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FINAL REPORT

AGL GLOUCESTER BASELINE METHANE MONITORING CAMPAIGN – PRELIMINARY REPORT

AGL

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CONTENTS

1 INTRODUCTION

The Gloucester Gas Project, operated by AGL Energy Limited (AGL), is a coal seam gas (CSG) project located in Gloucester, NSW. Once fully operational, the Gloucester Gas Project would comprise up to 110 gas wells and associated infrastructure.

In response to community and stakeholder concerns, AGL has undertaken baseline monitoring of ambient methane (CH_4) concentrations in the vicinity of the proposed Gloucester Gas Project wells and across the Gloucester region.

1.1 Objective

The objective of this screening baseline monitoring program is to determine the concentrations of CH_4 that are typically experienced at locations within the Gloucester Gas Project before the project becomes operational so as to establish a baseline case against which future monitoring results can be compared. The monitoring program has been designed to measure CH_4 over 202 kilometres (km) within the Gloucester Gas Project. A stationary monitor was also installed to characterise CH_4 concentrations over time.

This study is considered to represent a preliminary and indicative screening baseline analysis of the current conditions in the vicinity of the Gloucester area.

2 BACKGROUND

Methane is an important trace gas in atmospheric chemistry and climate. The most recent measurements report by the World Meteorological Organisation (WMO) indicate the global average CH_4 concentration to have risen to 1.819[a]ppm (**WMO, 2013**). The methane concentration has reportedly doubled over the past two hundred years determined primarily through ice core analyses.

In urban areas, CH_4 concentrations are generally slightly higher due the potential influence of a greater number of sources known to release fugitive CH_4. As part of this study, preliminary monitoring in Sydney's CBD indicates that CH_4 concentrations typically range between 1.8ppm and 2.0ppm. A recent study investigating CH_4 in the city of Boston, USA (**Phillips et al., 2013**) measured concentrations up to 28.6ppm when mapping urban pipeline leaks across the city using a Picarro fixed within a vehicle. This study was able to differentiate between fugitive emissions of CH_4 from urban pipeline leaks and other known sources of CH_4, such as landfill and sewage systems.

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 $\delta^{13}C$-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.) **Lowry et al. (2001)** also identified a relationship between wind speed and CH_4 concentration, with higher concentrations associated with lower (<2m/s) wind speeds.

Methane is an effective greenhouse gas, with a global warming potential 28 times greater compared to carbon dioxide, when considered over a 100 year time frame (**IPCC AR5, 2013**).

Natural sources of fugitive CH_4 can include:

- Micro-organisms that live in wetlands

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

- Termites (methane generated by micro-organisms contained within their digestive tract)
- Volcanoes
- Naturally occurring open coal seams
- Permafrost thawing
- Hydrates and clathrates (CH_4 trapped in very cold continental and oceanic waters).

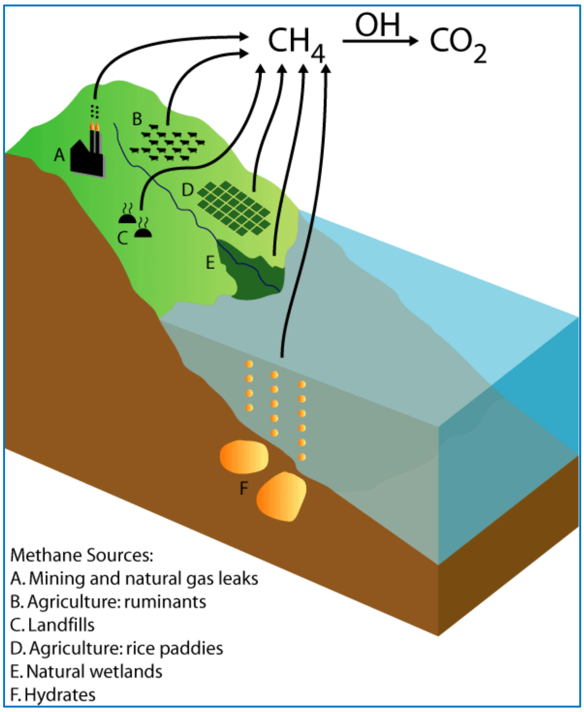
Anthropogenic sources (those generated by human activities), are commonly associated with agricultural practices, such as livestock emissions (ruminant digestion processes) or from rice paddies. Fugitive CH_4 emissions from waste, such as sewage and landfill are primarily generated through fermentation processes and are most significant in urbanised areas. Other fugitive sources of CH_4 are released during mining of coal or oil and gas production.

Figure 2-1 graphically depicts the main sources and sinks of methane 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 methane and it is not defined as a hazardous air pollutant (**US EPA, 2014**). As discussed in above there are trigger level concentrations for CH_4 that are governed by its potential for asphyxiation or explosivity.

The primary removal mechanism of methane 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.

As an organic molecule, advanced analytical techniques may be applied to determine the source of the methane. This can be achieved by measuring the proportion of ^{12}C compared with ^{13}C within a given sample of CH_4 molecules (referred to as the isotopic ratio).



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

Figure 2-1: Known sources of fugitive CH_4 emissions

2.1 Isotopic signature of CH_4

2.1.1 Description

The isotopic ratio of carbon in CH_4 ($\delta^{13}C-CH_4$, referred to above) is a measure of the stable isotopes of carbon ($^{13}C:^{12}C$) within the CH_4 gas sampled, reported in parts per thousand.

Often referred to as the isotopic signature or fingerprint, this parameter is relevant since different sources and sinks of CH_4 have different affinity for the ^{12}C and ^{13}C isotopes. By analysing the $\delta^{13}C-CH_4$, different sources of CH_4 in the atmosphere may be distinguished.

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 than thermogenic CH_4 (i.e. that created via the thermal breakdown of heavier hydrocarbons under high temperature/pressure conditions).

The units of $\delta^{13}C$ are parts per thousand (per mil, ‰), and involve measurement against a calcium carbonate standard referred to as Pee Dee Belemnite. This material has an unusually high $^{13}C:^{12}C$ ratio, and as a result, most natural material analysed in this manner results in a negative $\delta^{13}C$. The more negative the $\delta^{13}C-CH_4$ value, the lower the $^{13}C:^{12}C$ ratio, and thus the lighter the CH_4 being sampled.

The isotopic composition of common methane sources has been characterised in a number of studies of the past several decades. **Table 2-1** provides a summary of the most common methane sources and the $\delta^{13}C-CH_4$ for each source. These $\delta^{13}C-CH_4$ 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 than -55‰ are associated with biogenic methane and $\delta^{13}C-CH_4$ values above -55‰ are related to thermogenic sources of methane. 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 2-1: $\delta^{13}C$-CH_4 of common natural and anthropogenic methane sources

Source	$\delta^{13}C$-CH_4 (‰)
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
Residential	-38

Source: **Montiel et al. (2011), Dlugokencky et al. (2011)**

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 2-1**, or known sources of methane in the area being studied (e.g. landfills, wetlands, 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 1.8ppm (**WMO, 2013**) will be by definition a mixture of multiple sources, meaning 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. 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 to be considered indicative.

2.1.2 Determination of isotopic signature specific to Gloucester area

Prior to the commencement of the baseline CH_4 monitoring screening 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.

Two additional 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

Photos during the collection of the samples are shown in **Figure 2-2**.

The landfill and livestock 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 2-3**. 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 general 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. The results also compare well with those reported in the literature (**Montiel et al. 2011**). To provide a more robust dataset it is recommended that additional reference samples are collected.

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 2-3 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.

Keeling plots can also be used to determine the isotopic signature of a CH_4 source (**Keeling, 1961**). By plotting $\delta_{13}C$-CH_4 versus the inverse of the CH_4 concentration the y-intercept is the isotopic signature of the source. This is explained since when the CH_4 concentration when x = 0 is infinite, this represents the isotopic composition of atmosphere if all the CH_4in the atmosphere were due to the source. A Keeling plot is presented in **Figure 2-5** of the CH_4 collected from the wells as described above. The 'isotopic signature' of the dataset is -50.

