DETAILED PART 2A INSPECTION: ADDITIONAL WORKS REPORT

FORMER BROOKS TIP, BORDER ROAD, UPTON, POOLE

WPA CONSULTANTS LTD

FOR

PURBECK DISTRICT COUNCIL

J. Wilson

ISSUED V1 10/12/2013

Contents

Drawings

Appendices

1.0 INTRODUCTION

The aim of this report is to provide Purbeck District Council (PDC) with an opinion on the risk to human health and property at Tree Hamlets posed by ground gas originating from the former Brooks Tip Landfill Site and conclude on the significance of the contaminant linkages as far as the information available to-date allows. The works undertaken have been funded by a DEFRA Contaminated Land Capital Projects (CLCP) Grant and the framework of the assessment detailed below is provided by a variety of statutory, non-statutory and technical guidance which has all been subject to various debate and interpretation since publication. The approach followed in this detailed inspection reflects existing Environment Agency guidance and industry good practice, and is structured as follows:

1. Identify the problem – Preliminary Risk Assessment. This has previously been established in the CLCP bid[1].

2. Screen out linkages where risks are negligible, in the context of Part 2A of the Environmental Protection Act 1990, via the selection and use of relevant and appropriate screening criteria. In this case human health specific soil guide line values or generic assessment criteria, gas screening values and, for controlled waters, environment quality standards or relevant drinking water standards. This work has been under taken in the Draft Part 2A Investigation and Risk Assessment[2], which identified the need for further work with respect to offsite ground gas risk that this report details.

3. Consideration of the significance of the remaining contaminant linkages in the context of Part 2A.

4. Provide an opinion on whether it is reasonable to conclude the condition of the land is such that there is a significant possibility of significant harm to humans using the site and to other receptors identified and provide an opinion on whether the land falls in to category 1, 2, 3 or 4.

Guidance most pertinent to the risk evaluation stage is provided by DEFRA[3]. This statutory guidance for Part 2A defines the relevant test in this case as the significant possibility of significant harm or significant harm (SPOSH) being caused to humans as a result of the presence of contaminants being present in, on, or under the land in question or the pollution of controlled waters (POCW). Whilst statutory guidance defines significant harm and the significant possibility of significant harm in the form of two tables, the definitions are left open to interpretation which leaves the enforcing authority with a degree of discretion in making a decision.

Currently no Category 4 screening criteria are available and no guidance has been produced detailing a methodology for doing so. The purpose of the risk evaluation stage in this report is therefore to establish the potential significance of the ground gas levels and flow rates, and the reasonableness of the decision the risk estimation results point to, given the balance of evidence available.

[1] Supporting Evidence CPS Application, Scope for Part IIA Investigation, WPA, January 2013
[2] Draft Part 2A Investigation & Risk Assessment, WPA, February 2011
[3] Contaminated Land Statutory Guidance, Environmental Protection Act: Part 2A, DEFRA, April 2012

The site location is shown in Drawing 1.

WPA Consultants Limited (WPA) has assumed that the information and data provided by others is reliable and cannot accept responsibility for errors or omissions that are outside our immediate control.

This assessment and report is based upon the assumption that residential with private gardens use is the most sensitive usage occurring on site. Should the site's usage change then the conclusions and risk assessments contained within this report should be reviewed.

The information and data within this report are derived from boreholes located on council, highways and privately owned land that are adjacent to residential properties in close proximity to the Former Brooks Tip Landfill. The possibility however, of variations in the ground conditions between the sample locations should not be overlooked. Our opinion, expressed on the basis of the possible configuration of strata within the boreholes is conjectural and no liability can be accepted for unforeseen variations.

The Tier 2 Ground Gas Risk Assessment completed as part of the Part IIA Site Investigation & Risk Assessment[4] concluded that the Former Brooks Tip study area was characterised by Characterisation Situation 2 as per the modified Wilson and Card methodology detailed in CIRIA C665[5], and that were ground gas protection measures present within the buildings that meet these requirements then significant harm or a significant potential of significant harm under Part IIA of the Environmental Protection Act 1990 would not be likely. The properties adjoining the site in this area are of several types of design and construction and therefore it was not clear what inherent level of protection is present within the designs, whether landfilled material extended off site or whether gas was migrating beyond the sites boundary. As a precautionary measure offsite ground gas monitoring and a survey of the affected properties was required along with modelling of gas ingress into their underfloor voids and living spaces, where required, in order to robustly demonstrate that no unacceptable risk to residents and property is present. Modelling has taken the conservative assumption that no damp proof membrane was present as the type and status of the membrane is not possible to establish without destructive sampling and the age of the properties is such that what is present is unlikely to comply with present day practice.

[4] Former Brooks Tip; Part IIA Investigation & Risk Assessment, WPA Consultants Ltd, 2011
[5] CIRIA C665 Assessing Risks Posed by Hazardous Gases to Buildings, CIRIA, 2008

2.0 SITE INVESTIGATION WORKS

2.1 Approach and Methodology

The additional intrusive site works were completed between the 27th and 28th of March 2013 when 6 ground gas monitoring wells were installed. All site works were supervised by a Geologist from WPA Consultants Ltd.

Drawing 2 details the location of each borehole installed and the location of the existing monitoring wells.

Service plans were obtained prior to work commencing and permission to install the boreholes on land owned or controlled by parties other than PDC. As a precaution all borehole locations were checked with a hand held Cable Avoidance Tool and hand dug to 1.2 m depth.

2.2 Borehole Formation

Six boreholes were installed, labelled Boreholes BH211 to BH216. Boreholes were distributed in order to detect ground gas migrating from the Former Brooks Tip site, characterise soils on the north side of Boarder Road and provide data on the levels of ground gases in the vicinity of the residential housing/apartments to the north of Border Road known Tree Hamlets. Borehole depths ranged from a minimum of 2 m bgl to a maximum of 3 m bgl. Boreholes were drilled until they encountered natural ground, with shallower boreholes a results of boreholes collapsing prior to installation Each borehole was installed by Tor using their Competitor 130 tracked window sampling rig. Appendix A contains borehole logs produced by WPA Consultants supervising engineer in general compliance with BS5930, logs were also completed by Tor the drilling contractor. Boreholes form the additional works are prefixed with a 2 i.e BH211 and boreholes from the original investigation are prefixed with a 1 i.e. BH102. The later 2 numbers denote the number of the borehole.

2.3 Soil Sampling

The conceptual site model had identified that the majority of the Tree Hamlets Estate was madeground consisting of inert gravel/sand quarrying waste material and not considered to be material that posed a risk of contamination. Soil sampling equipment was present on site when boreholes were installed, but visual and olfactory inspection confirmed that drilling arising's were visually clean gravels, clays and sands an no samples were collected.

Table 2/3 below summarises the borehole logs contained in Appendix A.

