Report

AGL FUGITIVE METHANE EMISSIONS MONITORING CAMPAIGN - FINAL REPORT

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EXECUTIVE SUMMARY

INTRODUCTION

The Gloucester Gas Project, operated by AGL Energy Limited (AGL), is a coal seam gas (CSG) project located near Gloucester, NSW, approximately 100km north of Newcastle. The project is currently in the exploration stage to assess the gas reserves in the Gloucester Basin. The Waukivory Pilot Project was the exploration activity being conducted at the time of this assessment which included the construction and operation of four gas wells, flaring units, water and gas gathering lines and associated ancillary equipment. The Waukivory Pilot Project forms part of the proposed Gloucester Gas Project which is located within Petroleum Exploration licence (PEL) 285.

AGL has completed monitoring of fugitive methane (CH_4) concentrations in the vicinity of the proposed Gloucester Gas Project to assess background methane concentrations in the Gloucester Valley and quantify any potential impacts from its exploration activities. As such methane monitoring has been conducted prior to, during and post construction, well fracture stimulation and ongoing operation of the Waukivory Pilot Project.

This report provides a summary of the methane monitoring undertaken by AGL in the Gloucester Valley from 29/07/2013 to 19/05/2015.

OBJECTIVES

The objective of this monitoring program is to determine the typical background levels of methane in the Gloucester Valley and identify any land-use activities that generate methane. Additional methane monitoring was undertaken to assess fugitive emissions from the Waukivory Pilot Project.

The monitoring program has been designed to measure CH_4 over a predetermined route inside and outside PEL 285 for the Gloucester Gas Project. In addition, the route included surveys of ambient CH_4 concentrations in the vicinity of the four Waukivory Pilot Project wells.

The baseline study comprises the four weeks of data collected in August 2013 as well as data collected in January 2014 to represent summer and winter conditions.

Additional monitoring was undertaken during the fracture stimulation program and flaring associated with the Waukivory Pilot Project. This monitoring was completed in October/November 2014 and May 2015 respectively. The outcome of this study is to be used as baseline data as well as indicative operational CH_4 concentrations (during fracture stimulation and flaring activities).

RESULTS

The average CH_4 concentrations measured in the study area are the same as the global average background concentrations described in **WMO (2014)**. The average CH_4 concentration over the entire baseline monitoring period was found to be 1.8 parts per million (ppm). This value is typical of regional areas which generally have slightly lower CH_4 concentrations than urban areas.

During the entire sampling campaign 1 second CH_4 concentrations ranged from a minimum of 1.5ppm occurring during fracture stimulation activities (Run 14), to a maximum of 3.9ppm occurring at Showground during Run 5 of baseline monitoring. The highest average CH_4 concentration over a total run was 2.1ppm. This concentration is 0.3 ppm above the global average background concentration, a value that is typical of concentrations experienced in urban areas (between 1.8ppm and 3.0ppm, **Lowry *et al.*, 2001**). This average was recorded during Run 15 which took place during the morning of 19 May 2015. Isotopic ratio values of methane ($\delta^{13}C\text{-}CH_4$) recorded for all routes of this run indicate that there was a significantly negative $\delta^{13}C\text{-}CH_4$. These negative isotopic fingerprints show that the elevated average concentration during the run was likely caused by a biological source of CH_4 contributing to the concentrations at this time. All routes during this run were above the global average background methane concentration of 1.8 ppm, thus elevated values were not confined to any particular route and appeared to occur for the whole Gloucester Valley. Concentrations returned to levels that were measured during baseline monitoring, as evidenced by the data obtained during the afternoon sampling on the same day.

The averages for morning and afternoon datasets were both 1.8ppm which indicates that inversion conditions (known to increase concentrations of air quality indicators) were not significant in the Gloucester area during the mobile sampling. This is likely due to the timing of the mobile monitoring. Inversion conditions typically affect atmospheric CH_4 concentrations during the hours of 22:00 to 04:00. Inversion effects are evidenced at these times in the data from the stationary monitoring site (**Appendix C**).

The two sampling routes with the highest CH_4 concentrations over the entire sampling period were Route 17 (1.92ppm average) and Route 18 (1.86ppm average). These routes are located on Showground and South of Showground at Gloucester (inside the basin) respectively. Route 17 is located in the immediate vicinity of a sewage treatment plant which is a known source of CH_4 emissions. Route 18 is located in the Gloucester residential area. Concentrations of CH_4 are typically slightly higher in such areas (**Lowry *et al*, 2001; Montiel *et al*, 2011**).

As with all other routes, Waukivory Road experienced an average CH_4 concentration of 2.4ppm (slightly above background) on the morning of 19 May 2015 that was not typical of the previous sampling runs. The average concentration however was within the concentrations typically experienced in urban areas. The averaged $\delta^{13}C$-CH_4 value for this route and run was -57‰. Literature indicates that a $\delta^{13}C$-CH_4 value lower (more negative) than -55 is indicative of a biological contribution of CH_4 as opposed to thermogenic (i.e. CSG related) CH_4. This biological isotopic source signature supports the visual observations of saturated (methanogenesis conducive) soils over most of the Gloucester Valley, as well as the herds of cattle present on Waukivory Road on this day.

CONCLUSION

The average CH_4 concentration measured over the period during which the baseline monitoring occurred was 1.8ppm. This is equivalent to the global background average (**WMO, 2013**).

Following review of the locations of the highest CH_4 concentrations and the corresponding isotopic signature, the sources of the highest CH_4 concentrations were identified as dairy/livestock, landfill, open cut coal mine, sewage treatment plant and biological activity.

The baseline assessment CH_4 concentrations and $\delta^{13}C$-CH_4 values have been compared with the post-activity monitoring results (obtained during fracture stimulation and after flaring had commenced). It is concluded that there was no significant difference in the CH_4 concentrations observed during the baseline assessment compared with values measured during hydraulic fracturing. During one monitoring run which was performed after flaring had begun (Run 15), elevated CH_4 concentrations were measured. Whilst the concentrations measured during this run are considered somewhat elevated for the Gloucester region, they are not abnormal and are in line with typical concentrations in urban areas. Run 15 was the first of the two runs that were performed on the same day, after flaring had commenced. The highly negative $\delta^{13}C$-CH_4 values for this run are typical of a biological CH_4 source likely caused by saturated soils and livestock. The final run (Run 16) shows that CH_4 concentrations were reduced to levels that were not significantly different to baseline concentrations.

GLOSSARY

Term	Definition
AGL	AGL Energy Limited
Anthropogenic	Anthropogenic is a term used to describe activities that are human induced (e.g. farming and landfills, CSG activities)
Biogenic	Biogenic is a termed used to describe substances that are generated through life processes (i.e. produced by living organisms or biological processes)
Box and whisker plot	Box and whisker plots are a way of graphically presenting numerical data statistically. The centreline of the box indicates the median value. The left side of the box indicates the lower quartile and the right indicates the upper quartile. The far left and far right error bars indicate the minimum and maximum of the values measured.
Gloucester Gas Project	The Gloucester Gas Project is located approximately 100 kilometres north of Newcastle. The Gloucester Gas Project is owned and operated by AGL.
Coal seam gas (CSG)	CSG contains CH_4 that naturally occurs in coal seams below the surface of the earth. CSG typically comprises >90% CH_4 with the remaining gas being other hydrocarbons, carbon dioxide and nitrogen.
Fugitive methane emissions	Fugitive emissions refer to the release of unintended or irregular gas releases from a non-discrete source (that are not captured or controlled through an emission point such as an exhaust stack or vent). Emissions from livestock and wetlands are considered fugitive emissions as they are not captured first, while emissions from a compressor engine exhaust stack is considered a point source, as the emission is planned and controlled. In relation to AGL's Gloucester Gas Project fugitive methane emissions are commonly considered those that are due to leaks and pressure relief valves (essentially a designed leak).
Histogram	A histogram is a way of graphically presenting the frequency distribution of a dataset. The dataset is divided into bins, where the frequency of occurrence of values that fall within each bin is shown. A histogram can also display the relative frequency providing information on the percentage of occurrence.
Inversion	During the cooler months where on clear nights, night time drainage flows pool in valleys with the warmer air above trapping the air below. It is not until the mid-morning that an inversion is broken down by the influence of the heat of the morning sun that allows mixing of the stable layer with layers aloft, as experienced during daylight hours.
Isotopic ratio ($\delta^{13}C$-CH_4)	$\delta^{13}C$-CH_4 is the ratio of the stable isotopes of carbon (^{13}C:^{12}C) within the CH_4 gas sampled. Typically, anthropogenic or thermogenic methane sources have a higher proportion of ^{13}C than biogenic sources.
Isotopic signature	The isotopic signature can be used to analyse $\delta^{13}C$-CH_4 measurement and distinguish between different sources of CH_4 in the atmosphere. For example, there is a known preferential uptake of ^{12}C over ^{13}C by plants and microbial activity, which means that biogenic CH_4 is generally 'lighter' (more negative) than thermogenic CH_4 (i.e. that created via the thermal breakdown of heavier hydrocarbons under high temperature/pressure conditions).
Methane (CH_4)	CH_4 is a naturally occurring gas that is present in the atmosphere at trace concentrations. The global average methane concentration is 1.8 parts per million (ppm) (**WMO, 2014**). Methane can also be anthropogenically released through activities such as landfill, agricultural practices (i.e. livestock) and CSG projects. In urban areas, CH_4 concentrations are found to be slightly higher, with observations commonly ranging between 1.8ppm and 3.0ppm (**Lowry *et al.*, 2001**)

Term	Definition
Parts per million (ppm)	A measure of very dilute concentrations of substances. Just as per cent means out of a hundred, so parts per million or ppm means out of a million.
Picard analyser	The Picarro G-2201-i Cavity Ring Down Spectrometer (CRDS) uses a near-Infra Red laser to measure sample gas passed through an optical measurement cavity. The instrument has an effective path length of up to 20 km inside the cavity, which results in high precision, and low-volume cavity to ensure better temperature stability, faster gas exchange, lower noise and higher sensitivity. The stability of the system means that minimal calibration is required (**Picarro, 2012**). The G2201-i is based on Picarro's CRDS technology, but also measures isotopic carbon ratios. Origins of methane (i.e. biogenic and thermogenic) have a characteristic ratio of ^{13}C to ^{12}C. The Picarro G2201-i makes precise $^{13}C/^{12}C$ ratio measurements that can potentially be used to distinguish between methane from different sources. This capability can be useful in measuring CH_4 in the vicinity of coal seam gas operations. This is since the isotopic carbon ratio of CH_4 generated from cattle, for example, will typically have a different signature from that of fugitive coal seam gas. It should be noted that there are limitations associated with the use of the Picarro equipment and the determination of $\delta^{13}C$-CH_4 values. The higher the concentration of CH_4 observed (i.e. the stronger the signal), the more effective the use of $\delta^{13}C$-CH_4 as a metric of CH_4 source. Therefore, at low, well mixed CH_4 concentrations (such as those observed during the study period) interpretation of the $\delta^{13}C$-CH_4 results are considered indicative.
Thermogenic	Thermogenic is a term used to describe hydrocarbons (i.e. methane) created via the thermal breakdown of heavier hydrocarbons under high temperature/pressure conditions. Such conditions occur where hydrocarbons are buried deep below the surface of the earth (i.e. due to the breakdown of fossil fuels), and may be taken as meaning 'associated with CSG' in the context of this report.

Pacific Environment Limited

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1 INTRODUCTION

1.1 Background

The Gloucester Gas Project, operated by AGL Energy Limited (AGL), is a coal seam gas (CSG) project located approximately 100km north of Newcastle. The project is currently in the exploration stage with four operating wells commonly known as the Waukivory Pilot Project. AGL gained project approval in February 2013 for Stage 1 which comprises up to 110 gas wells and associated infrastructure, a central processing facility, a gas fired electricity generating facility, a gas transmission pipeline and a delivery station at Hexham. The commencement of Stage 1 will be dependent on the exploration stage and assessment of the gas resource.

This technical report provides the results and analysis of a field monitoring campaign measuring the concentration and $\delta^{13}C$-CH_4 of fugitive CH_4 emissions in the Gloucester area completed by Pacific Environment on behalf of AGL.

The study is considered to represent an indicative screening analysis of the baseline conditions as well as an initial analysis of any potential impacts in ambient CH_4 concentrations in the vicinity of the Gloucester Gas Project.

1.2 Objectives

AGL commissioned Pacific Environment to monitor atmospheric methane (CH_4) concentrations in the vicinity of the existing Gloucester Gas Project. The objective of the monitoring program is to determine the background CH_4 concentrations in the Gloucester area and whether fugitive CH_4 emissions from AGL's CSG operations are currently influencing ambient CH_4 concentrations at locations within and near the Gloucester Gas Project. The monitoring program has been designed to measure CH_4 at sites within the Gloucester Gas Project and wider Gloucester Basin area.

2 SCOPE OF WORKS

2.1 Guideline documents for methane monitoring

There is currently no standard method for CH_4 monitoring, or the analysis of the $\delta^{13}C$-CH_4 in NSW or Australia. "*Queensland's Code of Practice for Coal Seam Gas Well Head Emissions Detection and Reporting*" (**DEEDI, 2011**) and the "*National Greenhouse and Energy Reporting System Measurement*" (**DIICCSRTE, 2013**) are identified as containing guidance on CSG/CH_4 monitoring, however these have limited application to the current study design.

The assessment has therefore been guided by good air quality monitoring practice including the Australian Standard (AS) 2922-1987 "*Guide for the siting of sampling units*" (**AS, 1987**), and its updated standard AS 3580.1.1:2007 "Methods for Sampling and Analysis of Ambient Air" (**AS, 2007**). The specific sampling methodologies employed are detailed in **Section 5**.

2.2 Initial sampling

The first phase of the project involved the identification of potential sources of CH_4 which could influence CH_4 concentrations in the Gloucester region. CH_4 samples of these potential sources were obtained using an isolation flux hood (**see Section 4.4**). This allowed for identification of the isotopic ratios of $^{12}C/^{13}C$ of each source. The isotopic ratio (or "isotopic signature"; referred to as $\delta^{13}C$-CH_4) was then used as a fingerprint to identify the sources of CH_4 in the area during mobile monitoring (**see Section 4.2**).

2.3 Mobile methane monitoring

Mobile methane monitoring was conducted over the following timeframes:

- Baseline mobile CH_4 monitoring -conducted from 29/07/2013 to 22/01/2014 (ten runs in total)
- Mid-fracture stimulation mobile CH_4 monitoring- conducted from 20/10/2014 to 08/11/2014 (four runs in total)
- Mid-flaring stimulation mobile CH_4 monitoring- conducted on 19/05/2015 (two runs in total)
- A stationary monitor was installed adjacent to AGL's weather station (see **Figure 5-1** for location) for a 10-day period (30/07/2013-09/08/2013) to characterise the diurnal CH_4 concentrations and assess any impacts on CH_4 concentrations caused by atmospheric inversion (see **Section 4.3**).

In total, 16 runs were performed during both the morning and afternoon over a total sampling campaign distance of 3,200 km. For analysis purposes the monitoring route was split into a subset of 18 routes. Further details are provided in **Section 5.3**.

2.4 Analysis of results and reporting

To date, previous interim monitoring reports have been compiled which include the results of baseline and mid-fracture stimulation monitoring (i.e. results from monitoring performed between 29/07/2013 to 08/11/2014). This is the final report which includes an assessment of all monitoring performed to date, including prior, during and post fracture stimulation which ceased on 26/11/2014, and during flaring activities and general operation of the Waukivory Pilot Project.

The average, minimum and maximum CH_4 concentrations and $\delta^{13}C\text{-}CH_4$ values were determined for each route and for each run with results prepared into tables, box plots and concentration maps (see **Section 6, Appendix A** and **Appendix B**). The natural variability in baseline concentrations and $\delta^{13}C\text{-}CH_4$ values were assessed and compared to the mid-fracture stimulation and flaring results. Where concentrations exceeded 1.8ppm, the $\delta^{13}C\text{-}CH_4$ was used as an indicator of the cause of these elevated concentrations.

3 AIR QUALITY CRITERIA

The composition of CSG typically constitutes high concentrations (>90%) of CH_4 (with the remaining gas being comprised of other hydrocarbons, carbon dioxide (CO_2) and nitrogen). There are no known health effects associated with ambient CH_4 and it is not defined as a hazardous air pollutant (**US EPA, 2014**). CH_4 only poses a health risk under extremely high concentrations in a confined environment. This is due to the ability of CH_4 to act as an asphyxiant, displacing oxygen in the blood. CH_4 is also highly explosive when mixed with oxygen at certain concentrations.

3.1 Health criteria

Currently, there are no NSW or international health criteria established for CH_4 that would be relevant to the ambient concentration increase that could be expected with CSG leakage or fugitive release.

Internationally, the (United States) National Institute for Occupational Safety and Health (NIOSH) references a maximum recommended safe CH_4 concentration for workers during an 8-hour period, referred to as a Threshold Limit Value (TLV), of 1,000ppm (**NIOSH, 2015**). Additionally, criteria are available related to explosivity, where a Lower Explosive Limit (LEL) value of 50,000ppm is referenced.

4 METHANE IN THE ENVIRONMENT

CH_4 is a naturally occurring compound which is found in low concentrations in ambient atmospheric air. The World Meteorological Organisation (WMO) indicates that the global average CH_4 concentration has risen in recent years to 1.824[a]ppm (**WMO, 2014**). This background value of CH_4 is

[a] For the purposes of this report this value has been rounded to 1.8ppm.

highly variable depending upon type of area (urban or rural), and time of day due to atmospheric inversion processes (discussed in **Section 4.3**).

In rural areas, CH_4 concentrations can be higher than the background value due the potential influence of a number of sources known to release fugitive CH_4. These include livestock, landfills, sewage treatment plants and coal mines. One recent study performed in a rural area of the upper Spanish plateau determined that hourly CH_4 concentrations ranged from 1.8 ppm to 3.9ppm with a mean of 1.9ppm (**Sánchez *et al*., 2014**)

Studies completed by **Lowry *et al*. (2001)** in London, where the greatest CH_4 contributors were reported to be associated with gas storage and distribution systems as well as sewage treatment, measured CH_4 concentrations as high as 6.1ppm when investigating diurnal patterns of CH_4 and δ13C-CH_4. This study observed hourly averages commonly ranging between 1.8ppm and 3.0ppm. Contributors to the diurnal fluctuations were not only influenced by the prevailing meteorological conditions (i.e. temperature inversions), but also periods when the general population tend to use gas appliances (i.e. cooking, hot water systems etc.).

The primary removal mechanism of CH_4 from the atmosphere is through chemical reactions with the hydroxyl radical (OH) forming carbon dioxide (CO_2). The OH reacts with a number of gases in the atmosphere and is commonly referred to as a chemical species that 'cleans' the atmosphere.

4.1 Sources of methane

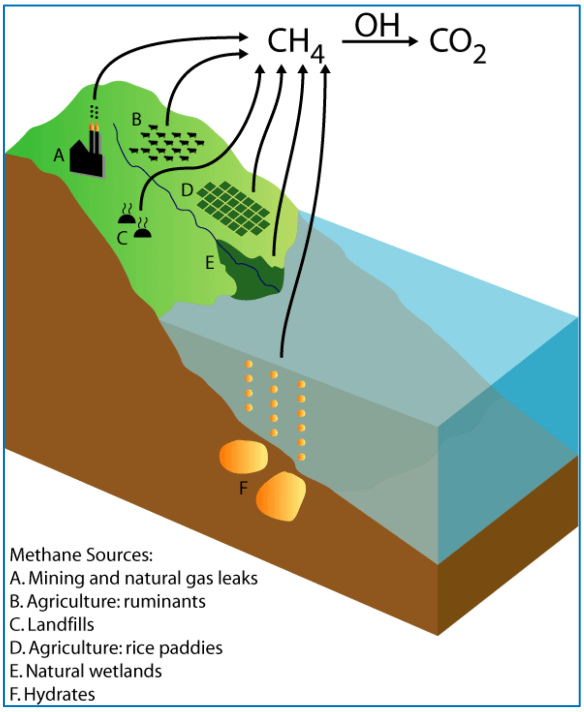
There are two major sources of CH_4 in the environment. These are biogenic (natural) sources and anthropogenic (human) sources.

CH_4 naturally occurs as a by-product of microbial respiration. This typically requires saturated environments where microbes called "methanogens" can thrive. Ideal environments include wetlands, bogs and stagnant waters. Another natural source of significance is CH_4 released by animals such as termites and wild animals.

Anthropogenic sources of CH_4 are caused by human activities such as landfills, sewage treatment plants, industrial emissions and coal seam gas extraction. Another large source of anthropogenic CH_4 is agricultural practices via ruminant digestion processes or rice paddies.

Figure 4-1 depicts the main sources and sinks of CH_4 in the environment. Any of these sources may be expected to yield CH_4 concentrations of >10ppm, however with no implications for health.