Figure 2-2: Photos during collection of reference samples

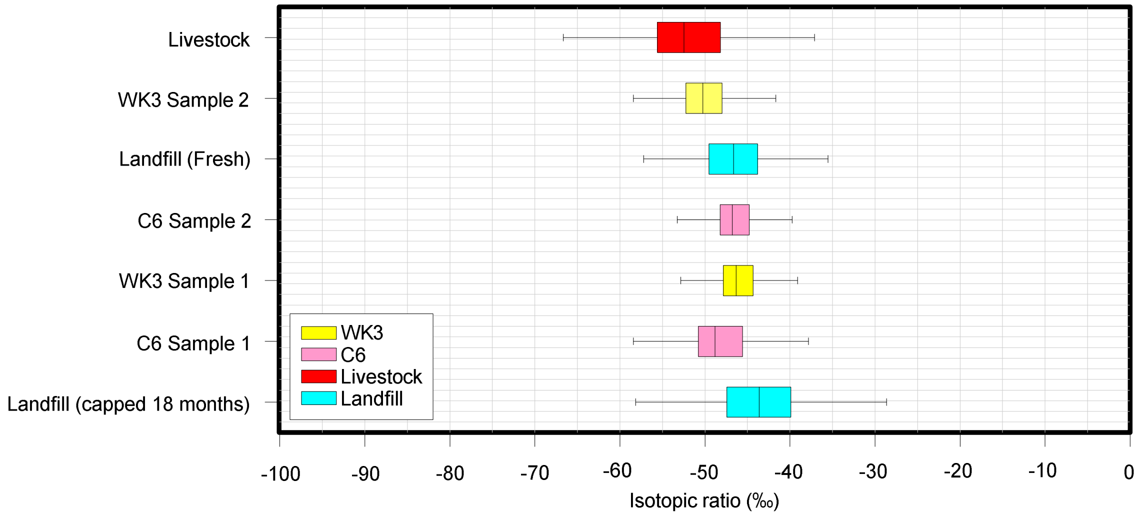


Figure 2-3 Box and whisker plot showing $\delta^{13}C-CH_4$

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.

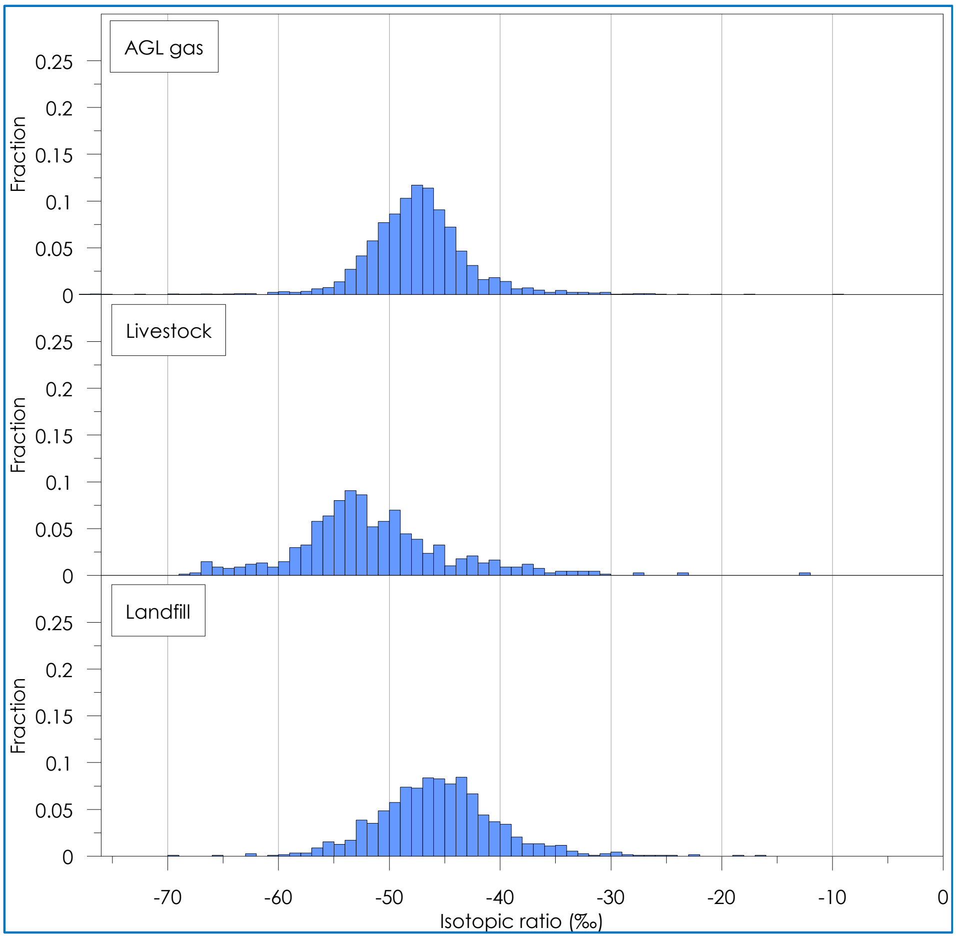


Figure 2-4: Histogram of $\delta^{13}C-CH_4$ of sample groups

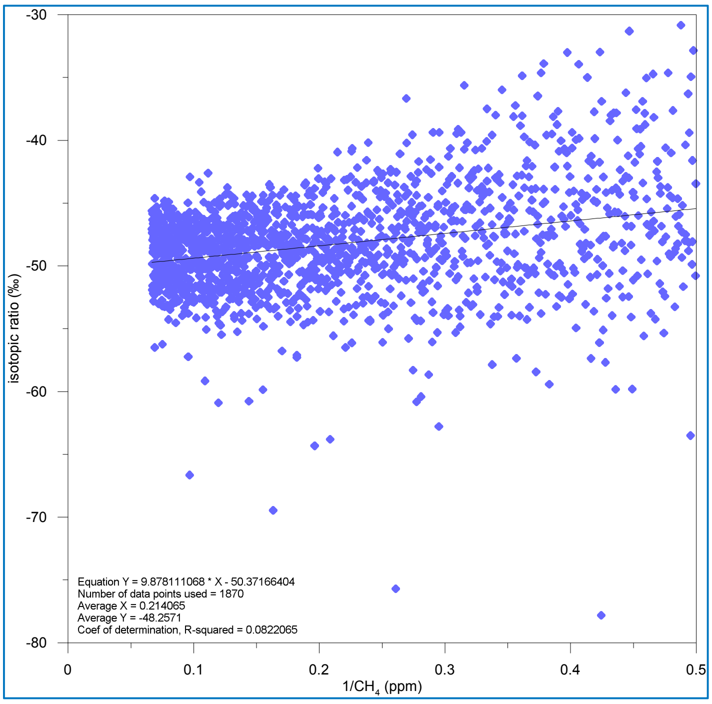


Figure 2-5: Keeling plot of gas bag sample data from Gloucester WK3 and C6 wells

3 METHODOLOGY

3.1 Baseline field study

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 screening assessment, AGL has committed to completing weekly monitoring over a four week period.

Mobile monitoring (i.e. surveying methane concentrations using an instrument mounted within a vehicle) was completed over 202 km each week. Further detail as to site selection is provided in **Section 3.3**. A stationary monitor was also installed to characterise CH_4 concentrations over time.

To complete the baseline survey of the Gloucester area, 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.

The screening baseline monitoring campaign commenced on 29 July 2013.

3.2 Instrumentation

The samples were analysed using a Picarro G-2031-i Cavity Ring Down Spectrometer (Picarro) that measures the CH_4 concentrations and corresponding $\delta^{13}C\text{-}CH_4$. 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** 3-1 provides an image of the mobile set up used in the AGL field study.

A second Picarro (G-2201-i) was also installed to provide continuous CH_4 concentration measurements at the 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**).

3.2.1 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, weekly single point calibrations were completed using bottled CH_4 gas of known concentration. On a monthly basis, multi-point calibrations were completed over a range of known CH_4 concentrations to ensure instrument linearity. All calibrations were completed using National Association of Testing Authority (NATA) certified calibration gases.

All calibration during the monitoring period showed little deviation in the CH_4 concentration measurements with time, and extremely good instrument linearity.

Figure 3-1: AGL mobile monitoring kit

3.3 Mobile monitoring route

To meet the objective of this screening 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 around the Gloucester region.

Figure 3-2 shows the routes used for the screening baseline study. **Table 3-1** provides a summary description of each route.

Figure 3-2 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.

