ENGINEERING DESIGN AND ASSEMBLY OF A SURFACE METHANE AND

CARBON DIOXIDE GAS FLUX MEASUREMENT CHAMBER WITH A

CASE STUDY ON THE UNIVERSITY OF UTAH CAMPUS

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

Atmospheric methane and carbon dioxide have been deemed significant "greenhouse gases" (GHG) which are thought to be responsible for major climate changes. Wastewater treatment plants have seen quite a lot of attention with respect to methane release, but little study of sewer transport (pipeline) contribution has been reflected in recent literature. This lack of analysis on sewer systems could be because of the Intergovernmental Panel on Climate Change report stating that in most developed countries, sewers are closed and underground, and therefore would not make a large contribution to carbon emissions (especially CH_4) emissions. Previous methods for quantifying sewer transport emissions have mainly utilized tracer gas coupled with measurement of flow or velocity rates within the sewer lines, or through lab studies.

The purpose of this study was to develop a direct flux emissions measurement method based on existing technology, soil flux chambers, for CH_4 and CO_2 using lab calibration and field testing. Such chambers were designed for measuring diffuse soil fluxes exclusively, and decades of such measurements indicate the validity of the approach. In this thesis study, the soil chamber was used as a basis for designing a larger chamber capable of handling relatively larger magnitude point fluxes from sewer access covers. The University of Utah campus consists of a series of mixed gravity sewer designs and ages, spanning the past century. Assuming this system was representative of the range of urban gravity sewer infrastructure typical to U.S. cities, a case study was done as part of this thesis. For this work, 11 sewer access covers were analyzed using a specifically designed flux chamber to measure gas fluxes directly from the sewer access covers. Based on these surveys, a preliminary estimate of annual carbon emissions from these 11 access

points was determined to be 1.066 Metric Tons CO_2 equivalent per year (Mt CO_2e). It is recommended that more calibration and continuous surveys of these, and all other sewer access points on campus, are done to facilitate the calculation and cumulative "carbon footprint" of the campus sewer system. Ultimately, the technology developed as part of this thesis work can form the basis of an effective methodology to measure CH_4 and CO_2 emissions from sewer lines and possibly other urban infrastructure, and quantify the relative major GHG emissions or "carbon footprint" of such emission sources.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

CRDS   Cavity Ring Down Spectrometer

CH4   Methane

CO2   Carbon dioxide

GHG   Greenhouse gases

HRT   Hydraulic retention time

LLGHG   Long-lived greenhouse gases

NDIR   Nondispersive infrared

ppmv   Parts per million volume

ppbv   Parts per billion volume

STD   Standard Deviation

VOC   Volatile organic compounds

INTRODUCTION

As population increases, the concentration of anthropogenic greenhouse gases (GHG) released into the atmosphere also increases. The top contributing long-lived greenhouse gases that occur naturally but are greatly increased by human activity are carbon dioxide, methane and nitrous oxide. According to the IPCC (*1*), long-lived greenhouse gases (LLGHG's) are classified as gases that are chemically stable and remain in the atmosphere up to decades or longer. These gases can have long term effects on climate change and become well mixed in the atmosphere much faster than they are removed (*1*).

Over the years the ambient concentrations have continued to rise. CO_2 is currently around 394 ppmv and CH_4 is about 1.8 ppmv in 2012, on average according to the Environmental Protection Agency (*2*). CO_2 has shown an approximate 100 ppmv increase in concentration since 1750 and has been attributed mainly to the burning of fossil fuels. CH4 has seen a concentration increase of about 1000 ppbv in the last two centuries, which can be accredited to many anthropogenic sources such as biomass burning and wastewater treatment (*1*). Locally, according to a report by Salt Lake City Energy and Carbon Advisory Committee and the Salt Lake City Division of Sustainability and Environment (*3*), the Salt Lake City community emission was 4.75 million Mt CO_2e per year.

It is hypothesized that increases in GHG emissions can lead to changes in global climate. Associated impacts can include higher sea levels, ocean acidification, animal extinctions, droughts in some areas or increased water availability, higher average global temperatures, and other potential factors that are yet to be foreseen (*1*). Within a local level, increasing droughts may

cause an increased demand on what can apparently be seen as an already strained water system. An escalation in wildfire frequency and less snow melt due to unusually longer periods of higher annual temperatures could also occur as well. This in addition can add to the overall bad air quality due to the local topology which traps pollutants effectively in the air through the inversions.

It is known that emissions of CO_2 and CH_4 by anthropogenic sources are increasing; therefore, it is important to identify, quantify and mitigate or reduce the release of these gases within the earth's atmosphere. There are significant data to represent the portion of emissions coming from many of these sources, such as sewage treatment plants. However there is little information on the sewer transport system as a whole, particularly pertaining to CH_4 and CO_2. Volatile organic compounds (VOC's) and hydrogen sulfide have been studied within the sewer transport system due to these gases' detrimental effects on human life and the regulations for exposure limits in the workplace. These regulations have however created the need for studies on gas transport in the sewer transport system specifically regarding VOC's. (*4*) (*5*).

Literature

Current literature suggests that release of CO_2 and CH_4 associated with wastewater transport may be significant. Foley et al. (*6*) measured the dissolved methane concentrations along a single rising main off the Gold Coast area in Queensland, Australia. Four major locations were measured: a pump station wet well, a pressurized sampling point 500 m downstream, a pressurized sampling point 1,100 m downstream, and a pressurized sampling point 1,900 m downstream of the pump station. The measured data were correlated with the sewer pipeline geometry (area and volume) and the hydraulic retention time (HRT) to determine a release rate. Assuming that all dissolved methane was assimilated as gas into the atmosphere, it was concluded

that based on the measurements there was substantial methane release potential of 230 Mt CO_2e per year.

A case study by Willis et al. (*7*) measured methane concentration released from wet wells in DeKalb County, GA and then used the monthly average flow rates to calculate the approximate emissions from 60 low flow (<700 gpm) gravity lift stations and 4 high flow (>2000 gpm) lift stations. The calculated methane emissions from these lift stations came to roughly 940 Mt CO_2e per year. Guisasola et al. (*8*) made simulated measurements in a lab experiment as well as field measurements at two pressurized rising mains of the Gold Coast area in Australia. This method used dissolved methane concentration and HRT to calculate the field methane flux. The lab scale measurements were done using a reactor based system and assumed all the dissolved methane from the sewage discharged was assimilated into the atmosphere. The methane released was approximated to be within the range of 900–5300 Mt CO_2e per year.

Transportation of gases through sewer systems was studied in reference to ventilation and horizontal gas transport. Madsen et al. (*9*) analyzed the horizontal gas transport process in an intercepting gravity sewer by measuring the velocity and dispersion of the gas in the sewer atmosphere in Denmark. Transport of sewer gas was determined by pulse injecting molecular oxygen at an injection station to change the composition of the sewer atmosphere. The oxygen concentration was measured downstream of the injection zone. This allowed the gas velocity, coefficient of dispersion and ventilation rate to be calculated. It was observed that gas transport was non-uniform. Dispersion was present in 71% of experiments and not present in 29%. Their system showed little to no ventilation or re-aeration. They concluded this could have been due to fewer openings and no side connections. When covers were opened there was an increase in ventilation but it was still considered low. The study concluded that the sewer gas transport was caused by an inflow of gas to the upstream part of the gravity sewer, followed by horizontal

transport along the sewer line and outflow of gas at the end of the sewer. It was also concluded that variations in climatic conditions did not influence gas velocity or the coefficient of dispersion.

Using carbon monoxide as a tracer gas, Parker et al. (*10*) injected the tracer gas into a full-scale collector sewer and the concentration was monitored along the upstream and downstream. Temperature, wind speed, and barometric pressure were also obtained and compared to the data. The data showed that the velocities and flow rates varied with distance and time along the sewer. Lower velocities resulted in higher tracer gas loss through the system, which was assumed to be lost through the sewer access cover. Higher velocities tended to show a smaller loss in tracer gas. Gas phase flows from the headspace were estimated and there was an increase in flow farther downstream. There was a lack of repeatability with the gas flow, suggesting that it was dependent upon a time-varying mechanism such as wind draft from the sewer access cover but was inconclusive.

In general, the literature provides little to no information on the release of CO_2 (into the atmosphere) from the sewers. Methane emissions described were mostly based on the potential of dissolved methane released or on lab scale testing, which was said to be an overestimate by the Guisasola et al. (*8*) experiment as mentioned previously. These studies do not directly measure flux out of the sewer access covers or other specific points in the sewer transport system. A better estimation of emissions from a given wastewater transport system could be determined by directly reading and quantifying the release from a direct source.

<u>Project Study</u>

The current studies present limited data on the contribution of CO_2 and CH_4 to the atmosphere and all vary in the methods and approach. In this thesis a new method was presented to measure directly from the source, the sewer access covers, which could reasonably measure

the gas release and accumulation rates. By studying the release of CO_2 and CH_4, the implementation of a direct, portable chamber method was systematically created for point emission sources enabling a simultaneous measurement CO_2 and CH_4 concentration and gas flux.

This thesis describes the study site, equipment, instrument design and assembly followed by the algorithms necessary for flux calculation. Surveys (field measurements) of CO_2 and CH_4 concentration and gas flux at the study site, the University of Utah campus, are presented and discussed. Efforts were made to verify and calibrate the on-site survey measurements through field and laboratory calibration with a summarization of how the measurements are used to determine an estimate of the annual emissions release from the 11 sewer access covers is provided. While 11 sewer access covers only represent a small sample of the overall system, the results could lead to understanding the release and behavior of the system on a larger scale.

RESEARCH APPROACH: EQUIPMENT, MEASUREMENTS

AND ANALYSIS

<u>University of Utah Campus Case Study: Site Description</u>

All data were collected on the University of Utah campus located in Salt Lake City, Utah. The study area focused on the gravity sewer lines around the Student Union, the Civil and Materials Engineering Building, HEDCO, Frederick Albert Sutton Building, William Browning Building, Orson Spencer Hall, Languages and Communications Building, Sterling Sill Center and the Experimental Studies Building. James Staples with the University of Utah Plumbing Shop provided general sewer line data as seen in Figure 1 and Table 1. The Student Union lines were completed in 1955; lines with the designation MHSU in Figure 1. The lines around the HEDCO were also completed in the 50s; lines designated with an MH in Figure 1. Therefore the sewer lines within the study area were around 59-64 years old.

Salt Lake City's climate is subhumid, with dry summers and wet winters. The concentration measurements discussed in this study were taken in late September 2012 and then sporadically, weather permitting, through July 2013. Flux measurements were taken from September 2013 through January 2014, again intermittently due to weather limitations. For the flux measurements 11 sewer access holes were studied along two separate sewer lines. Figure 1 shows the sewer access cover locations along the sewer lines, the flow regime and each access cover designation. More access covers were studied but many were outside of the scope of this study and some were found to be linked to inactive or abandoned lines and were not studied in great detail.

<u>Equipment</u>

A chamber method was designed around a viable and accepted method; a soil flux chamber. CO_2 and CH_4 soil flux chambers are separately, readily available from various suppliers of such technologies; however custom chambers would presumably need to be ordered for this project and would require two separate instruments. Due to limited resources and the availability of only two gas analyzers through the University of Utah, the design and construction of a custom chamber was done in house. The two gas analyzers used for these measurements utilize two different processes to determine gas concentration.

The Picarro G2311-F uses a laser-based cavity ring down spectroscopy (CRDS) method, which measures continuous streams of water vapor, CO_2 and CH_4 concentrations through an inlet tube that feeds directly to the instrument. The CRDS is highly sensitive, measuring absolute optical extinction by samples that scatter and absorb light at specific wavelengths. The CRDS unit measures the CO_2 concentration to one standard deviation precision of 200 parts per billion volume (ppbv), CH_4 to a precision of 2 ppbv, and water vapor to 20 parts per million volume (ppmv) precision (*11*). The CRDS on its own is only able to measure the concentration at a point or along a line; however it can also be fit to a chamber or a flux tower to measure concentration over a point source or area. The CRDS requires a 2000 watt inverter generator to accommodate the approximate 1000 watts necessary for the complete CRDS system to run. The generator allows for around 6-8 hours of run time with the CRDS system. For field measurements two heavy-duty wagons were used to tow the CRDS system, pump, generator, the CRDS GPS unit, battery and monitor. The system is more accurate when there is little to no wind to disrupt the concentration values.

The Li-COR 8100 is a nondispersive infrared (NDIR) gas analyzer that measures CO_2 soil flux. This technique uses energy absorption characteristics of a particular gas, CO_2, in the infrared

region to determine concentration. The flux is measured by observing the rate of CO_2 increase within a chamber to estimate the rate at which CO_2 diffuses into free air outside of a specified chamber. The Li-COR 8100 has an accuracy of 1.5% of the reading for both CO_2 and H_2O with a measurement range of 0-3000 ppm for CO_2 and 0-80 mmol/mol for H_2O. The NDIR analyzer can be fitted to various chambers developed by Li-COR Biosciences or can be fitted to a customary chamber measuring the concentration or flux over the chambers specified area. The Li-COR 8100 system has multiple components that were utilized in this study. The analyzer control unit houses the electronics, infrared gas analyzer, internal and external memory, and wireless communications compatible with a palm pilot with loaded software or with any apple ipod, iphone or ipad. The NDIR analyzer also has a 20 cm survey chamber that is utilized for calibration. The system has rechargeable batteries for easy use during field surveys as well as a 110V wall connector for lab experiments or use with a generator (*12*)*.*

<div align="center">CRDS Concentration Readings</div>

Using just the CRDS analyzer concentration readings were done primarily in the fall of 2012 and the summer of 2013. Most measurements were done along specific sewer lines, maintaining a measurement at the access holes for a few minutes at a time. The measurements focused on the area above the sewer lines and any sewer access covers. A few specific sites were chosen for long term measurements; defined as greater than 4-hour time increments. Measurements taken in the fall of 2012 were mostly done between 12:00 pm and 3:00 pm. During the summer of 2013, measurements were done on an almost daily basis running approximately the same route two to three times weekly. At least four 5 to 8-hour measurements were completed on an individual access cover that showed potential for larger concentrations. This was done to help determine the diurnal variations and to show any possible trends in the data. Over

35 days of readings were taken over the 10-month period, of which many of the measurements focused on other sewer access covers outside of the scope of this study. Limitations on the quantity of measurements able to be taken were incurred during this time due to weather and equipment related issues. The issues encountered were typically due to valve leaks, debris in the tube and a several month period where the equipment was sent back to the distributor to get the power board replaced.

<div align="center">Design and Development of a New Flux Chamber
Technology</div>

To determine the accumulation rates released from the sewer lines, two chambers were designed and built to determine the CH_4 and CO_2 flux simultaneously. A design was implemented to accommodate concentration measurements using the CRDS and the NDIR analyzer. Two 55-gallon plastic garbage cans were acquired for the chambers. The 55-gallon size fits completely around the sewer access covers 26 ½" diameter. A comparison study done by Pihlatie et al. (*13*) tested 15 chambers currently used in the biological community to compare each design for advantages and disadvantages. The study discussed how using a larger chamber reduces the negative effects of a chamber and minimizes the underestimation of the flux. These chamber sizes were significantly smaller than that of the 55-gallon chamber we experimented with, but it is hypothesized that the larger chamber size will hold to these conclusions.

Parkin et al. (*14*) presented a study through the National Laboratory of Agriculture and the Environment with their USDA-ARS GRACnet Project that put out a protocol for creating a flux chamber that measures trace gases. The project focused on N_2O, CO_2 and CH_4 measurements from soil. The chapter they presented goes through each issue presumably faced when creating a chamber and ways to mitigate these issues. Some issues do not directly apply to this study, mainly soil diffusion. Nevertheless their suggestions were helpful for current and future

deployment for site-specific uses. Parkin et al. (*14*) also suggested that using a larger chamber height as well as shorter deployment times would both decrease the negative chamber effects. Utilizing the CRDS ring down spectrometer allowed for shorter deployment times due to the ability to take accurate readings multiple times per second, instead of using a syringe at various times during the measurement as in the Parkin (*14*) study. Another relevant suggestion in the study is to use a manifold to pull gas from multiple areas of the chamber instead of mixing the inside of the chamber with a fan, which can cause pressure perturbations. The Parkin (*14*) study highly suggested that diurnal variation should be taken into account and can be done by measuring the fluxes at various times during the day. It was also recommended that flux is measured directly after a perturbation-induced event and properly venting the chamber to allow for natural movement of the gas (*14*).

Xu et al. (*15*) presented research *On Maintaining Pressure Equilibrium Between a Soil CO$_2$ Flux Chamber and the Ambient Air*. The research presented concern with the flux chamber regarding whether the equilibrium between the inside of the chamber and the surrounding air outside will be maintained during measurements. Having small pressure changes from the surrounding ambient pressure can cause anomalous mass flow, which can lead to over or underestimations of the flux. There has been research showing that using a vent tube connected to the chamber helps in maintaining the pressure. This method however presents the concern the vent tube will cause a significant loss. However if considerations were given to the internal diameter and length of the vent tube, the loss is not likely to be significant. The main issue with having a vent tube would be during windy conditions where negative pressure excursions will occur as wind blows over the vent tube's opening. There has been research on types of vent designs that would lessen this Venturi effect that could easily be used. The chamber measurements should also be made on a steady impermeable collar, for this study was

substituted for the manhole casing, which was both steady and impermeable. These chamber reports were based on a soil flux chamber and results and conclusions may vary based upon the different source and subsurface conditions. However the theory is assumed to be similar enough for relative accuracy. The assumption is also made that the large chamber and the CRDS unit vacuum suction would help to simulate natural flow. This assumption was not tested for accuracy.

To achieve a seal around the opening of the garbage can 1-inch diameter pipe insulation was used with a silicon caulking, along with a removable weight. The chamber's intent is to be used with the CRDS and the NDIR analyzer, so push lock fittings were obtained for easy transition and seal; the CRDS requires a 1/8" connection and a 1/4" for the NDIR analyzer. All tubing was high density, nonreactive polyethelene, used for its low permeability rate for the project's tested gases. The garbage can is gray, so to achieve a more reflective surface it was painted white using spray paint that was adhesive to plastic. This created a reflective, nonreactive surface which helped to prevent any drastic temperature changes within the chamber during deployment.

The deployment method was approximately 10 minutes with at least 2-3 back-to-back measurements. The chamber was evacuated after every reading to prevent issues with high headspace concentrations, which can affect the measured rates. Measurements were done repeatedly throughout different time periods to show the diurnal changes. Most sewer access cover measurements were only taken a few times per cover. However on a few occasions there were more long term readings, including two 24-hour sittings. Over 250 flux measurements were taken between September 2013 and January 2014 with the NDIR analyzer and CRDS over the 11 sewer access holes specified in the project area (Figure 1).

Most measurements were taken with the CRDS as it measures CH_4 and CO_2 simultaneously, but the NDIR analyzer was useful for verification of CO_2 measurements and trends. Laboratory and field calibration efforts were made to verify the data using the NDIR and

CRDS. The laboratory calibration involves a comparison of chamber measurements to artificial (controlled) fluxes, whereas the field calibration compared flux chamber measurements to natural (uncontrolled) fluxes. Both calibration efforts use both gas analyzers and the two built chambers for comparison; the lab calibration also incorporated the NDIR analyzer's custom 20 cm chamber. The NDIR measurements along with laboratory measurements used for calibration were discussed in the subsequent sections.

<u>Calibration Approach and Methods</u>

For the laboratory-based calibration, a CO_2 gas mixture required a concentration greater than ambient conditions, but not too high for equipment accuracy. The most reasonable range is between 800 and 2000 ppmv as it would adequately mimic the average elevated values seen in the field. Using a K sized partially filled nitrogen tank, pure CO_2 was added until reaching a value of CO_2 approximately equal to 1300 ppmv. Using the CRDS and NDIR analyzers, the built chambers were calibrated against the NDIR analyzer's original custom-built 20 cm survey chamber. The known CO_2 gas concentration cylinder was used to create a consistent flux using a pressure gauge and flow meter. The laboratory setup for the built chamber using either the NDIR analyzer or CRDS is shown in Figure 2.

A platform large enough to accommodate the chambers' diameter was created allowing for a point source leak using the gas from the cylinder with the known CO_2 concentration. Three separate flow rates were used to determine the relationship between the chambers and create a best-fit curve. This allowed for the creation of correction ratio curves which were used to determine a correction factor that was applied to each chamber measurement based on method and chamber type. The NDIR analyzer's chamber and built chambers were each used multiple times during the laboratory session to measure the flux from the lab generated point source in

order to generate a valid average and standard deviation. The CRDS analyzer was used right after the NDIR sensor and measured under the same conditions using the built chambers. The measurements were done one after another for 10-minute intervals with a 5-minute resting period in between to allow for gas evacuation from the chambers.

In the field the NDIR analyzer was used in conjunction with the CRDS as an additional way to calibrate the measurements. The NDIR analyzer was not used at the same time as the CRDS due to the system constraints. Each method was used on the same point source (sewer access) cover for 10 minutes with a 5-minute resting period for chamber gas evacuation and then following with the opposing analyzer method. This created a 10 to 20-minute gap between the data using the same chamber, due to swapping each analyzer method in between measurements. It was assumed that the short interval with which the chambers were switched would allow for an accurate calibration of the two analyzer methods, assuming the system did not change during this time. Only the built chambers were used for the point source due to the NDIR analyzer's chamber not being conducive to the large diameter of the sewer access cover. These back to back measurements were done for a 24-hour period on October the 25th – 26th and a few hours on October the 28th.

A soil flux measurement was also done using both analyzers. The NDIR analyzer was run using its original chamber for 10 measurements directly on the soil. Then the NDIR analyzer was set on the same soil area with the built chamber right next to the CSDR analyzer with the twin built chamber. The analyzers ran coincidentally for the same amount of time. These measurements analyzed whether the CRDS coupled with a built chamber would be valid for soil flux measurements; this information is presented in Appendix A.

The correction factors determined were assumed to be valid for both CO_2 and CH_4. This may cause an over- or underestimation for CH_4 flux considering the gas properties vary

significantly when compared to CO_2. This assumption was made based upon the inability to measure CH_4 with an accurate alternative method due to financial and time constraints. The correction ratio curves were developed in terms of flux and were curbed to the NDIR analyzer as it is an accepted method and used widely in the biological industry. The range of flux rates used in the lab experiments were assumed to validate the field data relatively based on similar gas concentrations seen in the field.

When analyzing the flux data potential, outliers were investigated and assumptions were made on the concentration versus time plots (used for calculating flux) shown to have sporadic data. The assumption was made that these inaccuracies were based on human error such as improper seal at the leak sight. It was also assumed that if the concentration versus time plots had high initial values contradictory to what should be seen with proper evacuation and then coincidentally had a lower concentration over time, indicating a negative flux, then these values were assumed to be errors from improper evacuation. Concentration versus time plots having less than a ~2 ppmv change for CO_2 and less than ~0.3 ppmv change for CH_4 were assumed to be a zero or no flux reading. Lab experiments were done to verify these assumptions; similar trends were seen when initiating a controlled leak and improper seal. Therefore the assumptions were assumed to be valid.

There was an issue with respect to the type of method each analyzer uses. It was unclear the effects using two different methods would have on the measurements and the limitation that only CO_2 could be compared and not CH_4. Some issues when using the NDIR analyzer in conjunction with the CRDS are the equations the NDIR analyzer use are more in depth and have more correction coefficients that are not necessarily readily available or relevant to this specific study site, considering the NDIR was specifically created for soil flux. This issue was bypassed by locating and directly reading the concentration data within the NDIR analyzer and using a more

generalized or site specific equation when determining the flux that corresponds well with the site specific built chamber. The equations and algorithms for data processing and interpretation of the measured field and laboratory data are discussed next section.

<u>Data Analysis: Algorithms for Processing and
Interpreting Measured Concentration and Flux Data</u>

The data are logged internally in the CRDS unit. The unit outputs the date, time, water vapor, CH_4, and CO_2 concentration for both dry concentration and in air. A GPS unit was fitted and gave the spatial location in latitude and longitude. Due to the excess of data from the CRDS unit, the data were queried to focus the information for better analysis. The CRDS creates large .dat files that are difficult for a word processing program; therefore a script in Matlab was created called pcut found in Appendix B. This script was used to import the data files, reformat the data and then cut both the CO_2 and CH_4 at a specific threshold value that eliminates ambient conditions and any outlying data determined by observation or user input. The observation value took into account the ambient concentrations for CO_2 (~290 ppmv) and CH_4 (~1.87 ppmv) as well as the typical concentrations that were created from outside sources, such as passing vehicles. The cut data were exported into a comma delineated format that is acceptable for importation into the ArcGIS program, a mapping and spatial visualization software. The data have the date, time, CH_4 and CO_2 concentrations, as well as spatial information from the GPS and any other user depicted values. The code was created for use in future analysis and allows for any delimited formatting. Details can be found in Appendix B.

Once the concentration data from the CRDS were reformatted, it could either import into ArcGIS or be used for flux calculation. The concentration measurements (no chamber readings) were imported in ArcGIS where the XY data were defined in latitude and longitude for spatial referencing. Shapefiles (a geospatial vector data format) of the sewer utility lines and

maintenance cover locations were acquired from the University of Utah Facilities Management and were overlayed on a tagged image file format (TIFF) map of the University of Utah. The TIFF file was obtained from gis.utah.gov. Both the campus map and the utility shapefiles originated in UTM coordinates. Therefore the CRDS data were projected from the WGS 1983 geographical projection to UTM 1987 zone 12 projected coordinates.

After the data were modified into a feature class (a classification format of geographic features and supporting data in a coverage) with the correct projection, the data were visually quantified by graduated symbols. The symbol values represent the CO_2 and CH_4 concentrations values in a range from low to high. The sewer line feature class was copied and modified to encompass only the area of analysis as shown in Figure 5 through Figure 10. These data were then used to create a flow regime, which was developed from observations of the campus topography and the sewer lines (Figure 1).

