 and 5 were on the same scissors jack, Mirror 5 was not directly above Mirror 4.

Appendix B OP-TDLAS Configuration Path Length Distances

Table B-1. Standard Distance of Path Lengths Used in OP-TDLAS Configurations.

Mirror Number	Area A			Area B (m)	Area D (m)
	09/08/03 (m)	09/09/03			
		Surface (m)	Vertical (m)		
1	41.0	136	48.1	82.4	52.2
2	76.3	146	83.6	80.9	52.5
3	118	174	119	79.6	50.0
4	119	143	120	79.3	84.9
5	119	114	120	79.3	87.5
6	173	156	156	80.6	88.2
7	203	193	194	87.1	107
8	195	105	106	153	126

Appendix C Methane Concentrations

Table C-1. Methane Concentrations Found during the Area A HRPM Survey.

Loop	Methane Concentration (ppm)								
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8	Mirror 9
1	1.81	1.83	1.81	1.81	1.81	1.81	1.86	1.83	1.83
2	1.81	1.83	1.81	1.81	1.82	1.80	1.84	1.81	1.82
3	1.80	1.82	1.78	1.79	1.80	1.79	1.83	1.80	1.79
4	1.79	1.82	1.80	1.80	1.80	1.78	1.83	1.80	1.80
5	1.79	1.81	1.78	1.79	1.79	1.78	1.83	1.79	1.78
6	1.79	1.81	1.78	1.76	1.79	1.77	1.83	1.79	1.78
7	1.78	1.80	1.78	1.77	1.79	1.77	1.82	1.78	1.79
8	1.78	1.80	1.78	1.77	1.78	1.71	1.82	1.78	1.78
9	1.80	1.79	1.78	1.77	1.77	1.76	1.82	1.78	1.78
10	1.77	1.79	1.77	1.77	1.78	1.76	1.83	1.78	1.78
11	1.77	1.79	1.78	1.78	1.80	1.77	1.81	1.78	1.78
12	1.78	1.80	1.78	1.78	1.79	1.77	1.83	1.80	1.79
13	1.78	1.79	1.77	1.78	1.78	1.77	1.81	1.79	1.77
14	1.78	1.80	1.77	1.78	1.79	1.77	1.82	1.78	1.77
15	1.77	1.79	1.78	1.78	1.78	1.76	1.81	1.78	1.78

Table C-2. Methane Concentrations Found during the Area B HRPD Survey.

Loop	Methane Concentration (ppm)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	1.90	1.81	1.90	1.83	1.92	1.83	1.82	1.88
2	1.91	1.81	1.89	1.82	1.94	1.82	1.82	1.90
3	1.89	1.82	1.89	1.82	1.93	1.82	1.81	1.89
4	1.90	1.81	1.90	1.83	1.92	1.82	1.81	1.89
5	1.90	1.81	1.89	1.80	1.91	1.82	1.81	1.90
6	1.85	1.82	1.90	1.81	1.92	1.81	1.82	1.88
7	1.90	1.80	1.89	1.82	1.92	1.82	1.80	1.88
8	1.89	1.80	1.88	1.80	1.92	1.82	1.81	1.88
9	1.89	1.80	1.87	1.81	1.92	1.81	1.80	1.88
10	1.89	1.80	1.89	1.81	1.90	1.81	1.81	1.88
11	1.90	1.81	1.89	1.81	1.89	1.81	1.80	1.88
12	1.89	1.80	1.90	1.82	1.92	1.81	1.80	1.80
13	1.83	1.81	1.89	1.81	1.91	1.81	1.81	1.89
14	1.84	1.80	1.90	1.81	1.90	1.82	1.83	1.91
15	1.92	1.82	1.92	1.82	1.92	1.82	1.82	1.89

Table C-3. Methane Concentrations Found during the Area C HRPD Survey.

Loop	Methane Concentration (ppm)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	1.78	1.74	1.73	1.71	1.71	1.72	1.73	1.76
2	1.78	1.74	1.72	1.71	1.71	1.72	1.73	1.77
3	1.78	1.75	1.73	1.71	1.72	1.73	1.73	1.77
4	1.79	1.76	1.75	1.72	1.73	1.74	1.74	1.78
5	1.79	1.75	1.73	1.73	1.72	1.74	1.74	1.78
6	1.78	1.76	1.75	1.73	1.73	1.74	1.74	1.78
7	1.79	1.76	1.74	1.72	1.73	1.74	1.74	1.78
8	1.80	1.76	1.75	1.73	1.73	1.74	1.74	1.79
9	1.80	1.76	1.74	1.73	1.73	1.75	1.75	1.79
10	1.80	1.76	1.76	1.74	1.74	1.76	1.75	1.80
11	1.81	1.77	1.76	1.74	1.74	1.76	1.76	1.79
12	1.81	1.77	1.76	1.73	1.73	1.75	1.75	1.79
13	1.80	1.76	1.75	1.73	1.74	1.75	1.75	1.79
14	1.81	1.77	1.76	1.74	1.74	1.75	1.75	1.79
15	1.81	1.77	1.76	1.74	1.73	1.75	1.75	1.79
16	1.80	1.77	1.75	1.74	1.74	1.76	1.75	1.80

Brownfield Landfill in Ft. Collins, Colorado**Table C-4. Methane Concentrations Found during the Area D HRPM Survey.**