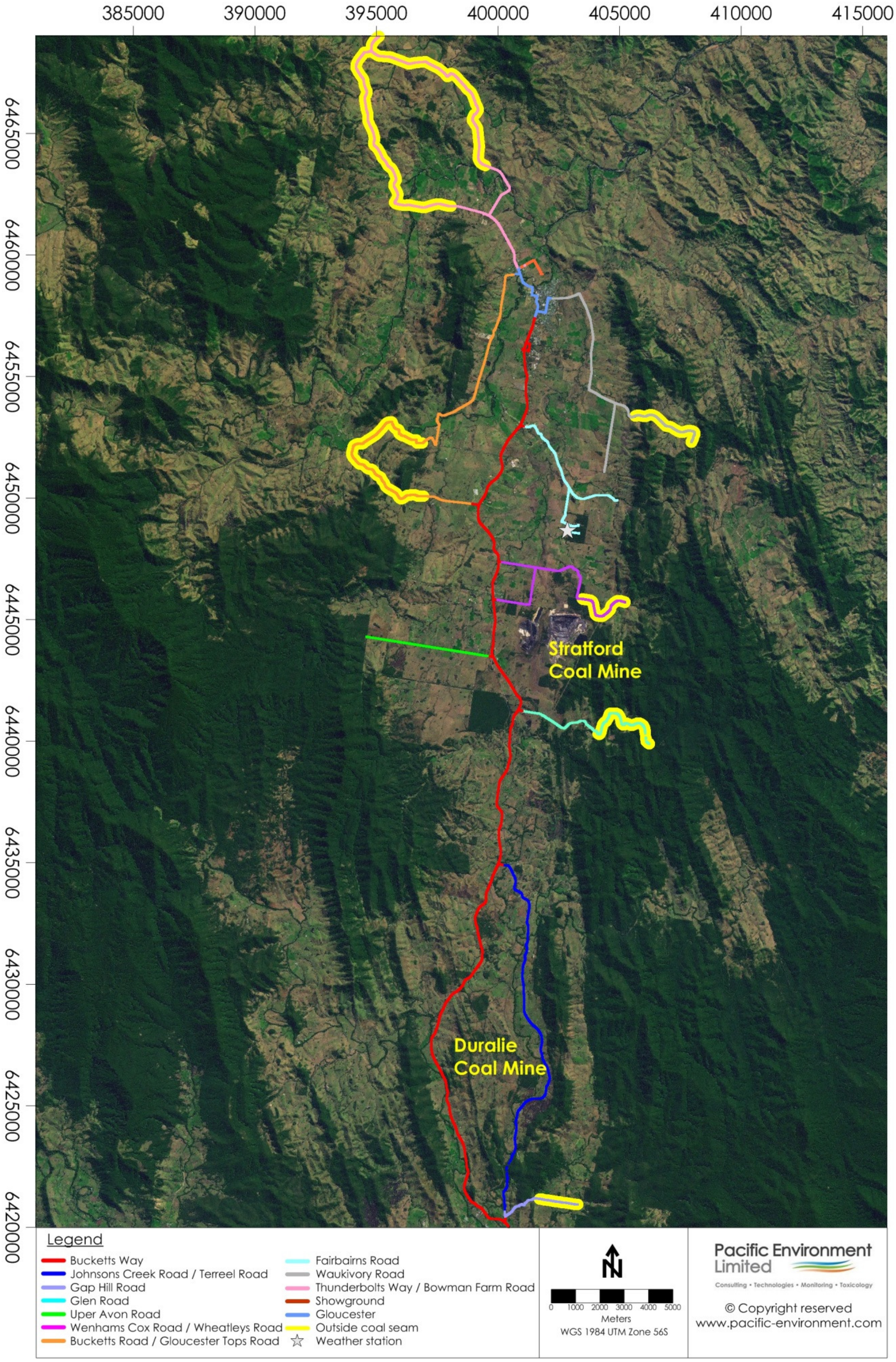


Figure 3-2: Monitoring routes

Table 3-1: Description of monitoring locations

Site number	Site description	Purpose
Route 1	Bucketts Way	Inside coal seam
Route 2	Johnsons Creek Road / Terreel Road	Inside coal seam
Route 3	Gap Hill Road	Inside coal seam
Route 4	Gap Hill Road	Outside coal seam
Route 5	Glen Road	Inside coal seam
Route 6	Glen Road	Outside coal seam
Route 7	Upper Avon Road	Inside coal seam
Route 8	Wenhams Cox Road / Wheatleys Road	Inside coal seam
Route 9	Wenhams Cox Road / Wheatleys Road	Outside coal seam
Route 10	Bucketts Road / Gloucester Tops Road	Inside coal seam
Route 11	Bucketts Road / Gloucester Tops Road	Outside coal seam
Route 12	Fairbairns Road	Inside coal seam
Route 13	Waukivory Road	Inside coal seam
Route 14	Waukivory Road	Outside coal seam
Route 15	Thunderbolts Way / Bowman Farm Road	Inside coal seam
Route 16	Thunderbolts Way / Bowman Farm Road	Outside coal seam
Route 17	Showground	Inside coal seam
Route 18	Gloucester	Inside coal seam

4 RESULTS AND DISCUSSION

The baseline monitoring campaign commenced on 29 July 2013 and continued on a weekly basis for 4 weeks with the last data set measured on 20 August 2013. 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 3-2** for the location of each route). A time series of the CH_4 concentration data measured at the stationary monitoring site is presented in **Appendix C**.

A significant amount of data has been collected during the four weeks of monitoring. Rather than discussing all monitoring results, additional discussion is provided where elevated CH_4 concentrations were measured or field observations warranted further investigation.

For the purposes of this study, a CH_4 concentration is considered 'elevated' if the concentration shows to be above the global average of 1.8 ppm for 2012 as established by **WMO (2013)**.

4.1 Key findings

The following points provide an overview of the monitoring results:

- The 1 second interval CH_4 concentration of CH_4 ranged between 1.7 ppm to 3.9 ppm across all routes and weeks investigated during the mobile monitoring.
- The highest 1-second CH_4 concentration was 3.9 ppm measured near the showground (Route 17) during Week 3 (Afternoon). The $\delta^{13}C$-CH_4 values measured on this route were also shown to be more negative (i.e. more biogenic) that values measured along other routes during this week. Route 17 is located adjacent to sewage treatment plant.

- On average, the CH_4 concentrations measured during mobile monitoring were lowest during Week 4.
- In general, CH_4 concentrations in the Gloucester area are considered low with an approximate baseline concentration of 1.8 ppm. This compares well with the global average background concentration report for 2012 by **WMO (2013).**
- Route 17 (Showground) experienced the highest CH_4 concentrations, followed by Route 14 (Waukivory Road – outside seam).
- There is negligible difference between the CH_4 concentrations measured inside and outside of the Gloucester Coal Seam.
- At the stationary monitoring location the highest CH_4 concentration was 4.1 ppm, 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 temperature inversion conditions.
- Temperature inversion conditions show 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. 10 pm to 4am) when CH_4 concentration is shown to be higher as evidenced with the data from the stationary monitoring site.
- Other sources of CH_4 in the Gloucester area have been identified and include:
    - Landfill
    - Sewage treatment Plant
    - Agriculture
- The average $\delta^{13}C$-CH_4 ranged between -37‰ and -46‰. It should be noted that these are averaged values, where the 1 second measurements fluctuate significantly.
- A greater number of gas samples are required to fully characterise the AGL coal seam gas in the Gloucester area.

5 CONCLUSION

This screening level baseline monitoring report provides the results and high level analysis of a mobile monitoring campaign measuring the concentration and $\delta^{13}C$-CH_4 of CH_4 in the Gloucester area completed by Pacific Environment on behalf of AGL.

This study is considered to represent a preliminary and indicative screening baseline analysis of the current conditions in the vicinity of the soon to be developed Gloucester Gas Project.

In general, and based on data collected to date, CH_4 concentrations in the Gloucester area are considered low with an approximate baseline concentration of 1.8 ppm.

The CH_4 concentrations measured in the study area are considered close to the global average background concentrations report by **WMO (2013)**.

The highest CH_4 concentrations were observed along Route 17 (Showground), adjacent to the sewage treatment plant with a 1-second CH_4 concentration of 3.9 ppm.

Other sources of CH_4 in the Gloucester have been identified and include:

- Landfill
- Sewage treatment Plant
- Agriculture

The baseline screening study can be used to identify key areas of interest that can be used as static monitoring locations for a potential future baseline monitoring campaign in the Gloucester area.

6 REFERENCES

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Appendix A: MONITORING RESULTS