The CRDS spectrometer was also used to gather headspace concentrations at each of the 11 sewer access holes. The covers were removed and the depth, headspace concentration and surface concentrations were measured using only the CRDS. These data were used with Fick's Law, Eq. 1, to calculate the diffusive flux gradient. This equation was used under the assumption that the sewer access covers were under a steady state and exhibit an ideal mixture relationship during the measurement time (<2-minutes). The diffusion coefficients for methane (CH_4) and carbon dioxide (CO_2) in air were found from the USDA Forest Service website. These values were determined with the understanding that this applies only for near standard temperature and pressure values. This assumption should be valid for this study because the analyzed sewer lines are no more than 11-feet below the surface. This method was used to determine any diffusional relationship in gas transport within the sewer.

$$J = -D\frac{\partial \varphi}{\partial x}$$
(Eq. 1)

$J = Diffusion\ Flux\ (amount\ of\ substance/Volume/Time)$
$\varphi = Concentration\ (amount\ of\ substance/Volume)$
$x = Position\ (length)$
$D = Diffusion\ coefficient\ or\ Diffusivity\ (area/time)$

In order to calculate the chamber flux, the data files from each analyzer required reformatting for compatibility into R, a statistical analysis program, and combined with the HMR package function. HMR is an R package found to calculate the flux for a static closed chamber. R is a free statistical analysis package created by Robert Gentleman and Ross Ihaka from the University of Auckland in New Zealand. The HMR package within R was created by Asger R. Pedersen to estimate flux within a static chamber using nonlinear regression or linear regression analysis. In most practices, a linear best fit curve is used on the data but according to a study by Pihlatie et al. (*13*), using an exponential fit when determining the flux rate, better captures the concentration development within the chamber when compared to a linear regression fit.

This HMR program package requires separated columns for the series name, chamber volume, chamber cross sectional area, time elapsed and the concentration in a comma separated value format (.csv). The series name in our case was the sewer access cover name (e.g., MH$_4$).

The Matlab scripts calculated the elapsed time from initiation to the end of deployment in minutes; the script for the CRDS analyzer is called Rflux and NDIR analyzer uses the Lflux script; both scripts are found in Appendix B. It should be noted that the CRDS records data in milliseconds, but the deployment time was taken manually to the nearest minute. Therefore these data were inspected manually within the said minute of recorded data and approximated to the nearest second. The volume remains constant and is based on the chamber used; for this study there were 2x55 gallon (208,198 cm^3) garbage cans or the 20 cm NDIR analyzer survey chamber (4,843 cm3). The cross sectional area is dependent upon the source. For the purposes of this study the area was unitized, giving flux in µL/min or grams/day. The concentrations were taken from the start and end time of deployment for either CH$_4$ or CO$_2$. The start and end time

are important as the flux is defined as the change in concentration over a corresponding change

in time according to the chamber volume and the source cross sectional area as shown in Eq. 2.

$$F = \frac{dC}{dt}\frac{V}{A}$$ (Eq. 2)

$F = Flux\ (\mu L/m^2/min)$
$dC = Change\ in\ concentration\ (ppmv\ or\ \mu L/L)$
$dt = Change\ in\ time\ (min)$
$V = Chamber\ volume\ (L)$
$A = Source\ Area\ (m^2)$

HMR uses a nonlinear function by Hutchinson and Moiser (Eq. 3) using a single parameter

(k) criterion or simple linear regression to determine the best fit for the flux data. The program

will then recommend the best fit for the data. Criterion plots were shown along with the data plot

and its various fit curves as seen in Figure 3 and Figure 4. In the figures it shows an MSE criterion

vs. log (k) on the upper left hand side. This was the mean squared error (MSE) for the feasible

values of k and the upper right hand plot was the close up for the recommended value for k shown

in blue. The actual data plot and curve fits were shown in the lower left corner along with the

recommendation. The recommendation will show as nonlinear (HMR) as in Figure 3 or linear (LR)

as shown in Figure 4. The buttons shown in the lower right hand corner were the choices for which

fit you would like to calculate the flux.

$$C_t = \varphi + f_0 e^{-kt}$$ (Eq. 3)

$C_t = Concentration\ at\ time\ t$
$\varphi = New\ chamber\ equillibrium\ concentration$
$f_0 = Initial\ flux$
$k = Adaptation\ rate\ depending\ on\ the\ soil, gas\ and\ chamber\ characteristics, k > 0$
$t = time$

After a fit was chosen by the user, values were determined for the estimated flux,

standard deviation, p-value for the null hypothesis of zero flux, the lower end point of the 95%

confidence interval, and the upper end point of the 95% confidence interval for the flux. The flux

units were determined by user input parameters and in this case the concentration was in ppmv

so the volume is in liters, area is in m², and time is in minutes. This will give us a flux in $\mu L/m^2/min$, but since the area is unitized the flux becomes $\mu L/min$. Along with imputing the flux data information for each chamber flux reading, the temperature and pressure during the reading time was recorded using the wunderground weather data. This information was then used to determine the density for CH_4 and CO_2 using their individual equations of state from the peace software website developed by the programmer Berndt Wischnewski from the Max Plank Institute for Human Development. The densities are used to convert the flux units of $\mu L/m^2/min$ to $g/m^2/day$ and $\mu Mole/m^2/sec$. These values can all be found in relation to their correlating flux measurement in Appendix C.

All flux calculations were quantified by converting the CH_4 and CO_2 into Metric Tons CO_2 equivalent (Mt CO_2e). This was done using Eq. 4. The time was expressed in 1 year for easy comparison. The Global Warming Potential (GWP) from US Environmental Protection Agency (EPA) for methane is 21, meaning methane has 21 times more potential for trapping heat in the atmosphere when compared to CO_2.

$$\left(\frac{Mt\ CO_2 e}{time}\right) = \left(\frac{g\ CO_2}{time}\right) \times \left(\frac{1\ Mt\ CO_2}{1000000\ g\ CO_2}\right) \times GWP \qquad \text{(Eq. 4)}$$

$GWP = Global\ warming\ potential$
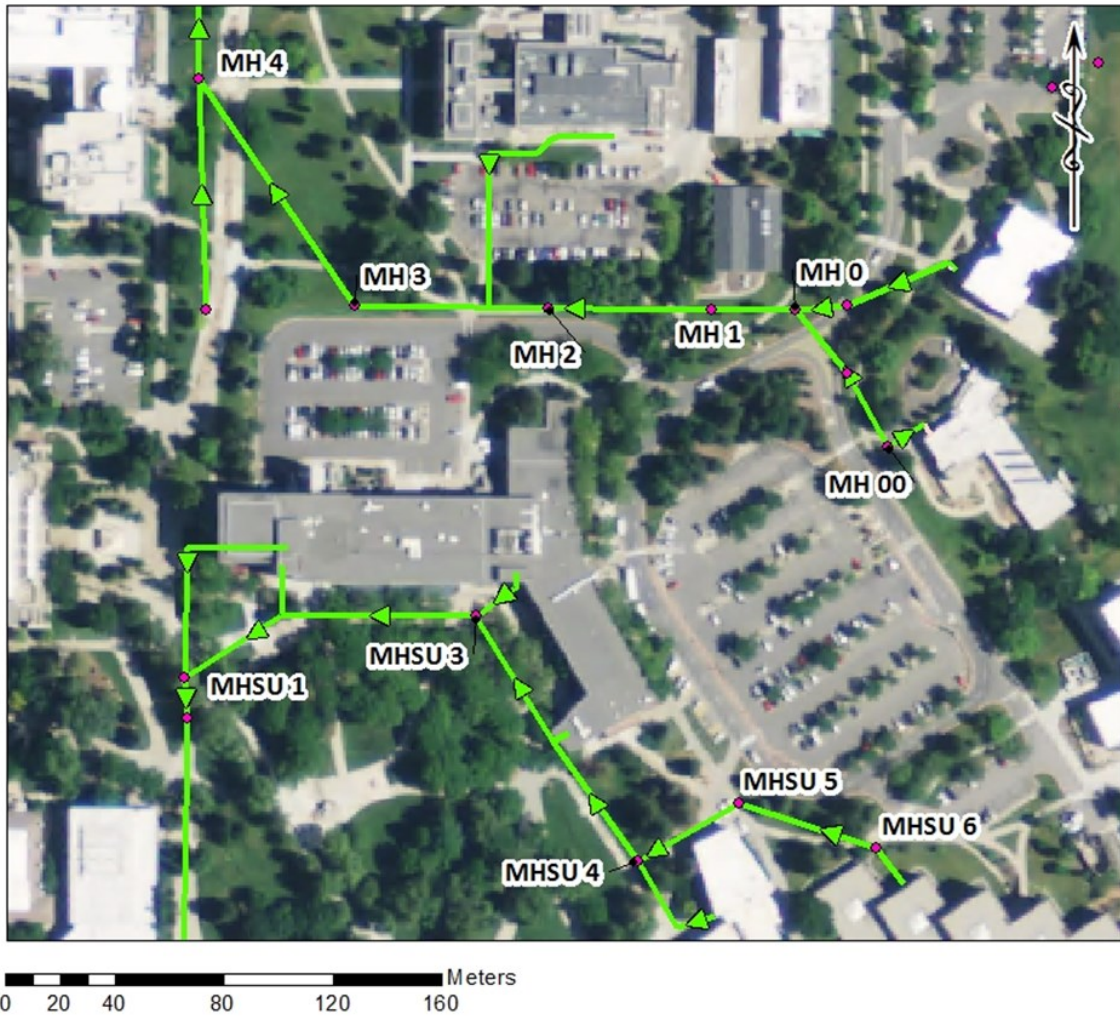
Figure 1: Aerial View of Study Site with Sewer Access Designations and Flow Regime

Table 1: General Sewer Access Cover and Line Data

Location	Length (m)	Depth (m)	% Slope	Source Area (m^2)	Pipe Diameter (m)[in]	Type
MH00		1.8		0.003		Concrete
	60.5		0.33		0.1524 [6]	
MH0		3		0.003		Concrete
	31.3		5.77		0.1524 [6]	
MH1		1.8		0.007		Concrete
	59.9		7.03		0.1524 [6]	
MH2		3		0.003		Concrete
	70.2		3.85		0.1524 [6]	
MH3		2.7		0.002		Concrete
	100.9		2.28		0.1524 [6]	
MH4		3		0.005		Concrete
MHSU6		3.4		0.005		Concrete
	53.0		3.02		0.1016 [4]	
MHSU5		3		0.004		Concrete
	42.8		5.85		0.1016 [4]	
MHSU4		1.5		0.005		Concrete
	107.9		1.95		0.1524 [6]	
MHSU3		2.6		0.004		Concrete
	113.7		4.58		0.2032 [8]	
MHSU1		1.8		0.002		Concrete
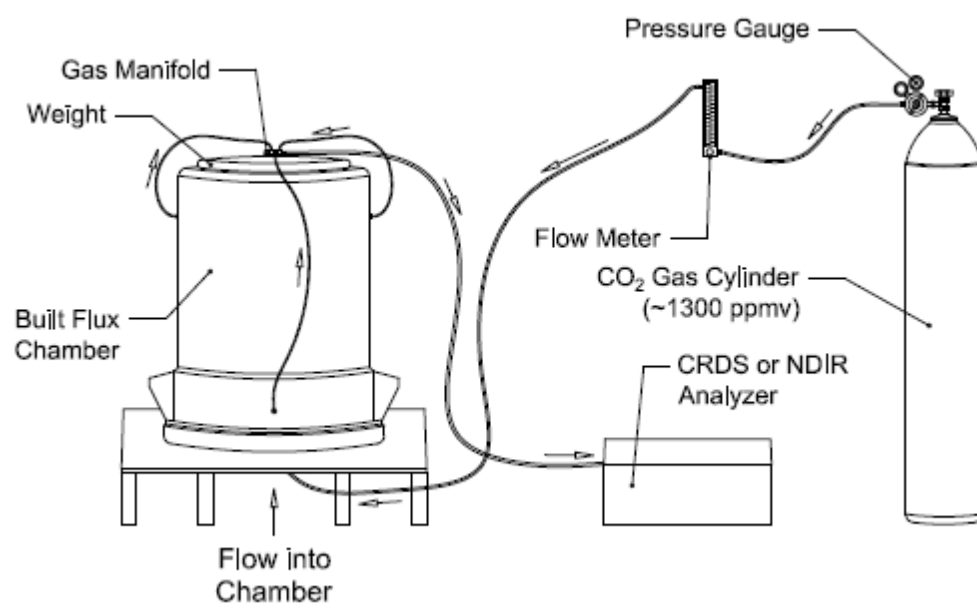
Figure 2: Laboratory Chamber Calibration Setup

Data series: MH3-1 (100%)
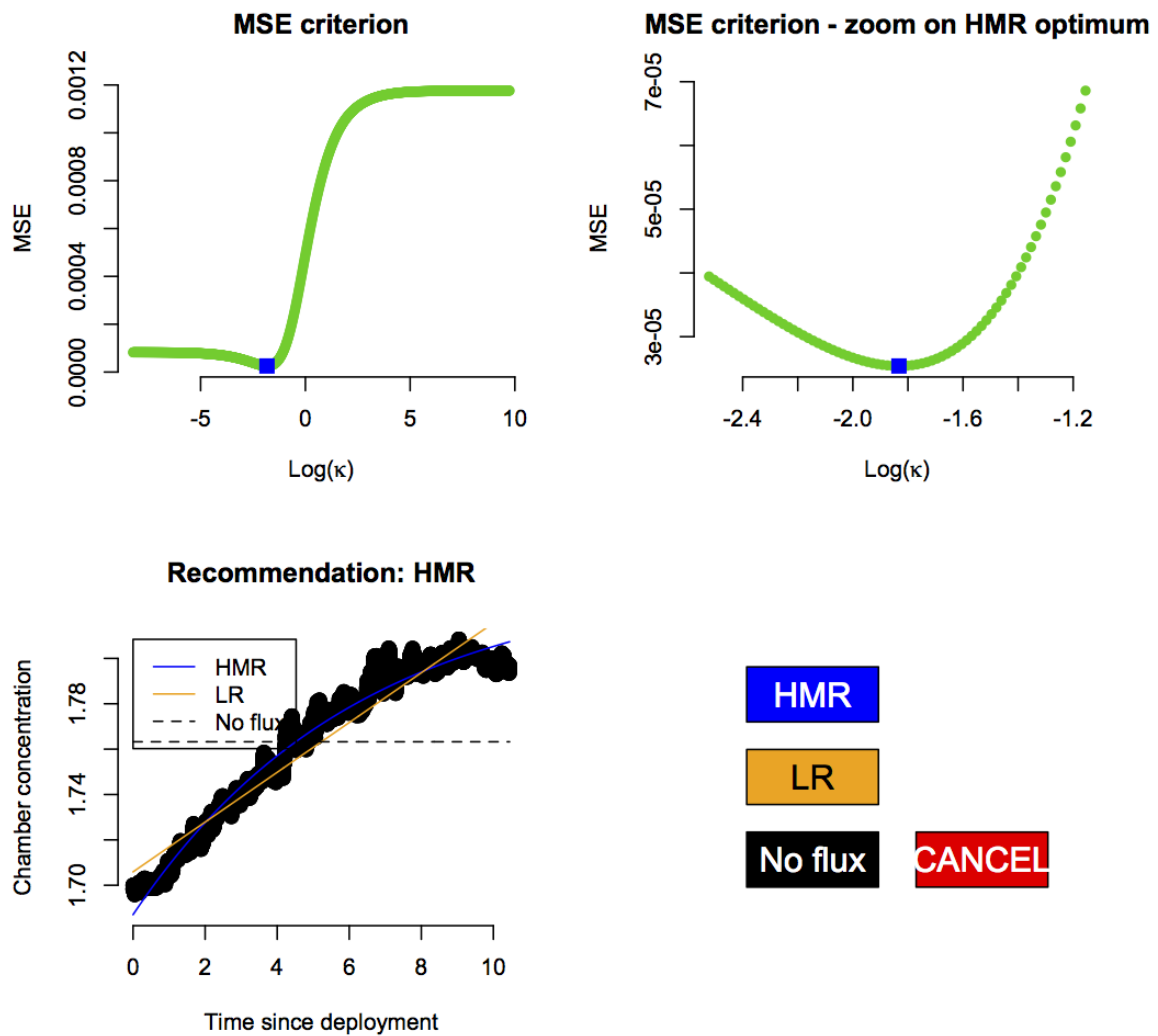
Figure 3: HMR Example of a Nonlinear Curve Fit

Data series: MH3-1 (100%)