There are no known health effects associated with CH_4 and it is not defined as a hazardous air pollutant (**US EPA, 2014**). Human health trigger level concentrations for CH_4 are governed by its potential for asphyxiation or explosivity.



(**Source: NASA GISS, 2013**)

Figure 4-1: Sources of methane in the environment

4.2 Methane isotopes and source signatures

CH_4 contains stable isotopes of hydrogen (H) and carbon (C). The ratio of stable C isotopes (^{13}C:^{12}C) in CH_4 provides information on the source of the CH_4 in a sample of gas. For example, biogenic sources of CH_4 typically contain more isotopically light CH_4 (i.e. a high proportion of the light isotope of carbon (^{12}C)) than anthropogenic or thermal sources. This is caused by a microbial preference to consume lighter C isotopes due to the lower energy requirements compared to consuming ^{13}C. The reduced proportion of ^{13}C in a sample of biogenic CH_4 causes a more negative value compared to anthropogenic CH_4 sources.

The ratio of CH_4 in a sample is expressed as a "$\delta^{13}C$" value in parts per thousand/per mil (‰) notation. This value is obtained upon comparison to a calcium carbonate standard referred to as Pee Dee Belemnite (PDB).

The isotopic composition of common CH_4 sources has been characterised in a number of studies of the past several decades. **Table 4-1** provides a summary of the most common CH_4 sources and the $\delta^{13}C$-CH_4 for each source. These $\delta^{13}C$-CH_4 values are consistent with those established in other studies discussed in Initial report on the Independent Review of Coal Seam Gas Activities in NSW (**CS&E, 2013**) where, broadly speaking, $\delta^{13}C$-CH_4 values less (or more negative) than -55‰ are associated with biogenic CH_4 and $\delta^{13}C$-CH_4 values above -55‰ are related to thermogenic sources of CH_4. It is important to note that the $\delta^{13}C$-CH_4 characteristic of a source is more commonly observed as a range of measurements than a single discrete number.

Table 4-1: $\delta^{13}C-CH_4$ of background atmospheric air and common natural and anthropogenic methane sources

Source	$\delta^{13}C-CH_4$ (‰)
Atmospheric	
Ambient air	-47
Natural sources	
Wetlands (swamps)	-55±3
Wetlands (bogs and tundra)	-65±5
Oceans	-59
Mud volcanoes	-40
Termites	-57
Wild animals	-62
Anthropogenic sources	
Biomass burning (C4 vegetation)	-17±3
Biomass burning (C3 vegetation)	-26±3
Enteric fermentation (C4 vegetation)	-49±4
Enteric fermentation (C3 vegetation)	-70±4
Landfill	-53±2
Domestic sewage	-57±3
Rice paddies	-62±3
Coal extraction	-35±3
Gas extraction (North Sea)	-34±3
Gas extraction (Siberia)	-50±3
Gas extraction (QLD, Australia)	-54±1
Residential	-38

Source: **Montiel *et al*. (2011), Dlugokencky *et al*. (2011), Tyler *et al*. (2007), Hamilton *et al*. (2003)**

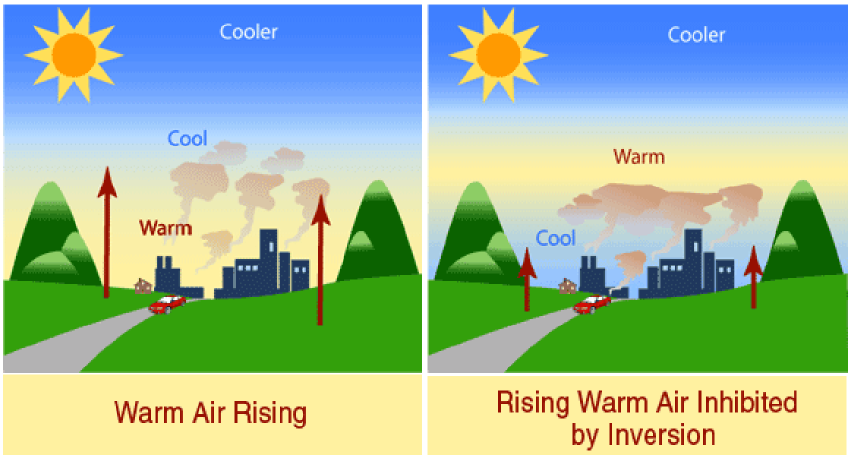
Scientists are able to ascertain the potential source of a fugitive CH_4 emission by comparing the $\delta^{13}C-CH_4$ of a sample with known ranges of $\delta^{13}C-CH_4$ determined from a reference data set. The reference data set could either be from values published in scientific literature, as shown in **Table 4-1**, or known sources of CH_4 in the area being studied (e.g. landfills, wetlands, and mining operations).

It should be noted that there are limitations associated with using of $\delta^{13}C-CH_4$ values to categorically identify a CH_4 source, particularly when measuring under ambient conditions. This is because at ambient concentrations (i.e. the global average being 1.8 ppm (**WMO, 2014**), the air will by definition be comprised of a mixture of multiple sources as opposed to one main source. This means that there is significantly more variability (or 'noise') in the $\delta^{13}C-CH_4$ values measured.

The higher the concentration of CH_4 observed (i.e. the stronger the signal), the more effective the use of $\delta^{13}C-CH_4$ as a metric of CH_4 source identification. Therefore, at low, well mixed CH_4 concentrations (such as those measured during the study period) interpretation of the $\delta^{13}C-CH_4$ results should be considered indicative.

4.3 Inversion conditions

Inversion conditions can occur during the cooler months where on clear nights, night time drainage flows pool in valleys with the warmer air above trapping the air below. Inversion conditions are conducive to higher CH_4 concentrations, as any CH_4 is trapped within a shallow (often only 50 meters high) layer of air. It is usually not until the mid-morning that an inversion is broken down by the influence of the heat of the morning sun that allows mixing of the stable layer with layers aloft, as experienced during daylight hours. This mixing allows any CH_4 to disperse and become less concentrated. **Figure 4-2** shows a graphical comparison of when the dispersion of emissions with and without an inversion.



(**Source: Pollutionfree, 2014**)

Figure 4-2: Temperature inversion

4.4 Sources applicable to the current study

Prior to the commencement of the baseline CH_4 monitoring program, the $\delta^{13}C$-CH_4 for potential sources of CH_4 in the Gloucester area has been characterised. A summary of the findings of this study are provided in the following section.

Samples of AGL gas from two representative gas wells were collected and analysed. In addition, two sample sites at a nearby landfill and livestock were selected based on the assumption that these would also be significant contributors of CH_4 in the Gloucester air shed. A description of each gas sample source is as follows:

- Landfill (fresh) – fresh landfill that was placed within the past month;
- Landfill (capped 18 months) – landfill that has been placed within the past 6 – 12 months;
- Livestock (cow manure) – fresh cow manure

Photographs taken during the collection of the samples are shown in **Figure 4-3**.

The landfill and livestock related CH_4 samples were collected using an isolation flux hood, configured in similar method as employed for area source odour sampling (**NSW EPA 2006**).

The results of the $\delta^{13}C$-CH_4 analysis are presented in **Figure 4-4**. The average $\delta^{13}C$-CH_4 across all samples ranged between -44‰ (landfill capped 18 months) and -51‰ (livestock). The samples collected from the landfill and AGL gas samples were in generally lower (more negative) than the sample for the livestock. This is in agreement with the preferential uptake of ^{12}C over ^{13}C by microbial activity discussed above, resulting in typically lighter CH_4, with a lower $\delta^{13}C$-CH_4, from biogenic sources.

For the gas well samples, the range of the average $\delta^{13}C$-CH_4 was between -50‰ and -44‰. This indicates that the $\delta^{13}C$-CH_4 of coal seam gas can vary across the gas well network. The $\delta^{13}C$-CH_4 can also vary within each gas bag sampled as shown in the range of $\delta^{13}C$-CH_4 measured from each gas bag (e.g. WK3 Samples 1 and 2).

Figure 4-4 shows a histogram of the $\delta^{13}C$-CH_4 for all samples. The three sample groups show a unique 'fingerprint' of the $\delta^{13}C$-CH_4 values measured. This data can be used to compare with field samples to ascertain the source of the CH_4.

Figure 4-3: Photographs during collection of reference samples

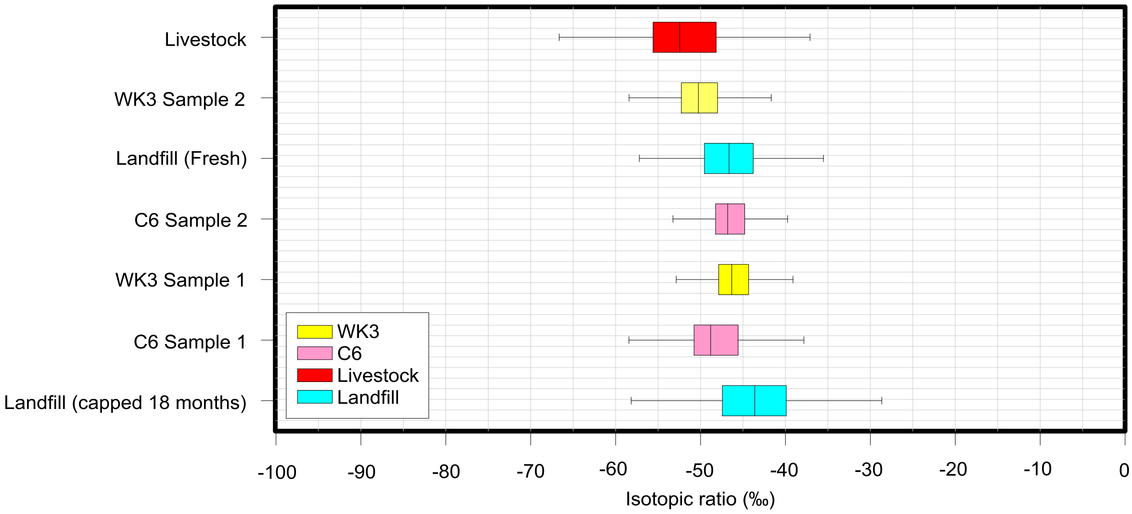


Figure 4-4 Box and whisker plot showing δ[13]C-CH4

Note: The centreline of the box indicates the median value. The left side of the box indicates the lower quartile and the right indicates the upper quartile. The far left and far right error bars indicate the minimum and maximum of the values measured.

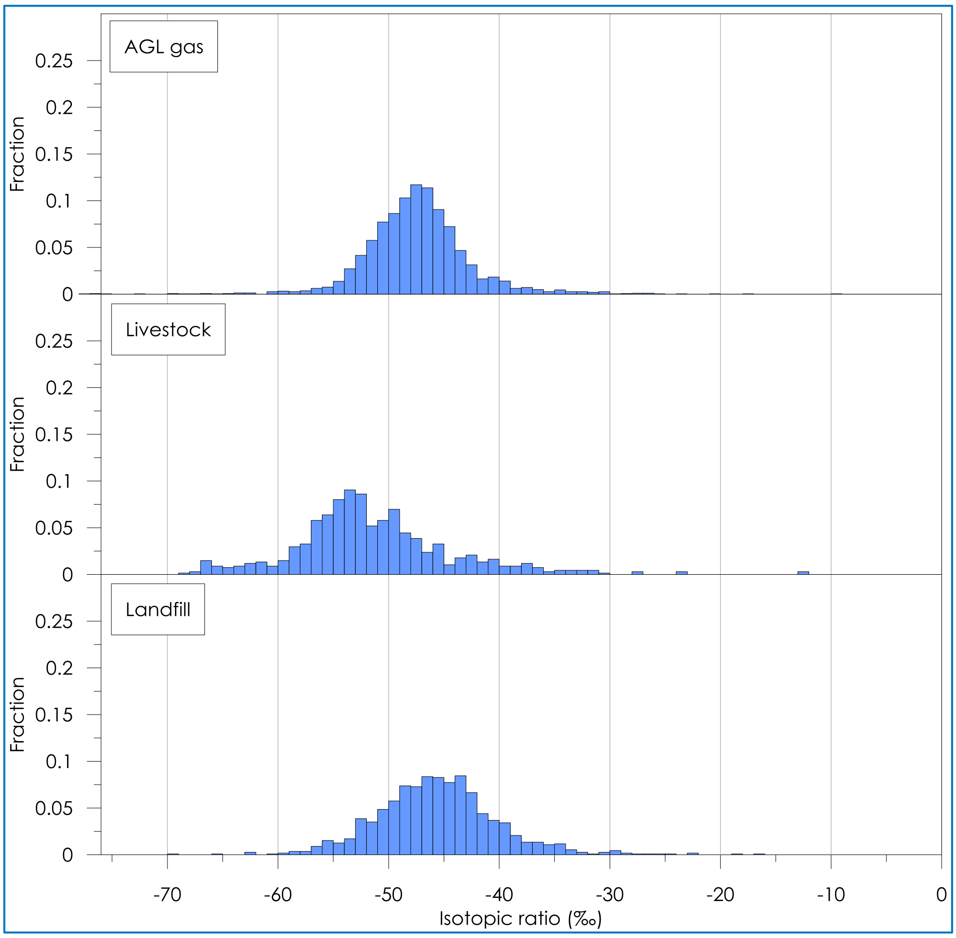


Figure 4-5: Histogram of δ[13]C-CH4 of sample groups

5 METHODOLOGY OF FIELD STUDY

5.1 Baseline Assessment

The field campaign has been designed to collect ambient CH_4 concentration data from across the Gloucester region. To gather a sufficient dataset for this baseline study, an initial four week campaign was completed in August 2013. Since then, four additional runs were completed in January 2014, October 2014, November 2014 and May 2015.

Mobile monitoring (i.e. surveying CH_4 concentrations using an instrument mounted within a vehicle) was completed over 202 km route. Further detail as to site selection is provided in **Section 5.3.** A stationary monitor was also installed as part of the August 2013 works to characterise the diurnal CH_4 concentrations.

To complete the baseline survey of the Gloucester area in August 2013 and January 2014, the monitoring was conducted over two weekdays with different days selected each week to remove the potential for systematic bias in the sampling. On each day the selected route was completed in either the morning or afternoon to account for potential diurnal variation in CH_4.

5.2 Activity Monitoring

Additional monitoring campaigns of the Gloucester area were undertaken during fracture stimulation, and during flaring in late-2014 and mid-2015. AGL completed hydraulic fracturing of four pilot wells between mid-October and late-November 2014.

The May 2015 monitoring survey was completed while flaring was occurring from the four Waukivory pilot wells. During the post-fracture stimulation and mid-flaring monitoring runs, monitoring was conducted over one weekday. The selected route was completed in the morning and afternoon to account for potential diurnal variation in CH_4.

In addition to the results presented in this report, Pacific Environment has also conducted a small scale monitoring study of an alternative route to the one used in this study. This was performed to compare baseline levels to those after hydraulic fracturing had begun in an additional nearby area in Gloucester (**Pacific Environment, 2014a**).

5.3 Monitoring route

To meet the objective of this baseline study 'to determine the concentrations of CH_4 that are typically experienced at locations within the Gloucester Gas Project area', the monitoring program has been designed to measure CH_4 over a 202 km route that is representative of the conditions in the Gloucester region.

Figure 5-1 shows the routes used for the study. **Table 5-1** provides a summary description of each route.

Figure 5-1 also shows the location of AGL's Gloucester weather station. The second stationary Picarro was installed adjacent to the weather station so that meteorological influences can be accounted for in the CH_4 concentration measurements.

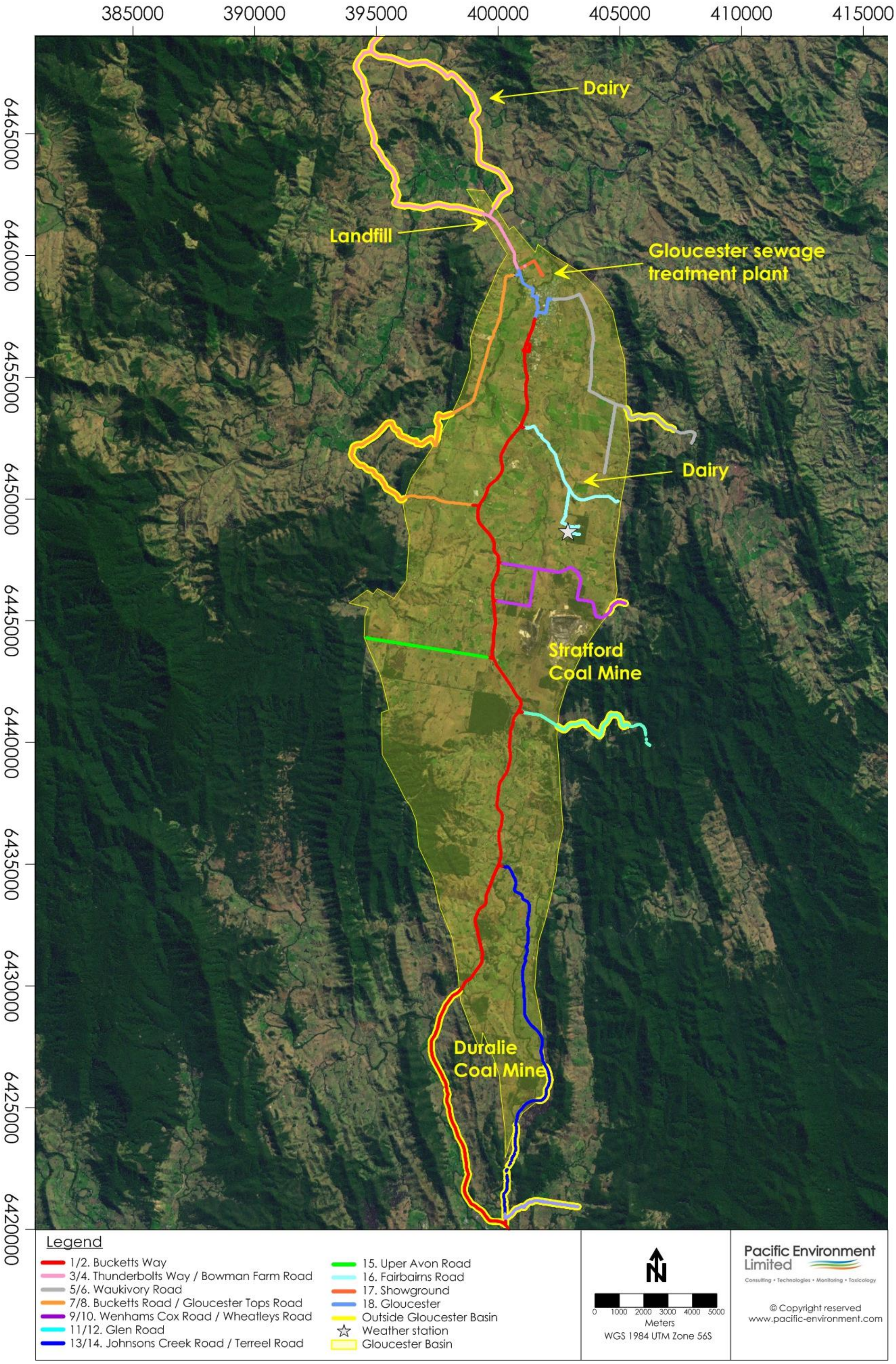


Figure 5-1: Monitoring routes

Table 5-1: Description of monitoring locations

Site number	Site description	Location relative to Gloucester geological basin (coal measures)
Route 1	Bucketts Way	Outside Basin
Route 2	Bucketts Way	Inside Basin
Route 3	Thunderbolts Way / Bowman Farm Road	Outside Basin
Route 4	Thunderbolts Way / Bowman Farm Road	Inside Basin
Route 5	Waukivory Road	Outside Basin
Route 6	Waukivory Road	Inside Basin
Route 7	Bucketts Road / Gloucester Tops Road	Outside Basin
Route 8	Bucketts Road / Gloucester Tops Road	Inside Basin
Route 9	Wenhams Cox Road / Wheatleys Road	Outside Basin
Route 10	Wenhams Cox Road / Wheatleys Road	Inside Basin
Route 11	Glen Road	Outside Basin
Route 12	Glen Road	Inside Basin
Route 13	Johnsons Creek Road / Terreel Road	Outside Basin
Route 14	Johnsons Creek Road / Terreel Road	Inside Basin
Route 15	Upper Avon Road	Inside Basin
Route 16	Fairbairns Road	Inside Basin
Route 17	Showground	Inside Basin
Route 18	Gloucester	Inside Basin

5.4 Instrumentation

The samples were analysed using a Picarro G-2201-*i* Cavity Ring Down Spectrometer (Picarro) that measures the CH_4 concentrations and corresponding $\delta^{13}C$-CH_4. The Picarro was operated in high precision mode.

The Picarro monitoring system was configured for this mobile monitoring campaign, measuring CH_4 concentration, isotopic values for CH_4 along with GPS coordinates. The system components are housed within an AGL vehicle (Toyota Land Cruiser Troop Carrier) and configured to meet the recommendations of the Picarro Mobile Kit User's Guide (**Picarro, 2011**). **Figure 5-2** provides an image of the mobile set up used in the AGL field study.