Table 2/3
Borehole Log Summary

Borehole ID	Soils Description
BH211	• 0-0.3 m bgl Brown soft clayey TOPSOIL. • 0.3-0.35 m bgl Loose orange medium SAND. • 0.35-0.5 m bgl Pale yellow loose fine, medium, coarse SAND. • 0.5-1.2 m bgl MADEGROUND: Brown black interbedded gravelly clay, gravelly silty clay and gravel. Gravel of coal, ash, brick, pottery and tiles. • 1.2-1.9 m bgl Grey black moderately soft becoming firm, v.sandy CLAY. • 1.9-2.2 m bgl Relict soil horizon. Loose Spongy fibrous plant fragments. Poor recovery less than 50%. • 2.2-3 m bgl Grey black becoming grey white, organic rich clayey SAND, becoming firm and cohesive at 2.5 m bgl.
BH212	• 0-0.4 m bgl Brown black soft clayey TOPSOIL. • 0.4-0.8 MADEGROUND: Yellow slightly gravelly fine, medium and coarse SAND. Gravel (5%) consists of brick bats. • 0.8-1.3 m bgl MADEGROUND: Brown, yellow, firm sandy v. gravelly CLAY. Gravel of pottery, tiles, brick fragments (30%). • 1.3-2 m bgl. No recovery. Potentially similar to BH211, adjacent locations, preceding succession similar and poor recovery shared in both wells.
BH213	• 0-0.5 m bgl Brown soft topsoil. • 0.5-1.0 m bgl MADEGROUND: Brown yellow orange moderately firm v. clayey SAND to v. sandy CLAY. Occasional plastic, tile, brick. Few blue crystals. • 1.0-1.4 m bgl; dark brown soft spongy fibrous PEAT. • 1.4-3 m bgl Yellow white v.firm clayey SAND becoming sandy CLAY. Water bearing horizon at 1.6 m bgl. Less than 50% recovery over last 1 m.
BH216	• 0-0.5 m bgl Brown soft topsoil. • 0.5-1.5 m bgl. Soft becoming firm orange gravelly v.clayey SAND with rare cobbles (2%). Gravel of rounded chert (15%). Mattress springs present in soil. • 1.5-2 m bgl. Firm black layer of clayey/silty becoming sandy fiborous PEAT. • 2-2.3 m bgl Dense grey silty SAND. • 2.3-3 m bgl Firm yellow grey orange s.sandy silty CLAY.

Borehole ID	Soils Description
BH214	• Grassed communal soft landscaped area. • 0 -0.6 m bgl brown moderate to firm slightly silty gravelly topsoil. • 0.6-0.8 m bgl orange very dense sandy GRAVEL with water seep at 0.62 m bgl. • 0.8-1.2 m bgl medium dense yellow orange gravelly SAND. • 1.2-1.4 m bgl dark brown soft spongy fibrous PEAT • 1.4-1.8 m bgl grey white firm silty v. clayey SAND with occasional rootlets. • 1.8-3 m bgl Poor recovery of 50%. Grey firm yellow medium SAND. Base of BH collapsed to 2.7 m.
BH215	• Grassed communal soft landscaped area. • 0 -0.75 m bgl Brown moderately firm slightly silty gravelly CLAY. • 0.75-1.5 m bgl. Noncohesive orange dense gravelly SAND with rare cobbles (2%). Gravel of rounded chert (15%). Water seep at 0.75 m in line with base clay. • 1.5-3 m Grey yellow firm silty very sandy CLAY interbedded with clayey SAND.

2.4 Site Visits

Table 2/4 below details the monitoring dates, sampling locations and any comments on the condition of the monitoring wells and surface water sampling locations noted by the sampling technician. Six ground gas monitoring visits were completed at approximately fortnightly intervals between the 17th April 2013 and 9th July 2013 in compliance with the requirements of CIRIA C665. The visits encompassed a range of atmospheric conditions with 4 visits conducted during periods of falling atmospheric pressure.

Visits dates and antecedent pressure conditions are detailed in Table 2/4.

Table 2/4

Brooks Tip Ground Gas Monitoring Events

Monitoring Date	Pressure at 0 am	Pressure at 6am	Pressureat 9am	Pressure at 12am	Pressure at 15.30	Time of 1st Measurment	Barometric Pressure of 1st Measurement (mb)	Pressure Trend	No. Boreholes Monitored	Comments
17-Apr-13	1018	1015.5	1015	1013.8	1011	14.30	1014	Falling Rapidly	BH102, BH104, BH11-16	
14-May-13	1010.7	1007.3	1006	1003.3	999.5	11.00	1008	Falling Rapidly	BH102, BH104, BH11-17	No VOC
23-May-13	1018.2	1016.5	1016	1014.8	1014.4	10.15	1019	Falling Rapidly	BH102, BH104, BH11-18	No VOC
12-Jun-13	1010.4	1009.4	1011.1	1011.7	1011.4	10.15	1016	Steady	BH102, BH104, BH11-19	No VOC
26-Jun-13	1031.4	1031.4	1031	1031.4	1031	10.05	1034	Steady	BH102, BH104, BH11-20	
09-Jul-13	1030	1029	1028	1027.3	1026	14.45	1027	Falling	BH102, BH104, BH11-21	BH16 left open

2.5 Ground Gas Monitoring Methodology

2.5.1 Gas Monitoring

The gas monitoring strategy was developed with reference to CIRIA-150[6] and CIRIA C665[7]. WPA Consultants uses a GA2000 Landfill Gas Analyser manufactured by Geotechnical Instruments (UK) Ltd., with an internal flow pod for measuring outflows. This instrument is serviced and calibrated by the manufacturer approximately every 6 months or whenever the instrument's own sensor indicates the need for calibration. The equipment is used, with respect to the best practice outlined in the operating manual, by experienced operatives. In addition a MiniRAE 2000, manufactured by RAE Systems, is used to monitor VOC emissions from boreholes. Again this equipment is serviced and calibrated by the manufacturer and measures total VOC content in the borehole atmosphere. It is a professional photoionization detector that measures toxic gasses in vapours in both low and high parts per million concentrations. It detects most volatile organic compounds (VOCs) with a carbon range from 1 (e.g. methylene chloride) to 10 (e.g. naphthalene). The gas monitoring protocols were as follows:

2.5.2 Methane, Carbon Dioxide, Oxygen, Hydrogen Sulphide, & Carbon Monoxide

Meteorological data – barometric pressure, temperature, wind, and rainfall - for the duration of the project were obtained to provide a dataset on antecedent conditions prior to each monitoring event. During each monitoring cycle and at each station qualitative/quantitative observations were made of the following meteorological/environmental conditions: relative pressure and barometric pressure are recorded first. Levels of flow into or out of the borehole are then recorded using the GA2000s internal flow pod with maximum and minimum values and trends over the monitoring window recorded (5 minutes or the time taken for values to stabilise). Percentage gas concentrations – methane, carbon dioxide, oxygen – along with hydrogen sulphide and carbon monoxide (expressed as ppm) are noted at three stages: (1) initial values when the gas meter is attached and the valve is opened, (2) steady state values, and (3) peak values if not the same as in (1). Recording is normally undertaken for at least 5 minutes or until the values stabilise and the rate of decline over this period is noted as the pump evacuates the borehole atmosphere. Water levels within the borehole are recorded along with any other relevant observations. The data is recorded in the field in written form and signed off by the operative.

2.5.3 VOC's.

The MiniRAE 2000 is operated according to the best practice identified within the operating manual for the instrument. The instrument is attached by a flexible tube to the borehole valve which is then opened. The MiniRAE 2000 is calibrated each time it is used using the standard gas mixture provided with the instrument. Monitoring is undertaken for a minimum of five minutes or until concentrations stabilise depending on which is a shorter duration. The data is recorded in the field in written form and signed off by the operative. All data is then entered into Microsoft Excel, from which reports can be generated for presentation for the client.

[6] Methane Investigation Strategies, Report 150, Raybould, Rowan & Barry, CIRIA, 1995
[7] Assessing risks posed by hazardous ground gases to buildings, CIRIA CC665, Wilson et al, CIRIA, 2006

2.6 Groundwater Levels

Ground water levels were recorded following each ground gas monitoring visit with levels converted to m Above Ordnance Datum (AOD) following completion of a RTK DGPS survey by Bournemouth University.

Appendix C tables and graphs show ground water levels recorded across the study area.

Boreholes BH102 and BH104 were located within the footprint of the adjacent Former Brooks Tip landfill and show variable ground water levels through out the monitoring period with no discernible trend. Boreholes BH201 to BH216, located outside the former landfill area, generally show a reduction in ground water levels over the monitoring period. This accords with normal UK trends where ground water levels are usually most elevated over the winter and reduce over the course of the summer and start to rise again from Autumn onwards.