Loop	Methane Concentration (ppm)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	1.78	1.73	1.71	1.75	1.72	1.73	1.70	1.69
2	1.77	1.74	1.72	1.76	1.71	1.74	1.71	1.70
3	1.78	1.73	1.72	1.76	1.71	1.73	1.70	1.69
4	1.79	1.73	1.71	1.75	1.72	1.73	1.70	1.70
5	1.78	1.74	1.72	1.76	1.72	1.73	1.69	1.70
6	1.78	1.74	1.71	1.76	1.72	1.74	1.70	1.69
7	1.78	1.73	1.72	1.75	1.72	1.73	1.70	1.70
8	1.78	1.73	1.71	1.76	1.72	1.73	1.71	1.69
9	1.77	1.74	1.71	1.75	1.71	1.72	1.70	1.69
10	1.78	1.73	1.71	1.76	1.72	1.73	1.70	1.70
11	1.78	1.74	1.72	1.77	1.73	1.73	1.70	1.70
12	1.79	1.75	1.72	1.76	1.72	1.73	1.71	1.70
13	1.78	1.74	1.71	1.77	1.73	1.73	1.71	1.71
14	1.78	1.75	1.72	1.76	1.73	1.73	1.71	1.71
15	1.79	1.75	1.73	1.77	1.74	1.74	1.71	1.71
16	1.80	1.75	1.73	1.78	1.74	1.75	1.72	1.73
17	1.81	1.74	1.74	1.79	1.76	1.76	1.73	1.73
18	1.81	1.82	1.77	1.78	1.73	1.76	1.73	1.73
19	1.85	1.77	1.73	1.78	1.75	1.77	1.74	1.74
20	1.82	1.77	1.75	1.81	1.76	1.79	1.74	1.73
21	1.83	1.77	1.75	1.79	1.75	1.77	1.73	1.73
22	1.82	1.77	1.75	1.80	1.76	1.78	1.74	1.74
23	1.82	1.79	1.75	1.78	1.74	1.77	1.72	1.72
24	1.80	1.76	1.73	1.77	1.74	1.76	1.72	1.72
25	1.80	1.75	1.74	1.78	1.73	1.76	1.72	1.72
26	1.80	1.76	1.70	1.77	1.73	1.75	1.73	1.73
27	1.80	1.77	1.75	1.79	1.76	1.76	1.73	1.73
28	1.80	1.78	1.76	1.80	1.77	1.77	1.75	1.74
29	1.82	1.77	1.75	1.81	1.75	1.77	1.74	1.73
30	1.81	1.76	1.74	1.78	1.74	1.76	1.72	1.73

Table C-5. Methane Concentrations Found during the Downwind VRPM Survey Run 1.

Loop	Methane Concentration (ppm)				
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
1	1.92	1.87	1.82	1.83	1.81
2	1.91	1.86	1.81	1.83	1.84
3	1.90	1.87	1.84	1.86	1.87
4	1.97	1.92	1.83	1.81	1.81
5	1.97	1.88	1.81	1.81	1.80
6	1.91	1.84	1.80	1.82	1.80
7	1.85	1.84	1.79	1.81	1.79
8	1.89	1.83	1.81	1.86	1.85
9	1.90	1.86	1.81	1.83	1.81
10	1.91	1.86	1.82	1.83	1.81
11	1.90	1.85	1.81	1.83	1.82
12	1.91	1.86	1.83	1.87	1.86
13	1.92	1.88	1.85	1.86	1.83
14	1.91	1.86	1.84	1.85	1.84
15	1.94	1.89	1.84	1.87	1.84
16	1.92	1.87	1.82	1.83	1.84
17	1.92	1.86	1.85	1.90	1.88
18	1.93	1.89	1.84	1.84	1.85
19	1.91	1.87	1.84	1.87	1.84
20	1.95	1.88	1.85	1.88	1.82
21	1.92	1.86	1.82	1.84	1.84
22	1.90	1.89	1.87	1.90	1.86
23	1.93	1.91	1.86	1.88	1.88
24	1.95	1.90	1.85	1.87	1.87
25	1.92	1.88	1.84	1.88	1.86
26	1.93	1.87	1.84	1.87	1.85
27	1.93	1.87	1.84	1.84	1.85
28	1.94	1.91	1.88	1.87	1.85
29	1.99	1.92	1.87	1.89	1.85
30	2.00	1.94	1.88	1.88	1.85

Brownfield Landfill in Ft. Collins, Colorado

Table C-6. Methane Concentrations Found during the Downwind VRPM Survey Run 2.

Loop	Methane Concentration (ppm)				
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
1	1.70	1.84	1.83	1.85	1.84
2	1.71	1.85	1.83	1.82	1.84
3	1.72	1.85	1.82	1.84	1.84
4	1.70	1.84	1.82	1.83	1.83
5	1.70	1.85	1.82	1.84	1.84
6	1.70	1.84	1.83	1.84	1.83
7	1.70	1.83	1.82	1.83	1.83
8	1.70	1.84	1.82	1.86	1.84
9	1.71	1.85	1.83	1.86	1.84
10	1.71	1.85	1.84	1.86	1.85
11	1.72	1.85	1.83	1.84	1.84
12	1.70	1.84	1.82	1.84	1.83
13	1.70	1.84	1.82	1.84	1.84
14	1.71	1.85	1.84	1.86	1.85
15	1.73	1.86	1.85	1.91	1.86
16	1.73	1.88	1.85	1.86	1.87
17	1.74	1.87	1.86	1.89	1.87
18	1.75	1.90	1.88	1.91	1.90
19	1.77	1.90	1.88	1.90	1.91
20	1.77	1.93	1.92	1.97	1.94
21	1.81	1.95	1.92	1.94	1.93
22	1.80	1.95	1.92	1.94	1.92
23	1.80	1.94	1.92	1.94	1.92
24	1.79	1.93	1.90	1.93	1.90
25	1.78	1.92	1.90	1.92	1.91
26	1.78	1.93	1.89	1.95	1.90
27	1.78	1.92	1.90	1.96	1.91