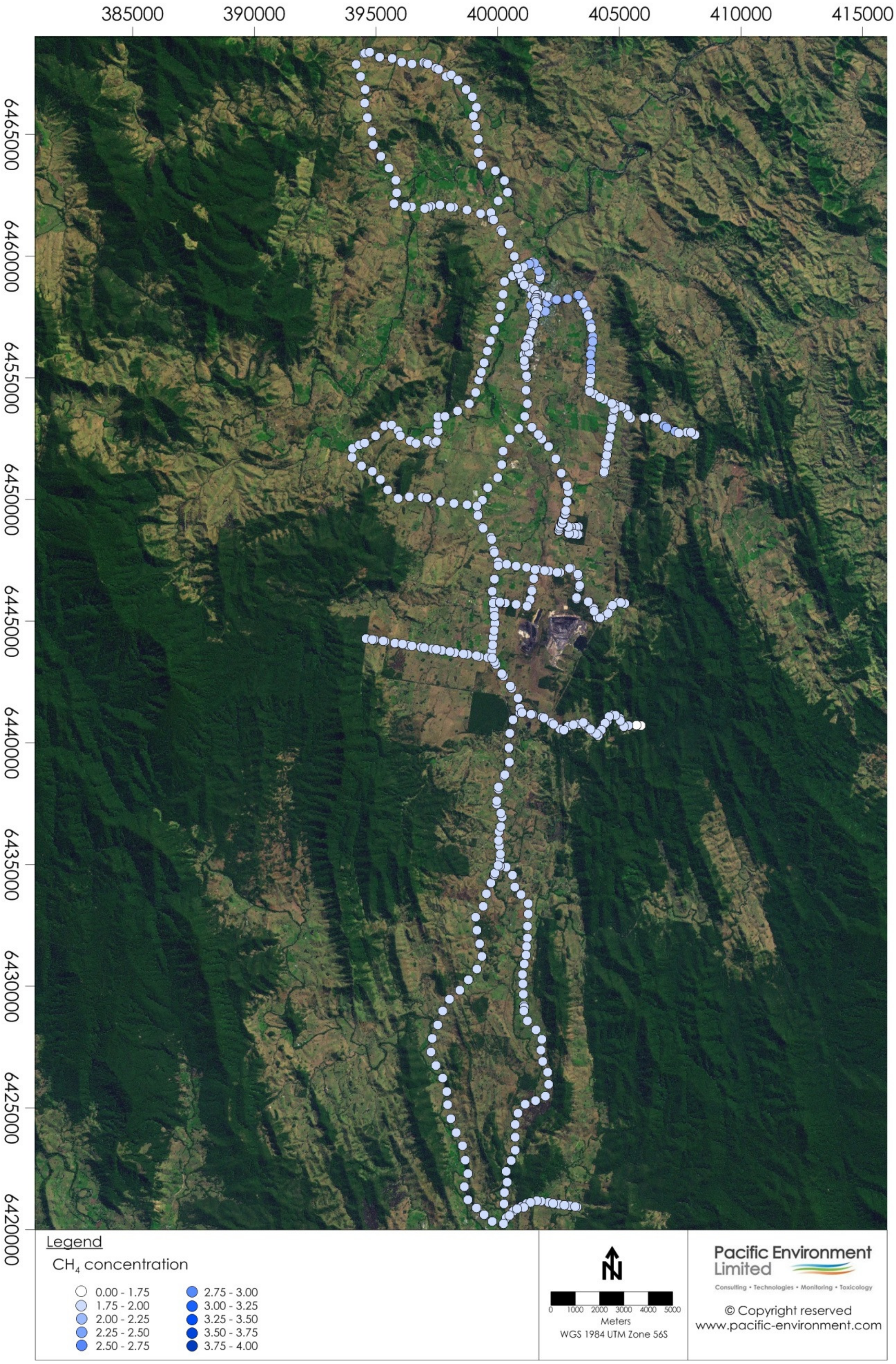


Figure A- 1: CH_4 concentration for Week 1 Morning

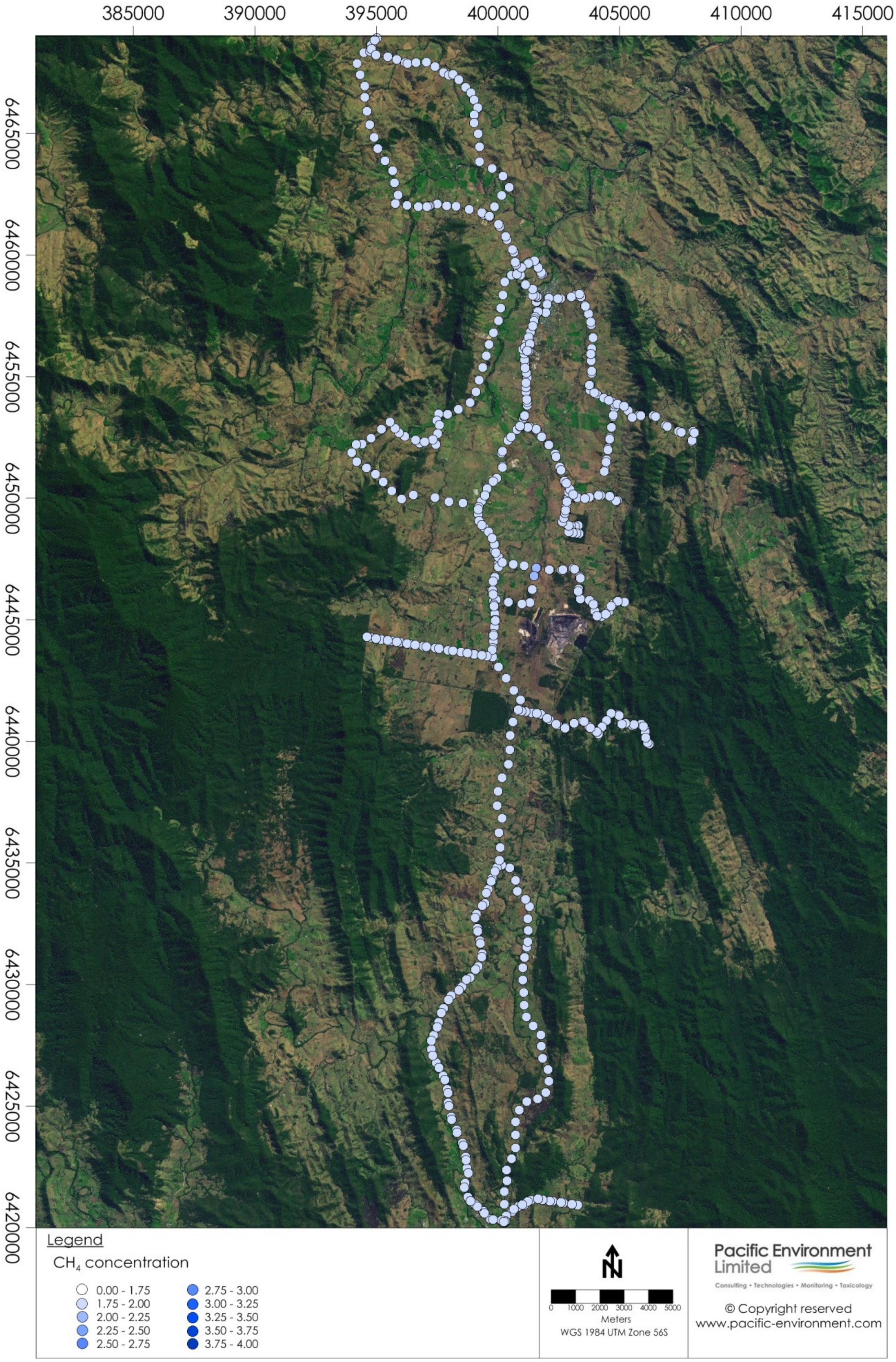


Figure A- 2: CH_4 concentration for Week 1 Afternoon

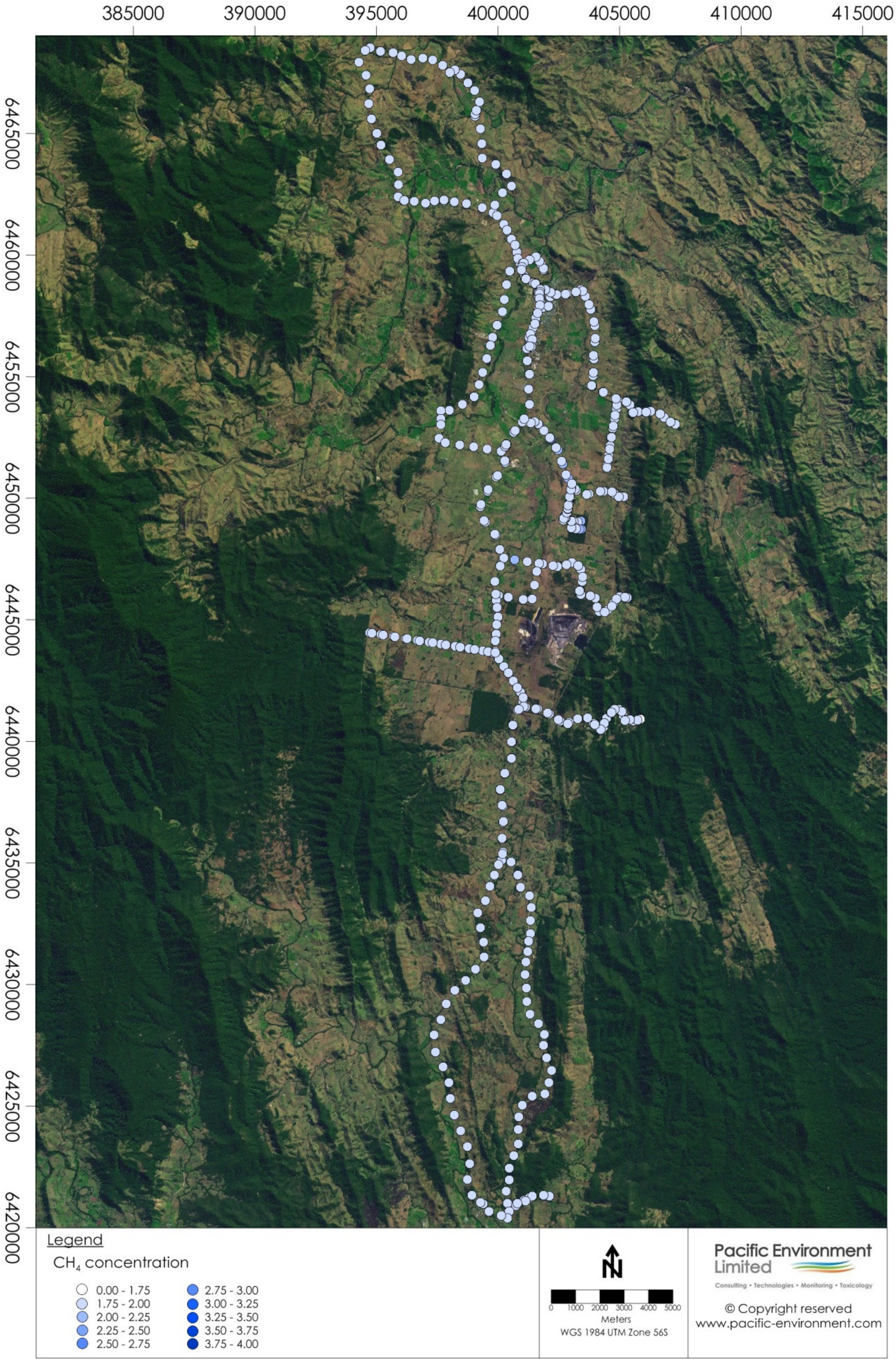


Figure A- 3: CH_4 concentration for Week 2 Morning

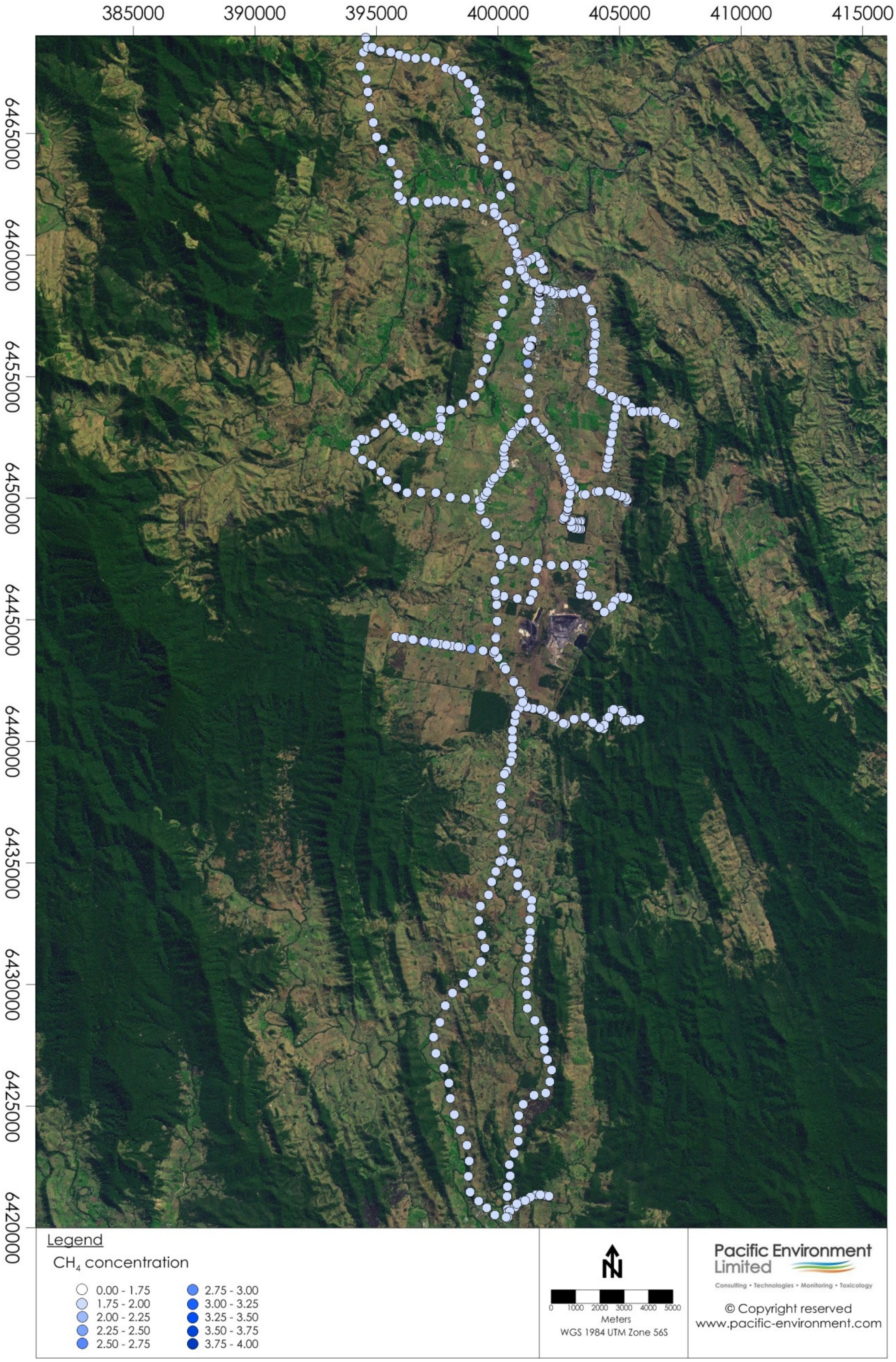


Figure A- 4: CH_4 concentration for Week 2 Afternoon

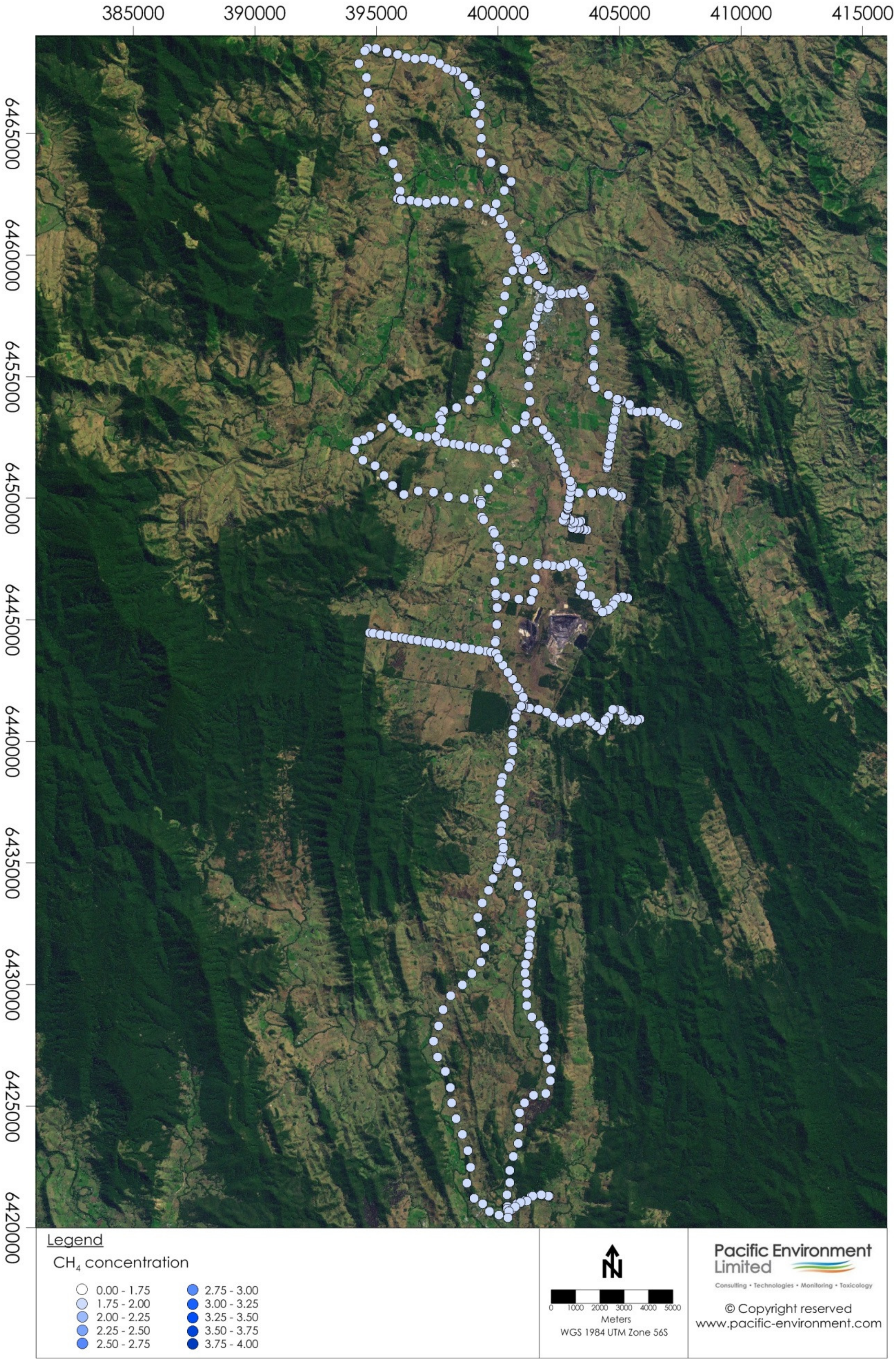


Figure A- 5: CH_4 concentration for Week 3 Morning

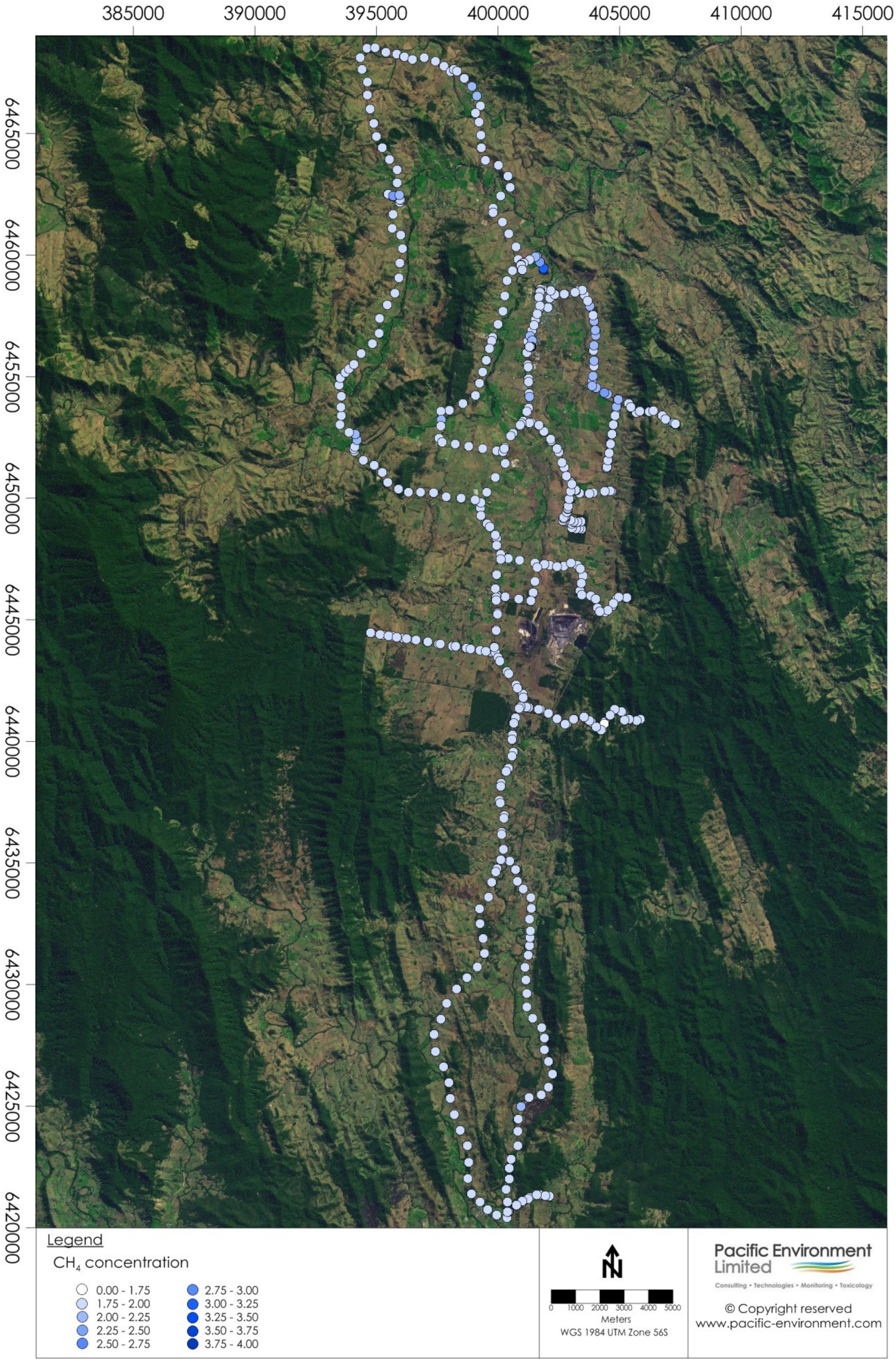


Figure A- 6: CH_4 concentration for Week 3 Afternoon

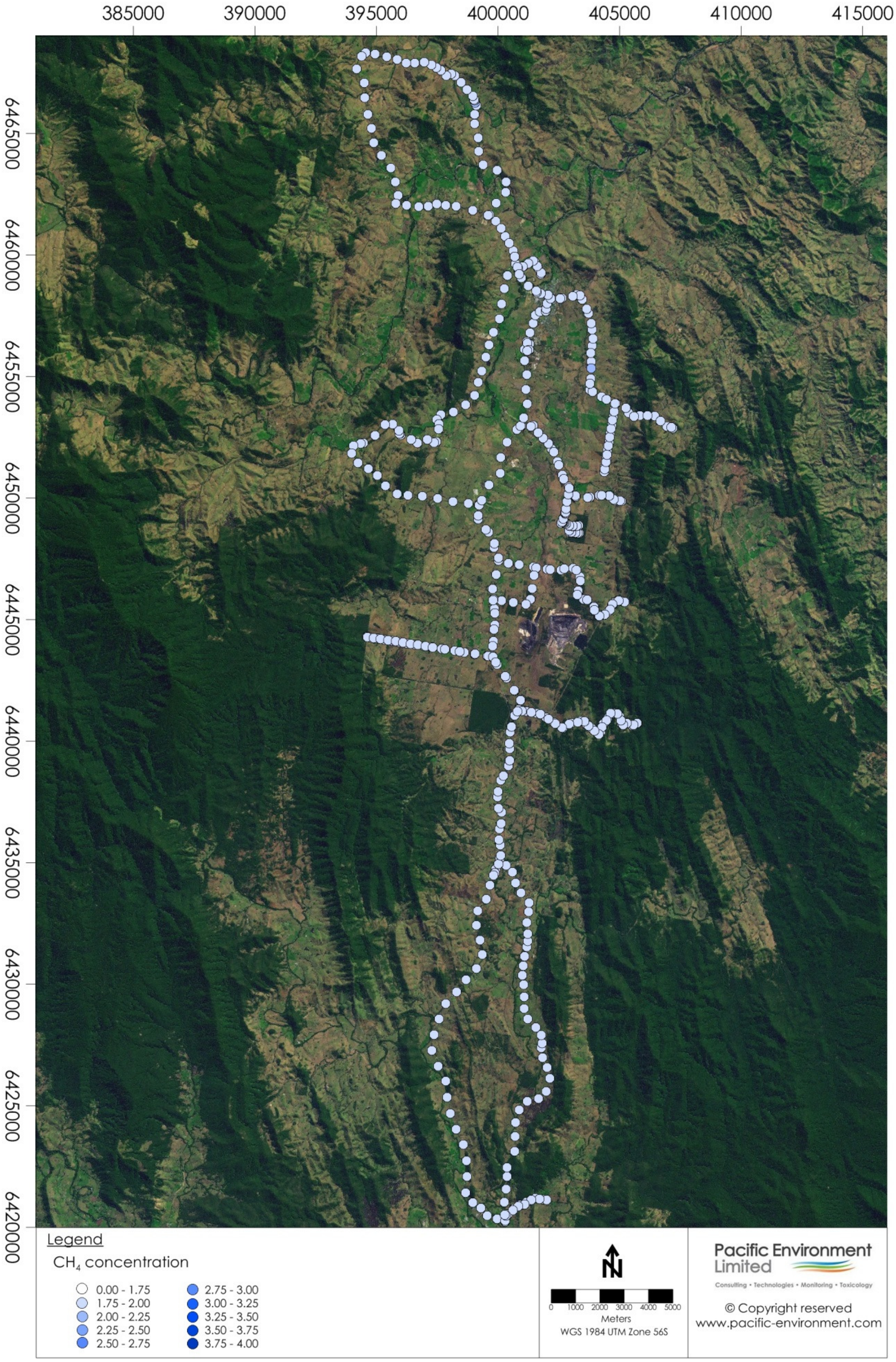


Figure A- 7: CH_4 concentration for Week 4 Morning

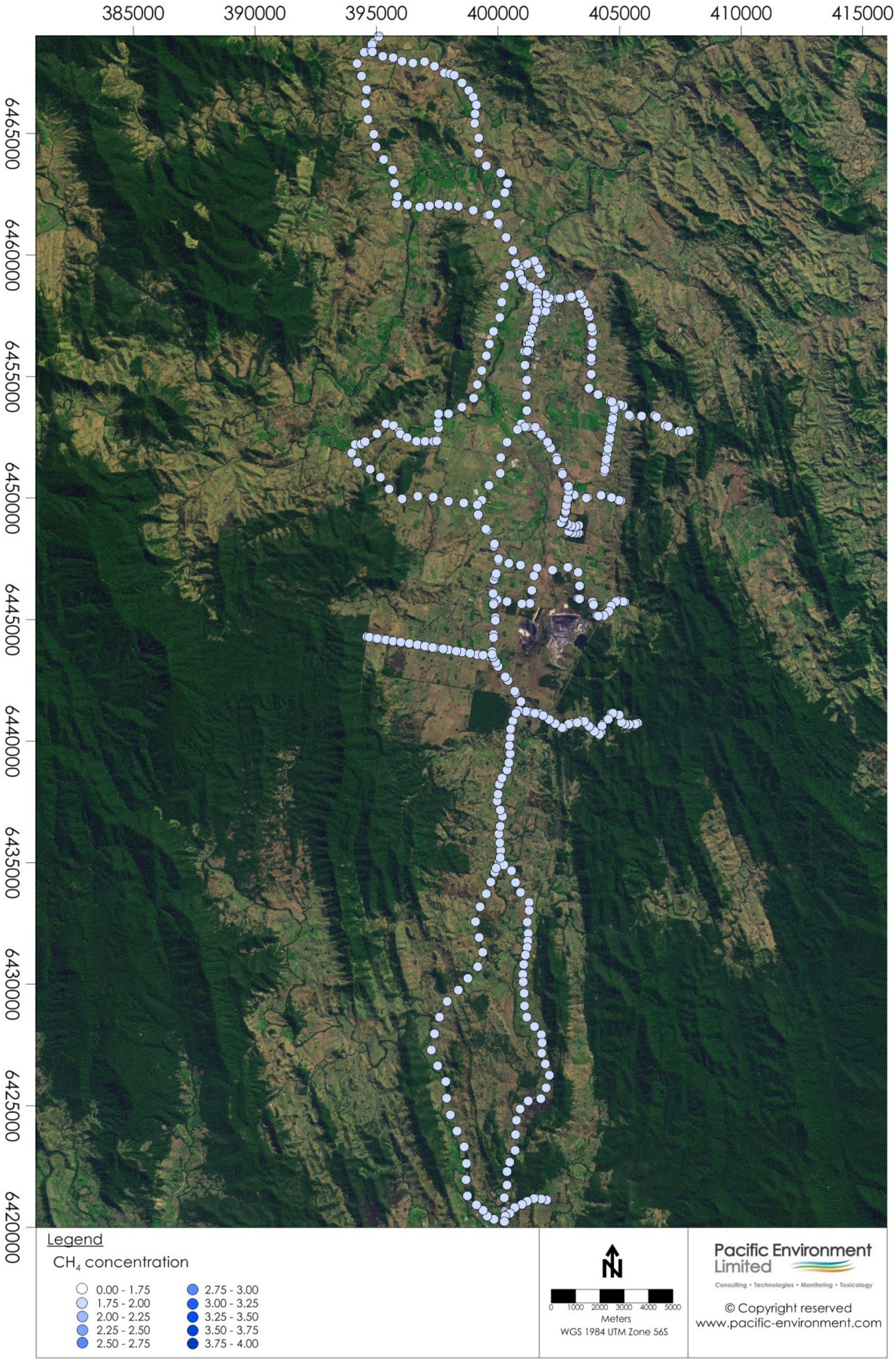


Figure A- 8: CH_4 concentration for Week 4 Afternoon

Appendix B: RESULTS SUMMARY TABLES

Table B- 1: Results for Week 1: 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	1.9	1.8	2.2	-41
Route 2	30/07/2013	Clear	1.8	1.8	1.8	-41
Route 3	30/07/2013	Clear	1.8	1.8	1.8	-41
Route 4	30/07/2013	Clear	1.8	1.8	1.8	-44
Route 5	30/07/2013	Clear	1.8	1.8	1.9	-41
Route 6	30/07/2013	Clear	1.8	1.7	1.8	-42
Route 7	30/07/2013	Clear	1.8	1.8	1.8	-41