A second Picarro (G-2132-i) was also installed to provide continuous CH_4 concentration measurements at one location.

The Picarro has been used extensively in other overseas studies (**Phillips *et al.*, 2012**) and in Australia as outlined in the *Initial report on the Independent Review of Coal Seam Gas Activities in NSW* (**CS&E, 2013**).

5.5 Calibration

Prior to the commencement of the monitoring campaign the Picarro was calibrated using CSIRO's calibration gases located at their Energy Technology Centre in Mayfield West, NSW.

To ensure the ongoing accuracy and consistency of the CH_4 concentrations, single point calibrations were completed using bottled CH_4 gas of known concentration on the day of each run.

During the monitoring campaign both instruments were calibrated by the University of New South Wales using 20 calibration gases that are referenced against the high precision gas chromatography isotope ratio mass spectrometry that is operated by the Greenhouse Gas Laboratory, Royal Holloway, University of London.

Figure 5-2: AGL mobile monitoring kit

6 RESULTS AND DISCUSSION

A summary of the monitoring dates and whether the run was completed in the morning (between 7am – 12pm) or afternoon (12pm – 6:30pm) are provided in **Table 6-1**.

Table 6-1: Summary of monitoring runs

Run number	Date	time
Baseline monitoring		
Run 1	29/07/2013	Afternoon
Run 2	30/07/2013	Morning
Run 3	06/08/2013	Afternoon
Run 4	07/08/2013	Morning
Run 5	14/08/2013	Afternoon
Run 6	15/08/2013	Morning
Run 7	19/08/2013	Afternoon
Run 8	20/08/2013	Morning
Run 9	21/01/2014	Afternoon
Run 10	22/01/2014	Morning
Mid-fracture stimulation monitoring		
Run 11	20/10/2014	Morning
Run 12	20/10/2014	Afternoon
Run 13	07/11/2014	Afternoon
Run 14	08/11/2014	Morning
Mid-flaring monitoring		
Run 15	19/05/2015	Morning
Run 16	19/05/2015	Afternoon

Provided in **Appendix A** are a series of maps showing the CH_4 concentrations as measured along each route measured on the day of the monitoring. Summary tables of the monitoring results for the 18 routes within the Gloucester area are provided as **Appendix B** (see **Figure 5-1** for the location of each route). A time series during the initial four week campaign of the CH_4 concentration data measured at the stationary monitoring site is presented in **Appendix C**.

As a significant amount of data has been collected during the 16 monitoring runs completed to date, discussion is focused and provided where elevated CH_4 concentrations were measured or field observations warranted further investigation.

Over the duration of the monitoring period, 80 hours of 1 second measurements of CH_4 concentration were recorded over 3,200 km of the Gloucester region. To provide a holistic view of the variability of CH_4 concentration, box and whisker plots of the entire data set by site and by week have been prepared in **Figure 6-1** and **Figure 6-2**, respectively.

Over the entire monitoring program the average CH_4 concentration was 1.8ppm, consistent with the global average of 1.8ppm (**WMO, 2014**)

Table 6-2 presents the data by each route, with the average, the maximum and the minimum measured. The average of the data ranges between 1.8ppm and 1.9ppm. The CH_4 concentration data by site shows that the greatest 1 second CH_4 concentrations were measured on Route 17

(Showground). It is noted that Route 17 passes by the Gloucester sewage treatment plant, a known source of fugitive CH_4 emissions (see **Figure 5-1** for the location of the monitoring routes).

Table 6-3 presents the data by run, with the average, the minimum and maximum of the average data. Run 5 showed the greatest variability with the 1-second concentrations ranging between 1.7ppm and 3.9ppm.

Figure 6-3 and **Figure 6-4** show the corresponding $\delta^{13}C\text{-}CH_4$ values for the CH_4 concentration data presented in **Figure 6-1** and **Figure 6-2**, by route and by run, respectively. Route 13 averaged the lowest (most negative) $\delta^{13}C\text{-}CH_4$ values and Route 1 averaged the highest (least negative) $\delta^{13}C\text{-}CH_4$ values. The greatest variability in $\delta^{13}C\text{-}CH_4$ values was experienced on Route 13, while the most consistent $\delta^{13}C\text{-}CH_4$ values were recorded on Route 9. By run, the most consistent $\delta^{13}C\text{-}CH_4$ values were measured during Run 15, with greatest variability recorded during Run 13. Over the 10 week baseline monitoring program, the average $\delta^{13}C\text{-}CH_4$ was -41‰. During the mid-fracture stimulation and mid-flaring monitoring, the average $\delta^{13}C\text{-}CH_4$ was -46‰ and -50‰ respectively. Over the entire 16 week monitoring program the average $\delta^{13}C\text{-}CH_4$ was -43‰.

As noted above, there are limitations associated with using $\delta^{13}C\text{-}CH_4$ values to categorically identify a CH_4 source at the concentrations observed within the study. This is because close to background concentrations (i.e. the global average being 1.8ppm (**WMO, 2014**)), the CH_4 will be by definition a mixture of multiple sources, meaning there is significantly more variability (or 'noise') in the $\delta^{13}C\text{-}CH_4$ values measured.

Notwithstanding the above, the $\delta^{13}C\text{-}CH_4$ results from this study are provided as an indicator in assessing the origins of the CH_4 (i.e. biogenic or thermogenic). More detailed results for each individual site for each of the 16 runs are provided in **Appendix B**.

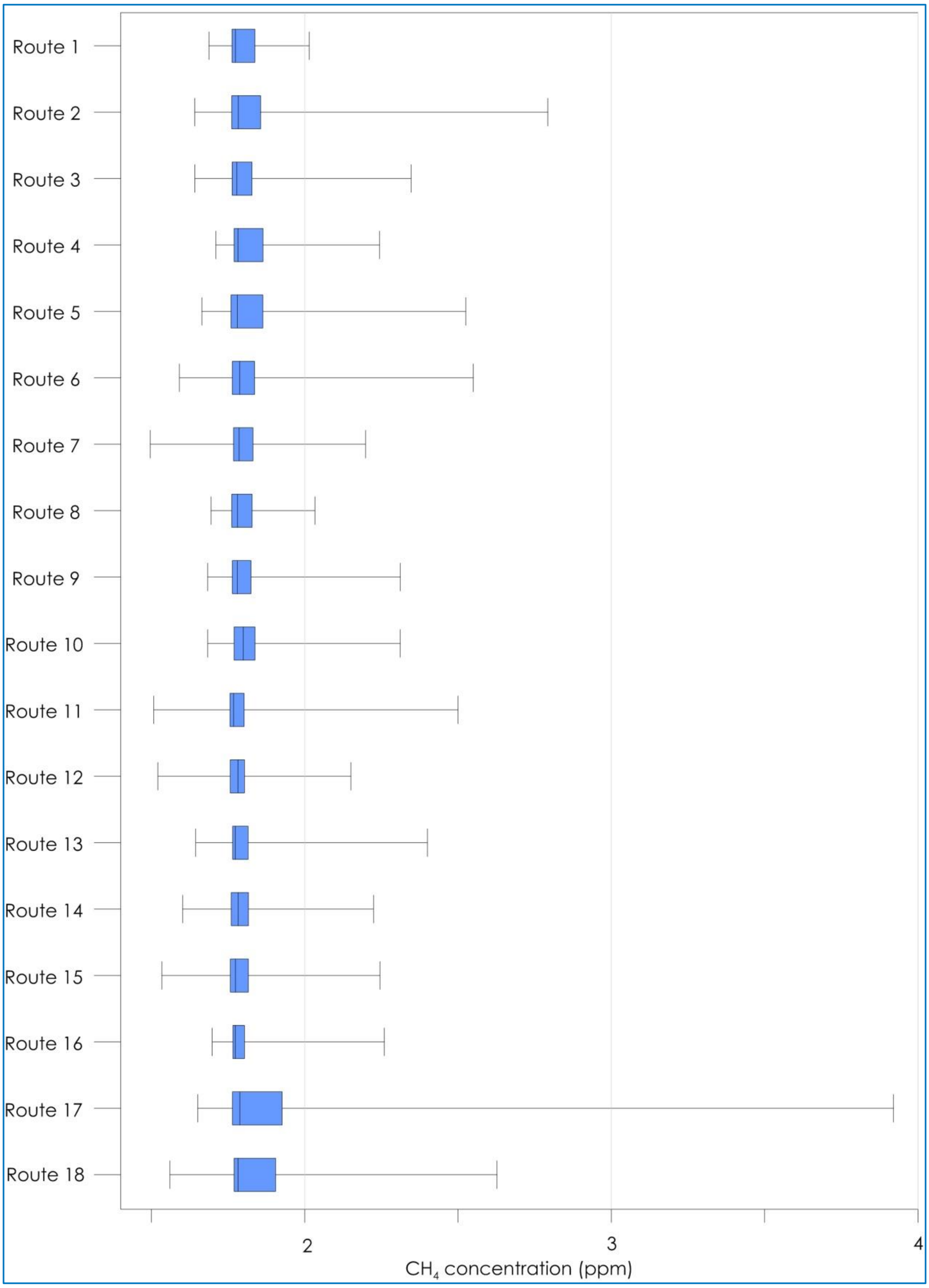


Figure 6-1: Box and whisker plot of CH_4 concentration for all monitoring data by route for the duration of the monitoring period (all runs combined)

Note: The centreline of the box indicates the median value. The left side of the box indicates the lower quartile and the right indicates the upper quartile. The far left and far right error bars indicate the minimum and maximum of the values measured.

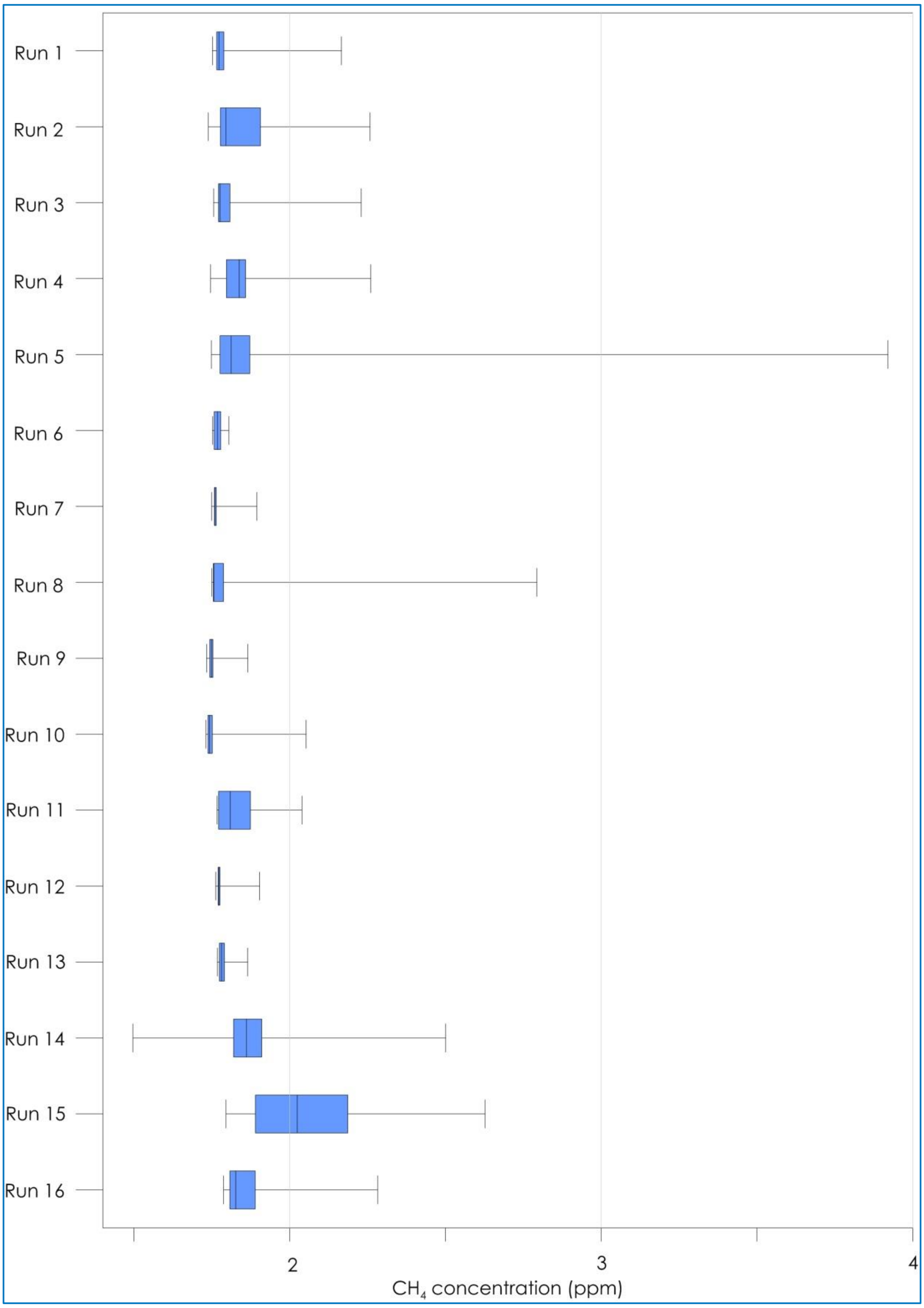


Figure 6-2: Box and whisker plot of CH_4 concentration for all monitoring data by run for the duration of the monitoring period (all routes combined)

Note: The centreline of the box indicates the median value. The left side of the box indicates the lower quartile and the right indicates the upper quartile. The far left and far right error bars indicate the minimum and maximum of the values measured.

Table 6-2: Summary of data by route

Monitoring site	Average	Minimum	Maximum
Route 1	1.8	1.7	2.0
Route 2	1.8	1.6	2.8
Route 3	1.8	1.6	2.4
Route 4	1.8	1.7	2.2
Route 5	1.9	1.7	2.5
Route 6	1.8	1.6	2.6
Route 7	1.8	1.5	2.2
Route 8	1.8	1.7	2.0
Route 9	1.8	1.7	2.3
Route 10	1.8	1.7	2.3
Route 11	1.8	1.5	2.5
Route 12	1.8	1.5	2.1
Route 13	1.8	1.6	2.4
Route 14	1.8	1.6	2.2
Route 15	1.8	1.5	2.3
Route 16	1.8	1.7	2.3
Route 17	1.9	1.7	3.9
Route 18	1.9	1.6	2.6

Table 6-3: Summary of data by run

Week	Average	Minimum	Maximum
Run 1	1.8	1.8	2.2
Run 2	1.8	1.7	2.3
Run 3	1.8	1.8	2.2
Run 4	1.8	1.7	2.3
Run 5	1.9	1.7	3.9
Run 6	1.8	1.8	1.8
Run 7	1.8	1.7	1.9
Run 8	1.8	1.7	2.8
Run 9	1.8	1.7	1.9
Run 10	1.7	1.7	2.1
Run 11	1.8	1.8	2.0
Run 12	1.8	1.8	1.9
Run 13	1.8	1.8	1.9
Run 14	1.9	1.5	2.5
Run 15	2.1	1.8	2.6
Run 16	1.9	1.8	2.3

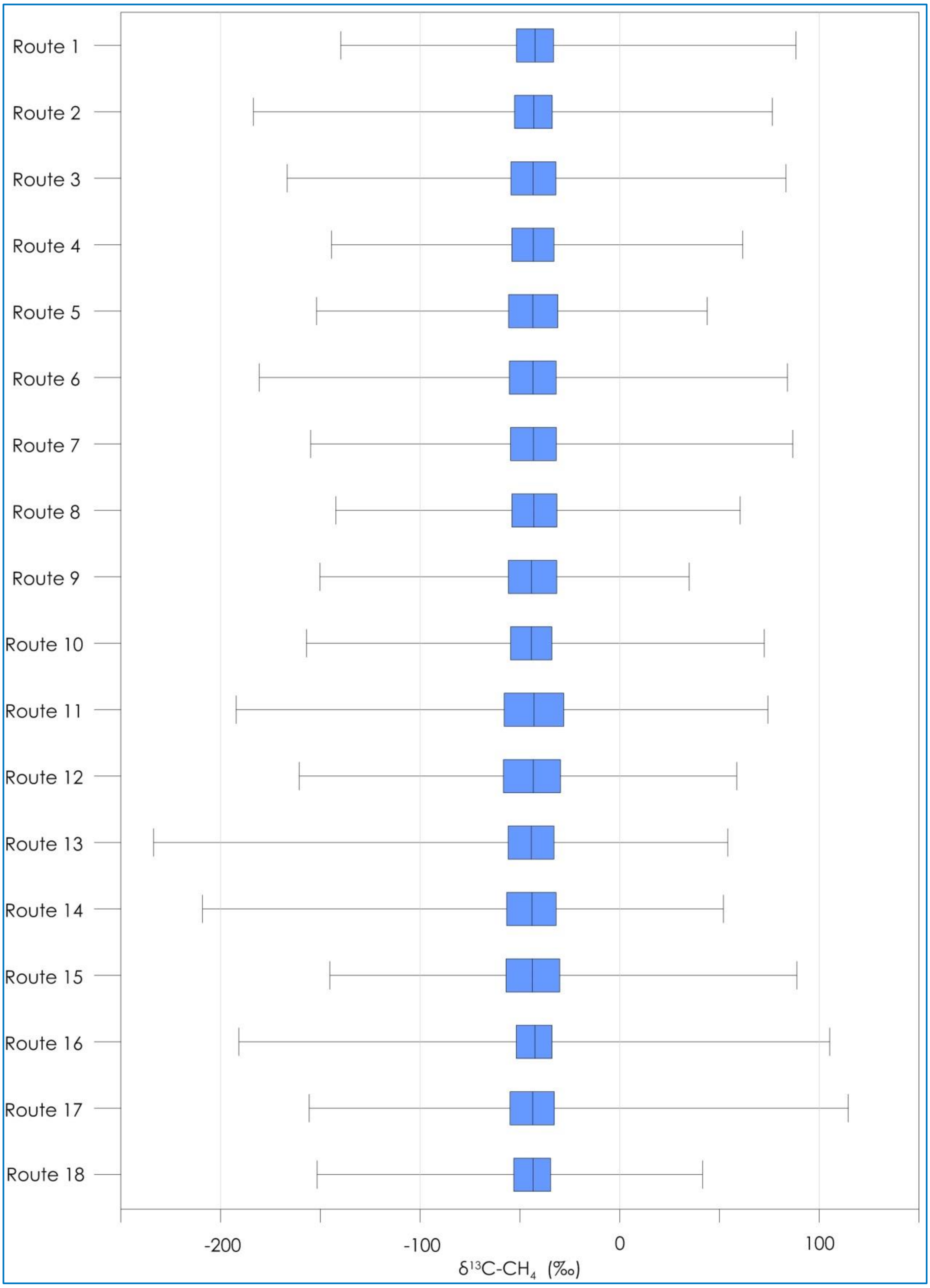


Figure 6-3: Box and whisker plot of δ13C-CH_4 for all monitoring data by route for the duration of the monitoring period

Note: The centreline of the box indicates the median value. The left side of the box indicates the lower quartile and the right indicates the upper quartile. The far left and far right error bars indicate the minimum and maximum of the values measured.