Ground water levels across the site vary significantly between boreholes with BH211, BH212 and BH213 showing levels that appear related and BH214, BH215 and BH216's levels having no discernibly relationship. Ground water levels are therefore considered to be perched and dependent on interbedded layers of sand, clay and gravel with varying levels of permeability.

3.0 GROUND GAS RISK ASSESSMENT

3.1. Outline for Ground Gas Risk Assessment Methodology, tier 1 and 2

Tier 1.

The previously obtained data and desktop information has been reviewed and an conceptual model prepared for the identification of potential ground gas related pollutant linkages. Table 3/2, below, presents the maximum steady gas concentrations, flow rates and attendant Gas Screening Values calculated for the different scenarios outlined above.

Following investigation of the Former Brooks Tip Site a CS2 or Amber 1 of risk was identified as potentially present along the sites northern boundary with respect to carbon dioxide adjacent to BH101, BH103 and BH104. This corresponds to a low risk situation as detailed in CIRIA C665 and reproduced in Table 3/3 band low to intermediate risk as described in the NHBC traffic light classification. Methane GSVs are typical of CS1 or Green characterisation situation which corresponds to very low risk along the northern boundary. Mean average VOC concentration within the perimeter boreholes were all below the 50 ppm screening level and not considered to pose a risk to off site receptors.

Tier 2.

The additional works ground gas data has been collated and assessed for trends and consistent elevated levels of gases (noting when the barometric pressure was falling or below 1000mb). Graphs and figures have been prepared. Gas Screening Values have been calculated in accordance with CIRIA C665. Please refer to the appendices and following discussion.

3.1.1 Risk Assessment

The data has been compared with generic reference data (CIRIA 655 tables 8.5 and 8.7) and the conceptual model has been developed. WPA has estimated risk based on Gas Screening Values and/or other criteria (UK indoor air quality objectives). Gas Screening Values have been calculated in accordance with the methodology outlined by Wilson and Card in CIRIA C665.

Existing building construction data, where available, has been considered for ground gas protective status of the various major site structures.

The risks and appropriateness of protective measures already in existence, where known, have been assessed in the context of C655 table 8.6 and Box 8.4. Recommendations for further implementation of risk management and/or assessment as necessary follow.

3.1.2 Additional Major Hazard Assessment

Due to the nature of the site and degree of risk identified by the calculated GSVs a fault tree analysis to determine the likelihood of a hazardous final event using a source pathway receptor approach has been completed and is presented in Appendix E.

3.1.3 Tier 1 Risk Assessment

The ground gas related pollutant linkages discussed in Section 3.1 are further developed in Table 3/1 below. Whilst previous investigations have established the potential for ground gas generation to be occurring the estimation of risk to human health or property was inadequate to allow a decision regarding determination of receptors that are adjacent to the site as contaminated land under Part IIA of the Environmental Protection Act 1990. Further data collection and assessment was required in respect to ground gas pollutant linkages so that their significance could be considered.

Table 3/1
Tree Hamlets Conceptual Model (ground gas pollutant linkages)

Source	Pathway	Receptor	Risk from	Recommended Action
Landfill gas, Methane (CH_4)	Made ground and service conduits	Adjacent buildings & service voids, site visitors and occupants/workers	Explosion	Ground gas characterisation and risk assessment.
Landfill gas, Carbon Dioxide (CO_2)	Made ground and service conduits	Adjacent buildings & service voids, site visitors and occupants/workers	Asphyxiation	Ground gas characterisation and risk assessment.
Landfill gas, Carbon Monoxide (CO)	Made ground and service conduits	Adjacent buildings & service voids, site visitors and occupants/workers	Asphyxiation	Concentrations not high enough to cause concern.
Landfill gas, Volatile Organic Compounds (VOCs)	Made ground and service conduits	Adjacent buildings & service voids, site visitors and occupants/workers	Explosion, Fire, degradation of services, human health affects	Concentrations not high enough to cause concern.
Landfill gas, Hydrogen Sulphide (H_2S)	Made ground and service conduits	Adjacent buildings & service voids, site visitors and occupants/workers	Explosion, Fire Asphyxiation	Concentrations not high enough to cause concern.

3.1.4 Tier 2 Risk Assessment

The data now collected has allowed a site specific Tier 2 risk assessment to be undertaken, as outlined above.

From the data Gas Screening Values (GSVs) have been calculated in accordance with CIRIA C665 and assessed using the modified Wilson and Card methodology with respect to the school buildings and the NHBC Traffic Light system for residential housing.

GSVs are calculated by multiplying the concentration of the ground gas of interest (methane. carbon dioxide) as measured in percentage by volume present in the air by the flow rate. This produces a GSV that takes into account the quantity of gas present and the rate at which it is generated, allowing a semi-quantitative risk assessment to be undertaken.

For example GSV (litres of gas per hour) = max borehole flow rate (l/hr.) x max gas concentration (%) therefore if 15 % v/v of methane is detected with a simultaneously occurring flow rate of 5 l/hr. then the GSV is calculated as shown below:

0.15 % x 5 l/hr. = 0.75 l/hr.

Assessment based purely on the gas concentration present in a borehole can be overly conservative as boreholes are enclosed spaces and ground gases will have considerable periods of time over which to accumulate. Even if gas production is very low and emissions to atmosphere from the ground would be considered negligible, (due to the void space within a borehole and impermeable seal placed at the surface to prevent mixing between the atmosphere and the contents of the borehole), gas concentrations can build up to a level that would be regarded as unacceptable within a property.

Guidance on assessing trace gas data is not part of the Card and Wilson Gas Screening Value protocol as human health effects can occur at concentrations significantly lower than the lower explosive or asphixiant limits of these gases which GSVs are designed to help assess. To provide some interpretation of the data for these gases reference is made to the approved work place exposure limits approved by the Health and Safety Commission and detailed in EH40/2005[8]. Direct comparison of the numbers, however, is not intended as an absolute determination of significant elevation as borehole data is not representative of indoor air character without further modelling (tier 3). Additionally it should be noted that monitoring boreholes are located adjacent to properties not directly beneath them and the gas concentrations and flows occurring within them do not describe the situation occurring within individual properties. Significant dilution and impedance in the process of migration to ventilated indoor voids will be occurring as is considered in a Tier 3 Risk Assessment.

Appendix B contains summaries of the ground gas monitoring completed and copies of the ground gas monitoring certificates.

Where flow rates have varied during the monitoring period careful consideration of the circumstances under which those flows were recorded and the flows range during the monitoring window has occurred. For example where ground water levels are above the slotted screen, effectively sealing the plain upper 1 m of borehole, and causing a piston effect flow data has been excluded from the risk assessment. Or where flows rates vary significantly between transitory high magnitude flows at the start of the monitoring period and steady but lower magnitude flows at the end a judgment has been made on which value to use in the risk assessment. Additionally where robust data is available and positive and negative flows have been recorded during different monitoring events, and the negative flow rate was of a greater magnitude than the peak positive flow, it has been assumed that a reciprocal positive flow of identical magnitude can occur and this value has been used to calculate the GSV.

[8] EH40/2005 Workplace exposure limits(as consolidated with amendments October 2007), Health and Safety Executive, 2007

Gas Screening Value Scenarios

GSVs based upon the following scenarios were calculated:

1. Monitoring event GSV based on peak steady methane, carbon dioxide and VOC concentrations and the concurrent representative flow rate at the time of monitoring. Contained in Appendix B.
2. Location worst case GSV based on the combination of steady gas concentrations and highest magnitude flow, linked by location that generate the greatest Gas Screening Value occurring at each monitoring location over the duration of the monitoring period.
3. Site worst case GSV based on the maximum recorded peak flow and maximum steady methane and carbon dioxide concentrations not linked by time across the entire site during the monitoring period.

Due to the robustness of the data set the highest GSV originating from scenario 1 is judged to provide a suitably conservative assessment of the circumstances occurring within the area of influence of each borehole location and is best used to assess the risk posed to the adjacent receptors. Situation 3 best describes the potential worst case risk to any developments planned upon the site.