MSE criterion

MSE criterion - zoom on HMR optimum

Recommendation: LR
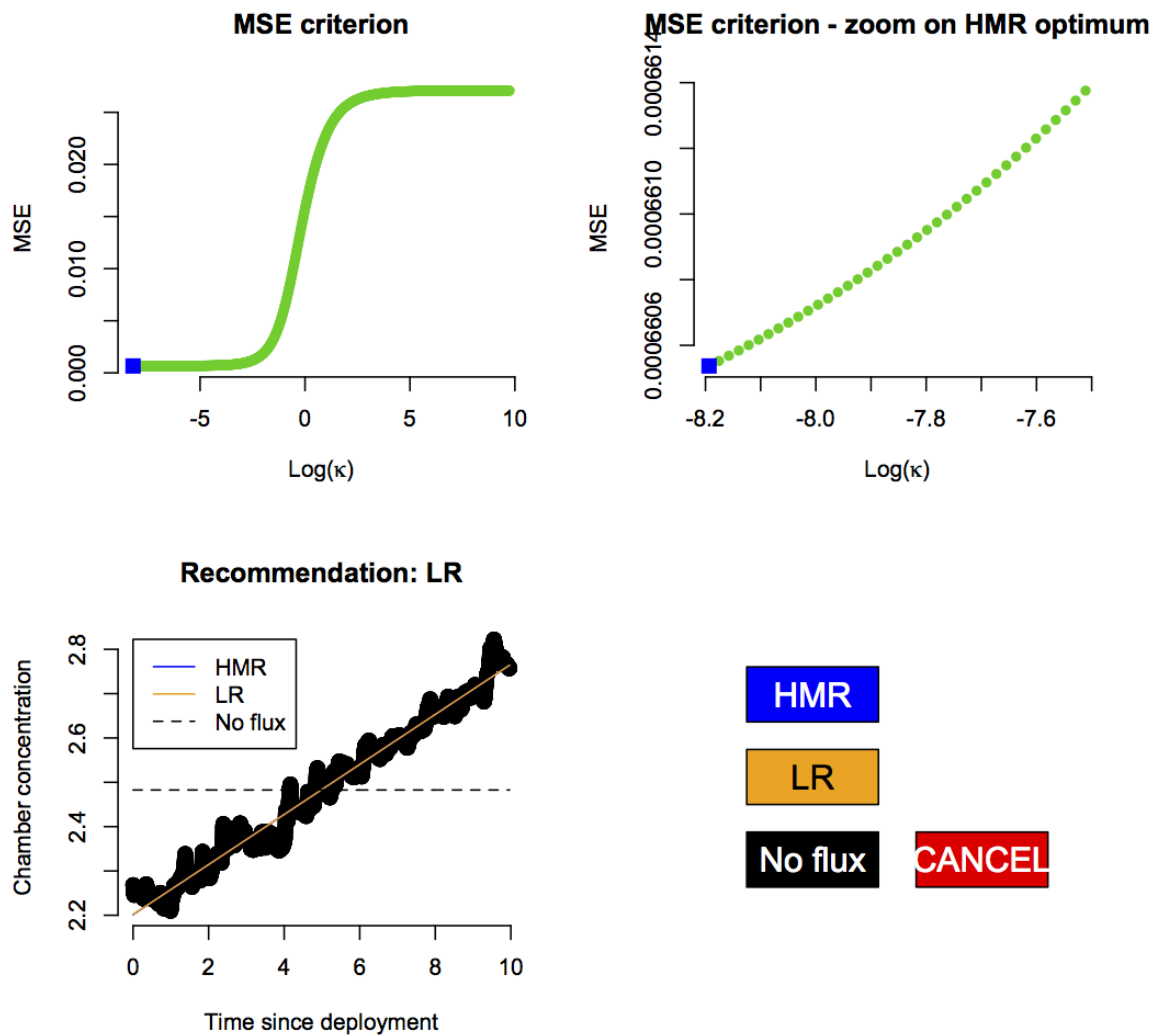
Figure 4: HMR Example of a Linear Curve Fit
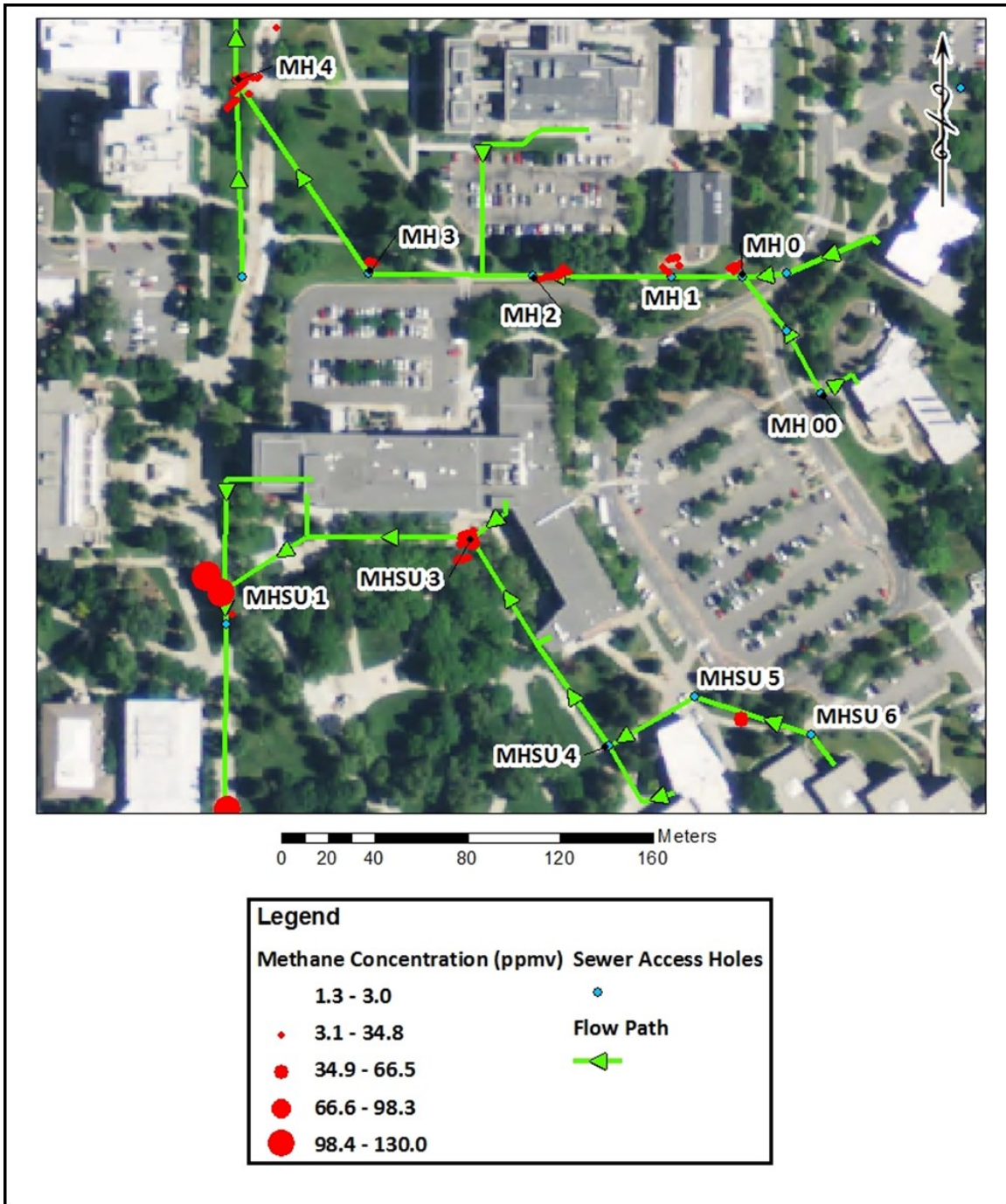
Figure 5: 2012 Methane Concentration Summary
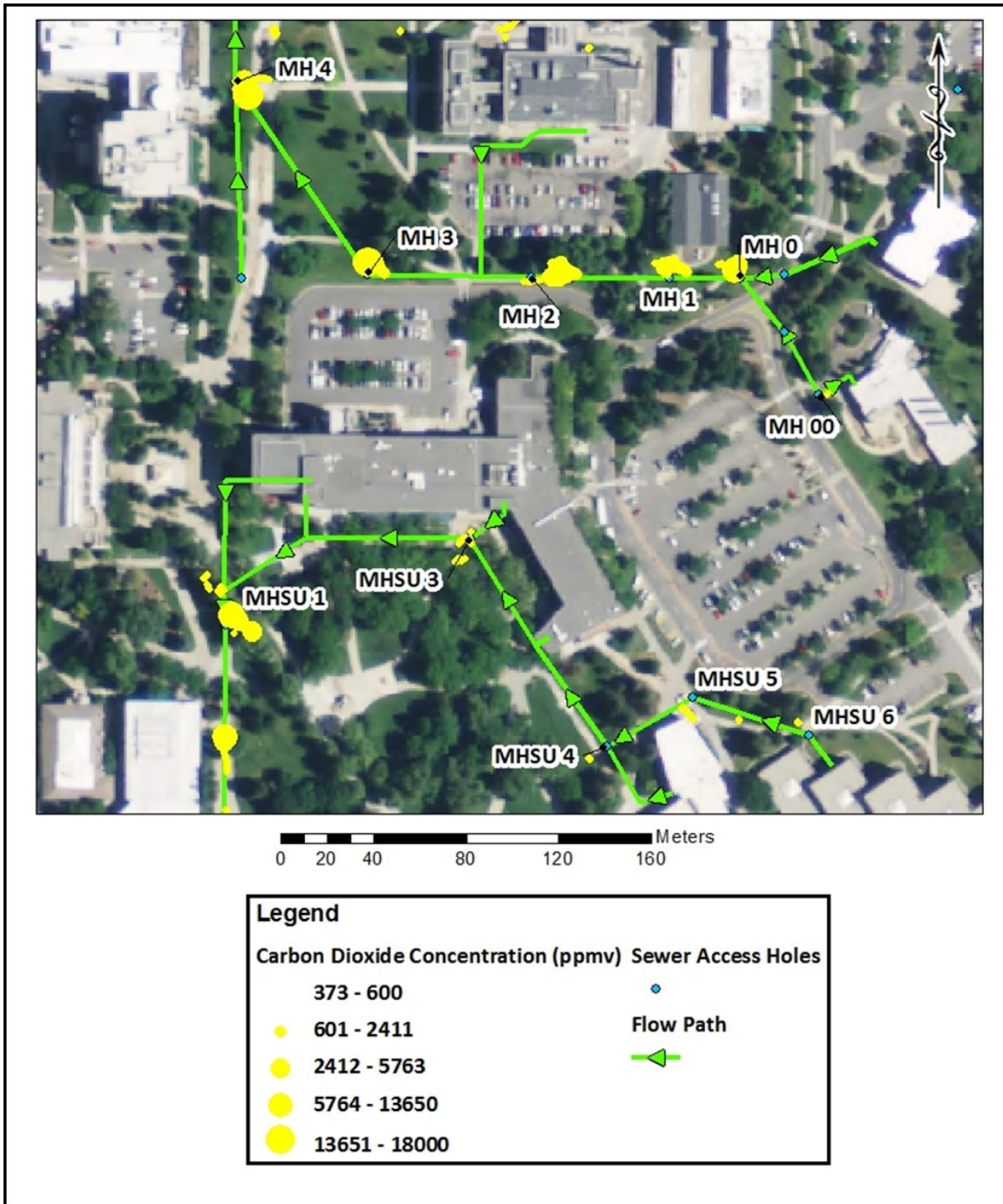
Figure 6: 2012 Carbon Dioxide Concentration Summary
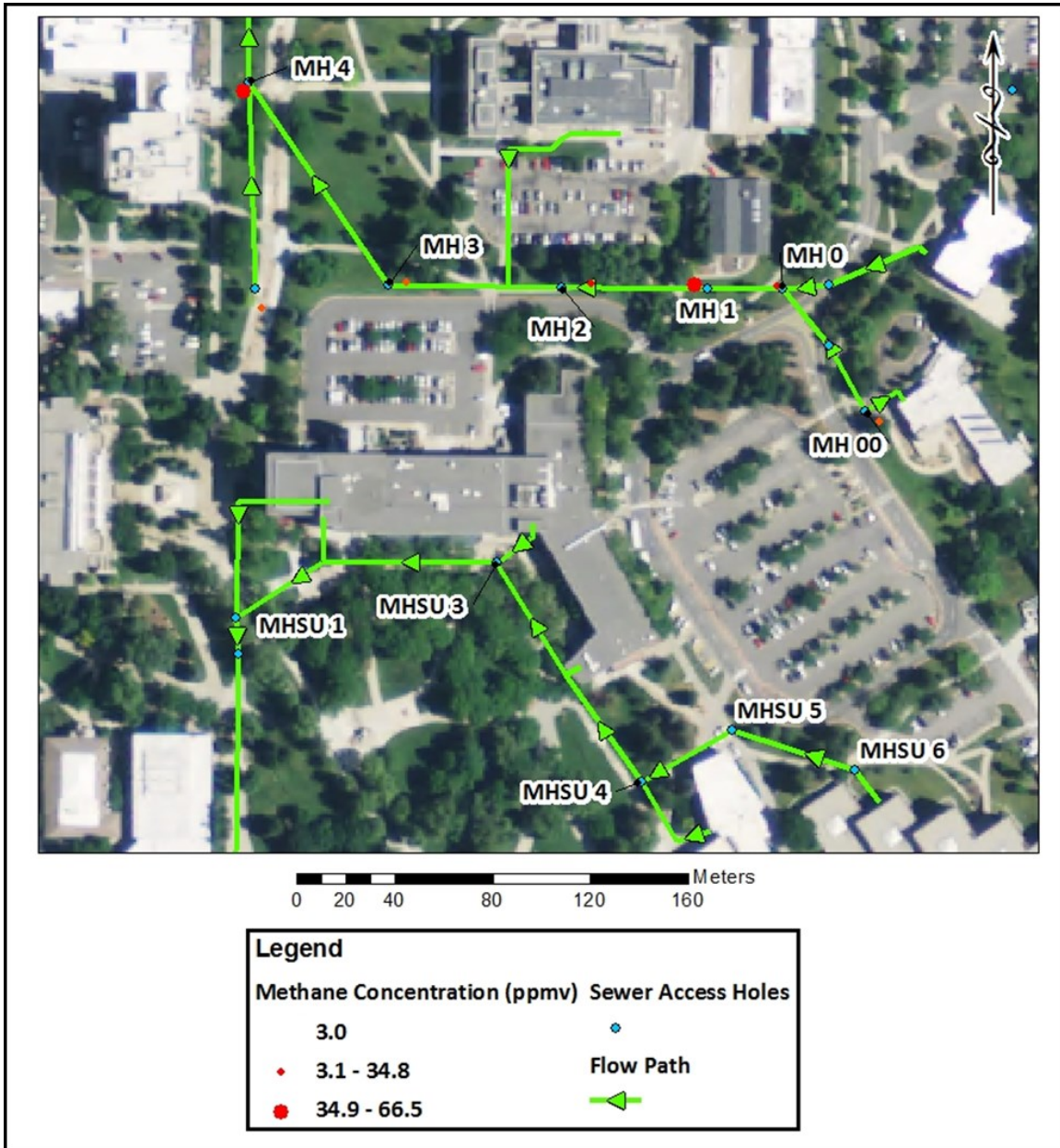
Figure 7: June 2013 Methane Concentration Summary
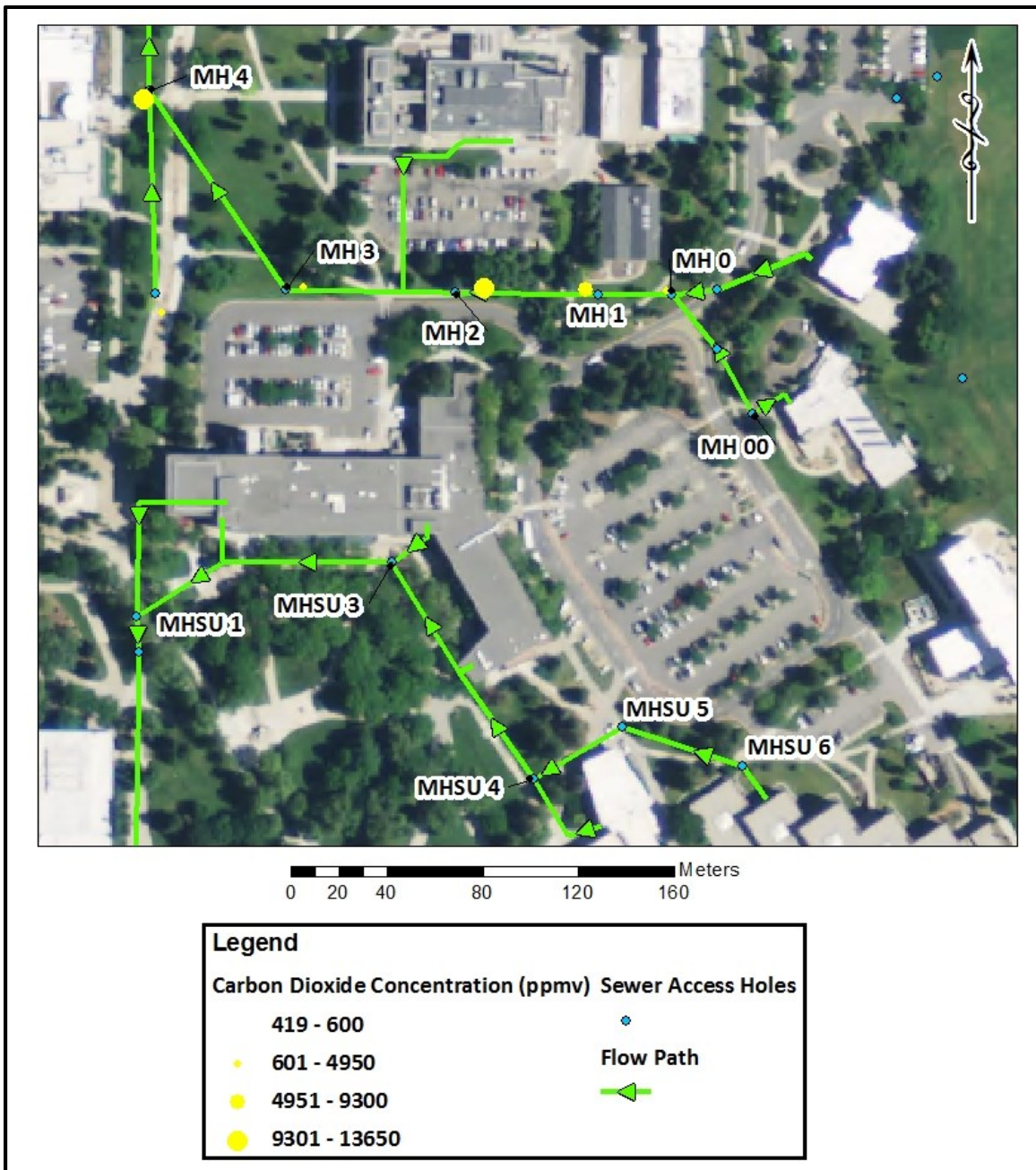
Figure 8: June 2013 Carbon Dioxide Concentration Summary
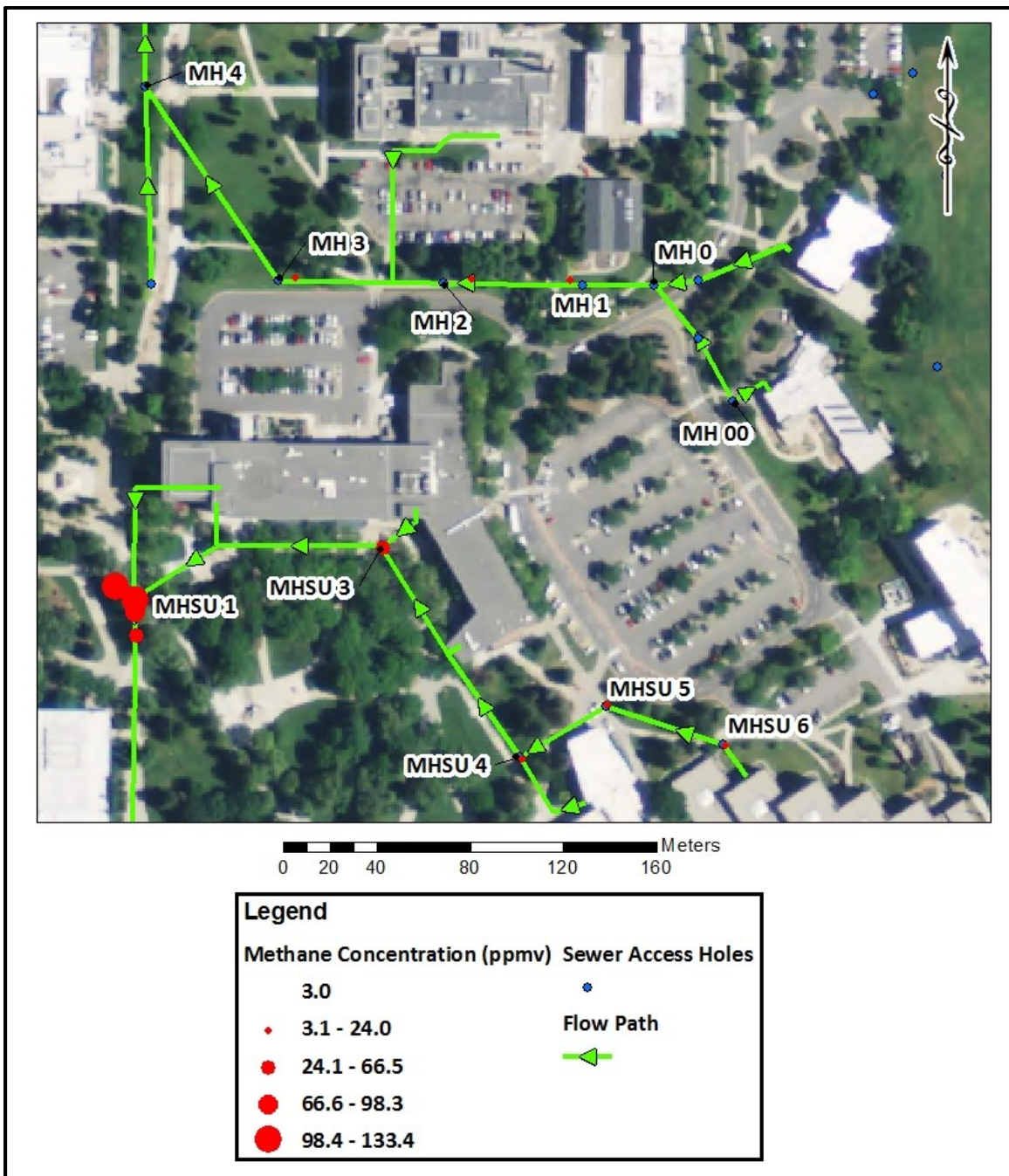
Figure 9: July 2013 Methane Concentration Summary
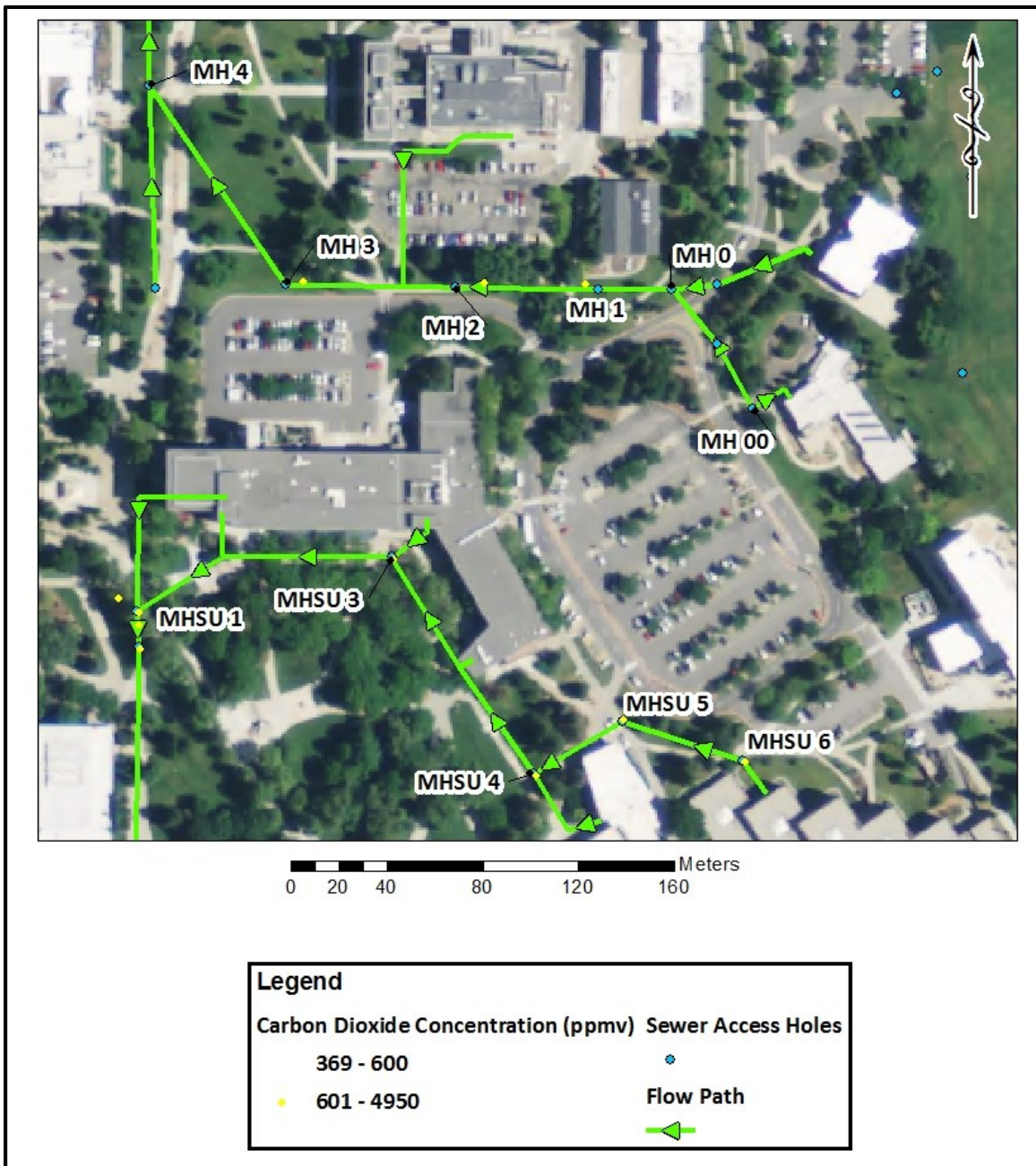
Figure 10: July 2013 Carbon Dioxide Concentration Summary

DISCUSSION OF ANALYSIS AND RESULTS

CRDS Concentration Measurements

Figure 5 through Figure 10 show symbolized values of the CO_2 and CH_4 measurements in concentration from low to high. The figures symbolize values relative to the sewer access covers but not necessarily directly over them. This was due to a proximity error with the equipment and GPS location accuracy at the time of measurement. The GPS was at times positioned as far as 2 meters away from the actual measurement location. This was done to mitigate the effects of the generator exhaust on the concentrations and close proximity of a body to the GPS creates interference with the accuracy.

The 2012 measurements have been summarized for the 2 months of viable data collected. The methane concentration values taken from the sewer access covers showed highs of up to 130 ppmv. The highest values were seen at MHSU1 and MHSU3 for methane. Carbon dioxide was seen in the 18,000 ppmv range, with the highest activity seen at MHSU1 and MHSU3 on the southern line located next to the Student Union and MH4, MH3 and MH0 having the highest readings on the northern line. June 2013 focused on the northern line and had highs in the 60 ppmv for methane and 13,650 ppmv for CO_2. The highest readings for methane were seen at MH4 and MH1 and MH4, MH2 and MH1 for CO_2.

July 2013 had high methane concentrations of 133 ppmv and in the high 4000 ppmv for carbon dioxide. This is 74 times greater than the ambient conditions for CH_4 and 1000 times greater for CO_2. Again the highest readings for methane were seen at MHSU1 and MHSU3. All of

these values can be relatively deduced by the data shown in Figure 5 through Figure 10. A basic range was set for the CH_4 and CO_2 concentrations to create consistent symbology sizing. This worked well in relating the values except during the July 2013 carbon dioxide readings that only showed the same circle sized based on the measured concentrations. Therefore this month's summary did not adequately show which sewer access cover had the highest concentration readings for that time period. During the fall of 2012 there were higher concentration measurements than the summer of 2013. This could be due to the less activity on campus.

Figure 11 through Figure 14 show 5 to 8-hour concentration measurements of sewer access covers MH1, MH0 and MHSU1. MH1 shows a series of small spikes in concentration before noon for both CH_4 and CO_2, then large more sporadic spikes in the afternoon (Figure 11). MH0 for June 26th stays at a fairly, consistently elevated concentration before 1:00 pm and then there was a gradual increase until 5:00 pm with sporadic downwards spikes in concentration. This was the observed trend for both CH_4 and CO_2 as shown in Figure 12. MH0 for the 27th of June shows a similar trend as June 26th for CO_2, but CH_4 stays fairly consistent throughout the whole time period, with more sporadic downtrend spikes after about 1:00 pm (Figure 13). MHSU 1 shows more elevated and inconsistent spikes prior to 1:00 pm and more consistent higher concentrations after 1:00 pm for both CH_4 and CO_2 (Figure 14).

Carbon dioxide and methane seem to show a proportional relationship during the same time of measurement as visually shown by the concentration measurements in Figure 11 through Figure 14. This could be due to formation from the same chemical reaction. Anaerobic conditions, the absence of oxygen, can occur within the sewer lines. These conditions could lead to methanogenesis. Methanogenesis can be formed from the biodegradation of organic matter, which will go through a 4 stage process to form CH_4 but also CO_2 as a byproduct; the four stages are hydrolysis, acidogenesis, acetogenesis and methangogenesis. There are many reactions

involved in generating methane but the main reactions involved which form both CO_2 and CH_4 are

shown in the reactions in Eq. 5 through Eq. 10 ((*16*)). This assessment could be verified through

testing the sewage for acetic acid and pH.

Hydrolysis is the process of turning the soluble organics (waste) to soluble monomers (e.g.

simple sugars).

Hydrolysis: $\quad\quad\quad\quad\quad C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2$ $\quad\quad\quad\quad$ (Eq. 5)
$\quad\quad\quad\quad\quad\quad\quad\quad\quad$ (Organic waste)$\quad\quad$(Glucose)
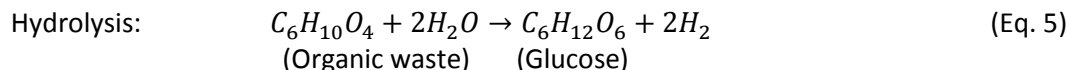
Acidogenesis turns the insoluble organics into volatile fatty acids, ketones and alcohols.

Acidogenesis: $\quad\quad\quad\quad C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2$ $\quad\quad\quad\quad$ (Eq. 6)
$\quad\quad\quad\quad\quad\quad\quad\quad$ (Glucose)$\quad\quad$(Ketone: ethanol)

$\quad\quad\quad\quad\quad\quad\quad C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O$ $\quad\quad\quad$ (Eq. 7)
$\quad\quad\quad\quad\quad\quad\quad$ (Glucose)$\quad\quad\quad\quad$(Volatile fatty acid: propionate)
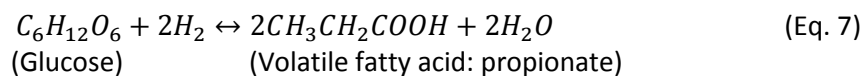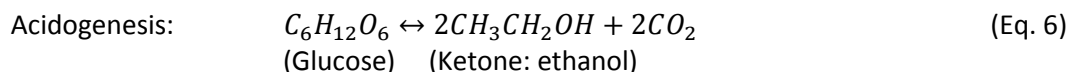
Acetogenesis turns the volatile fatty acids, ketones and alcohols into acetate, acetic acid

CO_2 and H_2.

Acetogenesis: $CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + 2HCO_3 + 3H_2$ $\quad$ (Eq. 8)
$\quad\quad\quad\quad\quad$ (Volatile fatty acid)$\quad\quad\quad\quad$(Acetate)

$\quad\quad\quad\quad\quad\quad\quad C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2$ $\quad\quad\quad$ (Eq. 9)
$\quad\quad\quad\quad\quad\quad\quad$ (Glucose)$\quad\quad\quad\quad$(Acetic acid)
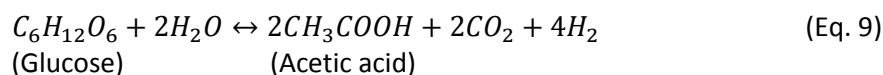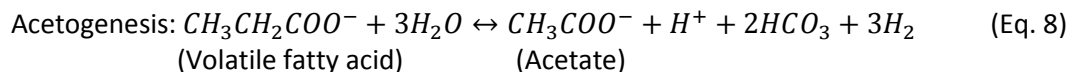
Methanogenesis turns acetate and acetic acid into methane and/or carbon dioxide

Methanogenesis: $\quad\quad\quad\quad CH_3COOH \leftrightarrow CH_4 + CO_2$ $\quad\quad\quad\quad\quad$ (Eq. 10)
$\quad\quad\quad\quad\quad\quad\quad\quad$ (Acetic acid)
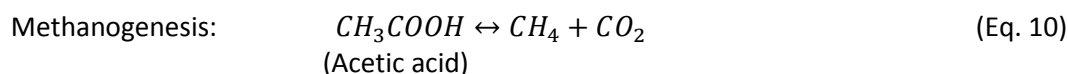
Calibration Results

The results for the chamber laboratory calibration are shown in Table 2 and Figure 15.

The calibration results show the flux for all chambers have a relatively logarithmic relationship

depending on the flow rate. The ratio best fit curve is shown as exponential when using the NDIR

analyzer with the built chamber, but had a more linear trend when using the CRDS with the built

chamber. It was observed that the greater the flux, the larger the discrepancy between curves when coupling the NDIR analyzer and built chamber. Most of the data measured fit within the allotted flux rates found in the lab, giving some confidence in using the correction values curve on the data. Eq. 11 and Eq. 12 were found to best represent the correction curves based on the laboratory calibration data. These equations were used to determine the correction ratio applied to each calculated flux value from the measurements made with either the CRDS or NDIR analyzer.

Figure 16 and Figure 17 show the NDIR and CRDS flux data measured back to back over a certain time period. Figure 16 encompasses an approximate 24-hour flux trend for the access cover MH4 on October 25th through the 26th. Figure 17 shows a few hours of back to back NDIR and CRDS flux measurements for the MHSU3 access cover on October the 28th. The figures show differences in measured flux values based on the analyzer.

$$y_L = 0.7745e^{-0.152x_L} \hspace{4cm} \text{(Eq. 11)}$$

$y_L = Correction\ ratio\ for\ NDIR\ measurements$
$x_L = Calculated\ Flux\ from\ measured\ NDIR\ values\ (grams/day)$

$$y_P = 0.0695x_P + 0.7583 \hspace{4cm} \text{(Eq. 12)}$$

$y_P = Correction\ ratio\ for\ CRDS\ measurements$
$x_P = Calculated\ Flux\ from\ measured\ CRDS\ values\ (grams/day)$

The chamber calibration indicated the built chambers, when using the NDIR analyzer system, were underestimating the flux results at smaller measured values and overestimating the flux results for higher calculated values. This could have been due to the large volume change or the chambers' area and volume ratio (A/V), which changes depending on the source cross sectional area. The built chambers have a smaller A/V ratio when compared to the NDIR analyzer, but the proportionality will remain the same when comparing the same source. The CRDS calibration in relation to the NDIR analyzer with NDIR analyzer chamber seemed to have a more

linear trend for the correction factor. This may have more to do with the system being designed specifically for use with the CRDS, the A/V ratio, and/or the analyzer's precision and accuracy.

Methane is lighter than air which means there could be more dispersion within the system than what was actually measured due to the inability to calibrate CH_4 for the built chamber as was done for CO_2. More calibration is recommended for all methods to get a better understanding of the discrepancy in readings, based on method and chamber type. The analyzers were also not calibrated to measure concentrations at these extremes, which would add question to the integrity of the data as the concentrations get into the tens of thousands range.