Route 8	30/07/2013	Clear	1.8	1.8	1.8	-40
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	-40
Route 11	30/07/2013	Clear	1.8	1.8	1.8	-40
Route 12	30/07/2013	Clear	1.8	1.8	1.8	-40
Route 13	30/07/2013	Clear	1.9	1.8	2.2	-43
Route 14	30/07/2013	Clear	1.9	1.8	2.1	-43
Route 15	30/07/2013	Clear	1.8	1.8	2.0	-40
Route 16	30/07/2013	Clear	1.8	1.8	1.8	-41
Route 17	30/07/2013	Clear	2.0	1.9	2.2	-43
Route 18	30/07/2013	Clear	1.9	1.8	2.3	-42

Table B- 2: Results for Week 1: 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	2.2	-39
Route 2	29/07/2013	Clear	1.8	1.8	1.8	-40
Route 3	29/07/2013	Clear	1.8	1.8	1.8	-41
Route 4	29/07/2013	Clear	1.8	1.8	1.8	-40
Route 5	29/07/2013	Clear	1.8	1.8	1.8	-38
Route 6	29/07/2013	Clear	1.8	1.8	1.8	-39
Route 7	29/07/2013	Clear	1.8	1.8	1.9	-42
Route 8	29/07/2013	Clear	1.9	1.8	2.1	-41
Route 9	29/07/2013	Clear	1.8	1.8	1.9	-41
Route 10	29/07/2013	Clear	1.8	1.8	2.0	-41
Route 11	29/07/2013	Clear	1.8	1.8	2.0	-41
Route 12	29/07/2013	Clear	1.8	1.8	2.0	-41
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	-39
Route 15	29/07/2013	Clear	1.8	1.8	1.9	-40