3.2 Ground Gas Risk Assessment

Ground gas monitoring was undertaken at Boreholes 211 through to 216 and at existing Boreholes identified as BH102 and BH104 installed in support of early investigation works at the Former Brooks Tip Site. Borehole locations are shown in Drawing 2. Boreholes were located adjacent to buildings to assess risk to onsite receptors and between adjacent property and the Former Brooks Tip to assess the potential for migration and along the landfill sites periphery in order to assess concentrations of gases at source.

Table 3/2 below contains a summary of the Gas Screening Values detailed in scenarios 1, 2 and 3 in section 3.1.4 above. The GSVs are calculated in accordance with the Wilson & Card Methodology detailed in CIRIA C665 and are based on gas concentrations and gas flow rates encountered during the 6 months of ground gas monitoring completed at the site. Borehole gas concentration Tables contained in Appendix B, detail the varying methane, carbon dioxide and oxygen concentrations of each borehole over the monitoring period.

Table 3/2
Ground Gas Monitoring Summary

BU Borehole Code	Peak Methane Steady (%)	Peak Carbon Dioxide Steady (%)	Oxygen Steady (%)	Peak Hydrogen Sulphide Steady (ppm)	Peak Carbon Monoxide Steady (ppm)	Peak VOC Steady (ppm)	Maximum Peak Flow Rate (l/h)	Min Flow Rate (l/h)	Time Linked			Non Time Linked Max Flow			Non Time Linked Min Flow		
									Highest Occuring Methane GSV#	Highest Occuring Carbon Dioxide GSV#	Highest Occuring VOC GSV#	Highest Occuring Methane GSV#	Highest Occuring Carbon Dioxide GSV#	Highest Occuring VOC GSV#	Highest Occuring Methane GSV#	Highest Occuring Carbon Dioxide GSV#	Highest Occuring VOC GSV#
BH102	0.0	5.4	18.3	0.0	0.0	0.5	0.0	-1.9	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.10	0.00
BH104	5.4	8.3	16.3	1.0	0.0	0.6	0.6	-0.3	0.00	0.00	0.00	0.03	0.05	0.00	0.02	0.02	0.00
BH211	0.4	10.8	20.2	0.0	0.0	1.9	0.1	-0.4	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.04	0.00
BH212	6.1	4.1	8.1	1.0	2.0	4.8	0.1	-0.2	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00
BH213	0.0	3.5	19.6	0	0	0.9	0.1	-0.7	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
BH214	0.0	3.6	20.6	1	0	0.6	0.7	-0.3	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.01	0.00
BH215	0.2	11.3	20.6	7	85	2.3	7.7	-4.0	0.01	0.26	0.00	0.02	0.87	0.00	0.01	0.45	0.00
BH216	80.4	13.6	2.7	2	7	0.0	2.0	0.5	0.24	0.02	0.00	0.40	0.07	0.00	0.40	0.07	0.00
Site Worst Case Value	**80.40**	**13.60**	**20.60**	**7.00**	**85.00**	**4.80**	**7.70**	**-4.00**	**0.24**	**0.26**	**0.00**	**6.19**	**1.05**	**0.00**	**3.22**	**0.54**	**0.00**

NB - GSVs are highest occuring from time linked gas concentrations and flows.
-Values in red are maximum recorded during monitoring period.
-Maximum flow 0f 7.8 result of piston affect, droped significantly over course of 5 minutes to 0.4, therefore discounted as worst case situation and -4.7 l/hr used

= CS1
= CS2
= CS3
= CS4
= CS5

NB: Monitoring occurred over a 6 month period.

3.2.1 Methane

As shown above in Table 3/2 maximum steady methane levels varied considerably across the site with values in BH216 ranging between 47.5 and 80.4 % v/v, during later monitoring events this borehole was left open to atmosphere, but this did not result in a significant change in methane concentrations. The values in BH216 are atypical of the rest of the data set and probably originate from a differing source such as a pocket of natural organic material associated with the nearby marsh land of Lytchett Bay and/or a historic creek running from the harbour to a former boat yard located to the north of the site and has been infilled for a considerable period of time. Excluding BH216 the maximum concentration in the vicinity of Tree Hamlets was 6.1 % to 1.5% that occurred in BH212. No values exceeding 1% or the lower explosive limit of 5% in the rest of the additional works boreholes (BH211, BH213, BH215). The boreholes located within the northern edge of the landfill that could be located (BH102 and BH104) recorded methane concentrations ranging between 0 % and 5.4% , these values are consistent with the concentrations recorded during monitoring of the former Brooks Tip Landfill completed in 2010.

3.2.2 Carbon Dioxide

Carbon dioxide concentrations were typically variable with maximum steady values ranging between 13.6 % v/v in BH216 and 3.5 % v/v in BH213, with the maximum values in BH102 and BH104 being respectively 5.4 % and 8.3 %. Values in BH2015 and BH2014 had a considerable range but in all other boreholes did not vary significantly between monitoring events. Mean average concentrations in all boreholes exceeded the 0.5% v/v long term OEL carbon dioxide screening threshold identified by CIRIA C149[9] and such readings would be regarded with concern if they occurred within a residential property.

3.2.3 VOCs

Maximum steady VOC concentrations range between 4.8 ppm in BH212 and 0.0 ppm in BH216 and with the maximum value from BH102 and BH104 being 0.4 ppm. Readings at all monitoring locations were typically very low (circa 0 ppm) with intermittently elevated concentrations. VOC data wasn't gathered during 3 rounds due to a fault requiring the PID to be repaired over these dates.

3.2.4 Hydrogen Sulphide & Carbon Monoxide

Hydrogen sulphide and carbon monoxide were intermittently detected a very low concentrations, with no detection occurring the majority of the time.

A maximum hydrogen sulphide value of 7 ppm, was recorded in BH215, with the next highest steady value being 2 ppm in BH216 followed by 1 ppm in BH104 , BH212 and BH214. Nothing was detected in BH102, BH211 and BH213.

Carbon monoxide was initially detected in BH212, BH216 and BH215 where respectively maximum steady readings of 2 ppm, 7 ppm and 85 ppm occurred. All values were recorded at the start of the monitoring window and are believed to have resulted from the gas pockets released upon installation of the monitoring wells, rather than active generation of carbon monoxide over the monitoring period. These results are therefore not considered in the risk assessment as they are not representative of site conditions, and therefore not consider as posing an unacceptable risk to the site.

[9] CIRIA C149 Protecting development from methane, Card, G, CIRIA 1995

3.2.5 Flow Rates

Flow rates on site varied highly between monitoring locations and during individual monitoring events. Where flow rates have varied during a monitoring event the circumstances have been evaluated and the most representative flows selected. Flow rates in BH215 are controlled by ground water levels elevated above the slotted screen of the monitoring well which cause piston effects to occur when the monitoring well was un sealed and pressure equalised. A considerable range of values occurring during each visit to BH215. BH215 values typically ranged between moderately negative and moderately positive. The maximum BH215 positive flow recorded was 7.7 l/hr, at the start of round 4, flow dropped rapidly over the 5 minute flow monitoring window to finish at -9.9 l/hr. Five rounds out of the six completed at BH215 exhibited negative flows, with flows typically being highly to moderately negative (-18.8, -4.6, -5 l/hr) at the start and rising rapidly to stabilise as moderate to low (-4, -0.8, -1 l/hr) over 2-3 minutes. Only the first monitoring round, completed on the 17th April encountered a consistently positive flow during the course of the monitoring window when flow started at 5. 1 l/hr and stabilised at 2.3 l/hr after 5 minutes. During all monitoring visits ground water was elevated at this location (ranging between 0.45-0.95 m bgl), and higher than the slotted section of the borehole well. The stronger and highly varying flows are considered to be due to a piston affect from elevated or reduced water levels being maintained in the unslotted upper metre of the well until opening of the gas tap allowed air pressure to equilibrate with atmosphere resulting in strong but transitory flows.