The NDIR analyzer and CRDS seem to have somewhat relative trends when looking at the flux plots versus time. Some of the discrepancy could be from the type of curve fit used to calculate the flux from one device to another. When using a nonlinear or linear fit to calculate the predicted or approximate flux there can be large differences, but all flux data were determined using the best fit curve. The morning and late evening measurements seem to follow a very similar trend. During the afternoon there were high variabilities in the readings, which were consistently shown in all the data and have shown large disparities within a short period of time. The inconsistencies could also be from the measurements not being done at the exact same time, at the same cover, and/or due to the limited predictability of the system. It may be reasonable to allow for a high degree of uncertainty when comparing actual values.

<u>Flux Analysis Results</u>

The results shown in Table 3 give the field measured concentration values and calculated flux gradient data for the 11 access covers assessed for diffusion calculated by Eq. 1. The flux gradient values are shown as negative only because they go from a high concentration to low concentration. Table 4 shows the theoretical trend for the flux release of the sewer access covers

based on the flux gradient (diffusion) and compares it to the actual measured values for flux. Specifically the table shows the sewer access covers that would theoretically have the highest values (left) to the lowest values (right) if the flux was primarily controlled by diffusion for both CH_4 and CO_2. This was done for both carbon dioxide and methane as they behave differently from one access cover to the next. No obvious trends were seen for the theoretical and actual in either CO_2 or CH_4. It should be noted that not all the sewer access covers had the same amount of measurements and were done at sporadic times throughout the week. This coupled with the inconsistencies observed from the sewer may have an impact on the averaging, quantification and trend correlations.

Table 5 shows the theoretical values for high flux rates according to the ventilation out of the sewer access covers according to the approximated potential area of release, meaning if the flux was controlled primarily by the source area (area of release potential) then theoretically the sewer access cover with the highest flux should be MH1 and sewer access cover MHSU1 should show the lowest flux for both gases. There were no obvious trends or connections between either the theoretical or actual values. The actual values for CO_2 and CH_4 when compared are also variable and have limited connections in terms of source area.

The flux data for each access cover were averaged over morning and afternoon. This was done because the trend in the concentration and flux data showed there were either higher values in the afternoon when compared to the morning or vice versa depending on the sewer access cover observed. Table 6 shows these averaged data as well as the total values expressed in g/day and the Mt CO_2e/yr. The fluxes for CH_4 were between 0.00002-35 g CH_4/day and CO_2 had fluxes around 0.04-32,000 g CO_2/day and an overall average of 62 g CO2/day and 0.412 g CH4/day. These data encompass all real data that were not deemed outliers or caused by human or mechanical errors, including all data measured using the NDIR analyzer. The total measured emissions from

the 11 sewer access covers were calculated to be 1.066 Mt CO_2e. All raw flux data are shown in Appendix C.

The average value of emissions of 1.066 Mt CO_2e per year for the 11 sewer access covers can be compared to the total estimated emissions for the University of Utah campus. There are 459 sewer access covers on campus making this sample set approximately 2% of the entire system. According to the University of Utah's Sustainability Resource Center (*17*) the total University of Utah campus emissions was 283,077 Mt of CO_2e; making this sample source accountable for 0.016% of the total campus wide emissions. The source is located at the further most upstream section of the system and therefore could be a very limited emissions contributor when compared to the main trunk lines in the system. As these lines would have higher flows and more continuous activity. The trunk lines may also have more flow data and a higher level of predictability.

Barometric temperature and pressure versus concentration plots were created for each access cover to see if there were any relations. Unfortunately no obvious trends were seen. Plots showing the methane and carbon dioxide seem to show a reasonable proportionality for each observation day. This was only true for the access covers that were active; this was not true for the abandoned lines which had a small but consistent flux of CO_2 but relatively no or negligible flux for CH_4.

The dates determined to have zero or no flux were days when the University of Utah campus had fall break. This could indicate for those specific sites that the lack of sewer use had no or very little flow, possibly creating no flux and possibly lowering concentrations. This could support the assumption that flow is one of the main driving forces for gas transport to the surface. This also supports the assumption that the sewer gas flux could be affected by the sewer's activity. After observing all the data, it was determined that many of the higher concentrations and flux

measurements tend to be more prevalent on sewer maintenance covers that are located at junction points. This could be due to the combining flows and subsequent turbulence. This however did not seem to correlate to the source area for the access covers.

The theoretical and actual flux comparisons from high to low were generally not accurate for both diffusion and source area ventilation. For diffusive flux this could have been due to limiting the flux gradient measurements for one day and there may be more accuracy in doing an average. This could also indicate the diffusion and/or ventilation area is not the main method of gas transport. This supports the Parker et al. (*10*) results indicating the release to the atmosphere of the tracer gas was dominated by advective processes and that diffusion could be neglected for gas transport in the sewer system.
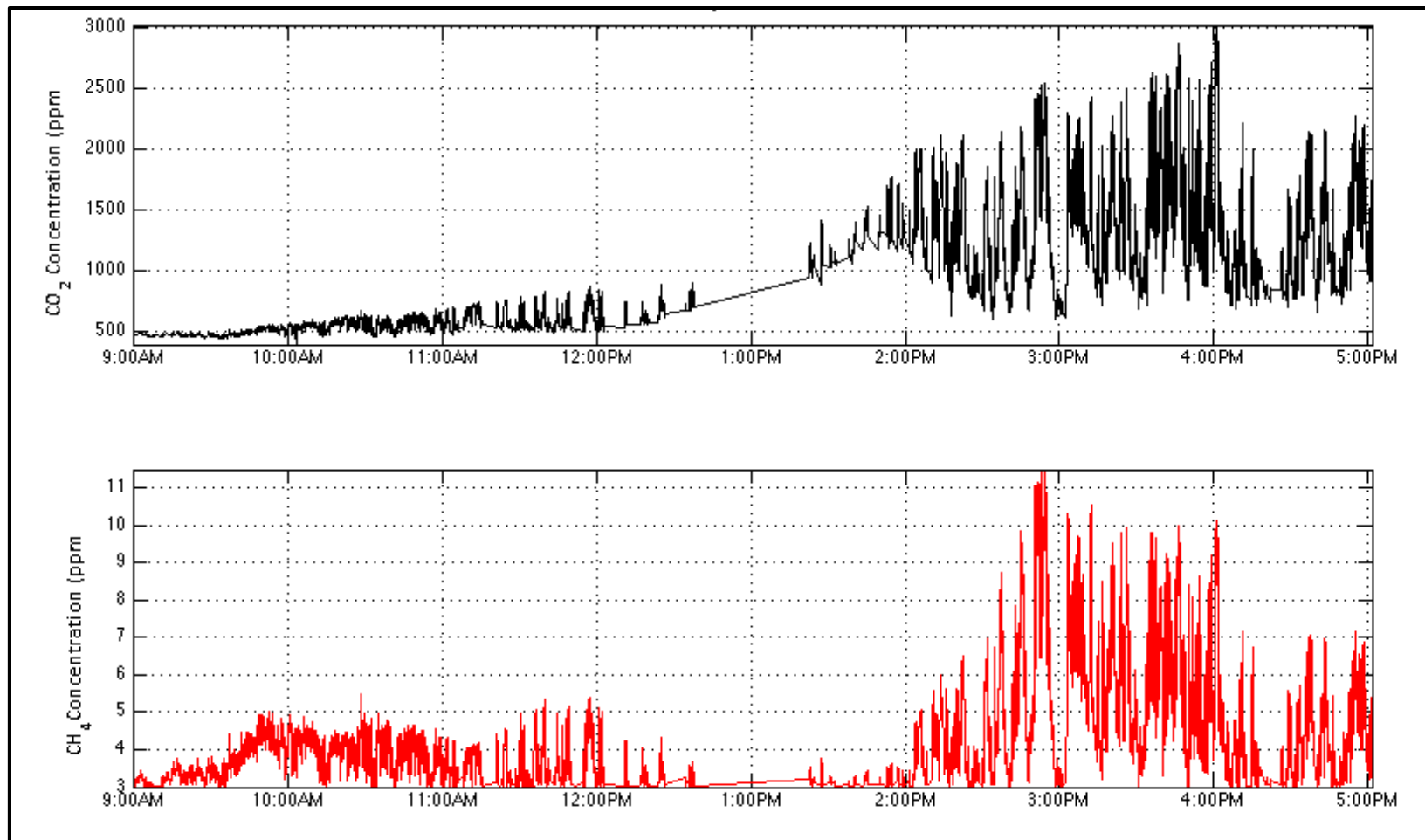
Figure 11: Concentration Measurements of CO2 (above) and CH4 (below) at Sewer Access Cover MH1 on June 21, 2013
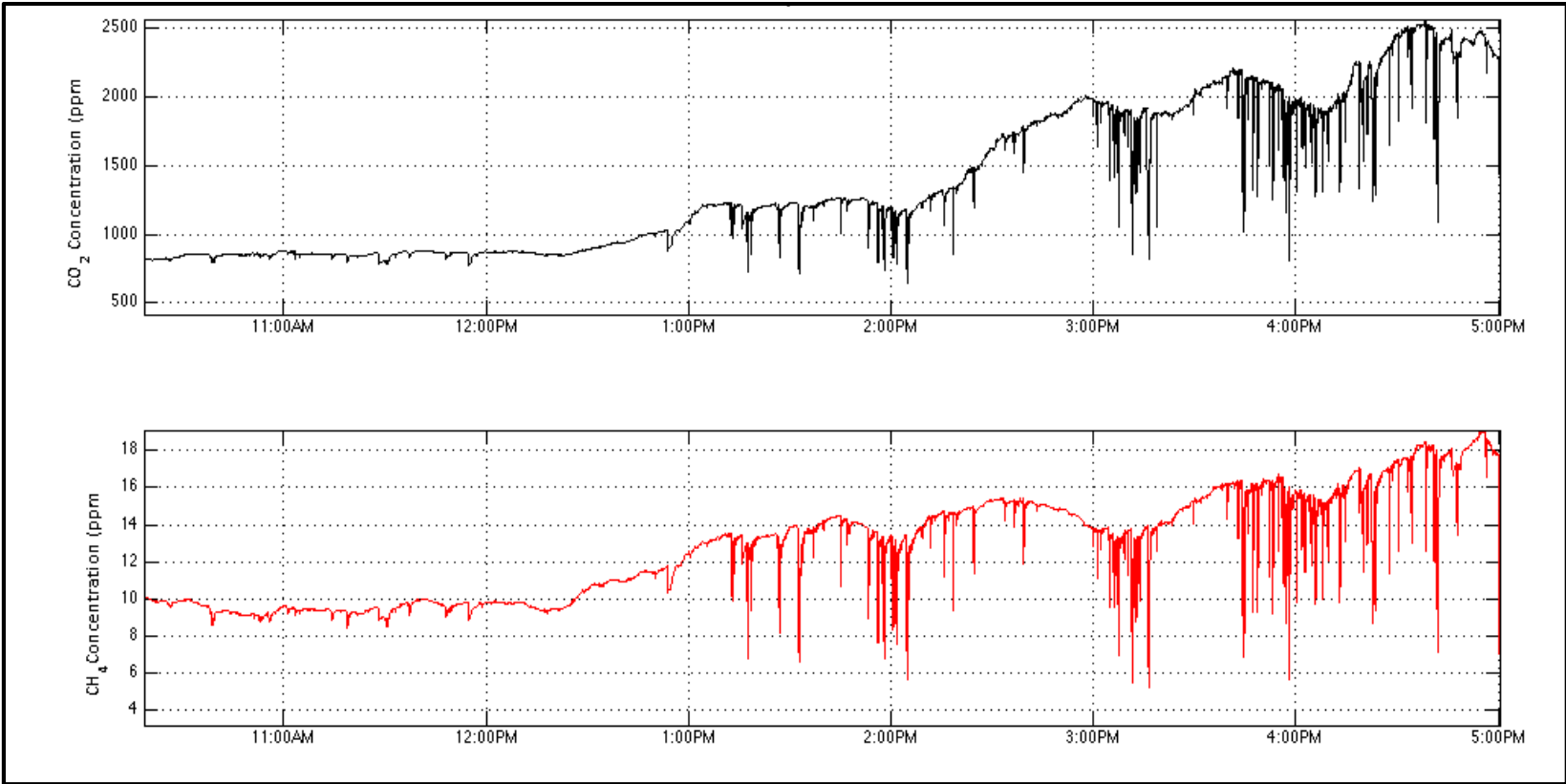
Figure 12: Concentration Measurements of CO2 (above) and CH4 (below) at Sewer Access Cover MH0 on June 26, 2013
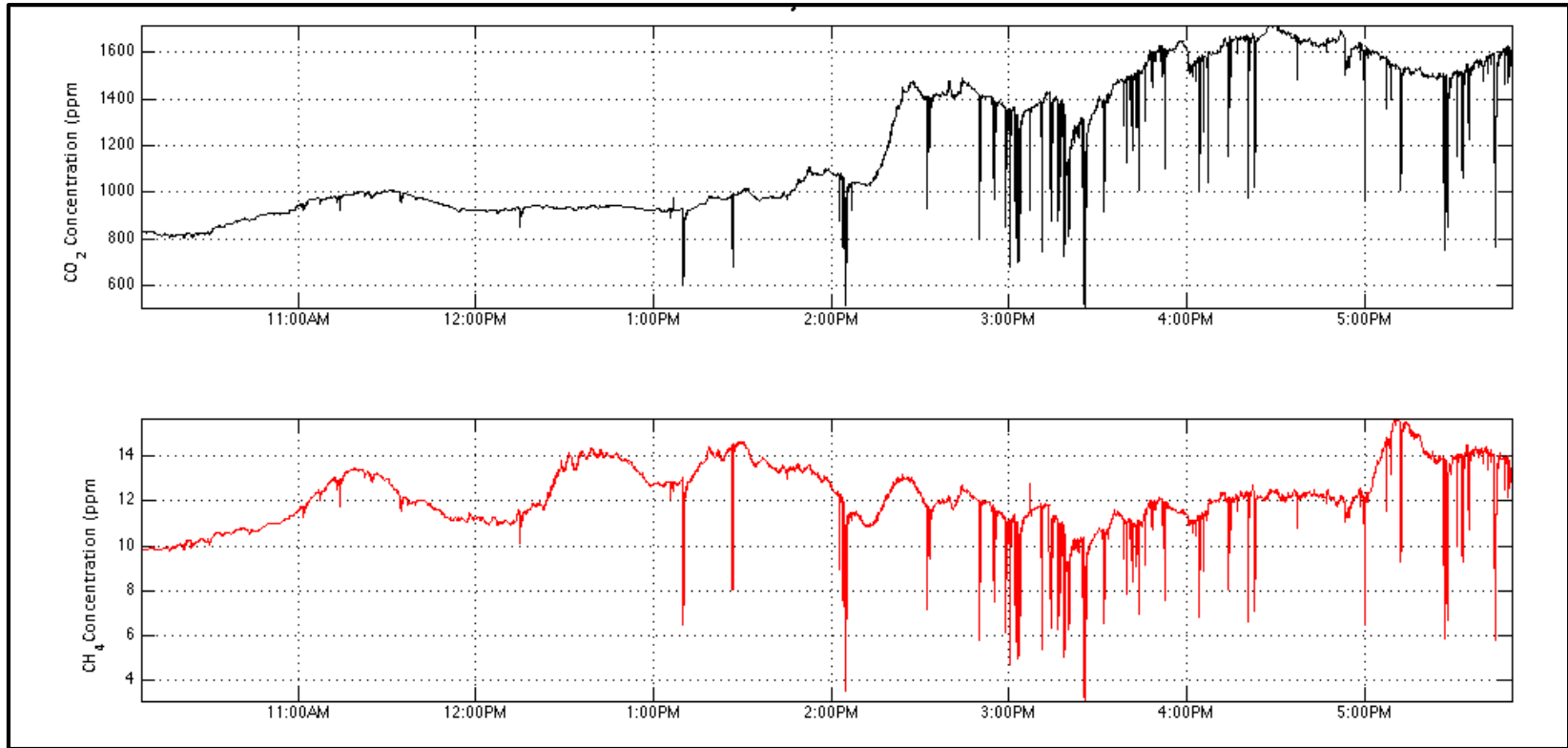
Figure 13: Concentration Measurements of CO2 (above) and CH4 (below) at Sewer Access Cover MH0 on June 27, 2013
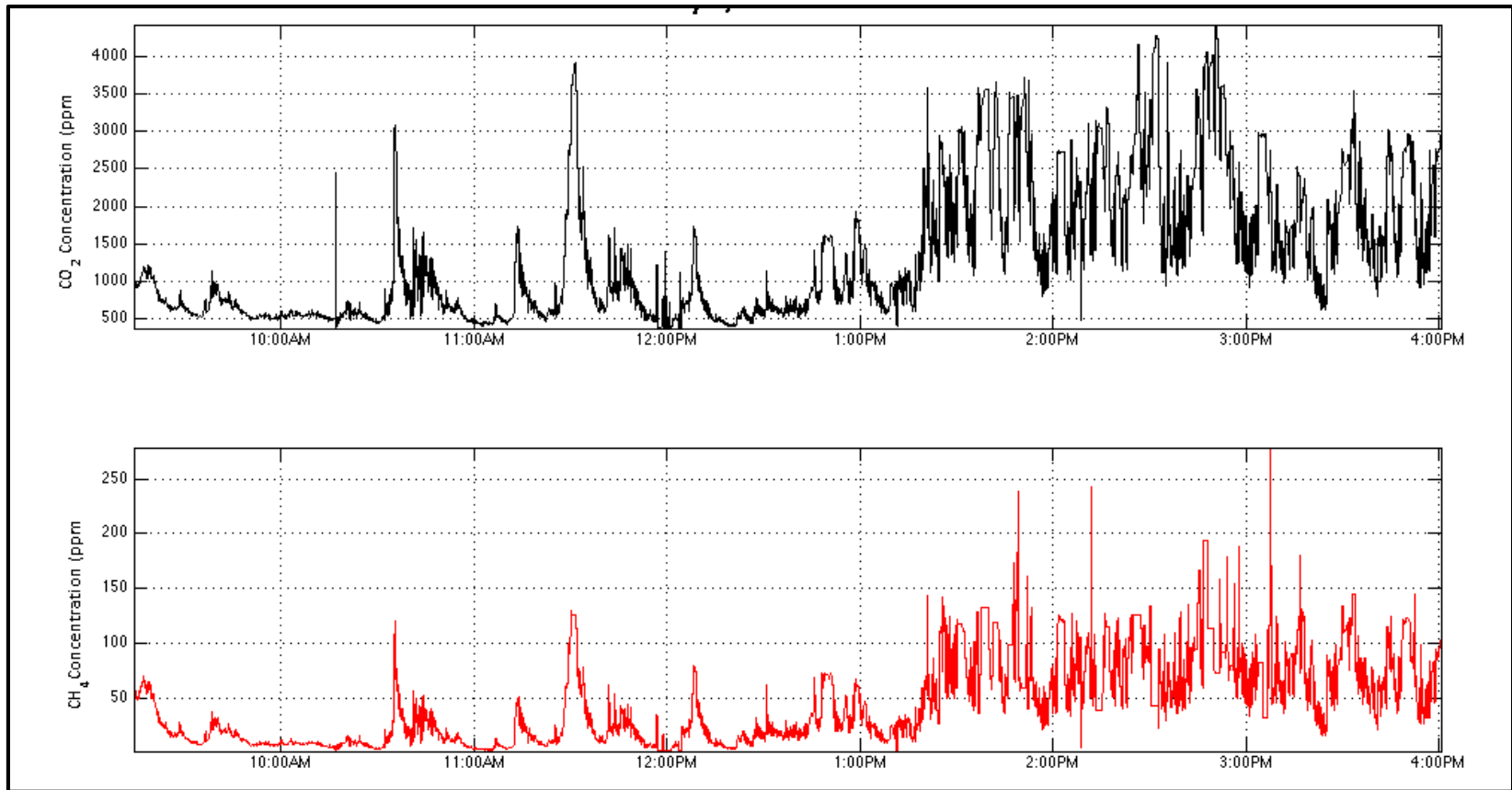
Figure 14: Concentration Measurements of CO2 (above) and CH4 (below) at Sewer Access Cover MHSU1 on July 3, 2013
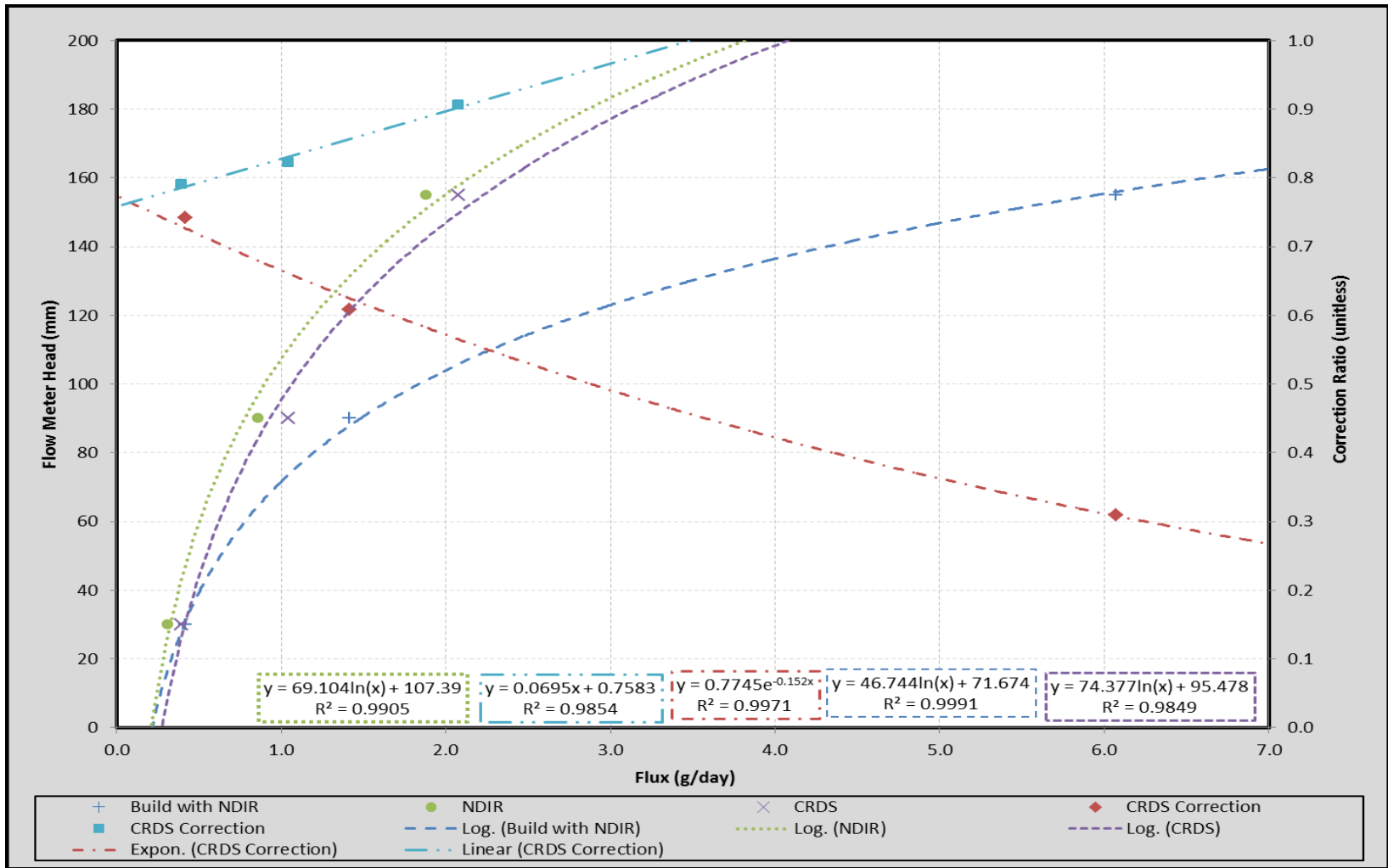
Figure 15: Chamber Laboratory Calibration Curves