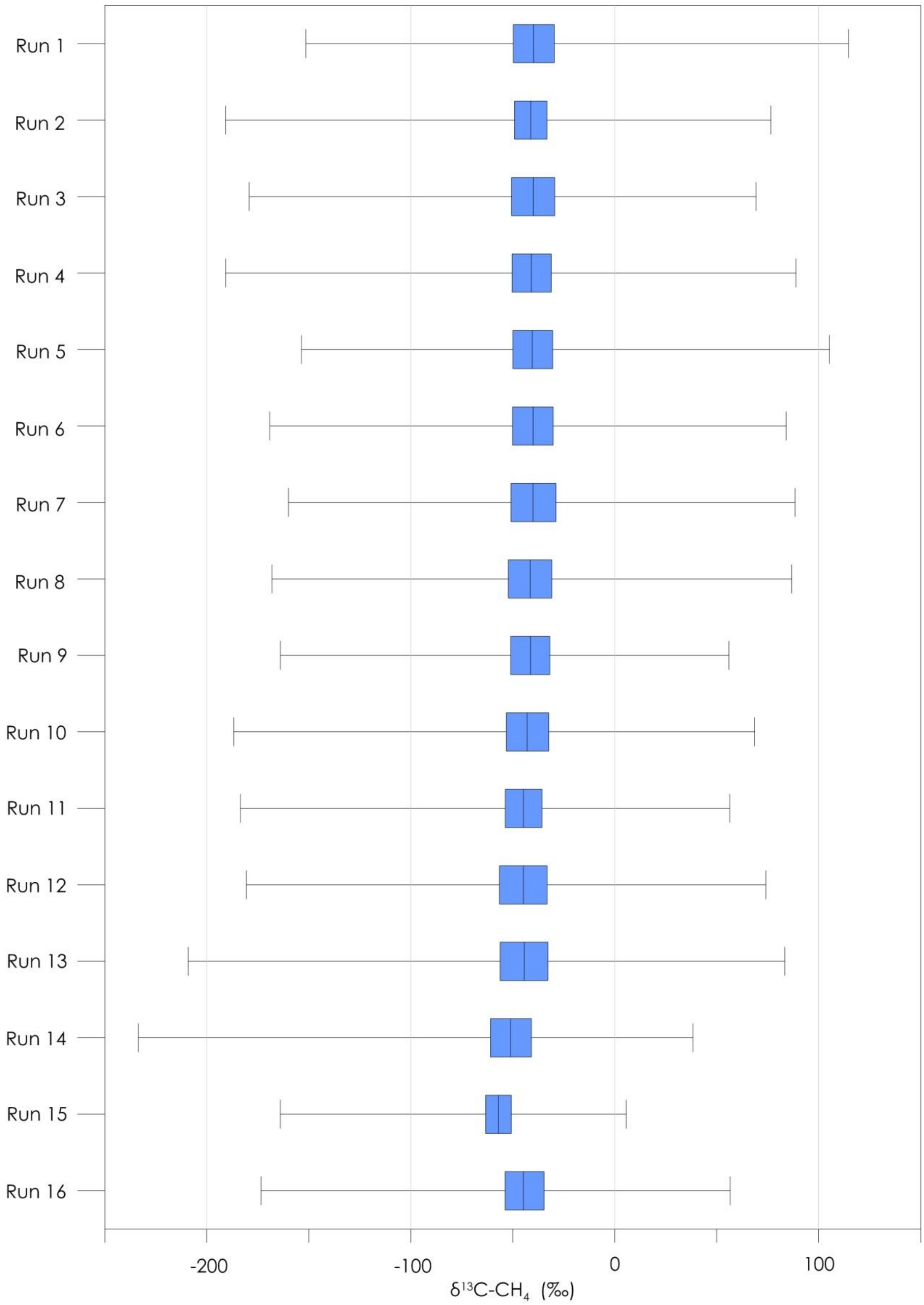


Figure 6-4: Box and whisker plot of δ13C-CH4 for all monitoring data by run for the duration of the monitoring period

Note: The centreline of the box indicates the median value. The left side of the box indicates the lower quartile and the right indicates the upper quartile. The far left and far right error bars indicate the minimum and maximum of the values measured.

A summary of key findings are presented in **Section 6.1** below.

6.1 Key findings

The following points provide an overview of the monitoring results:

- The 1 second interval CH_4 concentration ranged between 1.5ppm to 3.9ppm across all routes and runs investigated during the field campaign.
- Over the 12 week monitoring program the average CH_4 concentration was 1.8ppm. This value is consistent with the global average background of 1.8ppm (**WMO, 2014**). The corresponding average $\delta^{13}C\text{-}CH_4$ was -43‰, similar to values observed in residential areas reported in **Montiel *et al.* (2011)**.
- The highest 1-second CH_4 concentration was 3.9ppm measured near the showground (Route 17) during Run 5 (see **Table 6-1**). This was followed by Route 2 (Bucketts Way – inside basin) with a maximum of 2.8ppm.
- The $\delta^{13}C\text{-}CH_4$ values measured on Route 17 during Run 5 were shown to be more negative than values measured along other routes during this week. This indicated a biological source of CH_4 in the area. Route 17 is located adjacent to a sewage treatment plant which is a known source of fugitive CH_4 with a biological origin. This is therefore identified as the likely source of the methane in this area during Run 5.
- On average, the CH_4 concentrations measured during mobile monitoring were lowest during Runs 9 and 10, at 1.75ppm.
- The highest average CH_4 concentrations over a single run were observed during Run 15 at an average of 2.1ppm.
- There was negligible difference observed between the CH_4 concentrations measured inside and outside of the Gloucester Basin.
- At the stationary monitoring location the highest CH_4 concentration was 4.1ppm, measured at 1:43am on 31 August 2013.
- The stationary monitoring data indicate that there is a diurnal trend in CH_4 concentration, with the highest levels occurring during the late evening and early hours of the morning. This is most likely associated with meteorological conditions (i.e. low atmospheric mixing heights due to temperature inversion conditions).
- Temperature inversion conditions showed negligible influence on CH_4 concentrations in the Gloucester area measured using mobile monitoring. This is likely due to the mobile monitoring not capturing the hours of the day (i.e. 2200 to 0400) when CH_4 concentration is shown to be higher as evidenced with the data from the stationary monitoring site.
- Based on field observations and results of similar studies in Camden (**Pacific Environment, 2014b**) in addition to scientific literature (**Montiel *et al.*, 2011; Dlugokencky *et al.*, 2011)** sources of CH_4 in the Gloucester area have been identified and include:
  - Landfill
  - Sewage treatment Plant
  - Agriculture
  - Saturated soils
- The route averaged $\delta^{13}C\text{-}CH_4$ during individual runs ranged between -37‰ and -59‰. It should be noted that these are averaged values. The 1 second measurements fluctuate significantly more.

6.2 Inversion conditions

Figure 6-5 displays the average CH_4 concentrations measured during mobile monitoring by time of day. Whilst morning data appears to be somewhat higher and more variable, the inversion conditions described in **Section 4.3** in the Gloucester area during monitoring do not appear to be significant. This is likely due to the timing of the mobile monitoring. Inversion conditions typically affect atmospheric CH_4

concentrations during the hours of 22:00 to 04:00. Inversion effects are evidenced in the data from the stationary monitoring site (**Appendix B**).

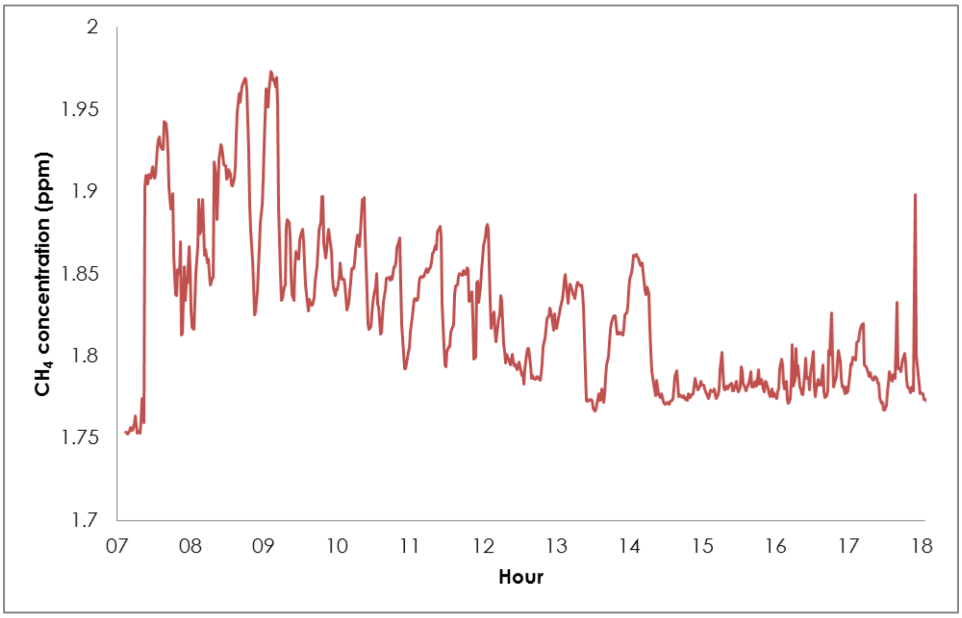


Figure 6-5: CH_4 concentrations averaged by time of day during mobile monitoring campaign

6.3 Methane concentrations

6.3.1 Methane concentrations by run

Aside from Run 15, average methane concentrations were all within 1.7ppm and 1.9ppm

RUN 15

The highest concentrations of CH_4 were observed during Run 15 where the average CH_4 concentration was 2.1ppm. This concentration is 0.2ppm – 0.3ppm higher than all of the other runs performed.

It was observed during this run that due to a prior rain event, large pools of stagnant water were observed on farms and on the side of the road. There was also a large herd of dairy cattle located adjacent Waukivory Road during the survey. These saturated soils and livestock are likely to have contributed to the elevated CH_4 concentrations in the area during this run.

All average $\delta^{13}C$-CH_4 values for all routes during run 15 were observed to be more negative than those observed during all other runs (**Table B-15**). Route-averaged $\delta^{13}C$-CH_4 values during Run 15 ranged between -55‰ to -59‰. These values indicate that the elevated CH_4 concentrations were not likely to be caused by CSG but rather caused by biological origin from saturated soils.

Run 16, which was performed during the afternoon of the same day, shows that CH_4 concentrations and $\delta^{13}C$-CH_4 values returned to the typical values observed in previous runs. The decreased concentrations in the afternoon during Run 16 may be attributed to the evaporation of pooled water through the course of the day.

6.3.2 Methane concentrations by route

Two sampling routes showed CH_4 concentrations greater than 1.8ppm over the entire sampling period. These were routes 17 and 18 which all experienced average concentrations of 1.9ppm. These routes are located on Showground and South of Showground in the Gloucester residential area respectively. These are discussed in further detail below.

ROUTE 17 (SHOWGROUND)

Route 17 is located in the immediate vicinity of a sewage treatment plant which is a known source of CH_4 emissions. **Figure 6-1** shows that Route 17 has the highest upper quartile range as well as the highest total range over the entire monitoring campaign than any other route. The highest CH_4 concentration (3.9ppm) for any route over all runs was experienced on Route 17 during the baseline monitoring.

ROUTE 18 (GLOUCESTER- INSIDE COAL SEAM)

Route 18 is located in the Gloucester residential area. Previous studies indicate that residential areas experience slightly higher CH_4 concentrations here compared to surrounding rural area (**Lowry *et al*, 2001; Montiel *et al*, 2011**). On this basis, a CH_4 concentration of 1.9ppm in this location can be considered normal.

6.4 Detection of fugitive methane emissions from gas well operations

To address community concern regarding fugitive CH_4 emissions from the AGL gas well operations, the monitoring data has been analysed to determine if there is a strong signal to determine the source(s) of CH_4 present in the area.

Results were analysed to identify areas where CH_4 concentrations exceed the global background average value of 1.8ppm. In all areas where this occurred, a source of biological CH_4 was identified nearby. These included saturated soils, landfill, a sewage treatment plant, and agriculture such as dairy farms and livestock.

Analysis of run-averaged measurements on CH_4 concentration prior to Waukivory Pilot fracture stimulation activities (runs 1-10) reveals a 95% confidence interval for the mean concentration of between 1.77ppm-1.83ppm (n=10 runs, average= 1.8, standard deviation= 0.05).

The monitoring that was performed during fracture stimulation (runs 11-14), as well as Run 16 which occurred after flaring operations had commenced, lie within the 95% confidence interval for the average of the baseline CH_4 concentrations.

The only run that did not fall within these bounds was Run 15 (Morning run- **Figure 6-6**). As discussed above, $\delta^{13}C\text{-}CH_4$ values for this run (**Figure 6-7**) strongly indicate that the elevated levels were caused by biological activity. These elevated levels did not exceed that which would be expected to occur in a rural area (**Sánchez *et al.*, 2014**) however did exceed typical Gloucester levels. **Figure 6-6** shows that these concentrations reduced during the afternoon run and did not remain elevated.

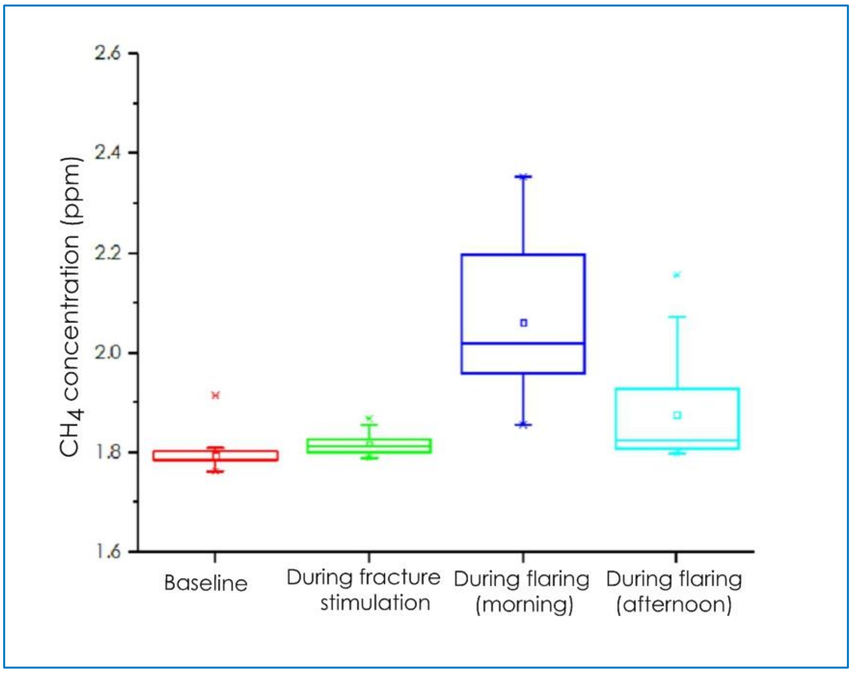


Figure 6-6: Box and whisker plot of route-averaged CH_4 concentration for baseline, during fracture stimulation, and mid-flaring data

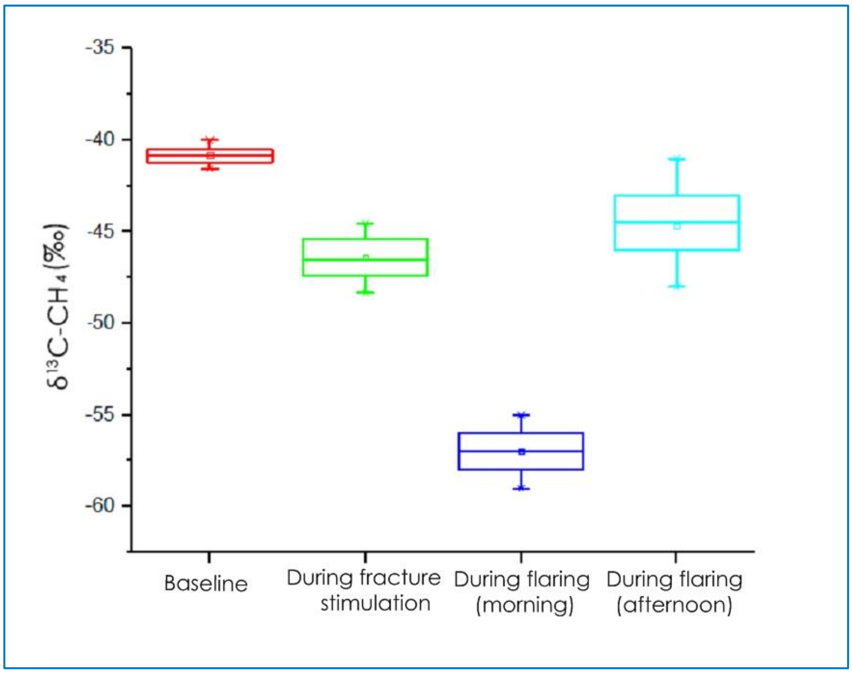


Figure 6-7: Box and whisker plot of route-averaged $\delta^{13}C$-CH_4 values for baseline, during fracture stimulation, and duringflaring data

Note: The centreline of the box indicates the median value. The lower bound of the box indicates the lower quartile and the upper indicates the upper quartile. The top and bottom error bars indicate the maximum and minimum of the values measured with stars denoting outliers.

7 CONCLUSIONS

Principle sources of methane emissions in the Gloucester region were identified as sewage, dairy cattle, landfill, and residential. Monitored 1 second interval CH_4 concentrations in the Gloucester Valley over the entire campaign ranged from 1.5ppm to 3.9ppm. These concentrations were largely identified as being directly related to land-use activities occurring at the time of monitoring. The minimum value was experienced during Run 14 after hydraulic fracturing activities had begun. The maximum was experienced during Run 5 during baseline monitoring prior to the commencement of the Waukivory Pilot Project. These concentrations are within normal ranges which would typically be experienced in rural areas (**Sánchez *et al.*, 2014**).

Over the ten baseline monitoring runs, the average CH_4 concentration was determined to be 1.8ppm (equivalent to the global average background concentrations described in **WMO (2013)**). The average CH_4 concentration measured during fracture stimulation and mid-flaring runs was 1.8ppm and 2.0ppm respectively, both within the normal range expected in rural areas. The higher average concentration after flaring commenced was strongly influenced by the morning run (Run 15) which, due to the particularly negative average $\delta^{13}C\text{-}CH_4$ value, was identified as being associated with biologically produced CH_4.

The highest route-averaged CH_4 concentrations were observed on Route 17 and 18, in the vicinity of a sewage treatment plant and Gloucester residential area. Both of these routes averaged 1.9 ppm CH_4 over the entire monitoring period. These findings indicate that these are likely contributors to fugitive CH_4 emissions in the study area. The landfill on Route 4 however did not appear to strongly influence the CH_4 concentrations in the area as the total average CH_4 concentration on this route was measured at 1.8ppm.

The baseline assessment CH_4 concentrations and $\delta^{13}C\text{-}CH_4$ values have been compared with the post-activity monitoring results (obtained during fracture stimulation and after flaring had commenced). It is concluded that levels of fugitive methane emissions did not increase as a result of the Waukivory Pilot Project including hydraulic fracture stimulation and flaring activities. The observed increase in CH_4 concentrations during Run 15 is attributed to biologically derived CH_4. All methane concentrations during monitoring of baseline, hydraulic fracturing and flaring are determined to be on the lower end of concentrations experienced in urban areas, and within the normal concentration range for a rural area with residential and agricultural land use.

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Appendix A SPATIAL DISTRIBUTION OF METHANE CONCENTRATIONS BY MONITORING RUN

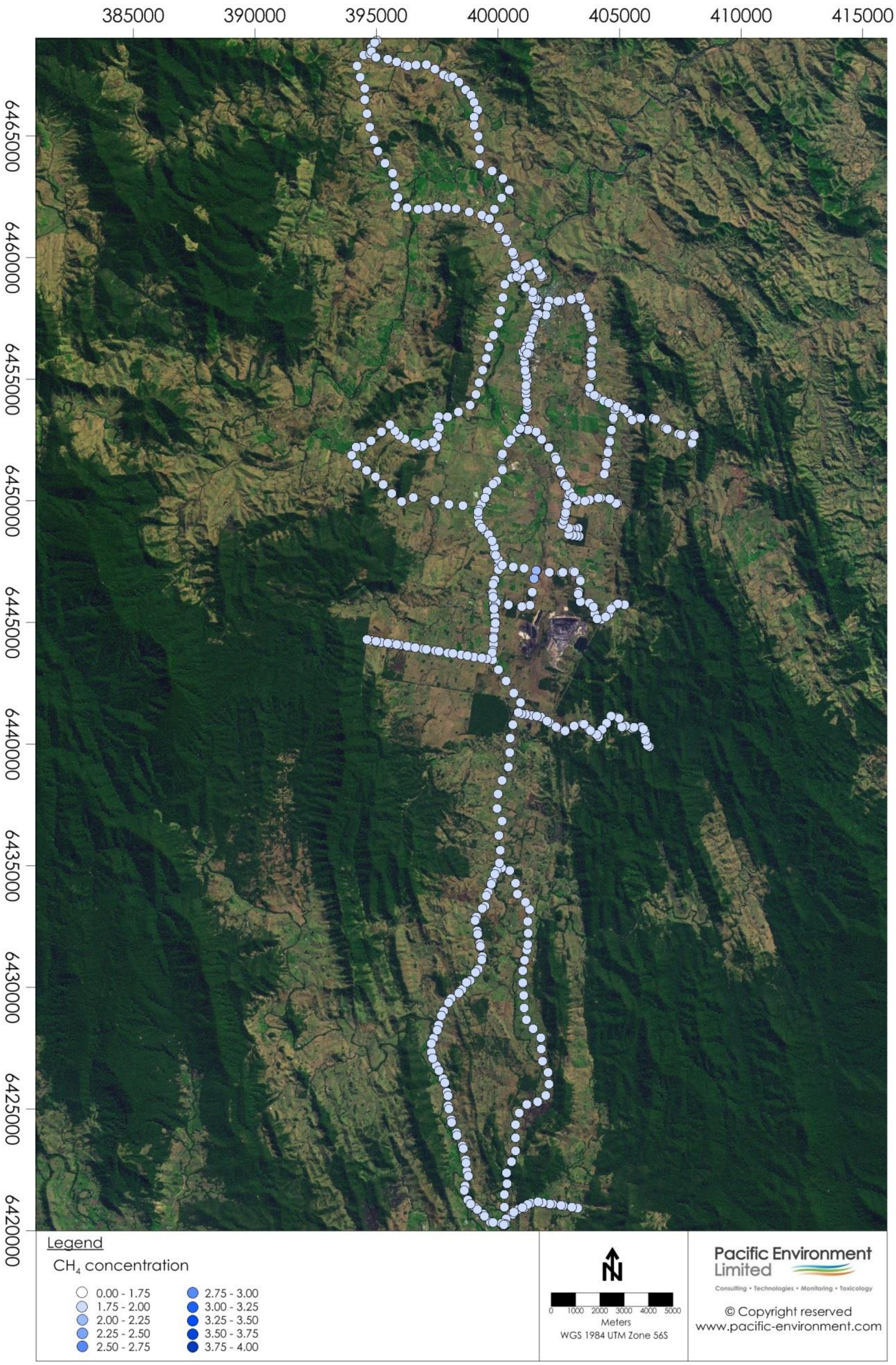


Figure A- 1: CH_4 concentration for Run 1 (29/07/2013 – Afternoon)