Values from BH215 have not been used in the risk assessment as they are not considered to be representative of actual ground conditions. Where flow rates have varied during a monitoring event the circumstances have been evaluated and the most representative flows selected. Excluding BH215 flows ranged between 2.3 l/hr in BH216 during the first round which then dropped rapidly to a stable flow of 0.5 l/hr and a stable value of 0.7 l/hr in BH214. During other monitoring rounds at these locations and at BH211, BH212 and BH213 flows tended towards low negative flows.

3.2.6 Gas Screening Values & Risk Assessment

Carbon monoxide, hydrogen sulphide and VOC concentrations are discussed in section 3.24 and 3.2.3 and due to these low values were not considered to be sufficiently elevated to pose a significant possibility of significant harm or significant harm to receptors at the site.

Table 3/2, above, presents the maximum steady gas concentrations, flow rates and attendant Gas Screening Values calculated for the different scenarios outlined above. Data from boreholes BH102 and BH104 are included for completeness, but are as they are located within the waste mass are not considered representative of conditions adjacent to the buildings north of Border Road.

Scenario 3 GSVs based on site worst case maximum steady methane and carbon dioxide concentrations of 80.4 % v/v and 13.6 % v/v respectively recorded in BH216 are combined with a flow of 0.5 l/hr, occurring in BH216 create Gas Screening Values for the site of:

Carbon Dioxide	13.6 % v/v x 0.5 l/hr	=0.07 l/hr
Methane	80.4 % v/v x 0.5 l/hr	= 0.4 l/hr

The scenario 3 GSV represents a conservative situation typically used to address planning issues with the GSV of 0.4 l/hr leading to the classification of the site to Characterisation Situation 2 using the

Wilson and card methodology of CIRIA 665. The NHBC traffic light classification system is not considered suitable as properties in the vicinity do not have underfloor ventilation.

Given the quality of the data set available WPA consider that the use of non time or location linked site worst case values taken from the entire data set is overly conservative and that the use of occurring GSVs from each individual borehole, scenario 1, is the most appropriate type of risk assessment. Using this information a CS2 level of risk is present across the site.

In scenarios 1 and 2 which use location and time linked gas concentrations and flows the highest occurring GSVs after exclusion of the previously identified outliers are:

Carbon Dioxide = 0.02 l/hr

Methane = 0.24 l/hr

Under scenarios 1 and 2 the highest methane GSV is 0.024 l/hr, and classified as CS2 under the Wilson and Card system. For carbon dioxide the highest GSV of 0.02 which is classified as Characterisation Situation 1 under the Wilson and Card system.

Characterisation Situation 1 as detailed in Table 8.5 of CIRIA C665 (CIRIA Table 8.5 is reproduced in Section 5.7 alongside further discussion of Gas Characterisation Situations) is a very low risk classification characterised by GSVs of less than 0.07 l/hr. Characterisation Situation 2 is a low risk situation typically characterised by GSVs of 0.07 to less than 0.7 l/hr. CIRIA C665 Table 8.6 Typical Scope of Gas Protective Measures and Box 8.4 indicate the precautions required for residential buildings that fall within this category.

No hydrogen sulphide was detected within the sites boundary and therefore no pathway for exposure occurs.

3.3 Characterisation Situations & Scope of Gas Protection Measures

The Gas Screening Values calculated above for the Brooks Tip site have been compared to the modified Wilson and Card Classification contained in Table 8.5 in CIRIA 665, these are reproduced in Tables 3/3. The assessment system allows a semi-quantitative estimate of risk to be made by placing GSVs into risk bands. CIRIA C665 Table 8.6 Typical Scope of Gas Protection Measures and Box 8.4, reproduced below, and then identifies the typical scope of gas protection measures required by each Characterisation Situation to reduce the risk to an acceptable level.

Table 3/3
Extract from CIRIA 665 Table 8.5 Modified Wilson & Card Classification

Characterisation Situation	Risk Classification	GSV Threshold (l/hr) CO_2 or CH_4	Additional Factors
1	Very Low Risk	<0.07	Typical methane 1% and or/carbon dioxide 5% otherwise consider situation 2.
2	Low Risk	<0.7	Borehole air flow rate not to exceed 70 l/hr. Otherwise consider increase to siutation 2
3	Moderate Risk	<3.5	

CIRIA C665s definitions of risk and those used within the context of this document are detailed below:

1. Very low risk is defined as "*there is a low possibility that harm could arise to a receptor. In the event of such harm being realised it is not likely to be severe".*
2. Low Risk is defined as *"It is possible that harm could arise to a designated receptor from an identified hazard, but it is likely that this harm, if realised, would at worst normally be mild".*
3. Moderate Risk is defined as *"It is possible that harm could arise to a designated receptor from an identified hazard. However, it is either relatively unlikely that any such harm would be severe, or if any harm were to occur it is more likely that the harm would be relatively mild.*

Where characterisation Situation 1 exists CIRIA C665 does not recommend any special precautions.

Where Characterisation Situation 2 exists Table 8.6 CIRIA 665 identifies the following typical gas protection measures or those that provide equivalent protection as being required for residential properties:

a. Reinforced concrete cast in situ floor slab (suspended, non suspended or raft) with at least a 1200 g DPM and under floor venting.

b. Beam and block or pre-cast concrete and 2000g DPM/reinforced gas membrane and under floor venting.

c. Possible underfloor venting or pressurisation in combination with a and b depending on use.

All joints and penetrations should be sealed.

While BS8485 requires private housing in areas where characterisation situation 2 is present to have gas protection measures with a total points score of 3 or greater as set out in Table 3 in BS8485.

Properties in the investigation area are residential and consist of a mixture of apartments and terraced houses. LPA records have previously been searched and no information on the properties design and construction details is available to the Local Authority. An external visual inspection identified:

- no underfloor ventilation;
- foundations consistent with a concrete reinforced floor slab that is assumed to be ground bearing; and
- the presence of a 1000 gauge DPM.
- no reliable information regarding installation and integrity of the DPM, sealing of service penetrations or water bars.

This construction equates to a point score of between 0.5 to 1.5 as per BS8485 Table 3. While the level of risk is considered to be low, as the point score of the properties is not robustly demonstrated as being equal to 3 WPA has completed ground gas ingress modelling and a more detailed survey of building design to support it, followed by a fault tree analysis presented in Appendix E.

4.0 BUILDING SURVEY

The acceptable levels of gas within a property's living space is considered to be 1 % v/v methane (CIRIA C149), 1.5% v/v carbon dioxide(CIRIA C149) and 5 ug/m^3 benzene (2010 UK Air Quality Objective), carbon monoxide 10 ppm (Chartered Institute of Building Service Engineers) and Hydrogen Sulphide 0.01 (Illinois Department of Public Health Guideline for Indoor Air Quality). The following assessments determine the likely concentration of methane and carbon dioxide within the living space of properties for comparison against the above levels. VOC's, Hydrogen sulphide and carbon monoxide are not considered within this report as they were not present within the monitoring wells at concentrations that cause concern.

The externally discernible construction details of representative properties have been determined via a visual survey completed by WPA Consultants Ltd. These properties are representative of others present within Tree Hamlets, Border Road which share the same construction details. Details of the housing survey are presented within Appendix D. Where a property was not surveyed it is assumed that these buildings fall within the characteristics of those surveyed.