Table 2: Chamber Flux Calibration Results

Flow Meter Head (mm)	Average Flux (g/day)			Standard Deviation of Flux (g/day)			Correction Ratio	
	Built Chamber with NDIR	Built Chamber with CRDS	NDIR Chamber with NDIR	Built Chamber with NDIR	Built Chamber with CRDS	NDIR Chamber with NDIR	NDIR	CRDS
30	0.420	0.395	0.312	0.075	0.006	0.020	0.74	0.79
90	1.41	1.05	0.861	0.253	0.233	0.072	0.61	0.82
155	6.07	2.08	1.88	0.544	0.135	0.340	0.31	0.91
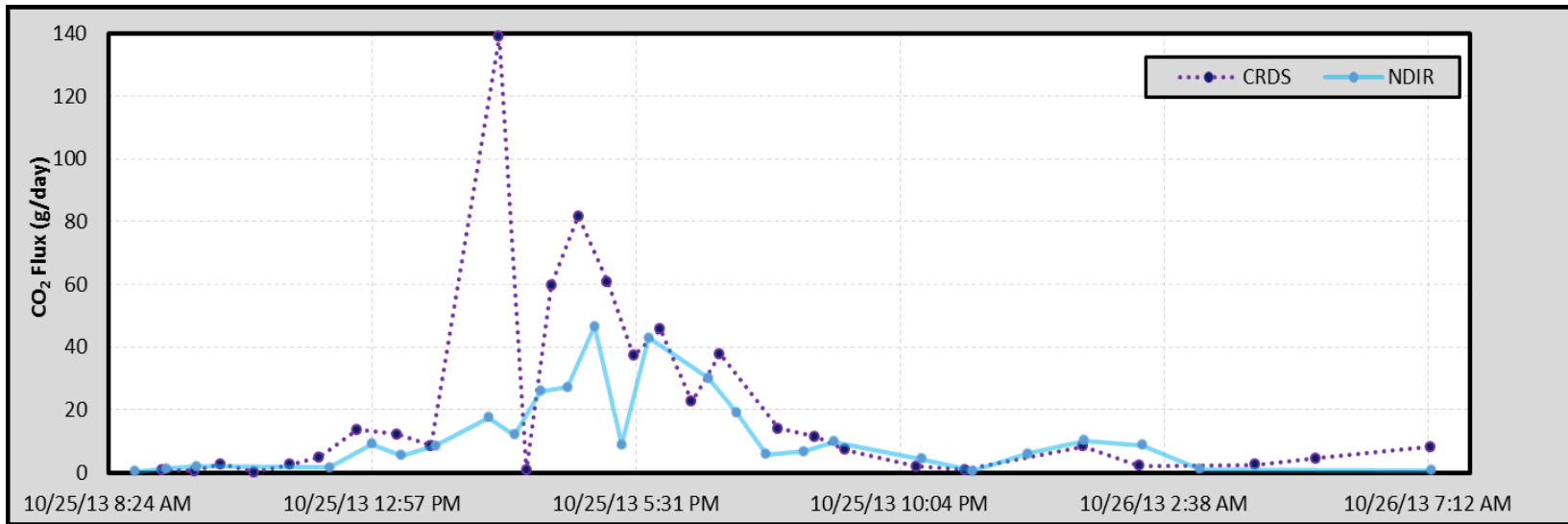
Figure 16: CRDS versus NDIR Analyzer Flux Data for MH4
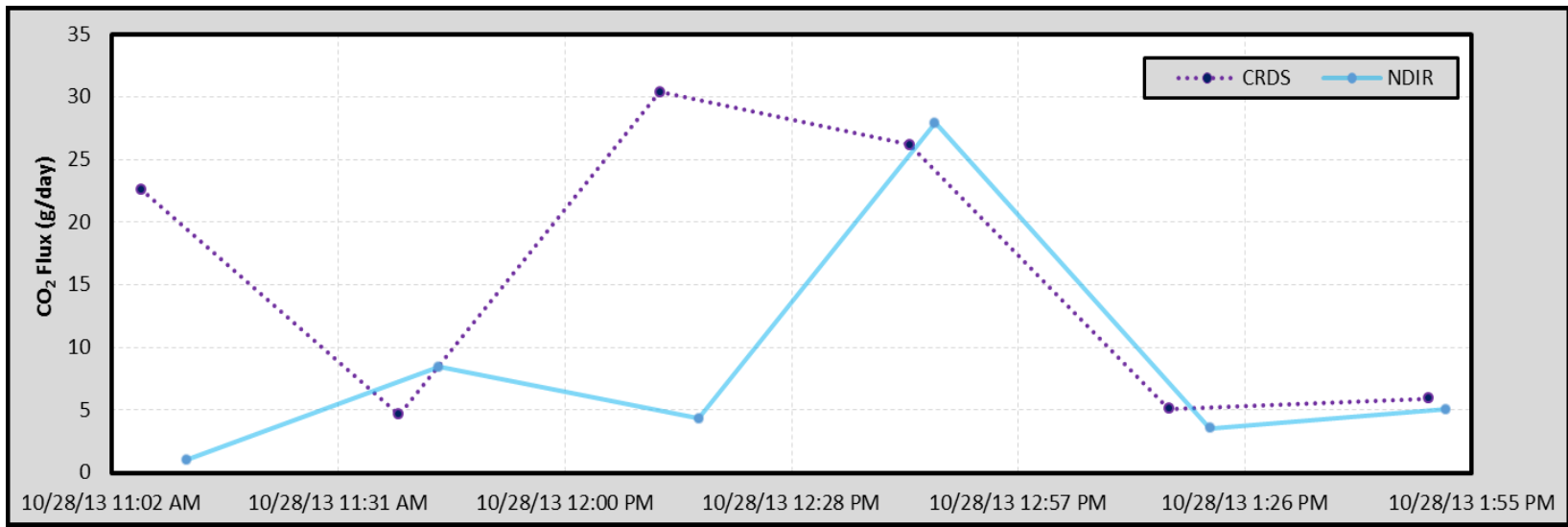
Figure 17: CRDS versus NDIR Analyzer Flux Data for MHSU3

Table 3: Flux Gradient Data

COVER ID	∂x (ft)	∂x (m)	$\Phi_{1,CO2}$ (ppmv)	$\Phi_{2,CO2}$ (ppmv)	$\partial\Phi_{CO2}$ (ppmv)	J_{CO2} (g/day)	$\Phi_{1,CH4}$ (ppmv)	$\Phi_{2,CH4}$ (ppmv)	$\partial\Phi_{CH4}$ (ppmv)	J_{CH4} (g/day)
MH4	9.8	3.0	397	387	10	-4.29	1.91	1.75	0.16	-0.117
MH3	9.0	2.7	460	410	50	-23.4	3.50	2.40	1.10	-0.176
MH2	9.8	3.0	630	480	150	-64.3	3.10	2.20	0.90	-0.148
MH1	6.0	1.8	480	430	50	-35.2	2.60	2.30	0.30	-0.253
MH0	10.0	3.0	690	630	60	-25.3	8.80	7.80	1.00	-0.514
MH00	6.0	1.8	430	415	15	-10.5	2.10	1.98	0.12	-0.218
MHSU6	11.0	3.4	440	420	20	-7.66	1.93	1.82	0.11	-0.109
MHSU5	9.8	3.0	512	505	7	-3.01	1.96	1.95	0.01	-0.111
MHSU4	5.0	1.5	390	387	3	-2.53	1.83	1.78	0.05	-0.234
MHSU3	8.5	2.6	485	440	45	-22.3	2.90	2.30	0.60	-0.178
MHSU1	6.0	1.8	400	395	5	-3.51	1.95	1.75	0.20	-0.192

Table 4: Sewer Access Cover Trends Based on Calculated Diffusive Flux Method versus Field Measured Flux

Flux Calculation Method	Sewer Access Cover ID										
CH_4	High Flux --> Low Flux										
Diffusion	MH0	MH1	MHSU4	MH00	MHSU1	MHSU3	MH3	MH2	MHSU5	MH4	MHSU6
Field	MHSU3	MH0	MHSU1	MHSU5	MH1	MH4	MHSU6	MH2	MH3	MHSU4	MH00
CO_2	High Flux --> Low Flux										
Diffusion	MH2	MH1	MH0	MH3	MHSU3	MH00	MHSU6	MH4	MHSU1	MHSU5	MHSU4
Field	MHSU3	MH0	MH1	MHSU1	MHSU5	MH4	MH2	MH3	MHSU6	MH00	MHSU4

Table 5: Sewer Access Cover Trends Based on Source Area versus Field Measured Flux

Flux Calculation Method	Sewer Access Cover ID									
	High Flux --> Low Flux									
Source Area	MH1	MH4, MHSU6, MHSU4		MHSU3	MHSU5	MH0	MH2	MH00	MH3	MHSU1
Field CH$_4$	MHSU3	MH0	MHSU1	MHSU5	MH1	MH4	MHSU6	MH2	MH3	MHSU4	MH00
Field CO$_2$	MHSU3	MH0	MH1	MHSU1	MHSU5	MH4	MH2	MH3	MHSU6	MH00	MHSU4

Table 6: Cover ID Flux Data

Cover ID	Morning	Afternoon	Morning	Afternoon	Sum of All Measurements
	(g/day)	(g/day)	(Mt CO_2e)	(Mt CO_2e)	(Mt CO_2e)
MH0					
Average of CO_2 Flux	983.1	18.69	0.3588	0.0068	0.3656
Average of CH_4 Flux	1,886	0.0818	0.05	0.0006	0.0501
MH00					
Average of CO_2 Flux	-	1.63	-	0.0006	0.0006
Average of CH_4 Flux	-	0.003	-	2.63E-05	2.63E-05
MH1					
Average of CO_2 Flux	185.4	15.74	0.0677	0.0057	0.0734
Average of CH_4 Flux	19.39	0.0366	0.0010	0.0003	0.0013
MH2					
Average of CO_2 Flux	6.906	12.73	0.0025	0.0046	0.0072
Average of CH_4 Flux	0.009	0.0199	0.0001	0.0002	0.0002
MH3					
Average of CO_2 Flux	2.484	11.93	0.0009	0.0044	0.0053
Average of CH_4 Flux	0.003	0.0254	0.00002	0.0002	0.0002
MH4					
Average of CO_2 Flux	3.630	22.99	0.0013	0.0084	0.0097
Average of CH_4 Flux	0.0356	0.0915	0.0003	0.0007	0.0010
MHSU1					
Average of CO_2 Flux	18.26	30.41	0.0067	0.0111	0.0178
Average of CH_4 Flux	0.2101	0.2464	0.0016	0.0019	0.0035
MHSU3					
Average of CO_2 Flux	7.347	1340	0.0027	0.4891	0.4918
Average of CH_4 Flux	0.2147	1.875	0.0016	0.0144	0.0160
MHSU4					
Average of CO_2 Flux	-	1.196	-	0.0004	0.0004
Average of CH_4 Flux	-	0.0162	-	0.00012	0.0001
MHSU5					
Average of CO_2 Flux	39.31	5.702	0.0143	0.0021	0.0164
Average of CH_4 Flux	1.513	0.4057	0.0000	0.0031	0.0032
MHSU6					
Average of CO_2 Flux	-	4.392	-	0.0016	0.0016
Average of CH_4 Flux	-	0.0311	-	0.0002	0.0002
TOTAL	**-**	**-**	**0.5090**	**0.5566**	**1.066**

CONCLUSIONS

A chamber method was developed to measure the CO_2 and CH_4 gas emissions from 11 sewer access covers upstream of the Salt Lake City sewer network. This method was developed based on a soil flux chamber design and modified to adapt to the study's site specific conditions. It is reasonable to assume this method is effective in measuring the gas release from point sources throughout the sewer. This chamber based method could also be a better solution when making assumptions on the overall sewer network CO_2 and CH_4 emissions contribution, as it measures the release directly. This method is versatile and can be retrofit to most any spectroscopy equipment, which allows for various gas types to be measured.

The spectroscopy equipment used for concentration and flux measurements are both widely used in the biological community for soil and atmospheric sciences. However the concentration and flux range typically seen in this field of study are on order of magnitudes greater than what they are traditionally used for. The equipment can handle these higher values, but they do tend to lose accuracy unless calibrated using higher concentrations, which was not done for this study. Therefore it is more prudent to look at the trends the data show rather than the actual values.

The data show there are high concentrations for both CO_2 and CH_4 over the sewer access covers when compared to ambient conditions; i.e., 394 ppmv ambient CO_2 to a high of 18,000 ppmv CO_2 and 1.8 ppmv ambient CH4 compared to a high of 130 ppmv CH_4. CO_2 and CH_4 concentration readings show a proportional relationship in measured field readings, i.e., they had

coincident peaks. This could indicate the gas creation for CO_2 and CH_4 concentrations are made or driven by the same reaction, such as methanogenesis.

The sewer access covers showed a positive accumulation of concentration (flux) within the chambers, indicating there is a release of methane and carbon dioxide into the atmosphere. The average values for both CO_2 and CH_4 flux show minor emission rates in terms of Mt CO_2e and were shown to be a significantly lower contribution than estimated in the previously discussed studies. The calculated values do not necessarily indicate the sewer system as a whole is not a significant contributor, but that the small data set and study site conditions are most likely insufficient to make any assumptions on the entire system without further study. More analysis should be done on the chamber assessment and design to get more realistic values for the emissions.

It is unclear whether the age of the sewer lines have an impact on the formation or emissions of CO_2 or CH_4 as this factor was not discussed in any of the emission studies cited. However it may be worth studying. No flow data were available for the sewer lines studied; therefore no definite conclusions can be made based on the flow or activity of the sewer. It should be noted that the sewer pipe line size, line depth, slope, age, pH, corrosion and actual sewer flow values were not a factor in determining any conclusions made from the data. It is recommended that in future research these components be used to make a more complete analysis.

Recommendations for Future Work

Recommendations for future work would include more frequent data during each seasonal change, more in depth analysis on the effects of temperature and pressure effects upon the system and determining the driving forces of transport. Other potential sewer gases could be assessed to determine interference within the system and how these may have an effect on the

measurements, such as gas displacement. For the flux gradient it may be prudent to make measurements at incremental depths to prove or disprove steady state assumption.

The built chamber is currently very user intensive and other designs and volumes should be considered to inhibit potential user error and for maximum efficiency. Obtaining another way to verify the chamber calibration for methane would also be beneficial in verifying or creating a more accurate correction curve for the methane flux data. It may also be valuable to do a more in depth study on the sewer concentration and any relationships or correlations it may have in determining the flux.

For future this chamber based method could be proposed for assessing general emissions. Recommendations for measuring gas quantification emissions could be made more accurate by defining the number of access covers using junctions, nonjunctions and depth relationships, determining where the highest potential contributors are within the system and what factors define them. This would allow for defining key areas that have the maximum release potential and making estimates for the system as a whole based on similar terrain and pipe properties throughout the sewer network. Methane and carbon dioxide have been shown to be released by sewer access covers. Therefore research should be considered on any possible mitigation or harnessing procedures.

APPENDIX A

SOIL FLUX CALIBRATION

Table 7: Soil Flux Chamber and Method Comparison Summary

Method & Chamber Type	CO$_2$ Flux (g/m^2/day)	STD (g/m^2/day)	Difference compared to Licor chamber	Difference compared to Picarro method
Licor w/ Licor chamber	8.41	1.00	1.00	1.26
Licor w/ built chamber	5.36	0.64	0.64	0.80
Picarro w/ built chamber	10.57	0.80	1.26	1.00

Table 8: NDIR Analyzer with NDIR Chamber Soil Flux Measurements

Cover ID	Date	Start Time	End Time	CO_2 Flux (microL/m^2/min)	CO_2 Flux (g/m^2/day)	CO_2 Flux (μmol/m^2/s)	STD	Lower 95% Confidence	Upper 95% Confidence
Grass	2/17/2014	Morning	2 minute measurement	2339	6.40	1.68	46.1	2248	2430
Grass	2/17/2014	Morning	2 minute measurement	3297	9.03	2.37	33.4	3231	3363
Grass	2/17/2014	Morning	2 minute measurement	3110	8.52	2.24	74.0	2963	3257
Grass	2/17/2014	Morning	2 minute measurement	2511	6.88	1.81	71.9	2368	2653
Grass	2/17/2014	Morning	2 minute measurement	2523	6.91	1.82	39.8	2444	2602
Grass	2/17/2014	Morning	2 minute measurement	3938	10.78	2.84	67.5	3805	4072
Grass	2/17/2014	Morning	2 minute measurement	4412	12.08	3.18	43.1	4326	4497
Grass	2/17/2014	Morning	2 minute measurement	2695	7.38	1.94	29.5	2637	2754
Grass	2/17/2014	Morning	2 minute measurement	3354	9.18	2.42	43.2	3268	3440
Grass	2/17/2014	Morning	2 minute measurement	2551	6.98	1.84	38.1	2475	2626
Average				**3073**	**8.41**	**2.21**	**48.7**	**2977**	**3169**

Table 9: NDIR Analyzer with Built Chamber Soil Flux Measurements

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (microL/m^2/min)	CO$_2$ Flux (g/m^2/day)	CO$_2$ Flux (µmol/m^2/s)	STD	Lower 95% Confidence	Upper 95% Confidence
Grass	2/17/2014	11:32 AM	11:42 AM	804	2.18	0.57	6.5	791	816
Grass	2/17/2014	11:45 AM	11:55 AM	2540	6.88	1.81	28.9	2483	2597
Grass	2/17/2014	11:58 AM	12:08 PM	788	2.13	0.56	6.1	776	800
Grass	2/17/2014	12:11 PM	12:21 PM	1938	5.23	1.38	11.1	1916	1960
Grass	2/17/2014	12:24 PM	12:34 PM	1797	4.85	1.27	9.4	1779	1816
Grass	2/17/2014	12:38 PM	12:48 PM	2953	7.97	2.10	13.0	2928	2979
Grass	2/17/2014	12:52 PM	1:02 PM	2344	6.31	1.66	21.3	2302	2386
Grass	2/17/2014	1:06 PM	1:16 PM	2944	7.90	2.08	32.0	2881	3006
Grass	2/17/2014	1:18 PM	1:28 PM	1187	3.19	0.84	14.3	1159	1215
Grass	2/17/2014	1:32 PM	1:42 PM	2597	6.97	1.83	26.0	2546	2648
Average				**1989**	**5.36**	**1.41**	**16.9**	**1956**	**2022**

Table 10: CRDS with Built Chamber Soil Flux Measurements

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (microL/m^2/min)	CO$_2$ Flux (g/m^2/day)	CO$_2$ Flux (μmol/m^2/s)	STD	Lower 95% Confidence	Upper 95% Confidence
Grass	2/17/2014	11:32:00 AM	11:42:00 AM	5078	13.79	3.63	20.6	5038	5119
Grass	2/17/2014	11:45:00 AM	11:55:00 AM	3900	10.56	2.78	20.1	3860	3939
Grass	2/17/2014	11:58:00 AM	12:08:00 PM	2791	7.55	1.98	23.4	2745	2837
Grass	2/17/2014	12:11:00 PM	12:21:00 PM	2783	7.51	1.98	19.8	2744	2821
Grass	2/17/2014	12:24:00 PM	12:34:00 PM	3035	8.18	2.15	19.9	2996	3074
Grass	2/17/2014	12:38:00 PM	12:48:00 PM	5742	15.50	4.08	63.6	5617	5867
Grass	2/17/2014	1:06:00 PM	1:16:00 PM	5740	15.41	4.05	45.0	5652	5828
Grass	2/17/2014	1:18:00 PM	1:28:00 PM	2962	7.95	2.09	16.5	2929	2994
Grass	2/17/2014	1:32:00 PM	1:42:00 PM	3222	8.64	2.27	18.6	3185	3258
Average				**3917**	**10.57**	**2.78**	**27.5**	**3863**	**3971**