Figure A- 2: CH_4 concentration for Run 2 (30/07/2013 – Morning)

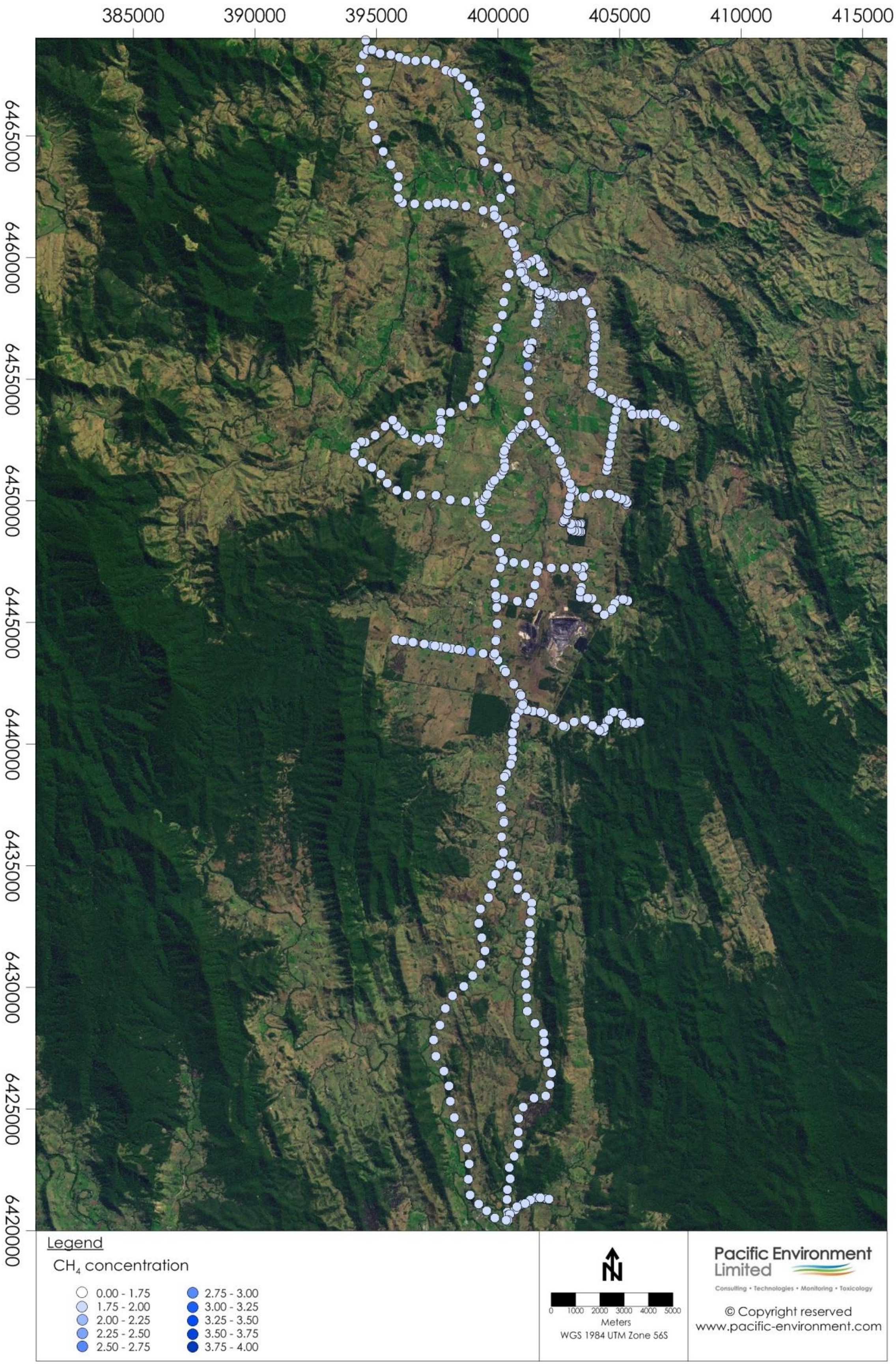


Figure A- 3: CH_4 concentration for Run 3 (06/08/2013 – Afternoon)

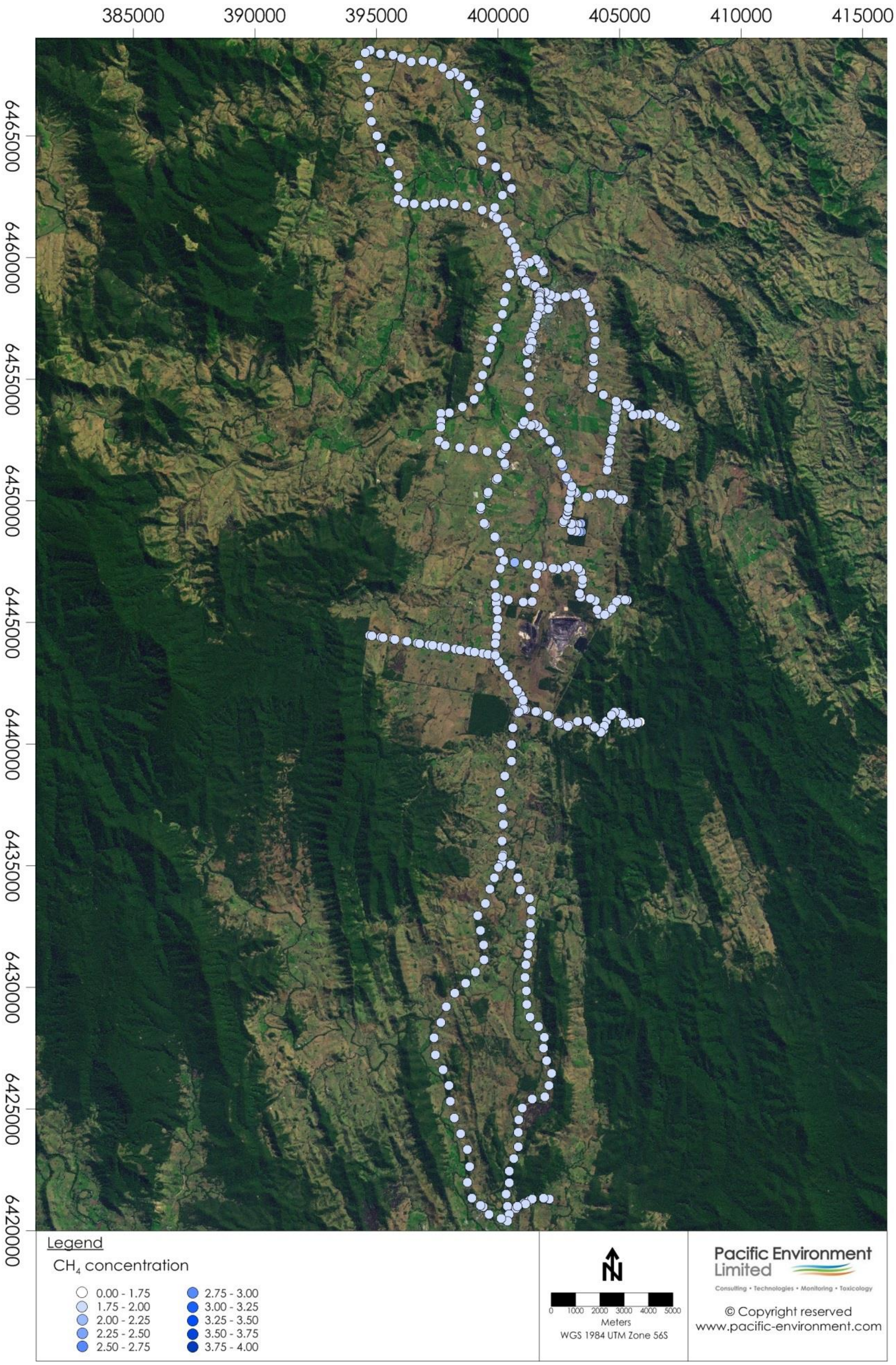


Figure A- 4: CH_4 concentration for Run 4 (07/08/2013 – Morning)

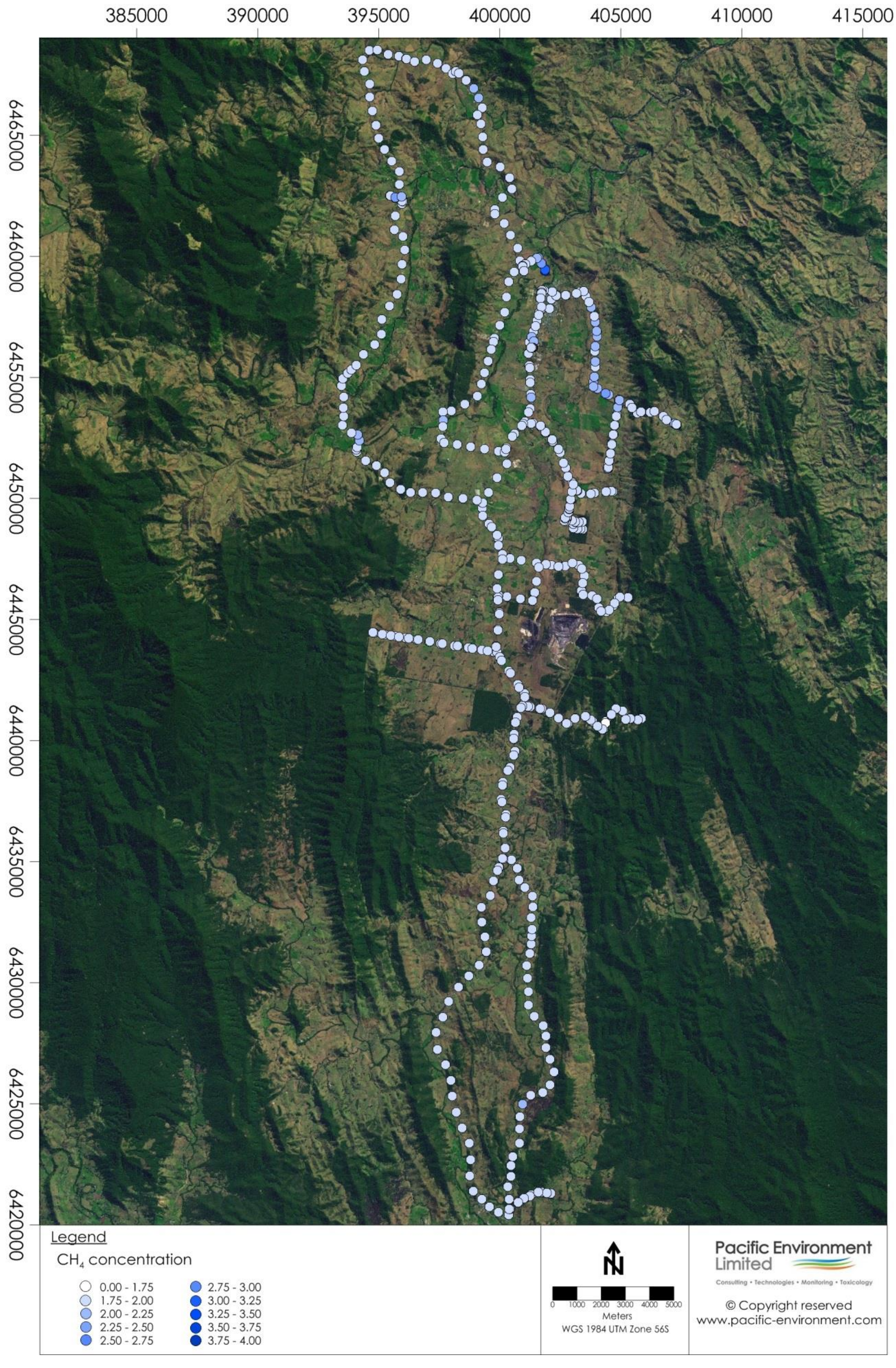


Figure A- 5: CH_4 concentration for Run 5 (14/08/2013 – Afternoon)

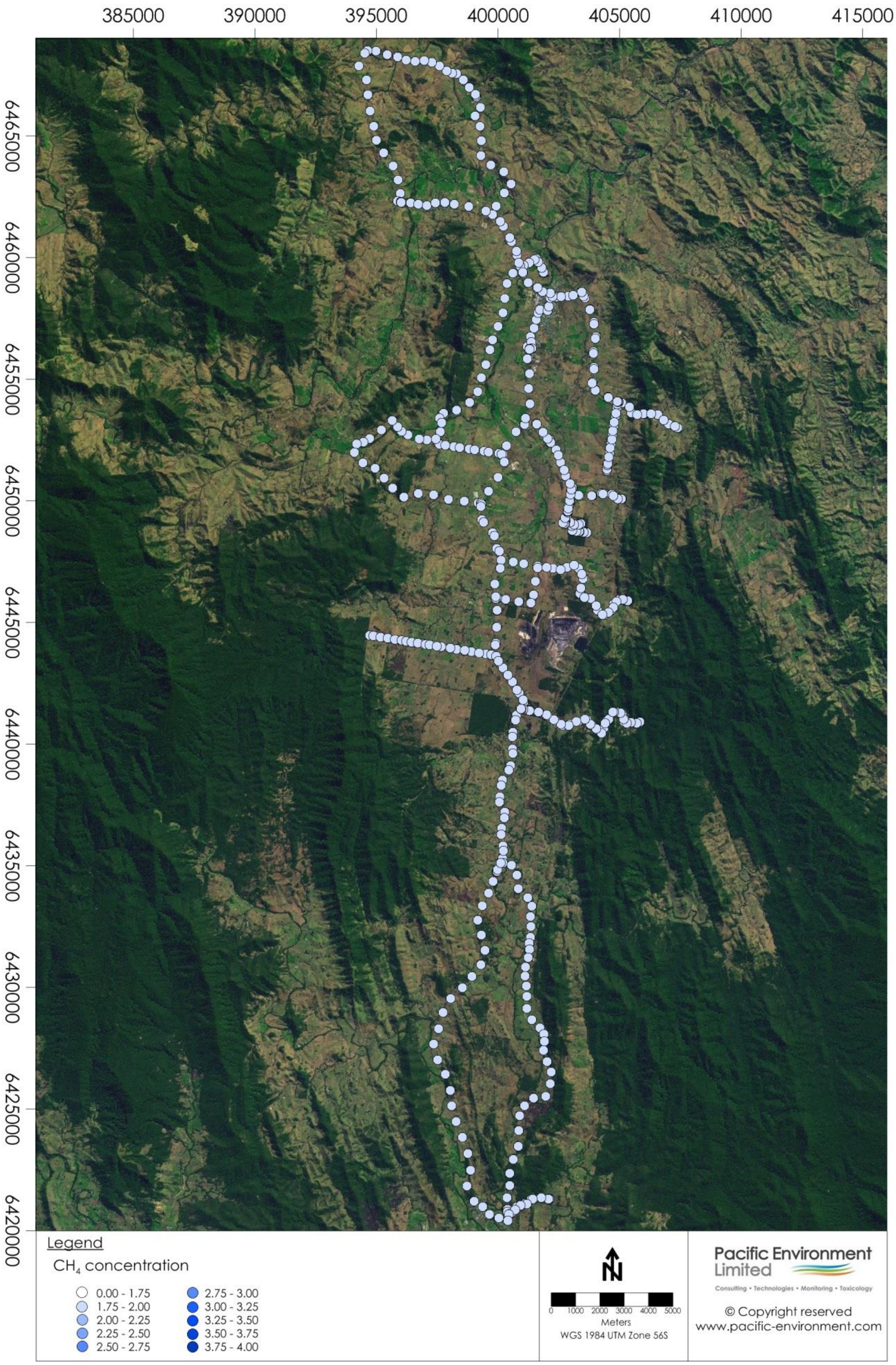


Figure A- 6: CH_4 concentration for Run 6 (15/08/2013 – Morning)

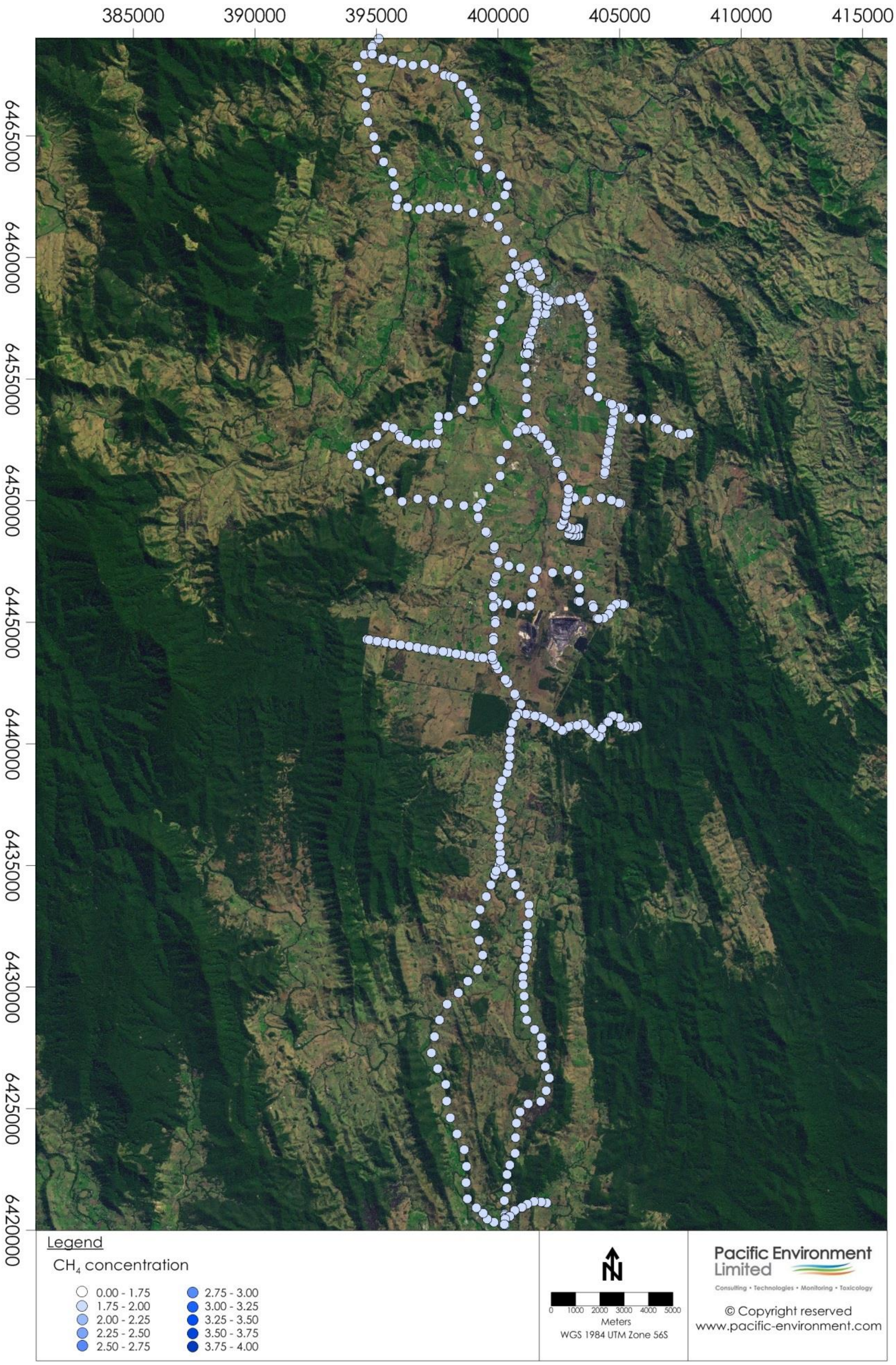


Figure A- 7: CH_4 concentration for Run 7 (19/08/2013 – Afternoon)