The main properties surveyed have ground bearing concrete slabs without underfloor ventilation. All properties constructed on concrete rafts or ground bearing concrete slabs have been treated as houses with a solid floor with no joints laid directly onto the ground. This scenario has been assessed following the guidance in the User's guide for evaluating subsurface vapour intrusion into buildings[10] using the Johnson and Ettinger Model. For the purposes of the assessment extensions and main property structures were treated as independent buildings as it is not practicable to assess them together. The extensions that are constructed upon concrete rafts have been assessed differently to those that are constructed upon concrete slabs. Where the extension foundation type is unknown it has been assumed to be a raft type foundation as gas ingress is greater for this type of construction. The different assessment approaches will be described in detail within the later sections. In addition to the guidance documents listed above CIRIA C665[11] Assessing Risks Posed by Hazardous Gases to Buildings has also been consulted during the assessment process along with Approved Document F[12]. The risk to garden structures will only be assessed where a potential risk has been identified within the main properties. This is considered appropriate as the ventilation capacity of the garden structures such as sheds and greenhouses will far exceed that of the properties.

4.1 Methodology

Property inspection was intended to be tiered, with no further work being required should each property be demonstrated to comply with the default level of gas protection required for categorisation situation 2 (CS2) . However none were identified as having a CS2 level of protection (no underfloor ventilation is present and no information indicating that a compliant gas resistant membrane has been installed) and it was therefore considered necessary to undertake gas ingress modelling to confirm that SPOSH or Significant Harm was not likely.

[10] User's guide for evaluating subsurface vapour intrusion into buildings, USEPA, 2003

[12] Ventilation, Approved Document F, The Building Regulations 2000, Office of the Deputy Prime Minister, 2006

5.0 LIVING SPACE ASSESSMENTS PROPERTIES WITH NO UNDER FLOOR VOIDS & EXTENSIONS

It is not clear from the inspection whether raft foundations or strip foundations with concrete slabs are present and the gas risk assessment has been undertaken for each foundation type following the guidance presented in the User's guide for evaluating subsurface vapour intrusion into buildings USEPA (2003). It is considered that the diameter of the crack will vary between 1 mm and 5 mm based on standard engineering tolerances for these types of structures. This is at the point of construction and it should therefore be noted that this may increase if settlement occurs. The data presented below has been calculated for a crack width of 2 mm and also run for a crack width of 5 mm.

For buildings constructed upon strip foundations with ground bearing concrete slabs, piled foundations or where the foundation type has not been established the gas migration pathway into the property will relate to the joint between the floor slab and the surrounding walls i.e. the perimeter of the slab. This is the gas migration pathway that will be considered during the assessment of properties with strip foundations and ground bearing slabs. CLEA SR3[13] states that the crack width to be considered should be 0.2 cm (2mm). This value has been adopted for the values presented in this document, however, the assessment has also been completed with a conservative crack width of 0.5 cm and no exceedances of the assessment criteria occurred. For both types of foundation an assessment was undertaken considering the Site Worse Case gas concentrations and flow rates.

Property based values have been obtained via measuring the perimeter and dimensions of the different property geometries using Purbeck District Councils Planweb GIS.

5.1 Methodology

A conservative approach has been adopted for the assessment. A worst-case scenario has been considered by assuming that the properties have no gas membranes or damp proof membrane. The accumulation of carbon dioxide, methane, and VOCs within the living space of the properties has been assessed through:

1. Calculation of gas flux into property based on likely migration pathways through cracks in the building foundation are based on a differential pressure derived from the flow rate of the borehole.
2. Calculation of soil vapour permeability.
3. Calculation of the dilution effect of the building based on its natural ventilation characteristics.
4. Determination of likely Equilibrium Conditions concentration within the building based on gas flow into the building and the building dilution effect.

All of the above steps have been undertaken following the guidance provided in the User's guide for evaluating subsurface vapour intrusion into buildings USEPA (2003).

---

[13] Science Report SC050021/SR3 Updated Technical Background to the CLEA Model, Environment Agency, January 2009

5.2 Gas Flux into Property

The gas flux into a property is calculated using Equation 15 from the User's guide for evaluating subsurface vapour intrusion into buildings USEPA (2003)[14]. This equation is presented below.

$$Q_{soil} = 2\Pi \Delta P K_v X_{crack} / \mu 1n(2Z_{crack}/R_{crack})$$

Q_{soil} = Volumetric flow rate of soil gas entering the building, cm^3/s

Where: Π= 3.14159

ΔP = Pressure differential between the soil surface and the enclosed space, g/cm/s/s

k_v = Soil vapour permeability, cm^2

X_{crack} = Floor-wall seam perimeter, cm

μ = Viscosity of air, g/cm/s

Z_{crack} = Crack depth below grade, cm

r_{crack} = Equivalent crack radius, cm.

The Z_{Crack} is based on information from CLEA SR3, the report produced to detail the technical basis of the Environment Agency's CLEA 1.04 software, and was 0.15 m. X_{crack} is building specific and is considered to be the extension or buildings perimeter length. Values for differential pressure were worse case values taken from the ground gas monitoring data presented in the section 3.2.

In addition to the differential pressure measured in the field the differential pressure relating to the 'Stack Effect' (the difference in temperature between the ground and the building interior) was considered. The value of 0.025 mb for two storey buildings from the CLEA SR3 was utilised. It is recognised that all ground floor flats are single level, however, first floor flats with a mezzanine floor in the roof space are also present, therefore however the two storey value was adopted as a worst case scenario to maintain the conservative approach. The viscosity of air is a reference value of 0.0175 g/cm/s based on a dynamic viscosity of 1.1X10-5 $N/s/m^2$. The r_{crack} is calculated from Equation 16 from the User's guide for evaluating subsurface vapour intrusion into buildings USEPA (2003). This equation is presented below;

$$R_{crack} = n(AB/X_{crack})$$

where

r_{crack} = Equivalent crack radius, cm

$\eta = A_{crack}/AB$, ($0 \leq \eta \leq 1$)

AB = Area of the enclosed space below grade, cm^2

X_{crack} = Floor-wall seam perimeter, cm.

[14] User's guide for evaluating subsurface vapour intrusion into buildings, USEPA, 2003

The values for the above parameters for the 5 different flat geometries present are presented in Table 5/1A and B.

Table 5/1A

Property Specific Parameters used to Determine r_{cack}

Property	Area (AB) cm2	Acrack cm2	n	Rcrack
Generic Flat 1	736800.00	688.40	0.0009	0.200
Generic Flat 2	731200.00	685.60	0.0009	0.200
Generic Flat 3	932576.00	792.00	0.0008	0.200
Generic Flat 4	1321240.00	919.60	0.0007	0.200

Table 5/1B

Building Parameters							
Property	Maximum Length m	Maximum Length cm	Maximum Width m	Maximum Width cm	Building Height m	Building Height	Measured Surface Area m2
Generic Flat 1	8.00	800.00	9.21	921.00	4.90	490.00	73.68
Generic Flat 2	8.00	800.00	9.14	914.00	4.90	490.00	53.48
Generic Flat 3	7.72	772.00	12.08	1208.00	4.90	490.00	61.82
Generic Flat 4	11.39	1139.00	11.60	1160.00	4.90	490.00	63.06
Generic Flat 5	7.96	796.00	11.28	1128.00	4.90	490.00	77.62

The soil vapour permeability (k_v) is derived from the soil permeability (k_i) by multiplying the k_i by the relative air permeability (K_{rg}). The soil permeability (k_i) was determined using equation 26 from the User's guide for evaluating subsurface vapour intrusion into buildings USEPA (2003). This formula is presented below.

$$\mathbf{K_i = K_s\, U_w/\rho_w\, g}$$

Where

k_i = Soil intrinsic permeability, cm^2

K_s = Soil saturated hydraulic conductivity, cm/s (=0.0074cm/s)

μ_w = Dynamic viscosity of water, g/cm/s (= 0.01307 at 10◦C)

ρ_w = Density of water, g/cm^3 (= 0.999g/cm^3)

The site investigation has shown that the dominant geology in the upper horizons at the site is sandy gravelly clay. The K_s was derived from Table 5 of the guidance that states that a value of 0.00013 is appropriate for sands. Using the above equation the gas k_i was calculated to be 9.87E-8 cm^2. The gas flux and equilibrium concentration into the different types of structure was then calculated as presented in Table 5/2.