APPENDIX B

MATLAB CODES

```
function [text_data, data] = importfile1(filename, anem, gps, startRow, endRow)
%
% THIS FILE was GENERATED USING THE MATLAB CODE GENERATION AND THEN   % was
MODIFIEDBY AMANDA VARLAND FOR SPECIFIC FILE IMPORTATION
%
% IMPORTFILE Imports data from a text file as a matrix.
% EXDAT = IMPORTFILE(FILENAME) Reads data from text file FILENAME
% for the default selection.
%
% EXDAT = IMPORTFILE(FILENAME, STARTROW, ENDROW) Reads data from
% rows STARTROW through ENDROW of text file FILENAME.
%
% anem was a string input that defines whether or not the imported
% data has anemometer data present in the file. Expressed as 'Y' 'y' % for yes there was
anemometer data present or 'N' 'n' for not
% present
%
% gps was a string input that defines whether or not the imported
% data has GPS data present in the file. Expressed as 'Y' 'y' for
% yes there was GPS data present or 'N' 'n' for not present
%
% Example:
%   exdat = importfile('CFHADS2005-20121001-124123Z-DataLog_User.
%   dat','n','n' 1, 1325);
%


%% Initialize variables.
delimiter = ' ';
if nargin <= 4
    startRow = 1;
    endRow = inf;
end

%% Read columns of data as strings:
% For more information, see the TEXTSCAN documentation.

formatSpec =
'%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%[
^\n\r]';

%% Open the text file.
%

fileID = fopen(filename);

%% Read columns of data according to format string.
% This call was based on the structure of the file used to generate
```

```
% this code. If an error occurs for a different file, try
% regenerating the code from the Import Tool.

dataArray = textscan(fileID, formatSpec, endRow(1)-startRow(1)+1,...
   'Delimiter', delimiter, 'MultipleDelimsAsOne', true, 'HeaderLines',...
   startRow(1)-1, 'ReturnOnError', false);
for block=2:length(startRow)
   frewind(fileID);
   dataArrayBlock = textscan(fileID, formatSpec, endRow(block)-startRow(block)+1, 'Delimiter',
delimiter, 'MultipleDelimsAsOne', true, 'HeaderLines', startRow(block)-1, 'ReturnOnError', false);
   for col=1:length(dataArray)
      dataArray{col} = [dataArray{col};dataArrayBlock{col}];
   end
end

%% Close the text file.
%

fclose(fileID);

%% Convert the contents of columns containing numeric strings to
% numbers. Replace non-numeric strings with NaN.
%

numericData = NaN(size(dataArray{1},1),size(dataArray,2));

%% Split data into numeric and cell columns.
%

b = length(dataArray);

new = cell(1,b);

for num = 1:b

   if(~strcmp('',dataArray{num}(1,1)))

      new{num} = dataArray{num};

   end
end

new = new(~cellfun('isempty',new));

c = length(new{end});

raw = cell(c,length(new));
```

```
for i = 1:length(new)

    raw(1:c,i) = new{i}(1:c);

end


%% Create output variables with columns based upon the users input
% values
%

[a,b] = size(raw);


if(strcmp(anem, 'y') && strcmp(gps,'y') || strcmp(anem,'Y') && strcmp(gps,'Y'))

    CH4 = find(ismember(raw(1,:),'CH4'));
    CO2 = find(ismember(raw(1,:),'CO2'));
    DCH4 = find(ismember(raw(1,:),'CH4_dry'));
    DCO2 = find(ismember(raw(1,:),'CO2_dry'));
    H2O = find(ismember(raw(1,:),'H2O'));
    ANC = find(ismember(raw(1,:),'ANEMOMETER_C'));
    ANUX = find(ismember(raw(1,:),'ANEMOMETER_UX'));
    ANUY = find(ismember(raw(1,:),'ANEMOMETER_UY'));
    ANUZ = find(ismember(raw(1,:),'ANEMOMETER_UZ'));
    GPSLat = find(ismember(raw(1,:),'GPS_ABS_LAT'));
    GPSLong = find(ismember(raw(1,:),'GPS_ABS_LONG'));

    data = zeros(a-1,11);

    if (nargin < 4)

        data = raw(2:end,[CH4 DCH4 CO2 DCO2 H2O ANC ANUX ANUY ANUZ GPSLat GPSLong]);
        data = str2double(data);
        text_data = cell(a,13);
        text_data(startRow,:) = raw(startRow,[1:2 CH4 DCH4 CO2 DCO2 H2O ANC ANUX ANUY
ANUZ GPSLat
        GPSLong]);
        text_data(startRow + 1:end,1:2) = raw(startRow + 1:end,1:2);

    elseif (nargin >= 4)

        data = raw(2:end,[CH4 DCH4 CO2 DCO2 H2O ANC ANUX ANUY ANUZ GPSLat GPSLong]);
        data = str2double(data);
        text_data = cell(a,13);
        text_data(2:end,1:2) = raw(2:end,1:2);

    end
```

```
elseif(strcmp(anem, 'y') || strcmp(anem,'Y') && strcmp(gps,'n') ||strcmp(gps,'N'))

   CH4 = find(ismember(raw(1,:),'CH4'));
   CO2 = find(ismember(raw(1,:),'CO2'));
   DCH4 = find(ismember(raw(1,:),'CH4_dry'));
   DCO2 = find(ismember(raw(1,:),'CO2_dry'));
   H2O = find(ismember(raw(1,:),'H2O'));
   ANC = find(ismember(raw(1,:),'ANEMOMETER_C'));
   ANUX = find(ismember(raw(1,:),'ANEMOMETER_UX'));
   ANUY = find(ismember(raw(1,:),'ANEMOMETER_UY'));
   ANUZ = find(ismember(raw(1,:),'ANEMOMETER_UZ'));

   data = zeros(a-1,9);

   if (nargin < 4)

      data = raw(2:end,[CH4 DCH4 CO2 DCO2 H2O ANC ANUX ANUY ANUZ]);
      data = str2double(data);
      text_data = cell(a,11);
      text_data(startRow,:) = raw(startRow,[1:2 CH4 DCH4 CO2 DCO2 H2O ANC ANUX ANUY
ANUZ]);
      text_data(startRow + 1:end,1:2) = raw(startRow + 1:end,1:2);

   elseif (nargin >= 4)

      data = raw(2:end,[CH4 DCH4 CO2 DCO2 H2O ANC ANUX ANUY ANUZ]);
      data = str2double(data);
      text_data = cell(a,11);
      text_data(2:end,1:2) = raw(2:end,1:2);

   end

elseif(strcmp(anem, 'n')  && strcmp(gps,'y') || strcmp(anem,'N') && strcmp(gps,'Y'))

   CH4 = find(ismember(raw(1,:),'CH4'));
   CO2 = find(ismember(raw(1,:),'CO2'));
   DCH4 = find(ismember(raw(1,:),'CH4_dry'));
   DCO2 = find(ismember(raw(1,:),'CO2_dry'));
   H2O = find(ismember(raw(1,:),'H2O'));
   GPSLat = find(ismember(raw(1,:),'GPS_ABS_LAT'));
   GPSLong = find(ismember(raw(1,:),'GPS_ABS_LONG'));

   data = zeros(a-1,7);

   if (nargin < 4)

      data = raw(2:end,[CH4 DCH4 CO2 DCO2 H2O GPSLat GPSLong]);
```

```
      data = str2double(data);
      text_data = cell(a,9);
      text_data(startRow,:) = raw(startRow,[1:2 CH4 DCH4 CO2 DCO2 H2O GPSLat GPSLong]);
      text_data(startRow + 1:end,1:2) = raw(startRow + 1:end,1:2);

   elseif (nargin >= 4)

      data = raw(2:end,[CH4 DCH4 CO2 DCO2 H2O GPSLat GPSLong]);
      data = str2double(data);
      text_data = cell(a,9);
      text_data(2:end,1:2) = raw(2:end,1:2);

   end

elseif(strcmp(anem, 'n') && strcmp(gps,'n') || strcmp(anem,'N') && strcmp(gps,'N'))

   CO2 = find(ismember(raw(1,:),'CO2'));
   CH4 = find(ismember(raw(1,:),'CH4'));
   CH4_dry = find(ismember(raw(1,:),'CH4_dry'));
   CO2_dry = find(ismember(raw(1,:),'CO2_dry'));
   H2O = find(ismember(raw(1,:),'H2O'));

   data = zeros(a-1,5);

   if (nargin < 4)

      data = raw(2:end,[CH4 CH4_dry CO2 CO2_dry H2O]);
      data = str2double(data);
      text_data = cell(a,7);
      text_data(startRow,:) = raw(startRow,[1:2 CH4 CH4_dry CO2 CO2_dry H2O]);
      text_data(startRow + 1:end,1:2) = raw(startRow + 1:end,1:2);

   else

      data = raw(2:end,[CH4 CH4_dry CO2 CO2_dry H2O]);
      data = str2double(data);
      text_data = cell(a,7);
      text_data(2:end,1:2) = raw(2:end,1:2);
   end
end

end
****************************************************************

function pcut(dat_files,CO2_file,CH4_file, CO2_threshold, CH4_threshold)
%
% THIS FUNCTION was FOR QUERYING THE CRDS DATA MEASURED ON CAMPUS.
% THIS QUERY WILL FIRST IMPORT ALL THE .DAT FILES THE CRDS
```

```
% INSTRUMENT CREATES, THEN IT WILL REMOVE OR CUT OUT ALL THE DATA
% THAT was AROUND AMBIENT CONDITIONS OR AT A USER SPECIFIED THRESHOLD
% VALUE. THE CUT DATA WILL THEN BE OUTPUT INTO A .TXT FILE THAT CAN % BE DIRECTLY
IMPORTED INTO GIS.
%
% AUTHOR: AMANDA VARLAND
%
% FUNCTION CALL: pcut
%
% INPUT VALUES:
%  NAME:        DESCRIPTION:              EXAMPLE:
%  dat_files     A .DAT FILE OR CELL ARRAY OF '/Volumes/
%           .DAT FILES WITH THE NAME AND CarbonData/
%           LOCATION             Geographical/GIS
%                          /Northern Utah
%                          /University of Utah
%                          Campus/Data/2012
%                          /10/Raw Data/09-Raw
%                          Data/CFHADS2005-
%                                              20121009-082949Z-  %
                                             DataLog_User.dat'
%
%  CO2_file      THE LOCATION AND NEW NAME OF '/Volumes/
%           THE CO2 DATA IN .TXT FORMAT  CarbonData
%                          /Geographical/GIS/
%                          Northern Utah
%                          /University of Utah %
              Campus/Data/2012/
%                                              10/CP09122012.txt'
%
%  CH4_file      THE LOCATION AND NEW NAME OF '/Volumes/
%           THE CH4 DATA IN .TXT FORMAT  CarbonData/
%                          Geographical/GIS/   %
              NortheRn Utah
%                          /University of Utah %
              Campus/Data/2012/
%                                              10/HP09122012.txt'
%
%  CO2_threshold   THE THRESHOLD LIMIT AT WHICH    800
%           CO2 DATA WILL BE CUT IN PPMV
%
%  CH4_threshold   THE THRESHOLD LIMIT AT WHICH    3
%           CH4 DATA WILL BE CUT IN PPMV
%
%
%
% IF THERE were MULTIPLE FILES THEN IT WILL CONCATINATE THEM OR
% COMBINE THEM INTO ONE FILE WITH HEADERS
```

```
%

%% ASKS THE USER WHAT INFORMATION THEY WILL REQUIRE BASED ON THE
%  CRDS ATTACHMENTS

anem = input('Is there Anemometer data (y/n)? ','s');
gps = input('Is there GPS data y/n? ','s');

%% DETERMINES HOW MANY .DAT FILES were WITHIN dat_files.
%

l = length(dat_files);

if  l == 1

    [text_data, data] = importfile1(dat_files,anem,gps);

else

    [text_data, data] = importfile1(dat_files{1},anem,gps);

    for i = 2:l

        [text_data2, data2] = importfile1(dat_files{i},anem,gps,1,inf);
        text_data = [text_data;text_data2];
        data = [data;data2];

    end
end

%% PREDEFINES THE SIZE OF THE .TXT FILES FOR FASTER COMPUTING
%

format longG

[u,v] = size(text_data);

H1 = data(data(:,1) >= CH4_threshold);
C1 = data(data(:,3) >= CO2_threshold);

H2 = length(H1);
C2 = length(C1);

cut_data = zeros(C2,v-2);
cut_data2 = zeros(H2,v-2);

Ccut = cell(C2,v);
Hcut = cell(H2,v);
```

```
Ccut(1,:) = text_data(1,:);
Hcut(1,:) = text_data(1,:);

%% CUTS THE DATA ACCORDING TO THE PREDEFINED THRESHOLD VALUES
%

[row,col] = size(data);

n1 = 0;
n2 = 0;

for r = 1:row

    if(data(r,3) > CO2_threshold)

        n1 = n1 + 1;
        cut_data(n1,:) = data(r,:);
        Ccut(n1 + 1,:) = text_data(r + 1,:);

    end

    if(data(r,1) > CH4_threshold)

        n2 = n2 + 1;
        cut_data2(n2,:) = data(r,:);
        Hcut(n2 + 1,:) = text_data(r + 1,:);

    end

end

%% COMBINES THE THE TEXT AND NUMERICAL DATA INTO ONE MATRIX
%

cut_data = num2cell(cut_data);
cut_data2 = num2cell(cut_data2);

[m,n] = size(Ccut);
[o,p] = size(Hcut);

for im = 2:m
    for in = 3:n

        Ccut{im,in} = cut_data{im - 1,in - 2};

    end
end
```

```
if(CO2_threshold == CH4_threshold)

    Hcut = Ccut;

else
    for io = 2:o
        for ip = 3:p

            Hcut{io,ip} = cut_data2{io - 1,ip - 2};

        end
    end
end

%% This removes any rows that have empty cells
%

Ccut(any(cellfun(@isempty,Ccut)'),:) = [];
Hcut(any(cellfun(@isempty,Hcut)'),:) = [];

%% TAKES THE DATA AND FORMATS IT INTO A GIS READABLE .TXT FILE
%

dlmcell(CO2_file, Ccut);
dlmcell(CH4_file, Hcut);


end

*****************************************************************

function timeplot(date,time,CO2,timecorrection,heading,CH4)
%
% THIS FUNCTION was FOR PLOTTING ALL THE DATA FROM A TXT FILE WHEN
% IMPORTED AS COLUMN VECTORS. PARTICULARLY ALL DAY CONCENTRATION
% MEASUREMENTS DONE AT A SEWER ACCESS HOLE.
%
% AUTHOR: AMANDA VARLAND
%
% FUNCTION CALL: timeplot
%
% INPUT VALUES:
%  NAME:       DESCRIPTION:              EXAMPLE:
%  date        DATE COLUMN VECTOR OF STRINGS   '2013-12-01'
%              GIVEN FROM BY CRDS IN THE    '2013-12-01'
%              FORMAT 'YYYY-MM-DD'          '2013-12-01'
%
%
```

```
%   time         TIME COLUMN VECTOR OF STRINGS   '13:45:01.123'
%                GIVEN FROM BY CRDS IN THE    '13:45:01.223'
%                FORMAT 'HH:MM:SS.FFF' IN 24      '13:45:01.323'
%                       HOUR FORMATTING                  '13:45:01.423'
%
%
%   CO2          THE CO2 CONCENTRATION GIVEN    '395'
%                BY THE CRDS IN PPMV AND       '400'
%                COLUMN VECTOR FORMAT          '405'
%
%
%   timecorrection  THE CRDS was MEASURED IN      0.25
%                MEAN GREENWICH TIME. THIS
%                           was THE CORRECTION VALUE FOR
%                           WHATEVER TIME ZONE was CHOSEN
%                           IN HOURS. NOTE THE VALUE was
%                           SUBTRACTED FROM THE TIME.
%
%
%   heading      THE PLOT TITLE               'JULY 21, 2013 -%
%                           MH0'
%
%
%   CH4          THE CH4 CONCENTRATION GIVEN     '10'
%                BY THE CRDS IN PPMV AND      '11'
%                COLUMN VECTOR FORMAT          '12'
%
%

%% COMBINES THE DATE AND TIME INFORMATION AND CORRECTS THE VALUE
%

ts = datenum(strcat(date,time),'yyyy-mm-ddHH:MM:SS');
ts = ts - timecorrection;

%% PLOTS BOTH THE CO2 AND CH4 CONCENTRATIONS OVER TIME WITH SPECIFIC
% PROPERTIES
%

subplot(2,1,1);

plot(ts,CO2,'Color',[0 0 0],'LineWidth',0.25)

t = title(heading);
set(t, 'FontWeight', 'bold','FontSize', 20,'FontName','Calibri')
ylabel('CO_2 Concentration (ppmv)')
h = get(gca, 'xlabel');
set(h, 'FontName', 'Calibri','FontSize',12)
```

```
g = get(gca, 'ylabel');
set(g, 'FontName', 'Calibri','FontSize',12)

grid on
axis tight
set(gca,'XTickLabelMode','auto')
datetick('x','HH:MMPM');
axis tight

subplot(2,1,2)

plot(ts, CH4,'Color',[1 0 0],'LineWidth',0.25)

ylabel('CH_4Concentration (ppmv)')
h = get(gca, 'xlabel');
set(h, 'FontName', 'Calibri','FontSize',12)
g = get(gca, 'ylabel');
set(g, 'FontName', 'Calibri','FontSize',12)

grid on
axis tight
set(gca,'XTickLabelMode','auto')
datetick('x','HH:MMPM');
axis tight

end

*****************************************************************

function timeplot1(date,time,st,et,ydata,timecorrection,heading)

%
% THIS FUNCTION was FOR PLOTTING DATA FROM A TXT FILE WHEN IMPORTED
% AS COLUMN VECTORS. PARTICULARLY CHAMBER FLUX MEASUREMENTS DONE AT
% A SEWER ACCESS COVER.
%
% AUTHOR: AMANDA VARLAND
%
% FUNCTION CALL: timeplot1
%
% INPUT VALUES:
%  NAME:        DESCRIPTION:              EXAMPLE:
%  date         DATE COLUMN VECTOR OF STRINGS   '2013-12-01'
%               GIVEN FROM BY CRDS IN THE    '2013-12-01'
%               FORMAT 'YYYY-MM-DD'          '2013-12-01'
%
%
%  time         TIME COLUMN VECTOR OF STRINGS   '13:45:01.123'
```

```
%          GIVEN BY CRDS IN THE       '13:45:01.223'
%          FORMAT 'HH:MM:SS.FFF' IN 24      '13:45:01.323'
%                        HOUR FORMATTING                '13:45:01.423'
%
%
%  st       THE START TIME OF CHAMBER      '2013-06-12
%           MEASUREMENT GIVEN BY CRDS    13:45:01.123'
%           IN THE FORMAT
%                        'YYYY-MM-DD HH:MM:SS.FFF' IN 24
%           HOUR FORMATTING
%
%
%  et       THE END TIME OF CHAMBER        '2013-06-12
%           MEASUREMENT GIVEN BY CRDS    13:45:01.123'
%           IN THE FORMAT
%                        'YYYY-MM-DD HH:MM:SS.FFF' IN 24
%           HOUR FORMATTING
%
%
%  ydata      THE CO2 OR CH4 CONCENTRATION    '395'
%           DATA GIVEN BY THE CRDS IN    '400'
%           PPMV AND COLUMN VECTOR FORMAT   '405'
%
%
%  timecorrection  THE CRDS was MEASURED IN     0.25
%           MEAN GREENWICH TIME. THIS
%                        was THE CORRECTION VALUE FOR
%                        WHATEVER TIME ZONE was CHOSEN
%                        IN HOURS. NOTE THE VALUE was
%                        SUBTRACTED FROM THE TIME.
%
%
%  heading     THE PLOT TITLE            'JULY 21, 2013 -
%                                                      MH0'
%

%% COMBINES THE DATE AND TIME INFORMATION AND CORRECTS THE VALUE
%

ts = datenum(strcat(date,time),'yyyy-mm-ddHH:MM:SS');
ts = ts - timecorrection;

stime = datenum(st,'yyyy-mm-ddHH:MM:SS');
etime = datenum(et,'yyyy-mm-ddHH:MM:SS');

a = length(ts);

new = zeros(a,2);
```

```
%% CALCULATES THE ELAPSED TIME
%

b = 0;

for i = 1:a

   if(ts(i) >= stime && ts(i) <= etime)

      b = b + 1;
      new(b,1) = ts(i);
      new(b,2) = ydata(i);

   end

end

new(all(new==0,2),:) = [];

%% PLOTS THE CONCENTRATION OVER TIME FROM START OF CHAMBER
%  MEASUREMENT TO THE END.
%

plot(new(:,1),new(:,2))

t = title(heading);
set(t, 'FontWeight', 'bold','FontSize', 15,'FontName','Comic Sans MS')
ylabel('Concentration (ppmv)')
h = get(gca, 'xlabel');
set(h, 'FontName', 'Calibri','FontSize',12)
g = get(gca, 'ylabel');
set(g, 'FontName', 'Calibri','FontSize',12)

axis tight
set(gca,'XTickLabelMode','auto')
datetick('x','HH:MMPM');
axis tight

end

*****************************************************************

 function Rflux(DATE, TIME, DATA, start, endtime, timecorr, Volume, Area, series)
%
% THIS FUNCTION was FOR CUTTING OUT THE FLUX CHAMBER DATA TAKEN FROM
% THE CRDS INTO INDIVIDUAL RUNS AND INTO A FORMAT ACCEPTABLE FOR
% THE R STATISTICAL ANALYSIS PROGRAMS BUILT IN PACKAGE R TO
```

```
% CALCULATE FLUX. IT was NECESSARY TO IMPORT THE CRDS DATA OR TEXT % FILE AS COLUMN
VECTORS.
%
% AUTHOR: AMANDA VARLAND
%
% FUNCTION CALL: Rflux
%
% INPUT VALUES:
%  NAME:        DESCRIPTION:              EXAMPLE:
%  DATE         DATE COLUMN VECTOR OF STRINGS   '2013-12-01'
%               GIVEN FROM BY CRDS IN THE    '2013-12-01'
%               FORMAT 'YYYY-MM-DD'          '2013-12-01'
%
%
%  TIME         TIME COLUMN VECTOR OF STRINGS   '13:45:01.123'
%               GIVEN FROM BY CRDS IN THE    '13:45:01.223'
%               FORMAT 'HH:MM:SS.FFF' IN 24     '13:45:01.323'
%                         HOUR FORMATTING                '13:45:01.423'
%
%
%  DATA         THE CO2 OR CH4 CONCENTRATION    '395'
%               GIVEN BY THE CRDS IN PPMV   '400'
%               AND COLUMN VECTOR FORMAT       '405'
%
%
%  timecorr     THE CRDS was MEASURED IN      0.25
%               MEAN GREENWICH TIME THIS
%                         was THE CORRECTION VALUE FOR
%                         WHATEVER TIME ZONE was CHOSEN
%                         IN HOURS NOTE THE VALUE was
%                         SUBTRACTED FROM THE TIME.
%
%
%  Volume       THE VOLUME OF THE FLUX        208.1976
%               CHAMBER IN LITERS
%
%
%  AREA         THE CROSS SECTIONAL AREA OF     0.0015
%               THE SOURCE AREA IN M^2
%
%
%  series                THE NAME DESIGNATION FOR EACH    'MH4'
%                        POINT OR THE SEWER ACCESS
%                         COVER NAME

%% COMBINES THE DATE AND TIME COLUMN VECTORS INTO A NEW COLUMN
%  VECTOR
%
```

```matlab
format longG

ts = zeros(length(DATA),1);

ts = datenum(strcat(DATE,TIME),'yyyy-mm-ddHH:MM:SS.FFF');
ts = ts - timecorr;

stime = datenum(start,'yyyy-mm-ddHH:MM:SS');
etime = datenum(endtime,'yyyy-mm-ddHH:MM:SS');

%% PREDEFINES THE NEW .TXT FILE FOR FASTER COMPUTING
%

a = length(ts);

new = zeros(a,5);

%% CALCULATES THEH ELASPED TIME SINCE START OF MEASUREMENT
%

b = 0;

for i = 1:a

    if(ts(i) >= stime && ts(i) <= etime)

        b = b + 1;
        new(b,1) = ts(i);
        new(b,5) = DATA(i);

    end

end

%% REMOVES EMPTY CELLS/ROWS
%

new(all(new==0,2),:) = [];

%% INPUTS THE REQUIRED VALUES INTO THE NEW MATRIX
%

for n = 1:(b - 1)

    new(n + 1,4) = new(n + 1,1) - new(n,1) + new(n,4);

end
```

```
new(:,2) = Volume;
new(:,3) = Area;
new(:,4) = new(:,4) .* 1440; %minutes

%% REMOVES DUPLICATES AND CHANGES TO CELL MATRIX, ENABLING IMPORTATION OF
%  STRINGS
%

[~,ia,~] = unique(new(:,1),'rows','stable');
new = new(ia,:);

new = num2cell(new);

[a,b] = size(new);

for row = 1:a

    new{row,1} = series;

end

%% ADDS THE HEADER ROW
%

head = {'series','V','A','Time','Concentration'};
new = [head;new];

%% CREATES THE .TXT FILE

file = input('Input the output file name: ','s');

dlmcell(file, new,'; ');

end

*****************************************************************

function Lflux(ETIME, DATA, Volume, Area, series)
%
% THIS FUNCTION was FOR CORRECTLY FORMATTING Li-COR 8100 RAW
% CONCENTRATION DATA INTO A FORMAT ACCEPTABLE FOR THE R STATISTICAL
% ANALYSIS PROGRAMS BUILT IN PACKAGE R TO CALCULATE FLUX. IT was
% NECESSARY TO IMPORT THE NDIR ANALYZER DATA OR TEXT FILE AS COLUMN
% VECTORS.
%
% AUTHOR: AMANDA VARLAND
%
```

```
% FUNCTION CALL: Lflux
%
% INPUT VALUES:
%  NAME:          DESCRIPTION:              EXAMPLE:
%  ETIME          THE ELAPSED TIME COLUMN VECTOR  '0'
%                 GIVEN FROM THE NDIR ANALYZER DATA    '1'
%                                          '2'
%
%
%  DATA           THE CO2 CONCENTRATION GIVEN     '395'
%                 BY THE NDIR ANALYZER IN PPMV AND      '400'
%                 COLUMN VECTOR FORMAT        '405'
%
%
%  Volume         THE VOLUME OF THE FLUX        208.1976
%                 CHAMBER IN LITERS
%
%
%  AREA           THE CROSS SECTIONAL AREA OF     0.0015
%                 THE SOURCE AREA IN M^2
%
%
%      series     THE NAME DESIGNATION FOR EACH    'MH4'
%                        POINT OR THE SEWER ACCESS
%                        COVER NAME

%% PREDEFINES THE SIZE OF THE NEW .TXT FILES FOR FASTER COMPUTING
%  AND MAKES SURE THE ELAPSED TIME STARTS AT 0
%

format longG

a = length(ETIME);

new = zeros(a,5);
b = 0;

for i = 1:a

   if(ETIME(i) >= 0)

      b = b + 1;
      new(b,4) = ETIME(i);
      new(b,5) = DATA(i);

   end

end
```

```matlab
%% REMOVES EMPTY CELLS/ROWS
%

new(all(new==0,2),:) = [];

%% INPUTS THE VOLUME, AREA AND ELAPSED TIME IN MINUTES AND SERIES
%  INTO THE APPROPRIATE COLUMNS IN THE NEW FILE
%

new(:,2) = Volume;
new(:,3) = Area;
new(:,4) = new(:,4) ./ 60; %minutes

[~,ia,~] = unique(new(:,4),'rows','stable');
new = new(ia,:);

new = num2cell(new);

[a,b] = size(new);

for row = 1:a

    new{row,1} = series;

end

%% INSERTS A HEADER ROW
%

head = {'series','V','A','Time','Concentration'};
new = [head;new];

%% PROMPTS THE USER FOR THE FILE NAME AND CREATES THE FILE
%

file = input('Input the output file name: ','s');

dlmcell(file, new,'; ');

end
```

APPENDIX C

RAW CHAMBER FLUX DATA

Table 11: Raw CO_2 Flux Chamber Data

Cover ID	Date	Start Time	End Time	CO₂ Flux (μL/min)	CO₂ Flux (g/day)	CO₂ Flux (μmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MH0	10/16/2013	12:52:37 PM	1:03:02 PM	3908	10.74	2.83	32.9	14024	14152	CRDS
MH0	10/16/2013	1:09:35 PM	1:19:30 PM	5763	15.85	4.17	34.0	20455	20588	CRDS
MH0	10/15/2013	2:07:57 PM	2:20:18 PM	3632	9.98	2.62	22.2	13075	13162	CRDS
MH0	10/15/2013	2:28:13 PM	2:38:46 PM	3719	10.21	2.69	13.2	13401	13452	CRDS
MH0	9/16/2013	2:48:02 PM	2:58:01 PM	9868	25.07	6.59	74.1	34257	34547	CRDS
MH0	9/16/2013	3:03:10 PM	3:13:02 PM	21213	53.89	14.17	110.9	69490	69925	CRDS
MH0	10/3/2013	3:05:20 PM	3:15:46 PM	760	2.07	0.54	3.3	2794	2807	CRDS
MH0	9/16/2013	3:20:08 PM	3:31:00 PM	15325	38.93	10.24	56.9	51751	51974	CRDS
MH0	10/3/2013	3:21:54 PM	3:32:12 PM	531	1.45	0.38	1.3	1956	1961	CRDS
MH00	10/16/2013	1:44:21 PM	1:54:16 PM	392	1.07	0.28	3.3	1441	1454	CRDS
MH00	10/15/2013	1:46:00 PM	1:58:41 PM	115	0.32	0.08	0.8	426	429	CRDS
MH00	10/14/2013	4:09:08 PM	4:13:00 PM	1282	3.51	0.92	40.6	4612	4771	CRDS
MH1	10/16/2013	12:16:21 PM	12:26:46 PM	1453	4.00	1.05	5.7	5346	5369	CRDS
MH1	10/16/2013	12:34:02 PM	12:44:31 PM	3426	9.44	2.48	5.5	12527	12549	CRDS
MH1	10/2/2013	2:40:25 PM	2:50:11 PM	7934	20.58	5.41	39.3	28545	28699	CRDS
MH1	10/15/2013	2:47:07 PM	2:56:43 PM	3333	9.15	2.41	5.4	12191	12213	CRDS
MH1	10/2/2013	2:54:22 PM	3:04:48 PM	18198	47.21	12.42	21.1	63538	63621	CRDS
MH1	10/15/2013	3:02:29 PM	3:12:53 PM	7789	21.39	5.62	32.6	28005	28133	CRDS
MH1	10/2/2013	3:11:57 PM	3:22:33 PM	17518	45.45	11.95	33.4	61564	61395	CRDS
MH1	9/16/2013	3:36:11 PM	3:46:00 PM	3403	8.63	2.27	11.0	12444	12487	CRDS

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (µL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (µmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MH1	10/3/2013	3:37:31 PM	3:47:04 PM	758	2.10	0.55	0.8	2799	2803	CRDS
MH1	9/16/2013	3:53:00 PM	4:03:45 PM	4238	10.74	2.82	20.8	15441	15522	CRDS
MH1	10/3/2013	3:53:47 PM	4:04:35 PM	1232	3.42	0.90	1.6	4543	4549	CRDS
MH1	9/16/2013	4:10:04 PM	4:20:00 PM	2675	6.78	1.78	17.6	9790	9859	CRDS
MH2	10/16/2013	11:39:17 AM	11:49:00 AM	2501	6.91	1.82	14.8	9051	9109	CRDS
MH2	10/16/2013	11:54:00 AM	12:04:37 PM	5175	14.29	3.76	19.6	18365	18442	CRDS
MH2	10/4/2013	1:13:00 PM	1:23:00 PM	1179	3.30	0.87	5930.5	4212	4444	CRDS
MH2	10/4/2013	1:27:18 PM	1:37:41 PM	225	0.63	0.17	2.0	828	836	CRDS
MH2	10/4/2013	1:40:39 PM	1:50:59 PM	160	0.45	0.12	2.8	586	597	CRDS
MH2	9/17/2013	3:16:00 PM	3:26:00 PM	14	0.04	0.01	0.2	52	53	CRDS
MH2	10/2/2013	3:35:17 PM	3:45:52 PM	11575	30.05	7.90	15.4	39505	39566	CRDS
MH2	10/2/2013	3:50:12 PM	4:00:56 PM	9155	23.80	6.26	12.3	31732	31780	CRDS
MH2	9/26/2013	3:52:13 PM	4:02:07 PM	9340	25.14	6.61	16.4	32255	32320	CRDS
MH2	9/26/2013	4:08:01 PM	4:17:01 PM	4300	11.57	3.04	15.5	15376	15436	CRDS
MH2	10/2/2013	4:06:47 PM	4:17:57 PM	6936	18.03	4.74	10.0	24401	24440	CRDS
MH2	9/26/2013	4:22:14 PM	4:32:02 PM	5801	15.66	4.12	8.3	20539	20571	CRDS
MH2	9/19/2013	4:34:54 PM	4:45:00 PM	4905	12.94	3.40	61.0	17390	17629	CRDS
MH2	9/26/2013	4:35:28 PM	4:45:00 PM	4273	11.57	3.04	6.1	15299	15323	CRDS
MH2	9/19/2013	4:50:15 PM	5:01:01 PM	4867	12.83	3.38	12.0	17355	17402	CRDS
MH2	9/19/2013	5:06:01 PM	5:16:00 PM	4064	10.72	2.82	15.3	14567	14627	CRDS