Route 16	29/07/2013	Clear	1.8	1.8	1.8	-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- 3: Results for Week 2: 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	2.0	-40
Route 2	7/08/2013	Clear	1.8	1.8	1.9	-42
Route 3	7/08/2013	Clear	1.8	1.8	1.8	-39
Route 4	7/08/2013	Clear	1.8	1.8	1.8	-39
Route 5	7/08/2013	Clear	1.8	1.8	1.8	-40
Route 6	7/08/2013	Clear	1.8	1.7	1.8	-44
Route 7	7/08/2013	Clear	1.8	1.8	1.8	-45
Route 8	7/08/2013	Clear	1.9	1.8	2.0	-42
Route 9	7/08/2013	Clear	1.8	1.8	1.8	-45
Route 10	7/08/2013	Clear	1.8	1.8	1.9	-40
Route 11	7/08/2013	Clear	1.9	1.8	2.3	-40
Route 12	7/08/2013	Clear	1.8	1.8	1.8	-42
Route 13	7/08/2013	Clear	1.8	1.8	1.8	-41
Route 14	7/08/2013	Clear	1.9	1.8	2.0	-40
Route 15	7/08/2013	Clear	1.8	1.8	2.0	-40
Route 16	7/08/2013	Clear	1.9	1.8	2.0	-39
Route 17	7/08/2013	Clear	1.8	1.8	2.0	-40
Route 18	7/08/2013	Clear	1.8	1.8	2.0	-40

Table B- 4: Results for Week 2: 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	2.0	-39
Route 2	6/08/2013	Clear	1.8	1.8	1.9	-40
Route 3	6/08/2013	Clear	1.8	1.8	1.8	-38
Route 4	6/08/2013	Clear	1.9	1.8	1.9	-39
Route 5	6/08/2013	Clear	1.8	1.8	1.9	-39
Route 6	6/08/2013	Clear	1.8	1.8	1.8	-41