Table 5/2
Gas Flux and Equilibrium Concentration

Property	Clean Air Flow into Property (Q) m3/hr	Clean Air Flow into Property (Q) L/hr	Dilution Factor (DF)	Equillibrium Concentration			
				Methane % v/v	Carbon Dioxide % v/v	VOCs % v/v	VOCs in ug/m3
Generic Flat 1	180.5	180516	1.18E-06	9.49E-05	1.60E-05	3.00E-10	0.010
Generic Flat 2	131.0	131026	1.62E-06	1.30E-04	2.20E-05	4.12E-10	0.013
Generic Flat 3	151.5	151459	1.62E-06	1.30E-04	2.20E-05	4.12E-10	0.013
Generic Flat 4	154.5	154497	1.84E-06	1.48E-04	2.50E-05	4.69E-10	0.015
Generic Flat 5	190.2	190169	1.25E-06	1.01E-04	1.70E-05	3.19E-10	0.010

In order to derive the likely concentration within the living space of the properties it is necessary to determine the dilution within the property based on the natural ventilation characteristics of the property.

Natural Ventilation

The natural ventilation characteristics of each extension was determined using Equation 16 from the User's guide for evaluating subsurface vapour intrusion into buildings USEPA (2003). This equation is presented below.

Q = Extension Length (m) x Extension Width (m) x Height Per Level (m) x Number Of Levels x Air Change Rate (dimension less)

As the properties are not irregular in shape the area component of this equation (Extension Length (m) x Extension Width (m)) has been established by measuring the area in m2 from Purbeck Councils GIS system.

As with the assessment of the main structures the ventilation rate for the living space of the property have been taken as 0.5 air changes per hour on the basis of that detailed in CLEA SR3. The building parameter including length, width and height are based on the actual dimensions of each building which were derived during the building survey. These are presented in Table 5/1B.

The acceptable level of gas within a property living space is considered to be 1 % v/v methane, 1.5 % v/v carbon dioxide and 5 ug/m^3 benzene (UK Air Quality Objective. Site worst case methane, carbon dioxide and methane were used with the VOC concentration measured in isobutylene equivalents being subject to the appropriate benzene correction factor. These are not shown to be exceeded by the above assessment and as such it is considered that the likely levels are acceptable.

6.0 CONCLUSIONS & RECOMENDATIONS

The following lines of evidence need to be considered when assessing risk and hazard at the site:

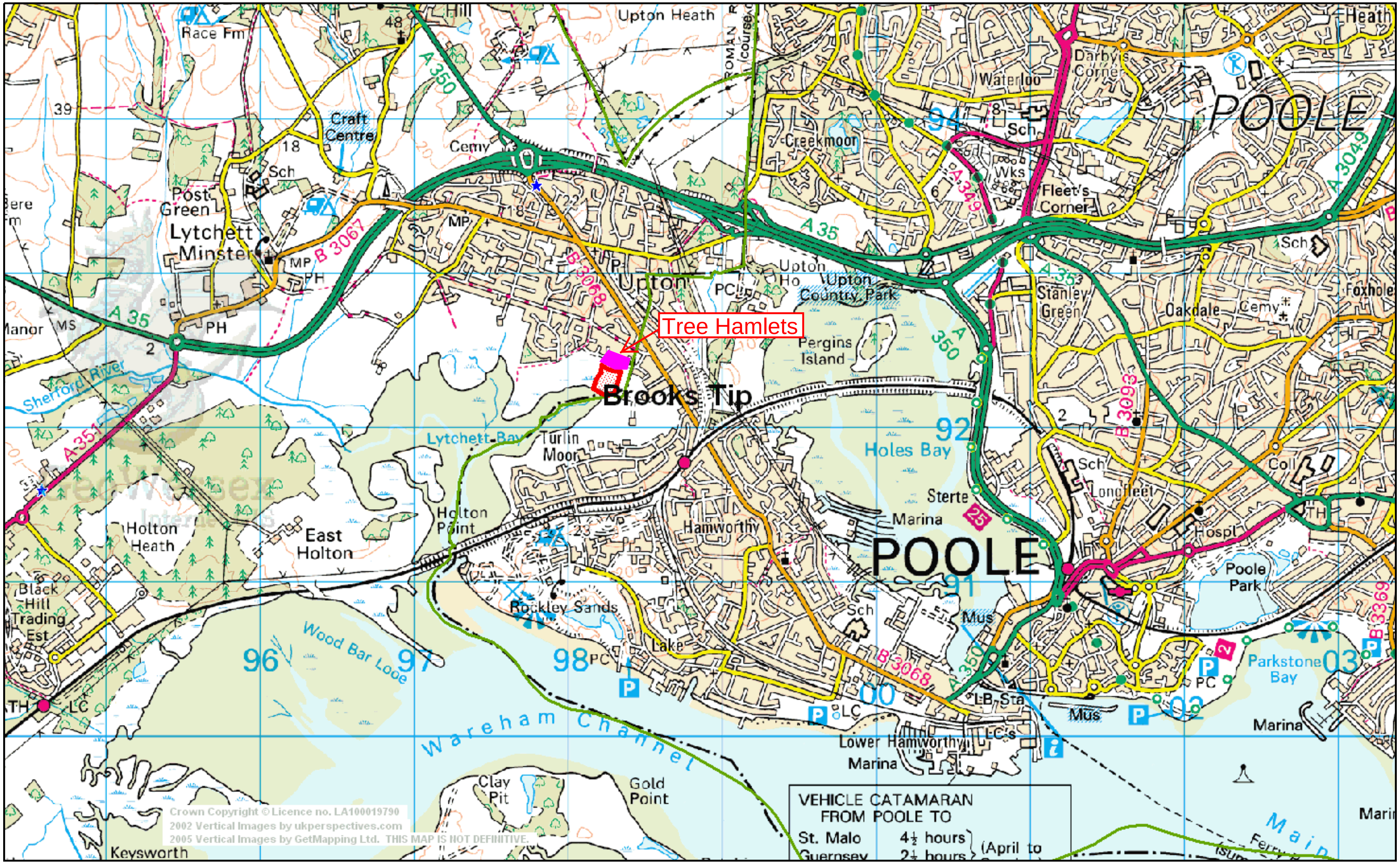
1. Ground gas concentrations and flow rates are variable across the site and following consideration of the conceptual site model and circumstances at each monitoring well are considered to be representative of a low to very low risk. Very low risk is defined in CIRIA C665 as "*there is a low possibility that harm could arise to a receptor. In the event of such harm being realised it is not likely to be severe"* while Low Risk is defined as *"It is possible that harm could arise to a designated receptor from an identified hazard, but it is likely that this harm, if realised, would at worst normally be mild"*. The low risk scenario is driven by elevated methane concentrations in BH216 that are considered to be atypical of the site, with the very low risk scenario present at the other locations.
2. Modern construction practice requires simple gas protection measures to be present when new properties are constructed and a low risk situation is considered to be present, these should deliver a protection score of 3, however, the points score calculated falls between 0.5 to 1.5 depending on the construction present. There is therefore some protection from the buildings foundation design but not as much as would be required in a modern building.
3. Following consideration of point 2 ground gas ingress modelling was completed and this calculation indicates that under equilibrium conditions gas concentrations within the properties would be considerably below an unacceptable level of gas within the living spaces of the properties.
4. Additionally fault tree analysis was completed to assess the probability that an event where ground gas levels within an enclosed space could reach an unacceptable level. This exercise considered different gas production scenarios and design characteristics, and concluded that a 1 in 65000 likelihood of explosion was present. This likelihood is highly influenced by BH216 where the methane concentrations are considerably more elevated than on the rest of the site (typically 47-80% compared to maximum values of 0-6.1% at the other monitoring locations) therefore were BH216 to be discounted from the assessment the likelihood of a potential explosive incident would decrease by approximately 13 times to 1 in 498000. Table A5.1 of CIRIA C665 sets out degrees of risk and there acceptability. A judgment need's to be made by the Local Authority of the acceptability of the risks outlined in the fault tree analysis. WPA consider the worst case event modelled to be representative of an event that may cause impairment and to be classified by table A5.1 as unlikely to very unlikely and therefore of little to no concern.
5. Landfilling adjacent to the site ceased circa 1980 and no incidents relating to ground gas have been reported to the Local Authority over the intervening 33 years. Peak gas production is considered to have passed and consequently the period of greatest risk to receptors in the vicinity.