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (µL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (µmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MH3	10/16/2013	11:06:02 AM	11:15:33 AM	456	1.26	0.33	6.5	1670	1695	CRDS
MH3	10/16/2013	11:23:22 AM	11:33:11 AM	305	0.84	0.22	2.7	1122	1132	CRDS
MH3	10/15/2013	3:27:00 PM	3:36:04 PM	1757	4.82	1.27	21.3	6357	6440	CRDS
MH3	10/15/2013	3:40:52 PM	3:52:03 PM	8715	23.93	6.29	19.1	29828	29903	CRDS
MH3	9/12/2013	3:25:06 PM	3:55:00 PM	8843	23.04	6.06	10.2	30360	30400	CRDS
MH3	9/12/2013	4:49:03 PM	5:19:27 PM	3204	8.28	2.18	10.8	11511	11553	CRDS
MH3	9/19/2013	5:23:04 PM	5:33:31 PM	595	1.57	0.41	3.3	2186	2199	CRDS
MH3	9/19/2013	5:35:53 PM	5:46:18 PM	407	1.08	0.28	2.0	1498	1506	CRDS
MH3	9/19/2013	5:50:02 PM	6:00:49 PM	1027	2.71	0.71	7.6	3756	3785	CRDS
MH4	10/26/2013	12:02:00 AM	12:13:42 AM	2113	5.91	1.55	3.2	7739	7752	CRDS
MH4	10/26/2013	1:03:29 AM	1:14:24 AM	2957	8.27	2.18	3.3	10789	10801	CRDS
MH4	10/26/2013	2:02:54 AM	2:12:46 AM	763	2.14	0.56	1.6	2814	2820	CRDS
MH4	10/26/2013	4:03:00 AM	4:13:01 AM	886	2.48	0.65	1.9	3265	3273	CRDS
MH4	10/26/2013	5:04:50 AM	5:15:52 AM	1612	4.54	1.19	6.8	5910	5937	CRDS
MH4	10/26/2013	7:03:42 AM	7:14:29 AM	2883	8.14	2.14	4.4	10519	10536	CRDS
MH4	10/25/2013	9:09:22 AM	9:19:25 AM	285	0.79	0.21	1.1	1053	1057	CRDS
MH4	10/25/2013	9:41:40 AM	9:52:52 AM	197	0.54	0.14	2.9	723	735	CRDS
MH4	10/25/2013	10:10:17 AM	10:20:31 AM	1003	2.76	0.73	4.8	3690	3709	CRDS
MH4	10/16/2013	10:32:51 AM	10:42:15 AM	603	1.68	0.44	1.2	2226	2231	CRDS

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (µL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (µmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MH4	10/25/2013	10:44:45 AM	10:55:29 AM	61	0.17	0.04	1.8	221	228	CRDS
MH4	10/16/2013	10:46:42 AM	10:56:50 AM	1253	3.48	0.91	4.3	4607	4624	CRDS
MH4	10/21/2013	10:59:35 AM	11:10:01 AM	2994	8.23	2.16	98.0	10740	11124	CRDS
MH4	9/30/2013	11:10:04 AM	11:19:57 AM	1199	3.10	0.82	9.9	4401	4439	CRDS
MH4	10/25/2013	11:20:10 AM	11:32:00 AM	948	2.59	0.68	11.0	3476	3519	CRDS
MH4	9/30/2013	11:26:00 AM	11:35:10 AM	1369	3.54	0.93	8.4	5024	5057	CRDS
MH4	9/30/2013	11:41:42 AM	11:51:16 AM	887	2.28	0.60	13.0	3247	3298	CRDS
MH4	10/25/2013	11:52:11 AM	12:02:28 PM	1772	4.82	1.27	12.0	6487	6534	CRDS
MH4	9/30/2013	11:55:55 AM	12:05:18 PM	2211	5.72	1.51	22.8	8065	8154	CRDS
MH4	9/30/2013	12:08:28 PM	12:18:28 PM	4720	12.22	3.21	46.7	17023	17206	CRDS
MH4	10/25/2013	12:32:37 PM	12:41:54 PM	5062	13.72	3.61	66.8	18175	18437	CRDS
MH4	10/25/2013	1:11:38 PM	1:23:27 PM	4555	12.29	3.23	69.9	16374	16648	CRDS
MH4	10/25/2013	1:48:43 PM	1:58:08 PM	3184	8.53	2.24	109.9	11402	11833	CRDS
MH4	10/25/2013	2:59:12 PM	3:08:45 PM	51984	139.03	36.56	364.6	158130	159550	CRDS

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (µL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (µmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MH4	10/25/2013	3:26:21 PM	3:37:16 PM	258	0.69	0.18	2.1	951	960	CRDS
MH4	10/25/2013	3:53:51 PM	4:03:17 PM	22417	59.81	15.73	114.1	75240	75687	CRDS
MH4	10/15/2013	4:01:20 PM	4:11:21 PM	8083	22.19	5.84	57.0	28701	28925	CRDS
MH4	10/15/2013	4:16:33 PM	4:25:21 PM	13473	36.91	9.71	44.8	46821	46997	CRDS
MH4	10/25/2013	4:20:22 PM	4:31:32 PM	30517	81.67	21.48	170.2	99420	100090	CRDS
MH4	10/25/2013	4:48:58 PM	5:00:55 PM	22639	60.79	15.99	150.0	75813	76401	CRDS
MH4	10/25/2013	5:16:16 PM	5:28:18 PM	13881	37.34	9.82	81.4	48138	48457	CRDS
MH4	10/25/2013	5:45:13 PM	5:56:09 PM	16947	45.69	12.02	61.1	58106	58346	CRDS
MH4	10/25/2013	6:17:52 PM	6:28:22 PM	8375	22.70	5.97	102.7	29629	30031	CRDS
MH4	10/25/2013	6:46:55 PM	6:57:53 PM	13555	37.73	9.92	22.0	47092	47178	CRDS
MH4	10/25/2013	7:46:24 PM	7:58:09 PM	5086	13.95	3.67	10.2	18364	18404	CRDS
MH4	10/25/2013	8:25:24 PM	8:36:12 PM	4170	11.45	3.01	5.1	15128	15148	CRDS
MH4	10/25/2013	8:56:50 PM	9:07:37 PM	2609	7.17	1.89	10.0	9525	9565	CRDS
MH4	10/25/2013	10:11:17 PM	10:21:34 PM	723	2.00	0.53	1.9	2665	2673	CRDS
MH4	10/25/2013	11:02:51 PM	11:12:00 PM	306	0.85	0.22	5.6	1122	1144	CRDS
MHSU1	10/14/2013	9:48:29 AM	9:56:52 AM	31167	86.36	22.71	460.1	85058	86861	CRDS
MHSU1	10/14/2013	10:01:01 AM	10:10:41 AM	1632	4.52	1.19	8.1	5894	5926	CRDS
MHSU1	10/14/2013	10:15:28 AM	10:25:32 AM	1923	5.31	1.40	37.8	6861	7010	CRDS

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (μL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (μmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MHSU 1	10/7/2013	10:23:26 AM	10:34:00 AM	5221	14.08	3.70	22.5	18035	18123	CRDS
MHSU 1	10/9/2013	10:24:27 AM	10:35:06 AM	9926	26.70	7.02	55.4	32539	32756	CRDS
MHSU 1	9/23/2013	10:28:08 AM	10:38:21 AM	3738	10.01	2.63	10.0	13160	13200	CRDS
MHSU 1	10/7/2013	10:38:56 AM	10:49:00 AM	4133	11.09	2.92	18.7	14465	14538	CRDS
MHSU 1	10/9/2013	10:39:53 AM	10:50:41 AM	14904	39.94	10.50	49.0	46677	46869	CRDS
MHSU 1	9/23/2013	10:44:07 AM	10:53:13 AM	4847	12.97	3.41	13.3	16839	16891	CRDS
MHSU 1	10/7/2013	10:54:58 AM	11:05:45 AM	6150	16.51	4.34	12.9	21047	21098	CRDS
MHSU 1	10/9/2013	10:59:34 AM	11:10:52 AM	5899	15.81	4.16	9.7	20252	20290	CRDS
MHSU 1	9/23/2013	11:02:20 AM	11:12:53 AM	2611	6.99	1.84	10.1	9319	9359	CRDS
MHSU 1	10/7/2013	11:10:54 AM	11:20:16 AM	5646	15.09	3.97	14.7	19435	19492	CRDS
MHSU 1	10/21/2013	11:31:19 AM	11:42:00 AM	2883	7.89	2.08	13.0	10244	10295	CRDS
MHSU 1	10/15/2013	11:48:23 AM	11:57:16 AM	209	0.58	0.15	1.0	770	773	CRDS
MHSU 1	10/21/2013	11:48:10 AM	12:00:49 PM	2171	5.92	1.56	8.9	7788	7823	CRDS

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (μL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (μmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MHSU 1	10/15/2013	12:01:06 PM	12:10:00 PM	1157	3.19	0.84	5.6	4206	4228	CRDS
MHSU 1	10/21/2013	12:08:18 PM	12:18:18 PM	2527	6.89	1.81	7.3	9030	9059	CRDS
MHSU 1	9/20/2013	12:35:53 PM	12:45:00 PM	16107	42.16	11.09	78.2	50027	50334	CRDS
MHSU 1	9/20/2013	12:49:08 PM	12:58:52 PM	38900	101.83	26.78	120.3	103380	103850	CRDS
MHSU 1	9/20/2013	1:06:13 PM	1:16:00 PM	25867	67.41	17.73	104.5	74609	75018	CRDS
MHSU 1	10/22/2013	3:01:24 PM	3:11:47 PM	5310	14.20	3.73	24.7	18328	18424	CRDS
MHSU 1	10/22/2013	3:15:11 PM	3:25:57 PM	6301	16.85	4.43	13.5	21533	21586	CRDS
MHSU 1	10/22/2013	3:28:25 PM	3:37:39 PM	5698	15.24	4.01	36.1	19559	19700	CRDS
MHSU 3	10/15/2013	10:43:23 AM	10:53:15 AM	1145	3.17	0.83	5.6	4206	4228	CRDS
MHSU 3	10/28/2013	10:56:00 AM	11:06:11 AM	8582	22.61	5.95	130.7	30178	30690	CRDS
MHSU 3	10/15/2013	10:57:17 AM	11:07:22 AM	1707	4.73	1.24	5.3	6256	6277	CRDS
MHSU 3	10/28/2013	11:28:10 AM	11:38:57 AM	1775	4.66	1.23	6.0	6505	6529	CRDS
MHSU 3	9/23/2013	11:41:43 AM	11:49:20 AM	2546	6.78	1.78	10.2	9284	9325	CRDS

Cover ID	Date	Start Time	End Time	CO₂ Flux (µL/min)	CO₂ Flux (g/day)	CO₂ Flux (µmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MHSU 3	10/7/2013	11:49:14 AM	11:59:57 AM	2756	7.33	1.93	12.7	10039	10089	CRDS
MHSU 3	9/23/2013	11:58:59 AM	12:08:47 PM	2486	6.62	1.74	8.7	9072	9106	CRDS
MHSU 3	10/28/2013	12:00:00 PM	12:12:04 PM	11629	30.40	7.99	217.3	40242	41094	CRDS
MHSU 3	10/7/2013	12:05:29 PM	12:15:16 PM	3656	9.73	2.56	17.9	13249	13319	CRDS
MHSU 3	9/23/2013	12:14:01 PM	12:24:14 PM	4216	11.21	2.95	18.2	15240	15312	CRDS
MHSU 3	10/7/2013	12:19:19 PM	12:25:54 PM	6750	17.84	4.69	39.7	24074	24229	CRDS
MHSU 3	10/28/2013	12:33:42 PM	12:43:49 PM	10011	26.17	6.88	137.2	35004	35542	CRDS
MHSU 3	10/28/2013	1:06:38 PM	1:16:44 PM	1955	5.11	1.34	17.2	7135	7202	CRDS
MHSU 3	10/21/2013	1:24:27 PM	1:35:05 PM	11832365	31961.02	8405.34	33799.0	4989800	5122300	CRDS
MHSU 3	9/20/2013	1:31:27 PM	1:41:18 PM	1740	4.53	1.19	6.3	6377	6402	CRDS
MHSU 3	10/28/2013	1:38:57 PM	1:49:43 PM	2264	5.92	1.56	26.8	8237	8342	CRDS
MHSU 3	10/21/2013	1:40:46 PM	1:51:05 PM	576	1.55	0.41	2.5	2123	2133	CRDS
MHSU 3	9/20/2013	1:44:30 PM	1:54:45 PM	1600	4.15	1.09	8.0	5862	5894	CRDS

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (μL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (μmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MHSU 3	10/21/2013	1:56:17 PM	2:07:07 PM	1458	3.93	1.03	10.1	5342	5381	CRDS
MHSU 3	9/20/2013	1:58:40 AM	2:08:42 PM	2054	5.33	1.40	21.7	7486	7571	CRDS
MHSU 3	10/24/2013	3:30:09 PM	3:40:31 PM	783	2.09	0.55	2.8	2885	2896	CRDS
MHSU 3	10/24/2013	3:44:03 PM	3:54:34 PM	847	2.26	0.60	3.8	3117	3131	CRDS
MHSU 3	10/24/2013	4:03:26 PM	4:13:49 PM	3181	8.51	2.24	9.5	11569	11606	CRDS
MHSU 3	10/16/2013	4:04:29 PM	4:15:08 PM	357	0.97	0.26	4.6	1312	1330	CRDS
MHSU 3	10/24/2013	4:16:00 PM	4:27:55 PM	3476	9.30	2.45	12.6	12618	12668	CRDS
MHSU 3	10/16/2013	4:20:34 PM	4:31:00 PM	1671	4.55	1.20	9.4	6116	6153	CRDS
MHSU 4	9/23/2013	12:33:11 PM	12:43:00 PM	156	0.41	0.11	3.5	570	583	CRDS
MHSU 4	9/23/2013	12:48:40 PM	12:58:00 PM	745	1.98	0.52	11.0	2730	2773	CRDS
MHSU 5	10/14/2013	2:17:01 PM	2:27:28 PM	3515	9.61	2.53	21.6	12702	12787	CRDS
MHSU 5	10/14/2013	2:30:55 PM	2:41:18 PM	2108	5.76	1.52	21.5	7666	7750	CRDS
MHSU 5	10/14/2013	2:45:52 PM	2:56:23 PM	1089	2.98	0.78	4.3	3999	4016	CRDS

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (µL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (µmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MHSU 5	10/16/2013	2:47:15 PM	2:56:51 PM	1355	3.69	0.97	9.8	4960	4998	CRDS
MHSU 5	10/16/2013	3:03:49 PM	3:15:01 PM	2374	6.47	1.70	4.5	8659	8676	CRDS
MHSU 6	10/16/2013	2:16:58 PM	2:26:59 PM	435	1.19	0.31	2.9	1603	1615	CRDS
MHSU 6	10/16/2013	2:32:19 PM	2:42:50 PM	761	2.07	0.55	3.8	2803	2818	CRDS
MHSU 6	10/14/2013	3:05:59 PM	3:16:39 PM	638	1.74	0.46	9.9	2339	2378	CRDS
MHSU 6	10/14/2013	3:24:42 PM	3:35:51 PM	86	0.24	0.06	1.9	315	323	CRDS
MHSU 6	10/14/2013	3:43:00 PM	3:54:20 PM	6107	16.72	4.40	196.1	21585	22354	CRDS
MH4	10/25/2013		8:52:00 AM	78	0.22	0.06	3.1	278	290	NDIR
MH4	10/25/2013		9:24:00 AM	416	1.15	0.30	14.9	1488	1546	NDIR
MH4	10/25/2013		9:56:00 AM	703	1.94	0.51	31.7	2505	2630	NDIR
MH4	10/25/2013		12:13:00 PM	561	1.53	0.40	20.7	2007	2088	NDIR
MH4	10/25/2013		12:57:00 PM	3372	9.17	2.41	106.2	12431	12848	NDIR
MH4	10/25/2013		1:28:00 PM	2018	5.43	1.43	60.2	7346	7583	NDIR
MH4	10/25/2013		2:03:00 PM	3167	8.49	2.23	87.2	11671	12013	NDIR
MH4	10/25/2013		2:58:00 PM	6561	17.55	4.61	68.2	25259	25527	NDIR
MH4	10/25/2013		3:25:00 PM	4511	12.05	3.17	824.7	15475	18714	NDIR
MH4	10/25/2013		3:52:00 PM	9739	25.99	6.83	920.9	37201	40819	NDIR

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (μL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (μmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MH4	10/25/2013		4:20:00 PM	10151	27.17	7.14	440.9	39999	41730	NDIR
MH4	10/25/2013		4:48:00 PM	17361	46.62	12.26	403.9	75795	77381	NDIR
MH4	10/25/2013		5:16:00 PM	3310	8.91	2.34	334.5	11739	13053	NDIR
MH4	10/25/2013		5:44:00 PM	15933	42.96	11.30	838.1	67339	70631	NDIR
MH4	10/25/2013		6:46:00 PM	11067	30.17	7.93	135.4	44871	45403	NDIR
MH4	10/25/2013		7:15:00 PM	6971	19.06	5.01	74.7	26994	27288	NDIR
MH4	10/25/2013		7:46:00 PM	2037	5.71	1.50	53.7	7435	7646	NDIR
MH4	10/25/2013		8:25:00 PM	2437	6.69	1.76	42.4	8971	9138	NDIR
MH4	10/25/2013		8:56:00 PM	3569	9.81	2.58	59.7	13295	13530	NDIR
MH4	10/25/2013		10:27:00 PM	1568	4.35	1.14	17.1	5743	5810	NDIR
MH4	10/25/2013		11:20:00 PM	196	0.55	0.14	9.8	695	733	NDIR
MH4	10/26/2013		12:17:00 AM	2129	5.93	1.56	37.2	7815	7961	NDIR
MH4	10/26/2013		1:16:00 AM	3669	10.27	2.70	47.0	13720	13905	NDIR
MH4	10/26/2013		2:16:00 AM	3126	8.75	2.30	86.9	11529	11870	NDIR
MH4	10/26/2013		3:16:00 AM	389	1.09	0.29	6.8	1402	1429	NDIR
MH4	10/26/2013		7:16:00 AM	270	0.76	0.20	10.2	962	1002	NDIR
MH3	10/18/2013	10:19:48 AM	10:29:49 AM	82	0.22	0.06	3.8	290	305	NDIR
MH3	10/18/2013	10:52:55 AM	11:02:55 AM	395	1.08	0.28	10.2	1425	1465	NDIR
MH3	10/18/2013	11:11:52 AM	11:21:51 AM	609	1.66	0.44	12.0	2212	2259	NDIR

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (µL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (µmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MH3	10/18/2013	11:32:17 AM	11:42:17 AM	995	2.71	0.71	13.6	3653	3706	NDIR
MH3	10/18/2013	11:48:38 AM	11:58:38 AM	972	2.64	0.69	16.2	3560	3624	NDIR
MH3	10/18/2013	12:39:43 PM	12:49:42 PM	3321	8.84	2.33	60.8	12732	12971	NDIR
MH3	10/18/2013	1:02:14 PM	1:12:14 PM	5078	13.56	3.57	788.0	18873	21968	NDIR
MH3	10/18/2013	1:28:11 PM	1:38:11 PM	15248	40.72	10.71	502.2	83779	85752	NDIR
MH3	10/18/2013	1:50:57 PM	2:00:57 PM	8664	23.13	6.08	297.5	37491	38659	NDIR
MH3	10/18/2013	2:08:02 PM	2:18:02 PM	9927	26.50	6.97	1148.6	42969	47481	NDIR
MH3	10/18/2013	2:39:26 PM	2:49:26 PM	16791	44.79	11.78	516.1	100440	102470	NDIR
MH3	10/18/2013	3:01:00 PM	3:11:00 PM	13162	35.09	9.23	211.6	66394	67226	NDIR
MH3	10/18/2013	3:25:33 PM	3:35:32 PM	13130	35.03	9.21	243.7	66111	67068	NDIR
MH3	10/18/2013	4:13:59 PM	4:23:59 PM	19990	53.37	14.04	691.4	173240	175950	NDIR
MH3	10/18/2013	5:02:18 PM	5:12:18 PM	361	0.97	0.25	68.5	1186	1455	NDIR
MH3	10/18/2013	5:22:18 PM	5:32:18 PM	549	1.47	0.39	40.9	1931	2092	NDIR
MH3	10/18/2013	5:39:03 PM	5:49:03 PM	1548	4.15	1.09	51.3	5683	5884	NDIR
MH3	10/18/2013	5:55:31 PM	6:05:31 PM	3631	9.75	2.56	65.4	14025	14282	NDIR
MH3	10/18/2013	6:11:58 PM	6:21:58 PM	3563	9.58	2.52	115.9	13640	14095	NDIR
MH3	10/18/2013	6:29:05 PM	6:39:05 PM	2497	6.74	1.77	52.1	9409	9613	NDIR
MH3	10/18/2013	8:09:09 PM	8:19:09 PM	574	1.57	0.41	17.8	2069	2139	NDIR
MH3	10/18/2013	8:39:11 PM	8:49:11 PM	1371	3.74	0.98	29.2	5050	5165	NDIR

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (μL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (μmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MH3	10/18/2013	8:53:12 PM	9:03:12 PM	180	0.49	0.13	10.7	634	676	NDIR
MH3	10/18/2013	9:08:05 PM	9:18:05 PM	2652	7.23	1.90	93.0	9956	10321	NDIR
MH3	10/18/2013	9:23:29 PM	9:33:29 PM	1194	3.26	0.86	23.9	4386	4480	NDIR
MH3	10/18/2013	9:38:07 PM	9:48:07 PM	545	1.49	0.39	21.0	1957	2039	NDIR
MH3	10/18/2013	9:53:18 PM	10:03:18 PM	1114	3.04	0.80	29.4	4070	4185	NDIR
MH3	10/18/2013	10:08:16 PM	10:18:16 PM	1407	3.84	1.01	14.9	5214	5273	NDIR
MH3	10/18/2013	10:23:44 PM	10:33:44 PM	380	1.04	0.27	7.9	1373	1404	NDIR
MH3	10/18/2013	10:47:53 PM	10:57:53 PM	2105	5.75	1.51	16.8	7924	7991	NDIR
MH3	10/18/2013	11:05:36 PM	11:15:36 PM	3450	9.43	2.48	22.8	13371	13461	NDIR
MH3	10/18/2013	11:26:28 PM	11:36:28 PM	2437	6.66	1.75	34.3	9209	9343	NDIR
MH3	10/18/2013	11:52:29 PM	12:02:29 AM	3460	9.45	2.49	30.0	13396	13514	NDIR
MH3	10/19/2013	4:44:47 PM	4:54:47 PM	3655	9.60	2.53	322.2	13596	14862	NDIR
MH3	10/19/2013	5:02:42 PM	5:12:42 PM	1056	2.78	0.73	76.8	3754	4056	NDIR
MH3	10/19/2013	5:22:38 PM	5:32:38 PM	3157	8.33	2.19	76.1	12022	12321	NDIR
MH3	10/19/2013	5:38:05 PM	5:48:05 PM	3450	9.12	2.40	78.3	13229	13537	NDIR
MH3	10/19/2013	5:53:57 PM	6:03:57 PM	2507	6.64	1.75	149.6	9245	9832	NDIR
MH3	10/19/2013	6:15:33 PM	6:25:33 PM	1458	3.87	1.02	29.4	5379	5494	NDIR
MH3	10/19/2013	6:32:39 PM	6:42:39 PM	5417	14.45	3.80	73.1	21808	22094	NDIR

Table 11: Continued

Cover ID	Date	Start Time	End Time	CO$_2$ Flux (µL/min)	CO$_2$ Flux (g/day)	CO$_2$ Flux (µmol/s)	STD	Lower 95% Confidence	Upper 95% Confidence	Spectrometer
MH3	10/19/2013	6:52:03 PM	7:02:03 PM	4998	13.36	3.51	48.8	19970	20161	NDIR
MH3	10/19/2013	7:13:53 PM	7:23:53 PM	6045	16.21	4.26	77.8	24720	25025	NDIR
MH3	10/19/2013	7:37:28 PM	7:47:28 PM	5199	13.96	3.67	73.9	20832	21123	NDIR
MHSU 3	10/28/2013		11:12:00 AM	389	1.02	0.27	38.7	1341	1493	NDIR
MHSU 3	10/28/2013		11:44:00 AM	3239	8.47	2.23	103.1	11956	12361	NDIR
MHSU 3	10/28/2013		12:17:00 PM	1657	4.33	1.14	26.3	6065	6168	NDIR
MHSU 3	10/28/2013		12:47:00 PM	10684	27.92	7.34	1070.2	41690	45894	NDIR
MHSU 3	10/28/2013		1:22:00 PM	1363	3.56	0.94	72.8	4871	5157	NDIR
MHSU 3	10/28/2013		1:52:00 PM	1933	5.05	1.33	110.3	6938	7371	NDIR
MHSU 5	1/25/2014	10:07:00 AM	10:17:32 AM	14068	39.31	10.34	6066.4	40182	64000	CRDS
MH0	1/25/2014	10:59:07 AM	11:09:37 AM	440188	1221.91	321.35	4209.6	1574800	1590000	CRDS
MH0	1/25/2014	11:13:23 AM	11:23:29 AM	268472	744.21	195.72	4509.6	967780	985000	CRDS
MH1	1/25/2014	11:27:27 AM	11:37:57 AM	58775	162.79	42.81	911.0	215140	219000	CRDS
MH1	1/25/2014	11:48:00 AM	11:58:36 AM	75083	207.91	54.68	1635.4	273580	280000	CRDS

Table 12: Raw CH$_4$ Flux Chamber Data

Cover ID	Date	Start Time	End Time	CH$_4$ Flux (µL/min)	CH$_4$ Flux (g/day)	CH$_4$ Flux (µmol/s)	STD	Lower 95% Confidence3	Upper 95% Confidence4	Spectrometer
MH0	10/16/2013	12:52:37 PM	1:03:02 PM	25.5	0.026	0.018	0.133	94.4	94.9	CRDS
MH0	10/16/2013	1:09:35 PM	1:19:30 PM	21.0	0.021	0.015	0.135	77.6	78.1	CRDS
MH0	10/15/2013	2:07:57 PM	2:20:18 PM	58.4	0.058	0.042	0.358	215.6	217.0	CRDS
MH0	10/15/2013	2:28:13 PM	2:38:46 PM	52.0	0.052	0.037	0.196	192.3	193.1	CRDS
MH0	9/16/2013	2:48:02 PM	2:58:01 PM	116.1	0.107	0.077	0.859	428.1	315.1	CRDS
MH0	9/16/2013	3:03:10 PM	3:13:02 PM	228.8	0.211	0.152	1.309	844.2	849.3	CRDS
MH0	10/3/2013	3:05:20 PM	3:15:46 PM	36.6	0.036	0.026	0.353	135.0	136.4	CRDS
MH0	9/16/2013	3:20:08 PM	3:31:00 PM	165.4	0.153	0.110	0.660	611.1	613.7	CRDS
MH0	10/3/2013	3:21:54 PM	3:32:12 PM	72.7	0.072	0.052	0.168	268.9	265.6	CRDS
MH00	10/16/2013	1:44:21 PM	1:54:16 PM	5.1	0.005	0.004	0.048	18.9	19.1	CRDS
MH00	10/15/2013	1:46:00 PM	1:58:41 PM	0.8	0.001	0.001	0.005	2.9	2.9	CRDS
MH00	10/14/2013	4:09:08 PM	4:13:00 PM	4.5	0.004	0.003	0.633	15.3	17.8	CRDS
MH1	10/16/2013	12:16:21 PM	12:26:46 PM	5.3	0.005	0.004	0.018	19.5	19.6	CRDS
MH1	10/16/2013	12:34:02 PM	12:44:31 PM	10.7	0.011	0.008	0.018	39.6	39.7	CRDS
MH1	10/2/2013	2:40:25 PM	2:50:11 PM	18.4	0.017	0.013	0.078	68.1	68.4	CRDS
MH1	10/15/2013	2:47:07 PM	2:56:43 PM	38.8	0.039	0.028	0.066	143.6	143.9	CRDS
MH1	10/2/2013	2:54:22 PM	3:04:48 PM	27.9	0.026	0.019	0.034	103.4	103.5	CRDS
MH1	10/15/2013	3:02:29 PM	3:12:53 PM	89.0	0.089	0.064	0.398	329.1	330.6	CRDS
MH1	10/2/2013	3:11:57 PM	3:22:33 PM	22.1	0.021	0.015	0.051	81.7	81.9	CRDS
MH1	9/16/2013	3:36:11 PM	3:46:00 PM	6.5	0.006	0.004	0.027	24.1	24.2	CRDS
MH1	10/3/2013	3:37:31 PM	3:47:04 PM	89.2	0.090	0.065	0.111	330.3	330.7	CRDS
MH1	9/16/2013	3:53:00 PM	4:03:45 PM	7.4	0.007	0.005	0.036	27.5	27.7	CRDS