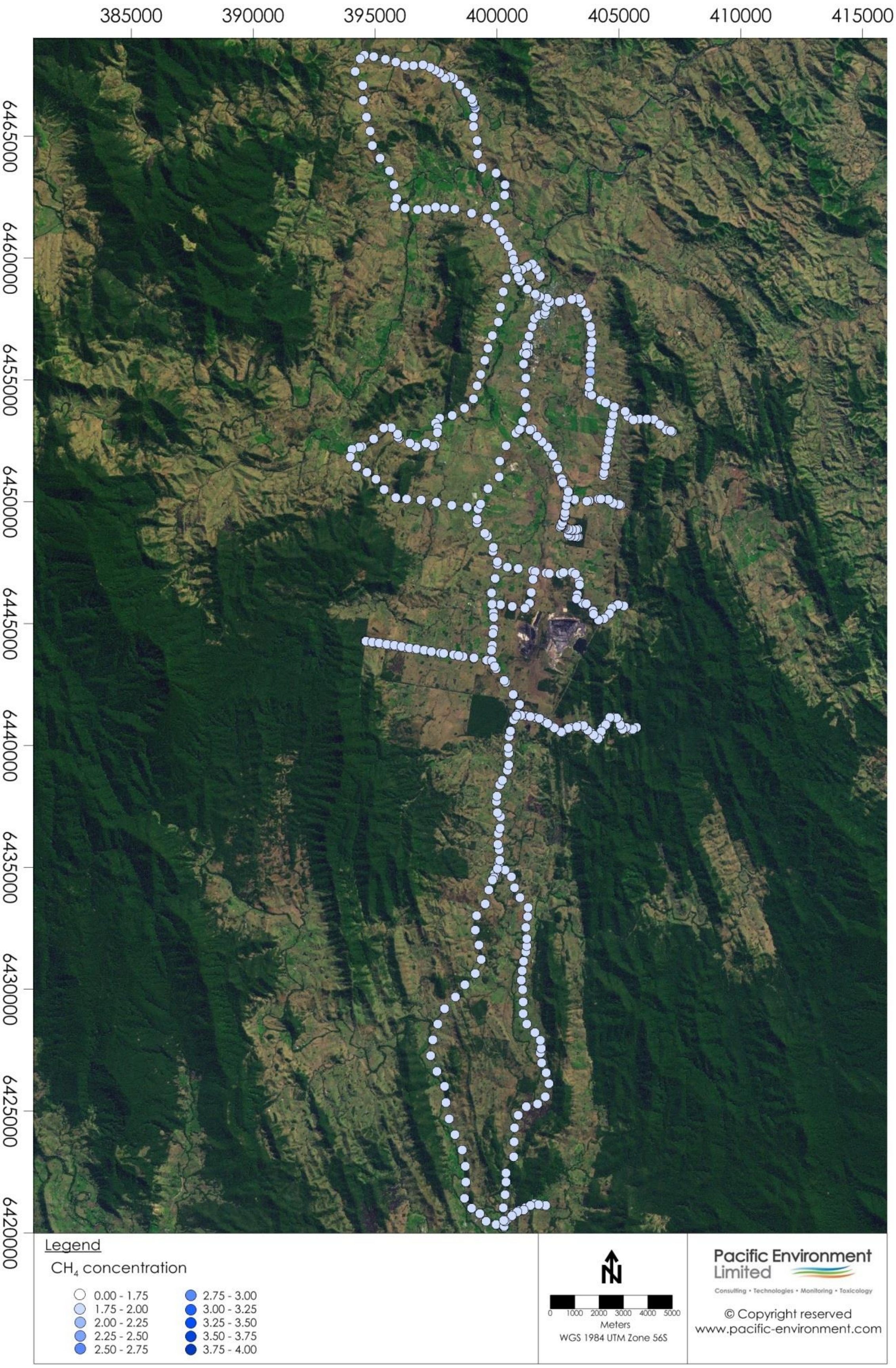


Figure A- 8: CH_4 concentration for Run 8 (20/08/2013 – Morning)

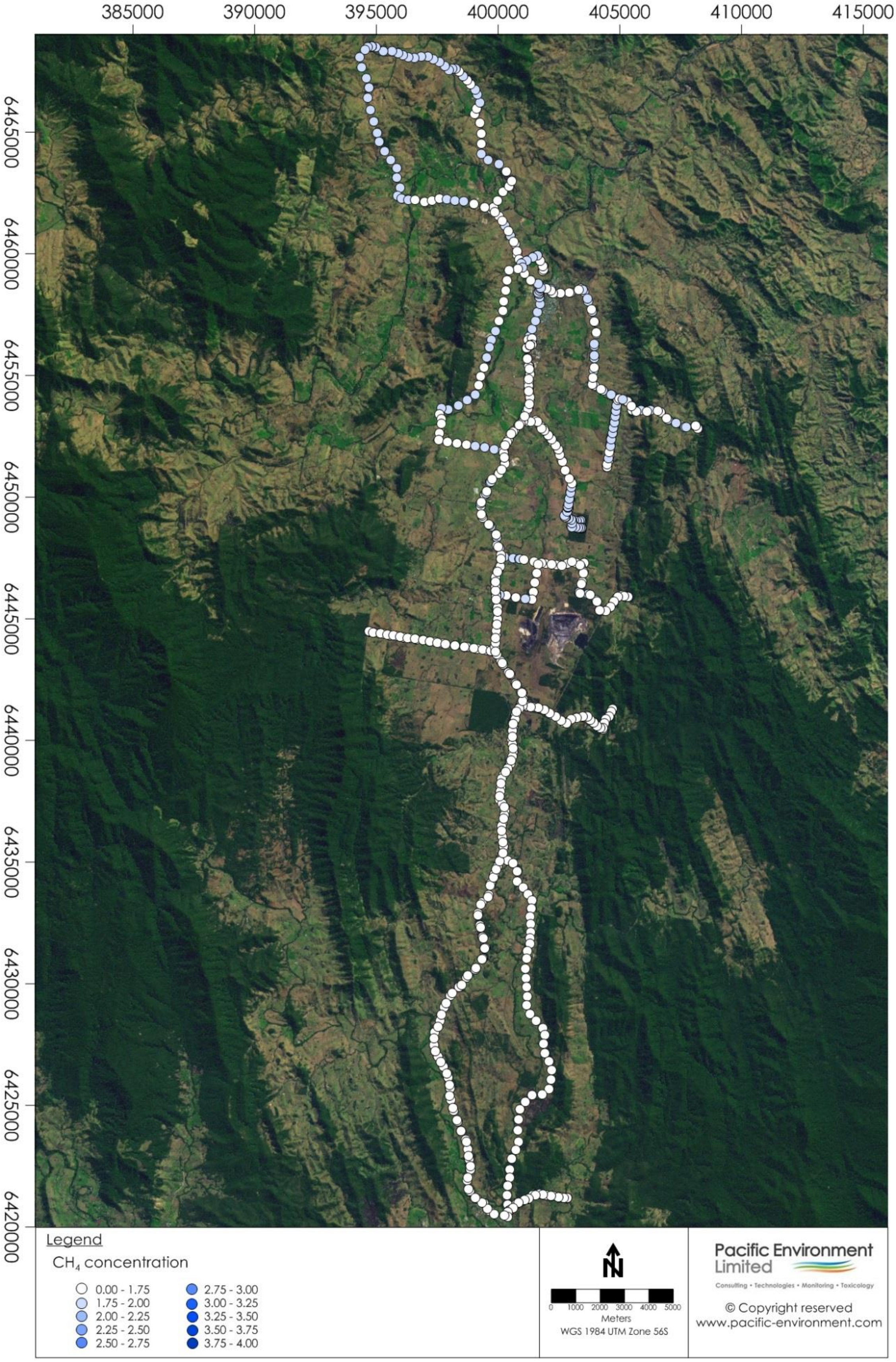


Figure A- 9: CH_4 concentration for Run 9 (21/01/2014 – Afternoon)

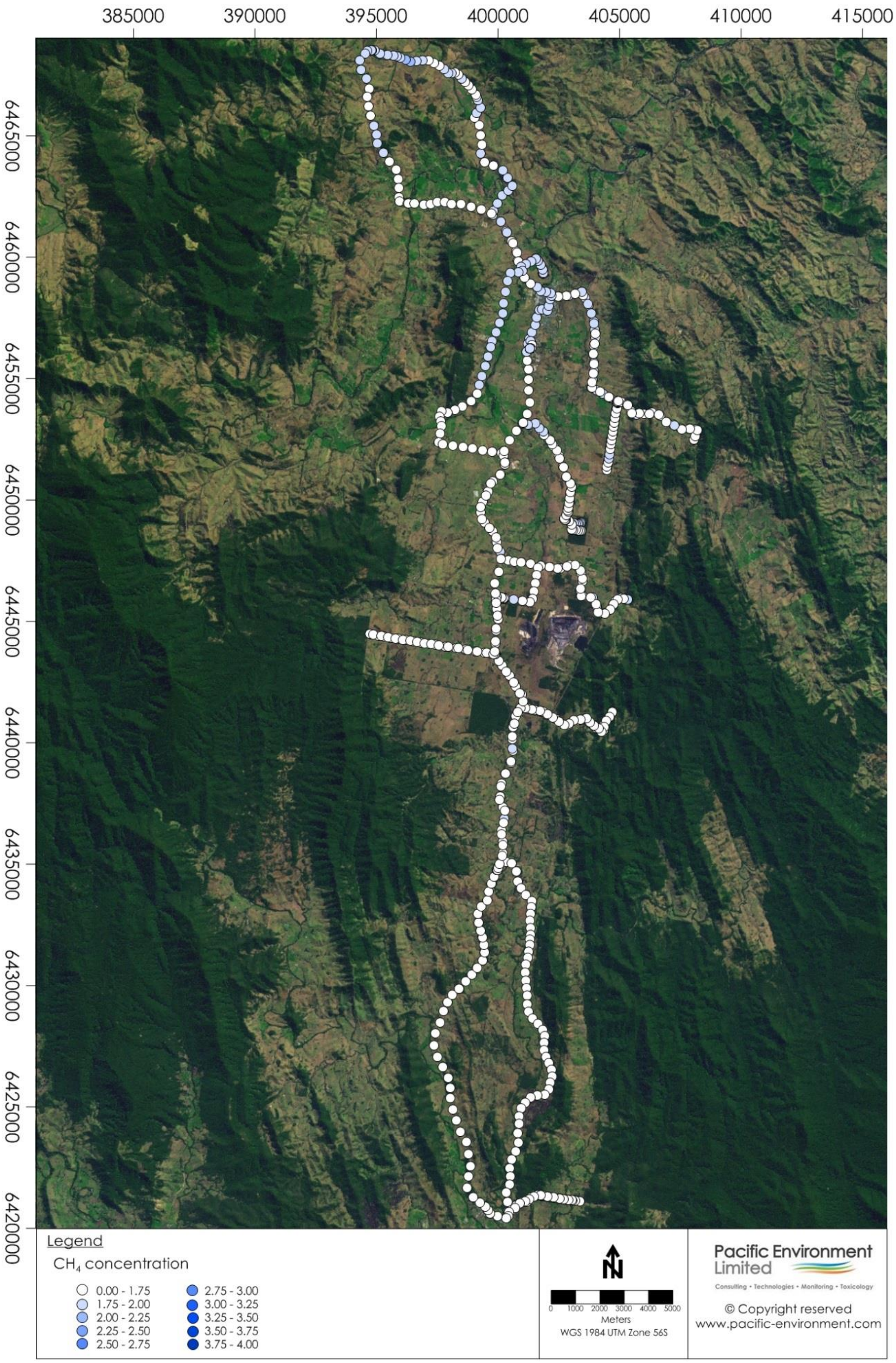


Figure A- 10: CH_4 concentration for Run 10 (22/01/2014 – Morning)

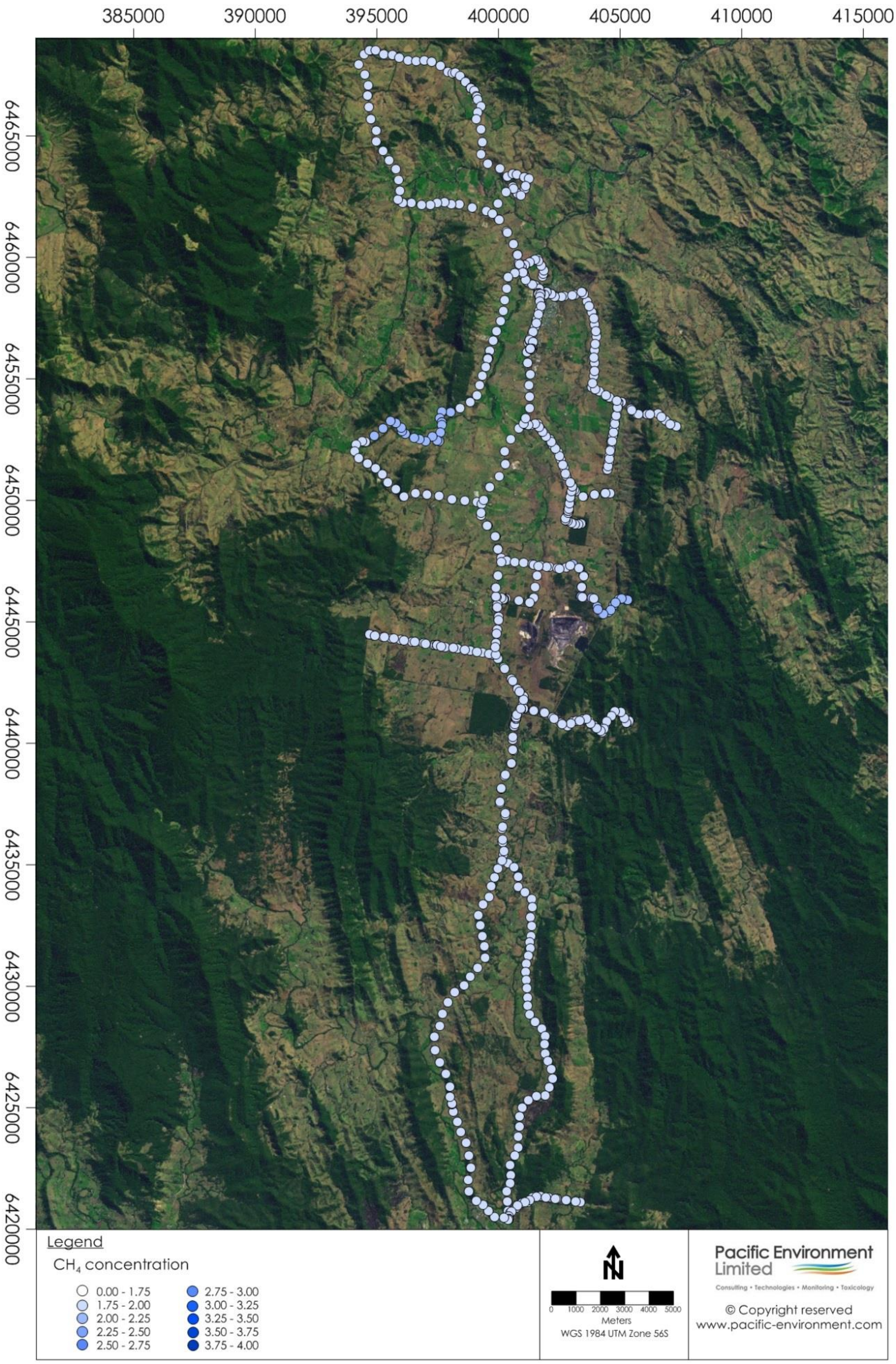


Figure A- 11: CH_4 concentration for Run 11 (20/10/2014 – Morning)

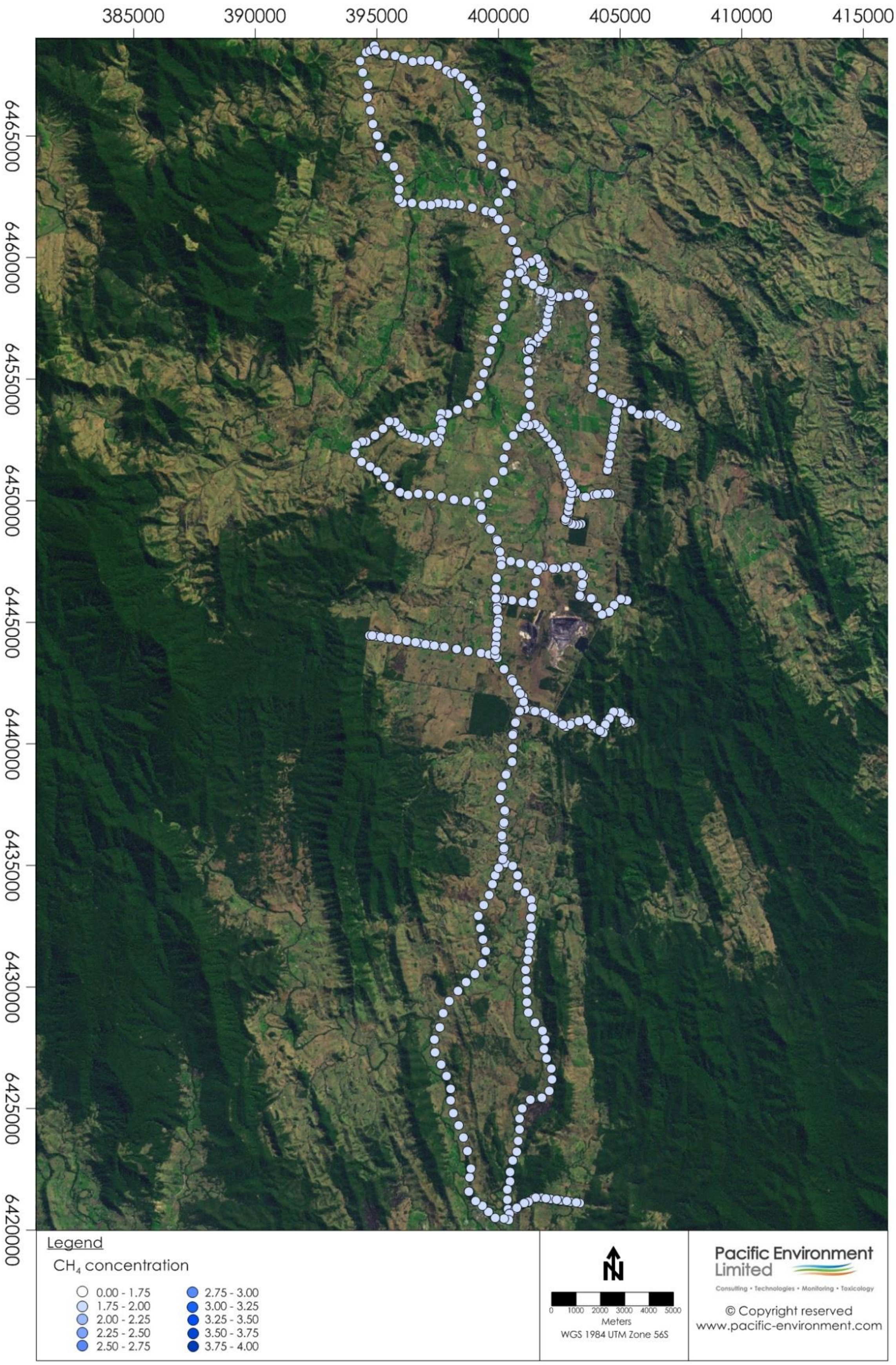


Figure A- 12: CH_4 concentration for Run 12 (20/10/2014 – Afternoon)