Route 7	6/08/2013	Clear	1.9	1.8	2.2	-41
Route 8	6/08/2013	Clear	1.8	1.8	1.9	-39
Route 9	6/08/2013	Clear	1.8	1.8	1.8	-40
Route 10	6/08/2013	Clear	1.8	1.8	1.8	-41
Route 11	6/08/2013	Clear	1.8	1.8	1.8	-41
Route 12	6/08/2013	Clear	1.8	1.8	1.8	-40
Route 13	6/08/2013	Clear	1.8	1.8	1.8	-40
Route 14	6/08/2013	Clear	1.8	1.8	1.8	-40
Route 15	6/08/2013	Clear	1.8	1.8	1.8	-40
Route 17	6/08/2013	Clear	1.8	1.8	1.9	-41
Route 18	6/08/2013	Clear	1.8	1.8	1.8	-38

Table B- 5: Results for Week 3: 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	-42
Route 3	15/08/2013	Clear	1.8	1.8	1.8	-42
Route 4	15/08/2013	Clear	1.8	1.8	1.8	-44
Route 5	15/08/2013	Clear	1.8	1.8	1.8	-41
Route 6	15/08/2013	Clear	1.8	1.8	1.8	-42
Route 7	15/08/2013	Clear	1.8	1.8	1.8	-40
Route 8	15/08/2013	Clear	1.8	1.8	1.8	-40
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	-38
Route 11	15/08/2013	Clear	1.8	1.8	1.8	-39
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	-40
Route 14	15/08/2013	Clear	1.8	1.8	1.8	-37
Route 15	15/08/2013	Clear	1.8	1.8	1.8	-38
Route 16	15/08/2013	Clear	1.8	1.8	1.8	-39
Route 17	15/08/2013	Clear	1.8	1.8	1.8	-38
Route 18	15/08/2013	Clear	1.8	1.8	1.8	-38