Table 12: Continued

Cover ID	Date	Start Time	End Time	CH$_4$ Flux (μL/min)	CH$_4$ Flux (g/day)	CH$_4$ Flux (μmol/s)	STD	Lower 95% Confidence3	Upper 95% Confidence4	Spectrometer
MH1	10/3/2013	3:53:47 PM	4:04:35 PM	123.7	0.124	0.090	0.117	457.9	458.4	CRDS
MH1	9/16/2013	4:10:04 PM	4:20:00 PM	4.2	0.004	0.003	0.031	15.7	15.8	CRDS
MH2	10/16/2013	11:39:17 AM	11:49:00 AM	9.2	0.009	0.007	0.061	34.1	34.3	CRDS
MH2	10/16/2013	11:54:00 AM	12:04:37 PM	18.2	0.018	0.013	0.069	67.4	67.7	CRDS
MH2	10/4/2013	1:13:00 PM	1:23:00 PM	0.7	0.001	0.001	0.026	2.6	2.7	CRDS
MH2	10/4/2013	1:27:18 PM	1:37:41 PM	27.1	0.028	0.020	0.060	100.5	100.7	CRDS
MH2	10/4/2013	1:40:39 PM	1:50:59 PM	21.6	0.022	0.016	0.118	79.6	80.1	CRDS
MH2	9/17/2013	3:16:00 PM	3:26:00 PM	0.0	0.000	0.000	0.001	0.1	0.1	CRDS
MH2	10/2/2013	3:35:17 PM	3:45:52 PM	14.6	0.014	0.010	0.020	53.9	54.0	CRDS
MH2	10/2/2013	3:50:12 PM	4:00:56 PM	13.5	0.013	0.009	0.019	50.0	50.1	CRDS
MH2	9/26/2013	3:52:13 PM	4:02:07 PM	50.1	0.049	0.035	0.088	185.5	185.9	CRDS
MH2	9/26/2013	4:08:01 PM	4:17:01 PM	29.6	0.029	0.021	0.113	109.3	109.8	CRDS
MH2	10/2/2013	4:06:47 PM	4:17:57 PM	6.7	0.006	0.005	0.010	24.6	34.7	CRDS
MH2	9/26/2013	4:22:14 PM	4:32:02 PM	39.4	0.039	0.028	0.063	145.7	145.9	CRDS
MH2	9/19/2013	4:34:54 PM	4:45:00 PM	6.6	0.006	0.005	0.028	24.5	24.6	CRDS
MH2	9/26/2013	4:35:28 PM	4:45:00 PM	44.5	0.044	0.032	0.058	164.6	164.8	CRDS
MH2	9/19/2013	4:50:15 PM	5:01:01 PM	12.5	0.012	0.009	0.060	46.4	46.6	CRDS
MH2	9/19/2013	5:06:01 PM	5:16:00 PM	19.2	0.018	0.013	0.091	70.9	71.3	CRDS
MH3	10/16/2013	11:06:02 AM	11:15:33 AM	3.6	0.004	0.003	0.056	13.1	13.3	CRDS
MH3	10/16/2013	11:23:22 AM	11:33:11 AM	2.7	0.003	0.002	0.023	9.9	10.0	CRDS
MH3	10/15/2013	3:27:00 PM	3:36:04 PM	26.6	0.027	0.019	0.284	98.2	99.3	CRDS
MH3	10/15/2013	3:40:52 PM	3:52:03 PM	100.8	0.100	0.073	0.239	372.8	373.7	CRDS
MH3	9/12/2013	3:25:06 PM	3:55:00 PM	25.2	0.024	0.017	0.036	93.3	93.5	CRDS

Table 12: Continued

Cover ID	Date	Start Time	End Time	CH$_4$ Flux (µL/min)	CH$_4$ Flux (g/day)	CH$_4$ Flux (µmol/s)	STD	Lower 95% Confidence3	Upper 95% Confidence4	Spectrometer
MH3	9/12/2013	4:49:03 PM	5:19:27 PM	11.8	0.011	0.008	0.052	43.7	43.9	CRDS
MH3	9/19/2013	5:23:04 PM	5:33:31 PM	3.7	0.004	0.003	0.015	13.8	13.9	CRDS
MH3	9/19/2013	5:35:53 PM	5:46:18 PM	3.4	0.003	0.002	0.012	12.6	12.6	CRDS
MH3	9/19/2013	5:50:02 PM	6:00:49 PM	9.0	0.009	0.006	0.061	33.3	33.6	CRDS
MH4	10/26/2013	12:02:00 AM	12:13:42 AM	11.1	0.011	0.008	0.012	41.0	41.1	CRDS
MH4	10/26/2013	1:03:29 AM	1:14:24 AM	17.2	0.017	0.013	0.039	63.6	63.8	CRDS
MH4	10/26/2013	2:02:54 AM	2:12:46 AM	8.0	0.008	0.006	0.021	29.5	29.6	CRDS
MH4	10/26/2013	4:03:00 AM	4:13:01 AM	5.2	0.005	0.004	0.011	19.4	19.5	CRDS
MH4	10/26/2013	5:04:50 AM	5:15:52 AM	34.8	0.035	0.026	0.168	128.5	129.1	CRDS
MH4	10/26/2013	7:03:42 AM	7:14:29 AM	171.1	0.175	0.126	0.251	633.1	634.0	CRDS
MH4	10/25/2013	9:09:22 AM	9:19:25 AM	20.2	0.020	0.015	0.064	74.8	75.0	CRDS
MH4	10/25/2013	9:41:40 AM	9:52:52 AM	31.0	0.031	0.022	0.462	114.0	115.8	CRDS
MH4	10/25/2013	10:10:17 AM	10:20:31 AM	124.0	0.124	0.089	0.438	458.3	460.0	CRDS
MH4	10/16/2013	10:32:51 AM	10:42:15 AM	10.4	0.011	0.008	0.019	38.6	38.6	CRDS
MH4	10/25/2013	10:44:45 AM	10:55:29 AM	9.4	0.009	0.007	0.137	34.4	35.0	CRDS
MH4	10/16/2013	10:46:42 AM	10:56:50 AM	17.6	0.018	0.013	0.061	65.0	65.2	CRDS
MH4	10/21/2013	10:59:35 AM	11:10:01 AM	6.7	0.007	0.005	0.041	24.7	24.8	CRDS
MH4	9/30/2013	11:10:04 AM	11:19:57 AM	32.5	0.031	0.022	0.258	119.8	120.8	CRDS
MH4	10/25/2013	11:20:10 AM	11:32:00 AM	48.9	0.048	0.035	0.387	180.6	182.1	CRDS
MH4	9/30/2013	11:26:00 AM	11:35:10 AM	36.8	0.035	0.025	0.232	135.9	136.8	CRDS
MH4	9/30/2013	11:41:42 AM	11:51:16 AM	20.2	0.019	0.014	0.295	74.3	75.5	CRDS
MH4	10/25/2013	11:52:11 AM	12:02:28 PM	112.0	0.111	0.080	0.756	413.2	416.2	CRDS
MH4	9/30/2013	11:55:55 AM	12:05:18 PM	42.9	0.040	0.029	0.405	158.0	159.6	CRDS

Table 12: Continued

Cover ID	Date	Start Time	End Time	CH$_4$ Flux (μL/min)	CH$_4$ Flux (g/day)	CH$_4$ Flux (μmol/s)	STD	Lower 95% Confidence3	Upper 95% Confidence4	Spectrometer
MH4	9/30/2013	12:08:28 PM	12:18:28 PM	83.8	0.079	0.057	0.795	308.7	311.8	CRDS
MH4	10/25/2013	12:32:37 PM	12:41:54 PM	95.8	0.094	0.068	1.092	352.8	357.0	CRDS
MH4	10/25/2013	1:11:38 PM	1:23:27 PM	46.7	0.046	0.033	0.705	171.7	174.5	CRDS
MH4	10/25/2013	1:48:43 PM	1:58:08 PM	18.0	0.017	0.013	0.628	65.3	67.8	CRDS
MH4	10/25/2013	2:59:12 PM	3:08:45 PM	258.1	0.251	0.181	2.150	951.2	959.7	CRDS
MH4	10/25/2013	3:26:21 PM	3:37:16 PM	90.2	0.087	0.063	1.000	332.1	336.0	CRDS
MH4	10/25/2013	3:53:51 PM	4:03:17 PM	87.3	0.085	0.061	0.422	322.5	324.2	CRDS
MH4	10/15/2013	4:01:20 PM	4:11:21 PM	99.7	0.099	0.072	0.754	367.9	370.9	CRDS
MH4	10/15/2013	4:16:33 PM	4:25:21 PM	127.6	0.127	0.092	0.422	471.9	473.6	CRDS
MH4	10/25/2013	4:20:22 PM	4:31:32 PM	114.8	0.112	0.081	0.694	423.8	426.6	CRDS
MH4	10/25/2013	4:48:58 PM	5:00:55 PM	95.4	0.093	0.067	0.554	352.2	354.3	CRDS
MH4	10/25/2013	5:16:16 PM	5:28:18 PM	78.8	0.077	0.056	0.456	291.1	292.8	CRDS
MH4	10/25/2013	5:45:13 PM	5:56:09 PM	95.1	0.093	0.067	0.341	351.5	352.9	CRDS
MH4	10/25/2013	6:17:52 PM	6:28:22 PM	60.4	0.059	0.043	0.887	222.2	225.7	CRDS
MH4	10/25/2013	6:46:55 PM	6:57:53 PM	101.8	0.101	0.073	0.177	376.6	377.3	CRDS
MH4	10/25/2013	7:46:24 PM	7:58:09 PM	46.5	0.046	0.033	0.076	172.2	172.5	CRDS
MH4	10/25/2013	8:25:24 PM	8:36:12 PM	42.7	0.043	0.031	0.054	158.0	158.2	CRDS
MH4	10/25/2013	8:56:50 PM	9:07:37 PM	37.3	0.037	0.027	0.163	137.9	138.5	CRDS
MH4	10/25/2013	10:11:17 PM	10:21:34 PM	6.7	0.007	0.005	0.014	25.0	25.0	CRDS
MH4	10/25/2013	11:02:51 PM	11:12:00 PM	306.2	0.309	0.223	5.551	1122.0	1143.8	CRDS
MHSU1	10/14/2013	9:48:29 AM	9:56:52 AM	715.5	0.720	0.519	13.536	2597.6	2650.6	CRDS
MHSU1	10/14/2013	10:01:01 AM	10:10:41 AM	56.3	0.057	0.041	0.284	207.9	209.0	CRDS
MHSU1	10/14/2013	10:15:28 AM	10:25:32 AM	66.1	0.066	0.048	1.552	241.6	247.7	CRDS

Cover ID	Date	Start Time	End Time	CH$_4$ Flux (μL/min)	CH$_4$ Flux (g/day)	CH$_4$ Flux (μmol/s)	STD	Lower 95% Confidence3	Upper 95% Confidence4	Spectrometer
MHSU1	10/7/2013	10:23:26 AM	10:34:00 AM	266.5	0.261	0.188	1.211	981.6	986.3	CRDS
MHSU1	10/9/2013	10:24:27 AM	10:35:06 AM	424.3	0.415	0.299	1.672	1560.0	1566.5	CRDS
MHSU1	9/23/2013	10:28:08 AM	10:38:21 AM	118.4	0.115	0.083	0.371	437.2	438.7	CRDS
MHSU1	10/7/2013	10:38:56 AM	10:49:00 AM	134.6	0.131	0.095	0.678	496.6	499.3	CRDS
MHSU1	10/9/2013	10:39:53 AM	10:50:41 AM	536.1	0.522	0.376	1.925	1968.3	1975.8	CRDS
MHSU1	9/23/2013	10:44:07 AM	10:53:13 AM	200.6	0.195	0.141	0.706	740.0	742.8	CRDS
MHSU1	10/7/2013	10:54:58 AM	11:05:45 AM	155.1	0.151	0.109	0.342	573.0	574.4	CRDS
MHSU1	10/9/2013	10:59:34 AM	11:10:52 AM	201.2	0.196	0.141	0.339	742.7	744.1	CRDS
MHSU1	9/23/2013	11:02:20 AM	11:12:53 AM	100.2	0.097	0.070	0.438	370.1	371.8	CRDS
MHSU1	10/7/2013	11:10:54 AM	11:20:16 AM	84.1	0.082	0.059	0.237	311.0	311.9	CRDS
MHSU1	10/21/2013	11:31:19 AM	11:42:00 AM	142.5	0.142	0.102	0.564	525.9	528.2	CRDS
MHSU1	10/15/2013	11:48:23 AM	11:57:16 AM	2.3	0.002	0.002	0.037	8.5	8.6	CRDS
MHSU1	10/21/2013	11:48:10 AM	12:00:49 PM	83.9	0.083	0.060	0.209	310.3	311.1	CRDS
MHSU1	10/15/2013	12:01:06 PM	12:10:00 PM	2.7	0.003	0.002	0.012	10.0	10.0	CRDS
MHSU1	10/21/2013	12:08:18 PM	12:18:18 PM	79.8	0.079	0.057	0.256	294.8	295.8	CRDS
MHSU1	9/20/2013	12:35:53 PM	12:45:00 PM	321.1	0.305	0.220	1.646	1181.3	1187.8	CRDS
MHSU1	9/20/2013	12:49:08 PM	12:58:52 PM	642.1	0.611	0.441	2.774	2353.3	2364.2	CRDS
MHSU1	9/20/2013	1:06:13 PM	1:16:00 PM	469.7	0.445	0.321	2.112	1725.4	1733.7	CRDS
MHSU1	10/22/2013	3:01:24 PM	3:11:47 PM	215.0	0.209	0.151	1.043	792.4	796.5	CRDS
MHSU1	10/22/2013	3:15:11 PM	3:25:57 PM	281.2	0.273	0.197	0.656	1036.7	1039.3	CRDS
MHSU1	10/22/2013	3:28:25 PM	3:37:39 PM	216.3	0.210	0.152	1.608	795.9	802.2	CRDS
MHSU3	10/15/2013	10:43:23 AM	10:53:15 AM	1145.4	1.152	0.832	5.578	4206.4	4228.2	CRDS
MHSU3	10/28/2013	10:56:00 AM	11:06:11 AM	54.0	0.051	0.037	0.765	198.6	201.6	CRDS

Cover ID	Date	Start Time	End Time	CH$_4$ Flux (µL/min)	CH$_4$ Flux (g/day)	CH$_4$ Flux (µmol/s)	STD	Lower 95% Confidence3	Upper 95% Confidence4	Spectrometer
MHSU3	10/15/2013	10:57:17 AM	11:07:22 AM	4.7	0.005	0.003	0.015	17.5	17.5	CRDS
MHSU3	10/28/2013	11:28:10 AM	11:38:57 AM	6.3	0.006	0.004	0.022	23.2	23.3	CRDS
MHSU3	9/23/2013	11:41:43 AM	11:49:20 AM	38.7	0.037	0.027	0.139	143.2	143.7	CRDS
MHSU3	10/7/2013	11:49:14 AM	11:59:57 AM	37.7	0.036	0.026	0.160	139.5	140.2	CRDS
MHSU3	9/23/2013	11:58:59 AM	12:08:47 PM	37.2	0.036	0.026	0.119	137.4	137.9	CRDS
MHSU3	10/28/2013	12:00:00 PM	12:12:04 PM	60.1	0.057	0.041	1.193	220.5	225.2	CRDS
MHSU3	10/7/2013	12:05:29 PM	12:15:16 PM	25.9	0.025	0.018	0.102	95.7	96.1	CRDS
MHSU3	9/23/2013	12:14:01 PM	12:24:14 PM	32.4	0.031	0.023	0.113	119.9	120.3	CRDS
MHSU3	10/7/2013	12:19:19 PM	12:25:54 PM	31.4	0.030	0.022	0.162	116.1	116.7	CRDS
MHSU3	10/28/2013	12:33:42 PM	12:43:49 PM	24.5	0.023	0.017	0.351	89.9	91.3	CRDS
MHSU3	10/28/2013	1:06:38 PM	1:16:44 PM	8.2	0.008	0.006	0.067	30.4	30.6	CRDS
MHSU3	10/21/2013	1:24:27 PM	1:35:05 PM	35716.5	35.020	25.269	780.350	111520.0	114580.0	CRDS
MHSU3	9/20/2013	1:31:27 PM	1:41:18 PM	11.3	0.011	0.008	0.040	41.9	42.0	CRDS
MHSU3	10/28/2013	1:38:57 PM	1:49:43 PM	7.5	0.007	0.005	0.088	27.6	27.9	CRDS
MHSU3	10/21/2013	1:40:46 PM	1:51:05 PM	8.3	0.008	0.006	0.020	30.7	30.8	CRDS
MHSU3	9/20/2013	1:44:30 PM	1:54:45 PM	12.9	0.012	0.009	0.065	47.6	47.8	CRDS
MHSU3	10/21/2013	1:56:17 PM	2:07:07 PM	15.6	0.015	0.011	0.084	57.5	57.8	CRDS
MHSU3	9/20/2013	1:58:40 AM	2:08:42 PM	17.7	0.017	0.012	0.158	65.3	65.9	CRDS
MHSU3	10/24/2013	3:30:09 PM	3:40:31 PM	4.8	0.005	0.003	0.014	17.9	17.9	CRDS
MHSU3	10/24/2013	3:44:03 PM	3:54:34 PM	4.7	0.005	0.003	0.020	17.5	17.6	CRDS
MHSU3	10/24/2013	4:03:26 PM	4:13:49 PM	150.6	0.146	0.106	0.439	556.8	558.5	CRDS
MHSU3	10/16/2013	4:04:29 PM	4:15:08 PM	1933.1	1.911	1.379	36.726	7015.6	7159.6	CRDS
MHSU3	10/24/2013	4:16:00 PM	4:27:55 PM	130.7	0.127	0.092	0.529	482.9	485.0	CRDS

Table 12: Continued

Cover ID	Date	Start Time	End Time	CH$_4$ Flux (µL/min)	CH$_4$ Flux (g/day)	CH$_4$ Flux (µmol/s)	STD	Lower 95% Confidence3	Upper 95% Confidence4	Spectrometer
MHSU3	10/16/2013	4:20:34 PM	4:31:00 PM	3.4	0.003	0.002	0.017	12.6	12.6	CRDS
MHSU4	9/23/2013	12:33:11 PM	12:43:00 PM	1.0	0.001	0.001	0.028	3.8	3.9	CRDS
MHSU4	9/23/2013	12:48:40 PM	12:58:00 PM	32.6	0.031	0.023	0.466	119.9	121.8	CRDS
MHSU5	10/14/2013	2:17:01 PM	2:27:28 PM	16.2	0.016	0.012	0.103	59.8	60.2	CRDS
MHSU5	10/14/2013	2:30:55 PM	2:41:18 PM	36.7	0.036	0.026	0.351	135.4	136.7	CRDS
MHSU5	10/14/2013	2:45:52 PM	2:56:23 PM	3.9	0.004	0.003	0.163	14.2	14.3	CRDS
MHSU5	10/16/2013	2:47:15 PM	2:56:51 PM	1993.3	1.971	1.422	71.873	7154.8	7436.6	CRDS
MHSU5	10/16/2013	3:03:49 PM	3:15:01 PM	0.9	0.001	0.001	0.013	3.4	3.4	CRDS
MHSU6	10/16/2013	2:16:58 PM	2:26:59 PM	0.9	0.001	0.001	0.008	3.2	3.3	CRDS
MHSU6	10/16/2013	2:32:19 PM	2:42:50 PM	25.5	0.025	0.018	0.568	93.5	95.7	CRDS
MHSU6	10/14/2013	3:05:59 PM	3:16:39 PM	1.8	0.002	0.001	0.043	6.8	6.9	CRDS
MHSU6	10/14/2013	3:24:42 PM	3:35:51 PM	3.2	0.003	0.002	0.029	11.8	12.0	CRDS
MHSU6	10/14/2013	3:43:00 PM	3:54:20 PM	125.3	0.125	0.090	5.265	453.9	474.5	CRDS
MHSU5	1/25/2014	10:07:00 AM	10:17:32 AM	6.8	0.006	0.004	0.450	24.4	26.1	CRDS
MH0	1/25/2014	10:59:07 AM	11:09:37 AM	10016.7	8.582	6.193	91.230	36900.0	37300.0	CRDS
MH0	1/25/2014	11:13:23 AM	11:23:29 AM	5047.4	4.318	3.116	77.870	18500.0	18800.0	CRDS
MH1	1/25/2014	11:27:27 AM	11:37:57 AM	134.1	0.115	0.083	1.960	493.0	501.0	CRDS
MH1	1/25/2014	11:48:00 AM	11:58:36 AM	170.0	0.145	0.105	3.500	623.0	637.0	CRDS

REFERENCES

1. Intergovernmental Panel on Climate Change. *Climate Change 2007 Synthesis Report;* Intergovernmental Panel on Climate Change, 2008.

2. Environmental Protection Agency. *Atmospheric Concentrations of Greenhouse Gases;* 2013.

3. Salt Lake City Energy and Carbon Advisory Committee and Salt Lake City Division of Sustainability and Environment. *Salt Lake City Community Carbon Footprint;* United States Department of Energy, 2010.

4. Quigley, C. J.; Corsi, R. L. Emissions of VOC's from a Municipal Sewer. *Air and Waste Management Association* 1995, *45* (5), 395-403.

5. Olson, D. A.; Varma, S.; Corsi, R. L. A New Approach for Estimating Volatile Organic Compound Emissions from Sewers: Methodology and Associated Errors. *Water Environmental Research* 1998, *70* (3), 276-282.

6. Foley, J.; Yuan, Z.; Lant, P. Dissolved Methane in Rising Main Sewer Systems: Field Measurements and Simple Model Developement for Estimation Greenhouse Gas Emissions. *Water Science and Technology* 2009, *60* (11), 2963-2971.

7. Willis, J.; Barnes, R.; Fillmore, L.; Shah, A. Quantifying Methane Evolution from Sewers: Phase 1 Results of the WERF/DeKalb County, Georgia, Case Study. *Proceedings of the Water Environment Federation*, 2010; pp 5411-5419.

8. Guisasola, A.; de Haas, D.; Keller, J.; Yuan, Z. Methan Formation in Sewer Systems. *Water Systems* 2008, *42* (6-7), 1421-1430.

9. Madsen, H. I.; Hvitved-Jacobsen, T.; Vollertsen, J. Gas Phase Transport in Gravity Sewers: A Methodology for Determination of Horizontal Gas Transport and Ventilation. *Water Environmental Research* 2006, *78* (11), 2203-2209.

10. Parker, W. J.; Ryan, H. A Tracer Study of Headspace Ventilation in a Collector Sewer. *Air and Waste Management Association* 2001, *51* (4), 582-592.

11. Picarro Inc. *Picarro G2311-f 10Hz CO2, CH4, and H2O Analyzer for Eddy Covariance Flux;* Picarro Inc: Santa Clara, CA, USA, 2012.

12. LI-COR. *LI-8100A Automated Soil CO2 Flux System and LI-8150 Multiplexer Instruction Manual;* LI-COR: Lincoln, NE, USA, 2010.

13. Pihlatie , M. K.; Christiansen , J. R.; Aaltonen , H.; Korhonen, J. F. J.; Nordbo, A.; Rasilo, T.; Benanti, G.; Giebels, M.; Helmy, M.; Sheehy, J.; Jones, S.; Juszczak, R.; Klefoth, R.; Lobo-do-Vale , R.; Schreiber, P.; Serça, D.; Vicca, S.; Wolf, B.; Pumpanen, J. Comparison of Static Chambers to Measure CH4 Emissions from Soils. *Agricultural and Forest Meterology* 2012, *171-172,* 124-136.

14. Parkin, T. B.; Venterea, R. T. *Chapter 3. Chamber Based Trace Gas Flux Measurements;* Aricultural Research Service, 2010.

15. Xu, L.; Furtaw, M. D.; Madsen, R. A.; Garcia, R. L.; Anderson, D. J.; McDermitt, D. K. On Maintaining Pressure Equillibrium Between a Soil CO2 Flux Chamber and the Ambient Air. *Journal of Geophysical Research: Atmospheres* 2006, *111* (2156-2202).

16. Ostrem, K. *Greening Waste: Anaerobic Digestion for Treating the Organic Fraction of Municipal Solid Wastes;* Thesis; Earth Engineering Center Columia University, 2004.

17. The Office of Sustainability; The President's Sustainability Advisory Board; The CAP Planning Team. *Energy and Environmental Stewardship Initiative: 2010 Climate Action Plan;* University of Utah: Salt Lake City, 2010.