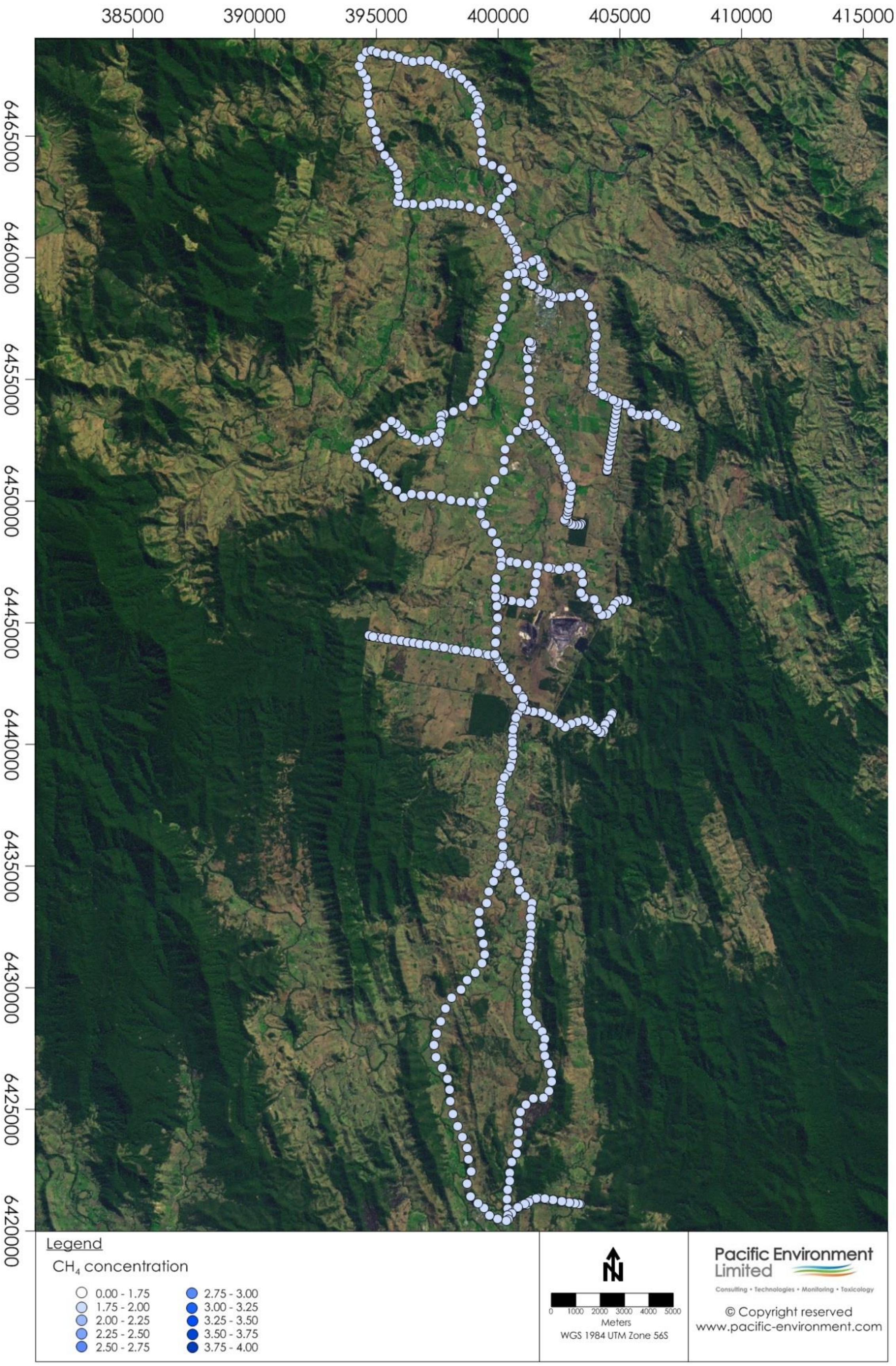


Figure A- 13: CH_4 concentration for Run 13 (7/11/2014 – Afternoon)

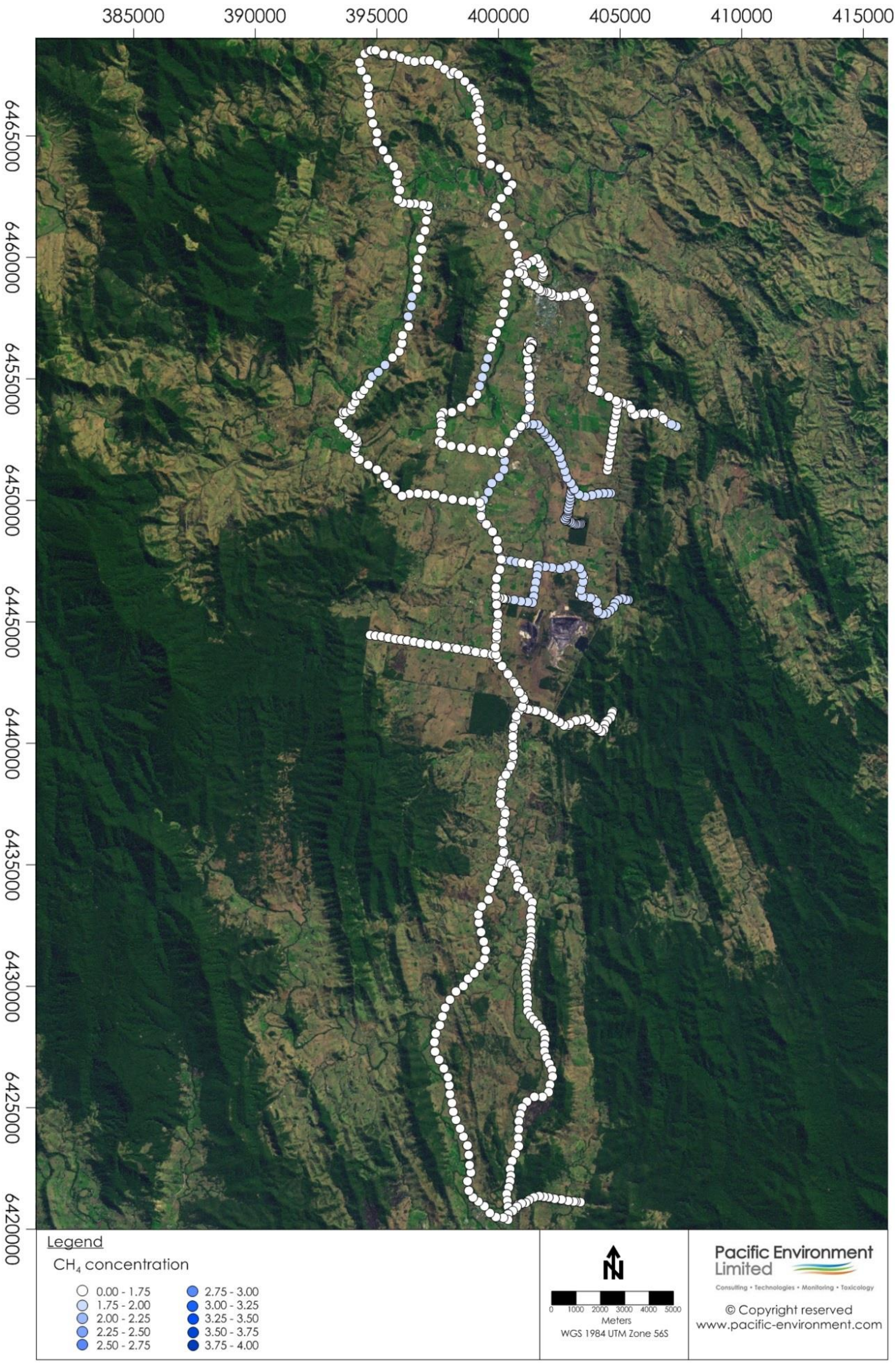


Figure A- 14: CH_4 concentration for Run 14 (8/11/2014 – Morning)

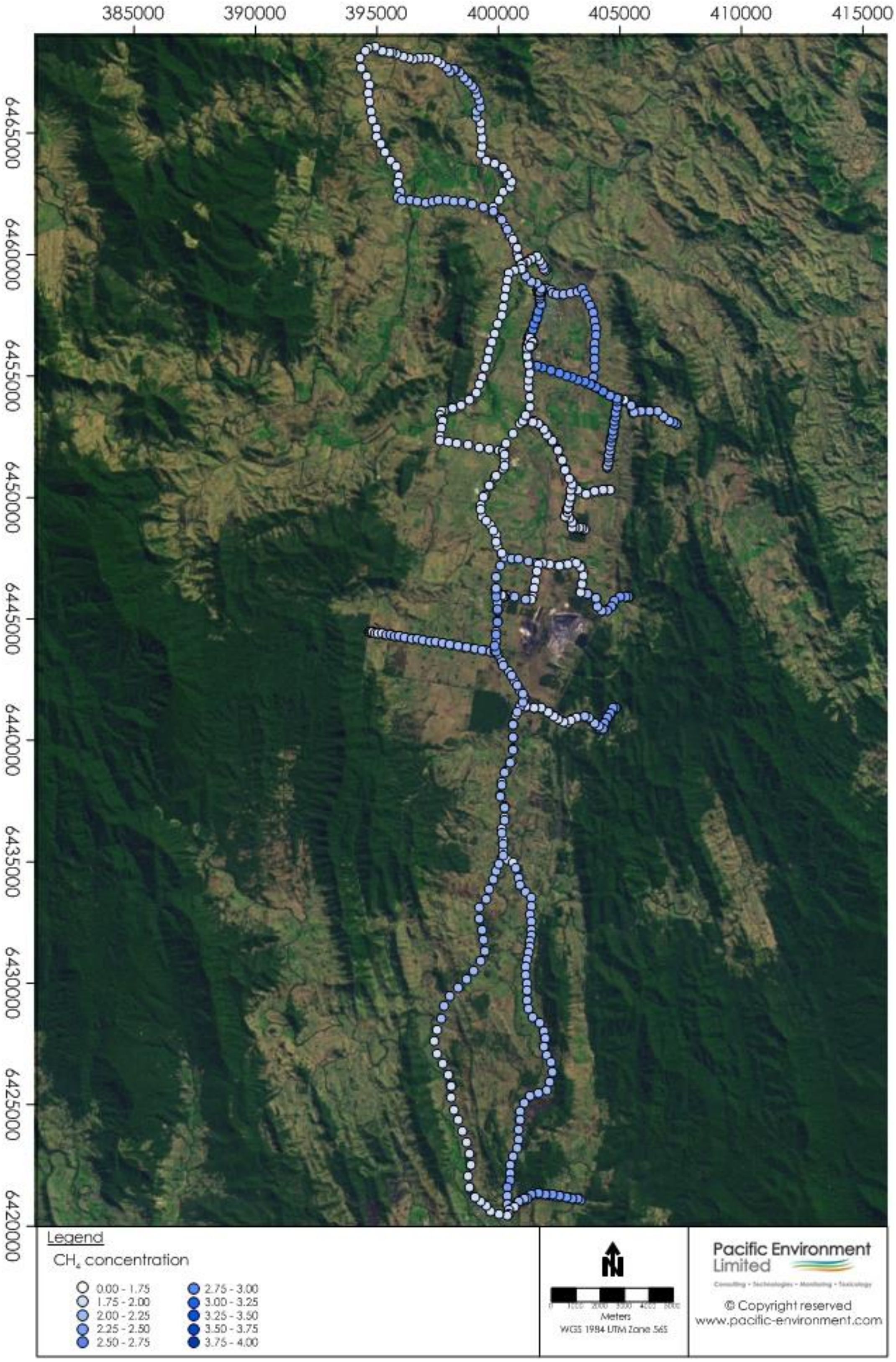


Figure A- 15: CH_4 concentration for Run 15 (19/05/2015 – Morning)

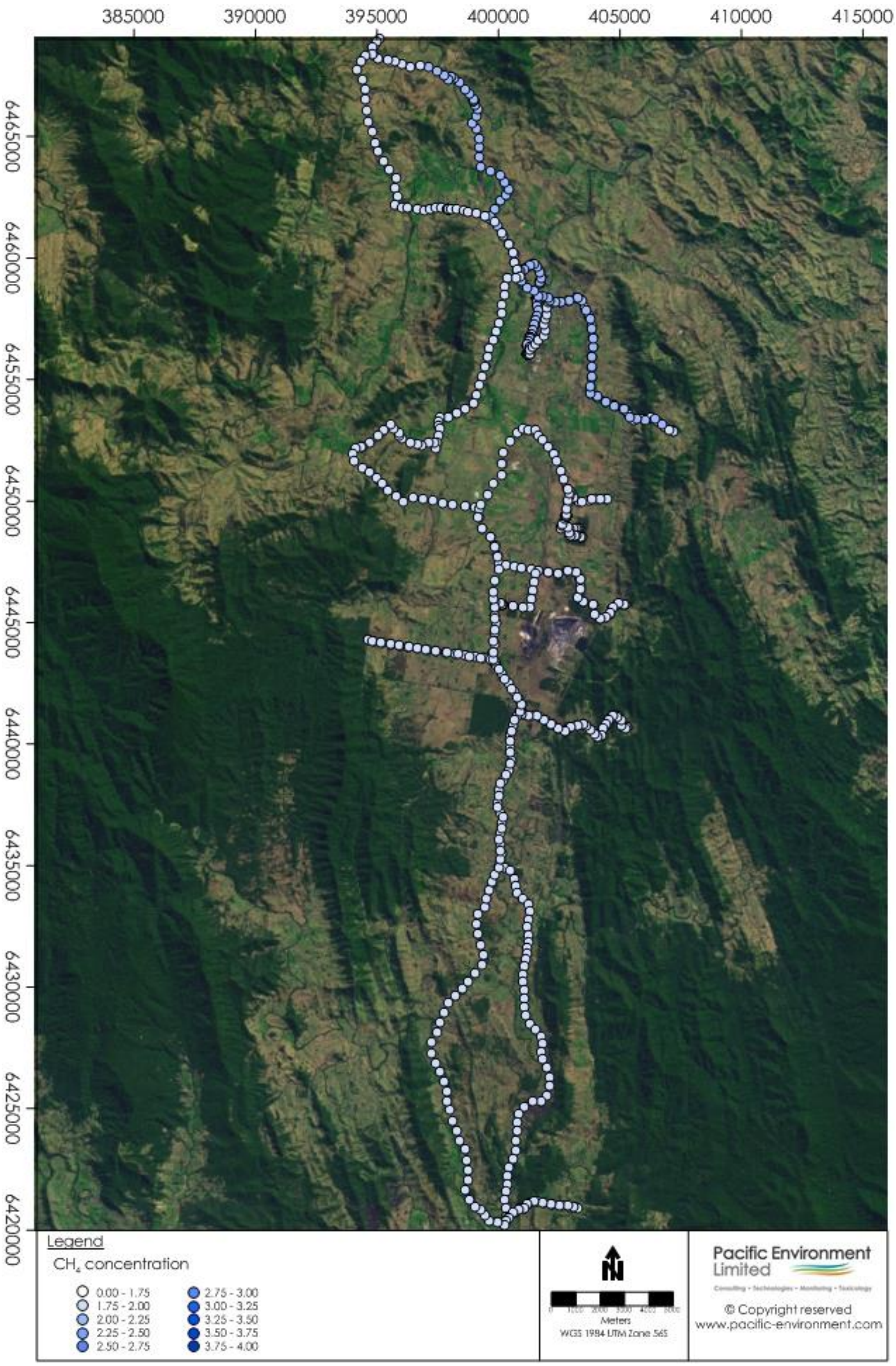


Figure A- 16: CH_4 concentration for Run 15 (19/05/2015 – Afternoon)

Appendix B TABULATED RESULTS

Table B- 1: CH_4 concentration for Run 1 (29/07/2013 – Afternoon)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	29/07/2013	Clear	1.8	1.8	1.8	-40
Route 2	29/07/2013	Clear	1.8	1.8	2.2	-39
Route 3	29/07/2013	Clear	1.8	1.8	1.9	-41
Route 4	29/07/2013	Clear	1.8	1.8	1.9	-40
Route 5	29/07/2013	Clear	1.8	1.8	1.8	-41
Route 6	29/07/2013	Clear	1.8	1.8	1.8	-39
Route 7	29/07/2013	Clear	1.8	1.8	2.0	-42
Route 8	29/07/2013	Clear	1.8	1.8	1.9	-40
Route 9	29/07/2013	Clear	1.8	1.8	1.9	-42
Route 10	29/07/2013	Clear	1.9	1.8	2.1	-41
Route 11	29/07/2013	Clear	1.8	1.8	1.8	-39
Route 12	29/07/2013	Clear	1.8	1.8	1.8	-38
Route 13	30/07/2013	Clear	1.8	1.8	1.8	-40
Route 14	30/07/2013	Clear	1.8	1.8	1.8	-39
Route 15	29/07/2013	Clear	1.8	1.8	1.9	-42
Route 16	29/07/2013	Clear	1.8	1.8	2.0	-41
Route 17	29/07/2013	Clear	1.8	1.8	2.0	-39
Route 18	29/07/2013	Clear	1.8	1.8	1.9	-37

Table B- 2: CH_4 concentration for Run 2 (30/07/2013 – Morning)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	30/07/2013	Clear	1.8	1.8	1.8	-39
Route 2	30/07/2013	Clear	1.9	1.8	2.2	-42
Route 3	30/07/2013	Clear	1.8	1.8	1.8	-40
Route 4	30/07/2013	Clear	1.8	1.8	2.0	-41
Route 5	30/07/2013	Clear	1.9	1.8	2.1	-43
Route 6	30/07/2013	Clear	1.9	1.8	2.2	-43
Route 7	30/07/2013	Clear	1.8	1.8	1.8	-40
Route 8	30/07/2013	Clear	1.8	1.8	1.8	-41
Route 9	30/07/2013	Clear	1.8	1.8	1.8	-42
Route 10	30/07/2013	Clear	1.8	1.8	1.8	-41
Route 11	30/07/2013	Clear	1.8	1.7	1.8	-41
Route 12	30/07/2013	Clear	1.8	1.8	1.8	-42
Route 13	30/07/2013	Clear	1.8	1.8	1.8	-41
Route 14	30/07/2013	Clear	1.8	1.8	1.8	-41
Route 15	30/07/2013	Clear	1.8	1.8	1.8	-40
Route 16	30/07/2013	Clear	2.0	1.9	2.2	-43
Route 17	30/07/2013	Clear	1.9	1.8	2.3	-42
Route 18	30/07/2013	Clear	1.8	1.8	1.8	-39

Table B- 3: CH_4 concentration for Run 3 (06/08/2013 – Afternoon)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	6/08/2013	Clear	1.8	1.8	1.9	-38
Route 2	6/08/2013	Clear	1.8	1.8	2.0	-40
Route 3	6/08/2013	Clear	1.8	1.8	1.9	-41
Route 4	6/08/2013	Clear	1.8	1.8	1.8	-39
Route 5	6/08/2013	Clear	1.8	1.8	1.8	-40
Route 6	6/08/2013	Clear	1.8	1.8	1.8	-41
Route 7	6/08/2013	Clear	1.8	1.8	1.8	-41
Route 8	6/08/2013	Clear	1.8	1.8	1.8	-42
Route 9	6/08/2013	Clear	1.8	1.8	1.9	-40
Route 10	6/08/2013	Clear	1.8	1.8	1.8	-39
Route 11	6/08/2013	Clear	1.8	1.8	1.9	-41
Route 12	6/08/2013	Clear	1.8	1.8	1.9	-39
Route 13	6/08/2013	Clear	1.8	1.8	1.9	-41
Route 14	6/08/2013	Clear	1.9	1.8	2.2	-41
Route 15	6/08/2013	Clear	1.8	1.8	1.8	-40
Route 17	6/08/2013	Clear	1.8	1.8	1.8	-39
Route 18	6/08/2013	Clear	1.8	1.8	1.8	-40

Table B- 4: CH_4 concentration for Run 4 (07/08/2013 – Morning)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	7/08/2013	Clear	1.8	1.8	1.9	-40
Route 2	7/08/2013	Clear	1.8	1.8	2.0	-41
Route 3	7/08/2013	Clear	1.8	1.8	2.0	-39
Route 4	7/08/2013	Clear	1.9	1.8	1.9	-41
Route 5	7/08/2013	Clear	1.8	1.8	1.8	-41
Route 6	7/08/2013	Clear	1.8	1.8	1.8	-42
Route 7	7/08/2013	Clear	1.8	1.8	1.9	-43
Route 8	7/08/2013	Clear	1.8	1.8	1.9	-39
Route 9	7/08/2013	Clear	1.8	1.8	1.8	-43
Route 10	7/08/2013	Clear	1.8	1.8	2.0	-44
Route 11	7/08/2013	Clear	1.8	1.7	1.8	-43
Route 12	7/08/2013	Clear	1.8	1.8	1.8	-38
Route 13	7/08/2013	Clear	1.8	1.8	1.8	-41
Route 14	7/08/2013	Clear	1.8	1.8	1.9	-42
Route 15	7/08/2013	Clear	1.8	1.8	1.8	-45
Route 16	7/08/2013	Clear	1.9	1.8	2.3	-40
Route 17	7/08/2013	Clear	1.9	1.8	1.9	-39
Route 18	7/08/2013	Clear	1.8	1.8	2.0	-40

Table B- 5: CH_4 concentration for Run 5 (14/08/2013 – Afternoon)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	14/08/2013	Clear	1.9	1.8	2.0	-41
Route 2	14/08/2013	Clear	1.8	0.2	2.2	-40
Route 3	14/08/2013	Clear	1.9	1.8	2.3	-40
Route 4	14/08/2013	Clear	1.8	1.8	2.0	-41
Route 5	14/08/2013	Clear	2.0	1.9	2.1	-40
Route 6	14/08/2013	Clear	2.0	1.8	2.3	-42
Route 7	14/08/2013	Clear	1.9	1.8	2.2	-41
Route 8	14/08/2013	Clear	1.8	1.8	2.0	-43
Route 9	14/08/2013	Clear	1.8	1.8	1.8	-40
Route 10	14/08/2013	Clear	1.8	1.8	1.9	-40
Route 11	14/08/2013	Clear	1.8	1.7	1.8	-38
Route 12	14/08/2013	Clear	1.8	1.8	1.8	-42
Route 13	14/08/2013	Clear	1.8	1.8	1.9	-41
Route 14	14/08/2013	Clear	1.8	1.8	2.0	-40
Route 15	14/08/2013	Clear	1.8	1.8	1.9	-40
Route 16	14/08/2013	Clear	1.8	1.8	1.8	-39
Route 17	14/08/2013	Clear	2.8	1.8	3.9	-46
Route 18	14/08/2013	Clear	1.9	1.8	1.9	-39