Table B- 6: Results for Week 3: 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	1.8	0.2	2.2	-40
Route 2	14/08/2013	Clear	1.8	1.8	2.0	-40
Route 3	14/08/2013	Clear	1.8	1.8	1.9	-41
Route 4	14/08/2013	Clear	1.9	1.8	1.9	-40
Route 5	14/08/2013	Clear	1.8	1.8	1.8	-40
Route 6	14/08/2013	Clear	1.8	1.7	1.8	-38
Route 7	14/08/2013	Clear	1.8	1.8	1.9	-40
Route 8	14/08/2013	Clear	1.8	1.8	1.9	-40
Route 9	14/08/2013	Clear	1.8	1.8	1.8	-40
Route 10	14/08/2013	Clear	1.9	1.8	2.1	-43
Route 11	14/08/2013	Clear	1.9	1.8	2.2	-40
Route 12	14/08/2013	Clear	1.8	1.8	1.8	-39
Route 13	14/08/2013	Clear	2.0	1.8	2.3	-42
Route 14	14/08/2013	Clear	2.0	1.9	2.1	-41
Route 15	14/08/2013	Clear	1.8	1.8	2.0	-40
Route 16	14/08/2013	Clear	1.9	1.8	2.3	-40
Route 17	14/08/2013	Clear	2.6	1.8	3.9	-46
Route 18	14/08/2013	Clear	1.9	1.8	1.9	-39

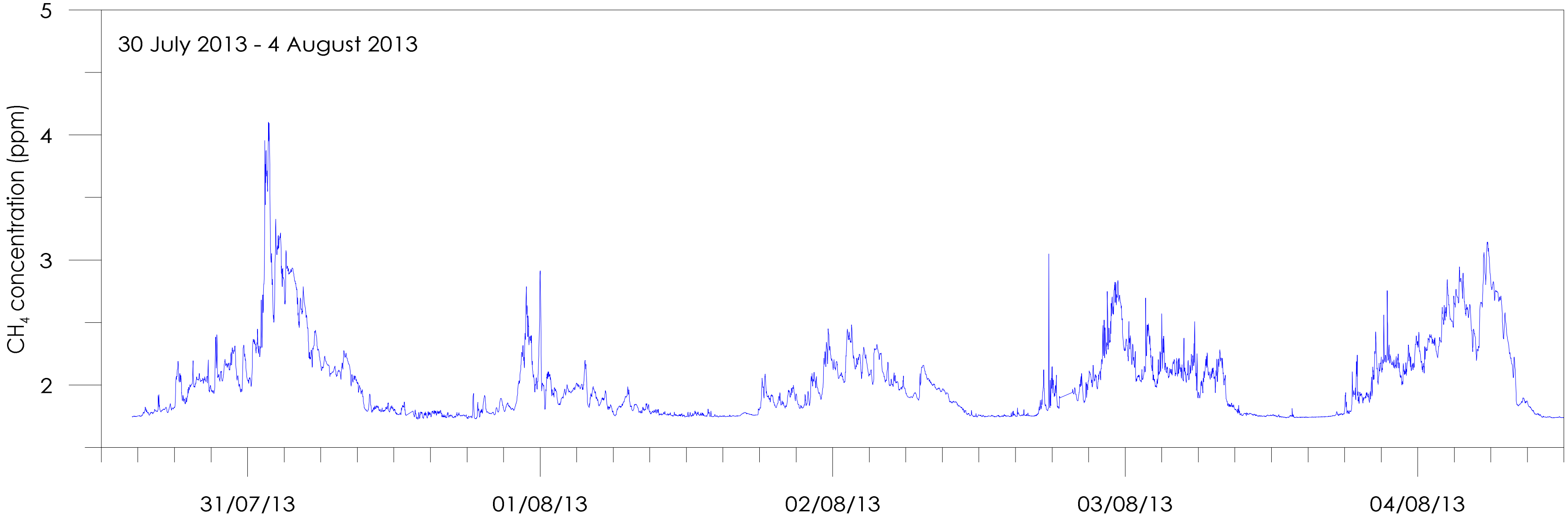
Table B- 7: Results for Week 4: Morning

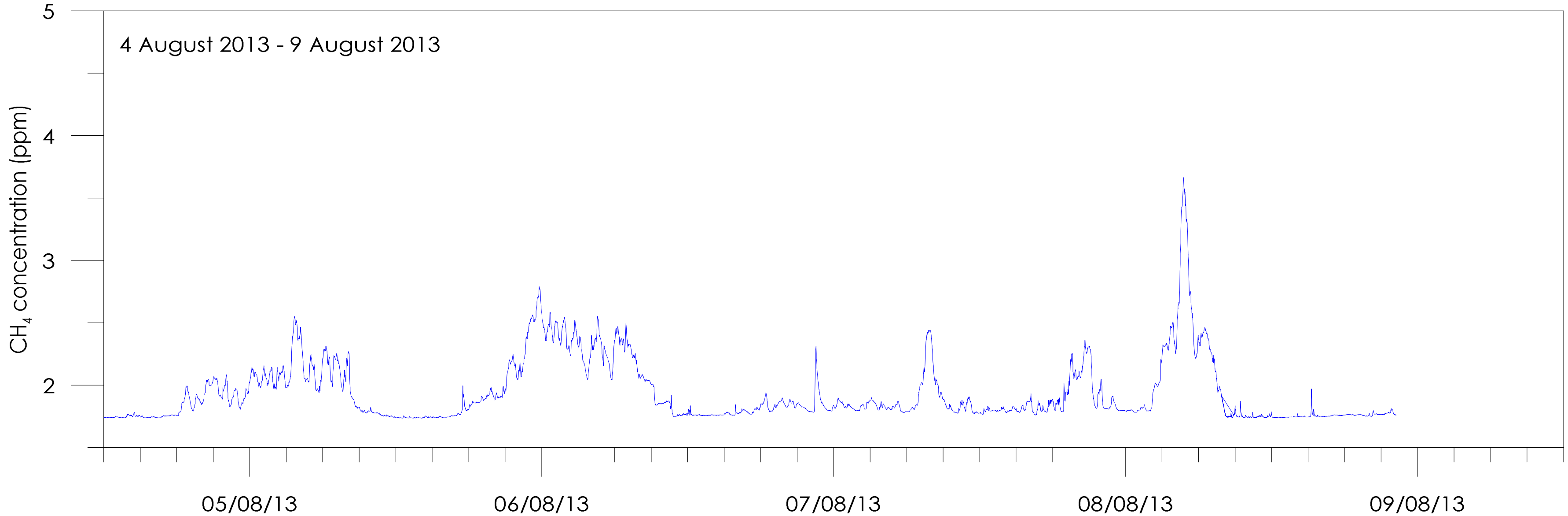
Site number	Date	Weather conditions	Average CH_4 (ppm)	Minimum CH_4 (ppm)	Maximum CH_4 (ppm)	Average $\delta^{13}C$-CH_4 (‰)
Route 1	20/08/2013	Clear	1.8	1.8	2.8	-42
Route 2	20/08/2013	Clear	1.8	1.8	1.8	-42
Route 3	20/08/2013	Clear	1.8	1.8	1.8	-42
Route 4	20/08/2013	Clear	1.8	1.8	1.8	-38
Route 5	20/08/2013	Clear	1.8	1.8	1.8	-43
Route 6	20/08/2013	Clear	1.8	1.7	1.8	-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	-43
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	-41
Route 11	20/08/2013	Clear	1.8	1.8	1.8	-42
Route 12	20/08/2013	Clear	1.8	1.8	1.8	-42
Route 13	20/08/2013	Clear	1.8	1.8	2.1	-41
Route 14	20/08/2013	Clear	1.9	1.8	1.9	-41
Route 15	20/08/2013	Clear	1.8	1.8	1.9	-40
Route 16	20/08/2013	Clear	1.8	1.8	2.0	-39
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- 8: Results for Week 4: 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	-40
Route 2	19/08/2013	Clear	1.8	1.8	1.8	-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	-41
Route 5	19/08/2013	Clear	1.8	1.8	1.8	-42
Route 6	19/08/2013	Clear	1.8	1.7	1.8	-42
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	-42
Route 9	19/08/2013	Clear	1.8	1.8	1.8	-42
Route 10	19/08/2013	Clear	1.8	1.8	1.8	-40
Route 11	19/08/2013	Clear	1.8	1.8	1.8	-41
Route 12	19/08/2013	Clear	1.8	1.8	1.8	-40
Route 13	19/08/2013	Clear	1.8	1.8	1.8	-38
Route 14	19/08/2013	Clear	1.8	1.8	1.8	-38
Route 15	19/08/2013	Clear	1.8	1.8	1.8	-40
Route 16	19/08/2013	Clear	1.8	1.8	1.8	-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

Appendix C: MONITORING RESULTS FOR STATIONARY PICARRO


30 July 2013 - 4 August 2013
CH_4 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
CH_4 concentration (ppm)
5
4
3
2
05/08/13
06/08/13
07/08/13
08/08/13
09/08/13