Table B- 6: CH_4 concentration for Run 6 (15/08/2013 – Morning)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	15/08/2013	Clear	1.8	1.8	1.8	-40
Route 2	15/08/2013	Clear	1.8	1.8	1.8	-40
Route 3	15/08/2013	Clear	1.8	1.8	1.8	-39
Route 4	15/08/2013	Clear	1.8	1.8	1.8	-38
Route 5	15/08/2013	Clear	1.8	1.8	1.8	-37
Route 6	15/08/2013	Clear	1.8	1.8	1.8	-40
Route 7	15/08/2013	Clear	1.8	1.8	1.8	-39
Route 8	15/08/2013	Clear	1.8	1.8	1.8	-38
Route 9	15/08/2013	Clear	1.8	1.8	1.8	-41
Route 10	15/08/2013	Clear	1.8	1.8	1.8	-40
Route 11	15/08/2013	Clear	1.8	1.8	1.8	-41
Route 12	15/08/2013	Clear	1.8	1.8	1.8	-41
Route 13	15/08/2013	Clear	1.8	1.8	1.8	-43
Route 14	15/08/2013	Clear	1.8	1.8	1.8	-42
Route 15	15/08/2013	Clear	1.8	1.8	1.8	-40
Route 16	15/08/2013	Clear	1.8	1.8	1.8	-41
Route 17	15/08/2013	Clear	1.8	1.8	1.8	-37
Route 18	15/08/2013	Clear	1.8	1.8	1.8	-39

Table B- 7: CH_4 concentration for Run 7 (19/08/2013 – Afternoon)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	19/08/2013	Clear	1.8	1.8	1.8	-39
Route 2	19/08/2013	Clear	1.8	1.0	1.9	-40
Route 3	19/08/2013	Clear	1.8	1.8	1.8	-40
Route 4	19/08/2013	Clear	1.8	1.8	1.8	-39
Route 5	19/08/2013	Clear	1.8	1.8	1.8	-39
Route 6	19/08/2013	Clear	1.8	1.8	1.8	-38
Route 7	19/08/2013	Clear	1.8	1.8	1.8	-41
Route 8	19/08/2013	Clear	1.8	1.8	1.8	-40
Route 9	19/08/2013	Clear	1.8	1.8	1.8	-41
Route 10	19/08/2013	Clear	1.8	1.8	1.8	-42
Route 11	19/08/2013	Clear	1.8	1.7	1.8	-42
Route 12	19/08/2013	Clear	1.8	1.8	1.8	-43
Route 13	19/08/2013	Clear	1.8	1.8	1.9	-40
Route 14	19/08/2013	Clear	1.8	1.8	1.8	-40
Route 15	19/08/2013	Clear	1.8	1.8	1.8	-42
Route 16	19/08/2013	Clear	1.8	1.8	1.9	-40
Route 17	19/08/2013	Clear	1.8	1.8	1.8	-39
Route 18	19/08/2013	Clear	1.8	1.8	1.8	-38

Table B- 8: CH_4 concentration for Run 8 (20/08/2013 – Morning)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C\text{-}CH_4$ (‰)
Route 1	20/08/2013	Clear	1.8	1.8	1.8	-40
Route 2	20/08/2013	Clear	1.8	1.8	2.8	-42
Route 3	20/08/2013	Clear	1.8	1.8	2.0	-39
Route 4	20/08/2013	Clear	1.8	1.8	1.9	-37
Route 5	20/08/2013	Clear	1.8	1.8	1.9	-42
Route 6	20/08/2013	Clear	1.8	1.8	2.1	-41
Route 7	20/08/2013	Clear	1.8	1.8	1.8	-42
Route 8	20/08/2013	Clear	1.8	1.8	1.8	-40
Route 9	20/08/2013	Clear	1.8	1.8	1.8	-43
Route 10	20/08/2013	Clear	1.8	1.8	1.8	-43
Route 11	20/08/2013	Clear	1.8	1.7	1.8	-42
Route 12	20/08/2013	Clear	1.8	1.8	1.8	-43
Route 13	20/08/2013	Clear	1.8	1.8	1.8	-41
Route 14	20/08/2013	Clear	1.8	1.8	1.8	-42
Route 15	20/08/2013	Clear	1.8	1.8	1.8	-42
Route 16	20/08/2013	Clear	1.8	1.8	1.8	-42
Route 17	20/08/2013	Clear	1.9	1.8	1.9	-39
Route 18	20/08/2013	Clear	1.9	1.8	1.9	-40

Table B- 9: CH_4 concentration for Run 9 (21/01/2014 – Afternoon)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	21/01/2014	Clear	1.7	1.7	1.7	-42
Route 2	21/01/2014	Clear	1.7	1.7	1.8	-41
Route 3	21/01/2014	Clear	1.8	1.7	1.8	-41
Route 4	21/01/2014	Clear	1.7	1.7	1.8	-41
Route 5	21/01/2014	Clear	1.7	1.7	1.8	-41
Route 6	21/01/2014	Clear	1.8	1.7	1.8	-40
Route 7	21/01/2014	Clear	1.8	1.7	1.8	-40
Route 8	21/01/2014	Clear	1.7	1.7	1.8	-41
Route 9	21/01/2014	Clear	1.7	1.7	1.8	-38
Route 10	21/01/2014	Clear	1.7	1.7	1.8	-40
Route 11	21/01/2014	Clear	1.7	1.7	1.7	-44
Route 12	21/01/2014	Clear	1.7	1.7	1.7	-43
Route 13	21/01/2014	Clear	1.7	1.7	1.7	-43
Route 14	21/01/2014	Clear	1.7	1.7	1.8	-45
Route 15	21/01/2014	Clear	1.7	1.7	1.8	-39
Route 16	21/01/2014	Clear	1.8	1.7	1.9	-42
Route 17	21/01/2014	Clear	1.7	1.7	1.8	-41
Route 18	21/01/2014	Clear	1.8	1.7	1.8	-40

Table B- 10: CH_4 concentration for Run 10 (22/01/2014 – Morning)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C-CH_4$ (‰)
Route 1	22/01/2014	Clear	1.7	1.7	1.7	-42
Route 2	22/01/2014	Clear	1.7	1.7	1.8	-43
Route 3	22/01/2014	Clear	1.8	1.7	2.1	-44
Route 4	22/01/2014	Clear	1.8	1.7	1.8	-44
Route 5	22/01/2014	Clear	1.7	1.7	1.8	-42
Route 6	22/01/2014	Clear	1.7	1.7	1.8	-44
Route 7	22/01/2014	Clear	1.7	1.7	1.7	-40
Route 8	22/01/2014	Clear	1.8	1.7	1.8	-44
Route 9	22/01/2014	Clear	1.8	1.7	1.8	-39
Route 10	22/01/2014	Clear	1.8	1.7	1.9	-43
Route 11	22/01/2014	Clear	1.7	1.7	1.8	-41
Route 12	22/01/2014	Clear	1.7	1.7	1.7	-41
Route 13	22/01/2014	Clear	1.7	1.7	1.8	-43
Route 14	22/01/2014	Clear	1.7	1.7	1.7	-44
Route 15	22/01/2014	Clear	1.7	1.7	1.7	-43
Route 16	22/01/2014	Clear	1.8	1.7	1.8	-42
Route 17	22/01/2014	Clear	1.8	1.7	1.8	-41
Route 18	22/01/2014	Clear	1.8	1.7	1.9	-42

Table B- 11: CH_4 concentration for Run 11 (20/01/2014 – Morning)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	20/10/2014	Overcast	1.8	1.8	1.8	-44
Route 2	20/10/2014	Clear	1.8	1.8	2.0	-44
Route 3	20/10/2014	Overcast	1.8	1.8	1.9	-44
Route 4	20/10/2014	Overcast	1.9	1.8	1.9	-47
Route 5	20/10/2014	Overcast	1.8	1.8	1.8	-45
Route 6	20/10/2014	Overcast	1.8	1.8	1.9	-46
Route 7	20/10/2014	Overcast	2.0	1.9	2.0	-46
Route 8	20/10/2014	Overcast	1.9	1.9	2.0	-45
Route 9	20/10/2014	Windy	2.0	2.0	2.0	-50
Route 10	20/10/2014	Windy	1.9	1.8	2.0	-46
Route 11	20/10/2014	Windy	1.8	1.8	1.9	-43
Route 12	20/10/2014	Rain	1.8	1.8	1.8	-43
Route 13	20/10/2014	Clear	1.8	1.8	1.8	-45
Route 14	20/10/2014	Clear	1.8	1.8	1.8	-46
Route 15	20/10/2014	Clear	1.8	1.8	1.8	-42
Route 16	20/10/2014	Clear	1.8	1.8	1.8	-44
Route 17	20/10/2014	Clear	1.9	1.9	1.9	-45
Route 18	20/10/2014	Clear	1.8	1.8	1.9	-45

Table B- 12: CH_4 concentration for Run 12 (20/10/2014 – Afternoon)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-44
Route 2	20/10/2014	Overcast / patchy rain	1.8	1.8	1.9	-44
Route 3	20/10/2014	Overcast / patchy rain	1.8	1.8	1.9	-45
Route 4	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-47
Route 5	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-49
Route 6	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-44
Route 7	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-46
Route 8	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-45
Route 9	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-48
Route 10	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-46
Route 11	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-43
Route 12	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-46
Route 13	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-45
Route 14	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-45
Route 15	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-46
Route 16	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-43
Route 17	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-46
Route 18	20/10/2014	Overcast / patchy rain	1.8	1.8	1.8	-46

Table B- 13: CH_4 concentration for Run 13 (7/11/2014 – Afternoon)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	7/11/2014	Clear	1.8	1.8	1.8	-48
Route 2	7/11/2014	Clear	1.8	1.8	1.8	-44
Route 3	7/11/2014	Clear	1.8	1.8	1.8	-44
Route 4	7/11/2014	Clear	1.8	1.8	1.8	-45
Route 5	7/11/2014	Clear	1.8	1.8	1.8	-43
Route 6	7/11/2014	Clear	1.8	1.8	1.8	-43
Route 7	7/11/2014	Clear	1.8	1.8	1.8	-47
Route 8	7/11/2014	Clear	1.8	1.8	1.8	-44
Route 9	7/11/2014	Clear	1.8	1.8	1.8	-45
Route 10	7/11/2014	Clear	1.8	1.8	1.8	-45
Route 11	7/11/2014	Clear	1.8	1.8	1.8	-45
Route 12	7/11/2014	Fog clearing	1.8	1.8	1.8	-44
Route 13	7/11/2014	Clear	1.8	1.8	1.8	-45
Route 14	7/11/2014	Clear	1.8	1.8	1.8	-47
Route 15	7/11/2014	Clear	1.8	1.8	1.8	-42
Route 16	7/11/2014	Clear	1.8	1.8	1.9	-44
Route 17	7/11/2014	Clear	1.8	1.8	1.8	-46
Route 18	7/11/2014	Clear	1.8	1.8	1.8	-43

Table B- 14: CH_4 concentration for Run 14 (8/11/2014 – Morning)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	8/11/2014	Clear	1.8	1.7	2.0	-52
Route 2	8/11/2014	Clear	1.9	1.6	2.1	-51
Route 3	8/11/2014	Clear	1.8	1.6	2.1	-48
Route 4	8/11/2014	Clear	1.8	1.7	2.0	-52
Route 5	8/11/2014	Clear	1.8	1.7	2.1	-48
Route 6	8/11/2014	Clear	1.8	1.6	2.2	-52
Route 7	8/11/2014	Clear	1.9	1.5	2.1	-48
Route 8	8/11/2014	Clear	1.8	1.7	2.0	-48
Route 9	8/11/2014	Clear	1.9	1.7	2.1	-49
Route 10	8/11/2014	Clear	1.9	1.7	2.1	-51
Route 11	8/11/2014	Clear	1.8	1.5	2.5	-49
Route 12	8/11/2014	Clear	1.8	1.5	2.1	-52
Route 13	8/11/2014	Partly cloudy	1.8	1.6	2.1	-52
Route 14	8/11/2014	Partly cloudy	1.8	1.6	2.1	-51
Route 15	8/11/2014	Partly cloudy	1.8	1.5	2.1	-49
Route 16	8/11/2014	Partly cloudy	1.9	1.7	2.1	-52
Route 17	8/11/2014	Partly cloudy	1.8	1.7	2.1	-55
Route 18	8/11/2014	Partly cloudy	1.8	1.6	2.0	-53

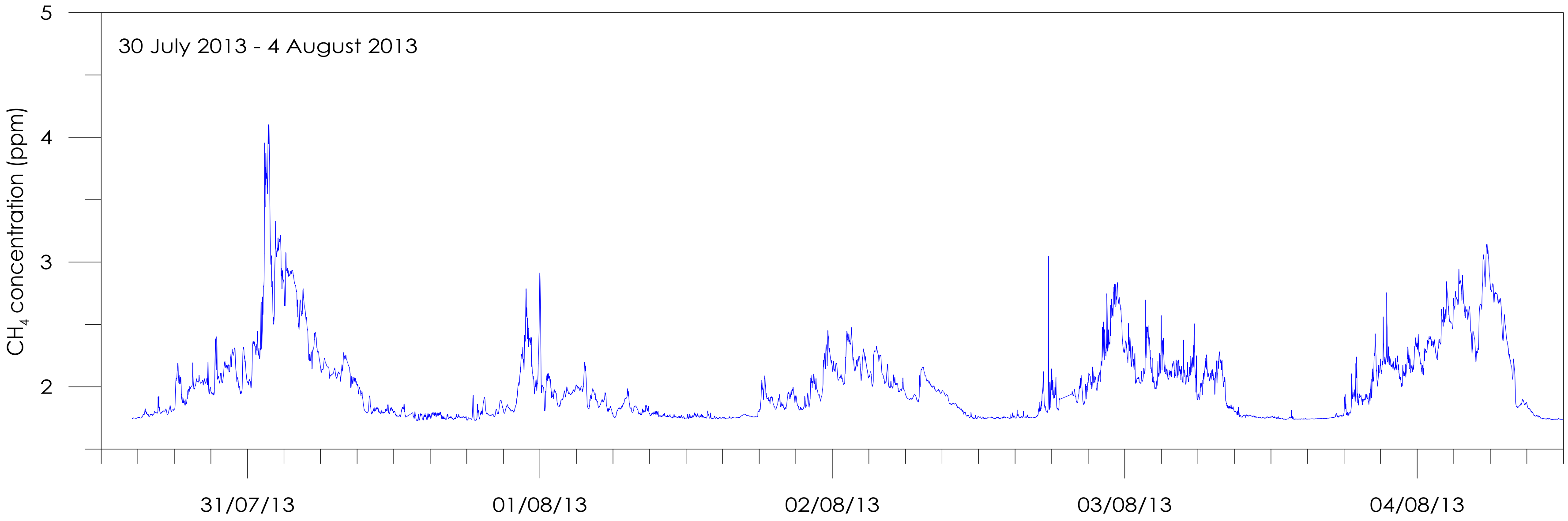
Table B- 15: CH_4 concentration for Run 15 (19/05/2015 – Morning)

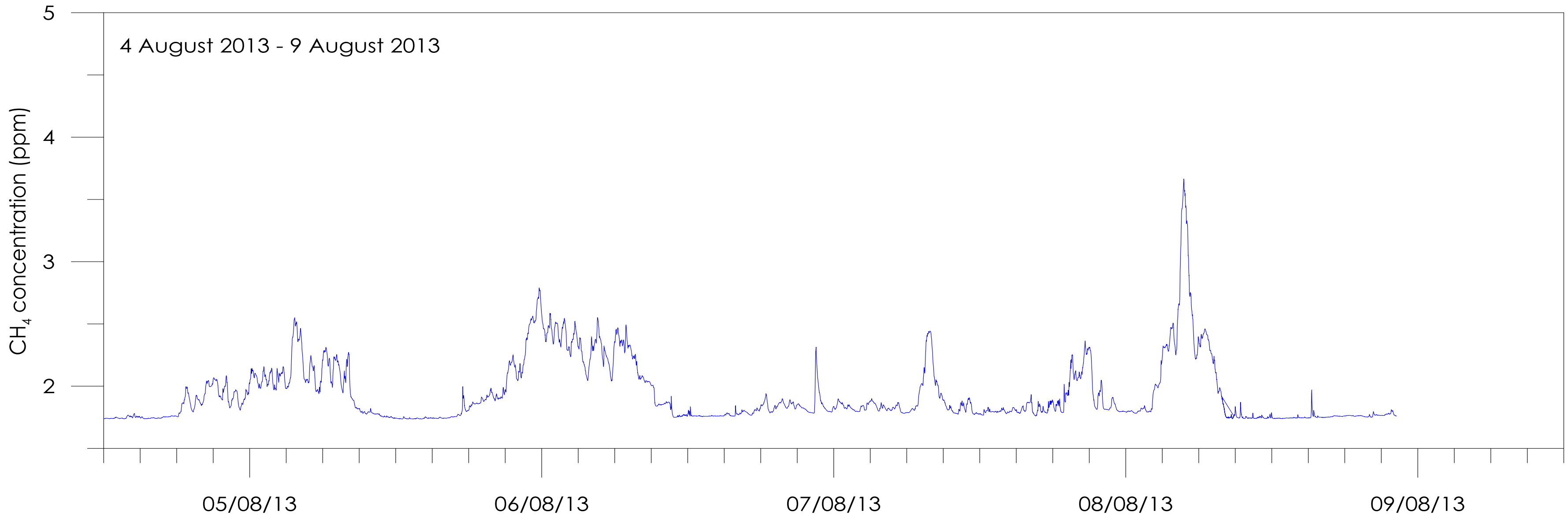
Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	19/05/2014	Clear	1.9	1.8	2.0	-56
Route 2	19/05/2014	Clear	2.0	1.8	2.6	-57
Route 3	19/05/2014	Clear	2.0	1.8	2.2	-56
Route 4	19/05/2014	Clear	2.0	1.9	2.2	-56
Route 5	19/05/2014	Clear	2.4	2.0	2.5	-57
Route 6	19/05/2014	Clear	2.2	1.9	2.5	-57
Route 7	19/05/2014	Clear	1.9	1.8	1.9	-55
Route 8	19/05/2014	Clear	1.9	1.8	1.9	-56
Route 9	19/05/2014	Clear	2.2	2.2	2.3	-58
Route 10	19/05/2014	Clear	2.0	1.9	2.3	-57
Route 11	19/05/2014	Clear	2.2	1.9	2.4	-59
Route 12	19/05/2014	Clear	2.0	1.8	2.2	-57
Route 13	19/05/2014	Clear	2.2	1.9	2.4	-58
Route 14	19/05/2014	Clear	2.1	2.0	2.2	-58
Route 15	19/05/2014	Clear	2.1	1.9	2.2	-58
Route 16	19/05/2014	Clear	1.9	1.8	2.0	-57
Route 17	19/05/2014	Clear	2.0	1.9	2.0	-57
Route 18	19/05/2014	Clear	2.2	1.9	2.6	-57

Table B- 16: CH_4 concentration for Run 16 (19/05/2015 – Afternoon)

Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C-CH_4$ (‰)
Route 1	19/05/2014	Clear	1.8	1.8	1.9	-44
Route 2	19/05/2014	Clear	1.9	1.8	2.3	-45
Route 3	19/05/2014	Clear	1.9	1.8	2.2	-46
Route 4	19/05/2014	Clear	2.1	1.8	2.2	-47
Route 5	19/05/2014	Clear	2.0	1.9	2.0	-47
Route 6	19/05/2014	Clear	1.9	1.8	2.1	-46
Route 7	19/05/2014	Clear	1.8	1.8	1.8	-45
Route 8	19/05/2014	Clear	1.8	1.8	1.8	-44
Route 9	19/05/2014	Clear	1.8	1.8	1.8	-44
Route 10	19/05/2014	Clear	1.8	1.8	1.8	-42
Route 11	19/05/2014	Clear	1.8	1.8	1.8	-43
Route 12	19/05/2014	Clear	1.8	1.8	1.8	-43
Route 13	19/05/2014	Clear	1.8	1.8	1.9	-45
Route 14	19/05/2014	Clear	1.8	1.8	1.8	-44
Route 15	19/05/2014	Clear	1.8	1.8	1.9	-41
Route 16	19/05/2014	Clear	1.9	1.8	1.9	-43
Route 17	19/05/2014	Clear	2.2	2.1	2.2	-48
Route 18	19/05/2014	Clear	2.0	1.8	2.2	-47

Appendix C TIME SERIES OF THE METHANE CONCENTRATION DATA MEASURED AT THE STATIONARY MONITORING SITE


30 July 2013 - 4 August 2013
CH4 concentration (ppm)
5
4
3
2
31/07/13
01/08/13
02/08/13
03/08/13
04/08/13


4 August 2013 - 9 August 2013
CH4 concentration (ppm)
5
4
3
2
05/08/13
06/08/13
07/08/13
08/08/13
09/08/13