WPA consider that the lines of evidence (data, ground gas ingress modelling, fault tree analysis and risk assessments) detailed in points 1 to 5 above demonstrate that on the balance of probabilities the inherent design and construction of the properties surveyed within Tree Hamlets is sufficiently protective against the ground gases present that no significant harm is likely to occur and that no significant potential of significant harm is likely. Therefore on the balance of probability's the evidence does not support determination of the site under Part IIA of the Environmental Protection Act 1990 with respect to ground gas.

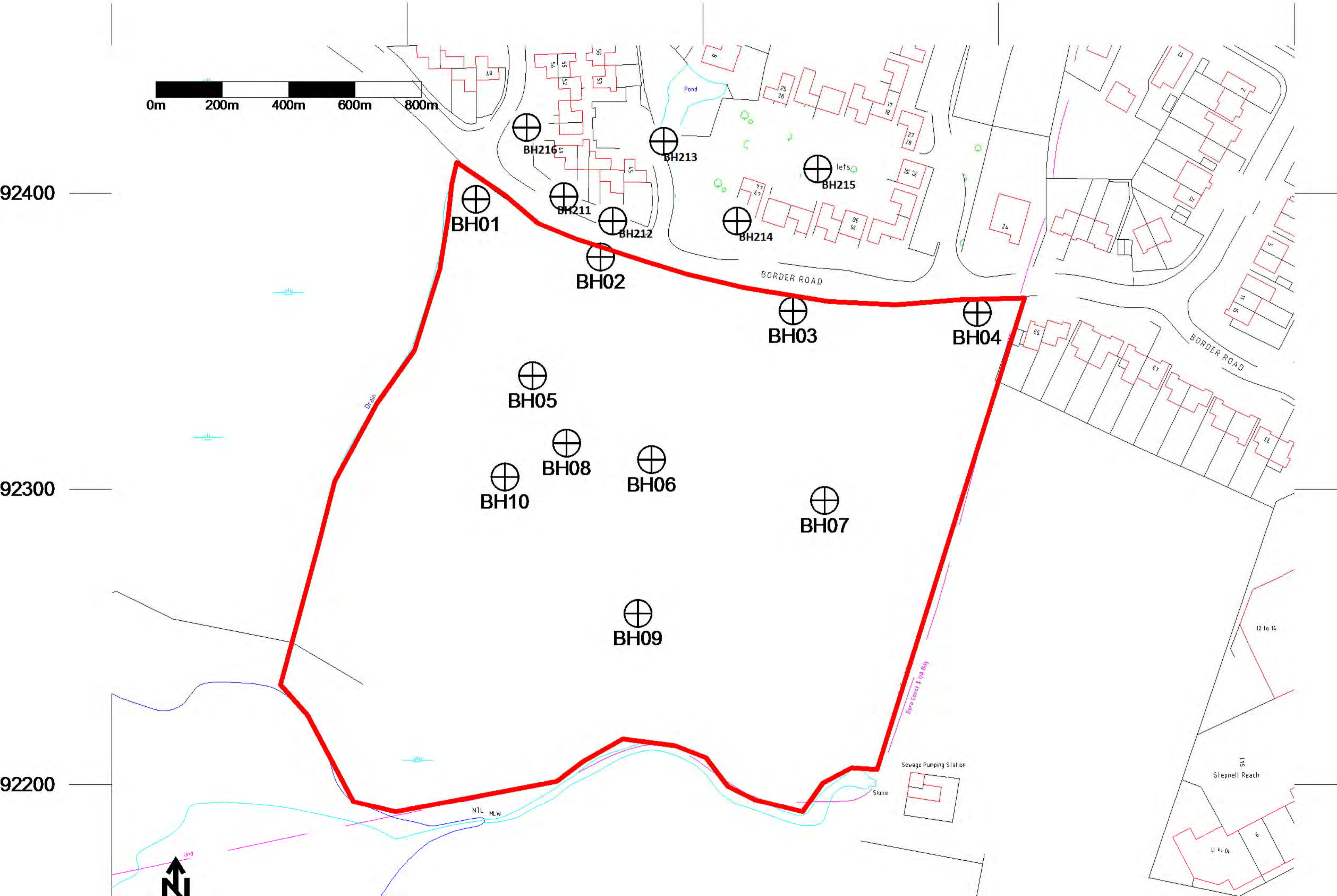
However, any further development at the site will require individual ground gas risk assessment and WPA recommends that planning permission with appropriate conditioning is required before any extensions to the existing properties can be permitted. WPA would also advise that residents be informed of the continuing need to maintain the passive ventilation arrangements for their property.

Worse case gas concentrations and relative pressures are derived from BH216 which the site conceptual model suggests is located above or immediately adjacent to a silted up/infilled creek that accessed a historic boat yard located to the rear of the site. The data from this location has a significant effect on the level of risk the site is exposed to and WPA recommends completing some further characterisation work here to identify whether gas at this location originates from the adjacent landfill or peat or organic material associated with the historic creek. Further assessment of the gas origin in this bore hole would additionally strengthen the fault tree analysis by reducing the likelihood of an event occurring.

Site Location Plan



DORSET County Council		Scale 1/34785 Centre = 398862 E 91968 N	Date 17/7/2009 WPA Consultants Ltd (JW17/07/2009)


0m
200m
400m
600m
800m
92400
92300
92200
BH01
BH02
BH03
BH04
BH05
BH06
BH07
BH08
BH09
BH10
BH211
BH212
BH213
BH214
BH215
BH216
BORDER ROAD
BORDER ROAD
Pond
Drain
Sewage Pumping Station
Sluice
NTL
MLW
Stepnell Reach
12 to 14
N

DORSET County Council

Scale 1/415

Centre = 398344 E 92387 N

Date 22/8/2013

APPENDIX A

BOREHOLE LOGS

Site :	Tree Hamlet Border Rd Upton	Ws/Dp Nº 10	TOR

Day & Date	M / T / W / (T) / F / S / S / 28 : 3 : 13	**A daily log sheet must be completed for each Day/Date/BH**
Concrete Coring	Yes / (No) Diameter =	Please ensure that these logs are fully completed & a copy
Vac- Excavation	Yes / (No) By Tor / By Others	should be issued in clean condition to the site engineer
Dig pit	(Yes) / No Depth = 1.2	Rig / System Used = Tracked Unit / Jackhammer System

Depths of change in Geology	Drillers Geology Description
	Pit to 1.2 Fill 0.8 natural sands Sandy clay -

ID Nº	Sample/Test Depth	Sample Type	Casing Depth	In- Situ Test Results or Sample Recovery %
10	0-1.2	Pit	1	
	1.2-2	ws	2	
	2-3	ws	3	

Test / Sample key: S = Spt / C = Cpt / Ws = Window sample / Bs = Bulk-Bag sample / Ds = Disturbed / T = Tub J = Jar / W = water

Dayworks & Standing Records (please note total hrs and a brief reason)

Dynamic Probing Count Chart (Heavy / Super Heavy) delete as appropriate

	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10
0.0 m										
1.0 m										
2.0 m										
3.0 m										
4.0 m										
5.0 m										
6.0 m										
7.0 m										
8.0 m										
9.0 m										
10.0 m										
11.0 m										
12.0 m										

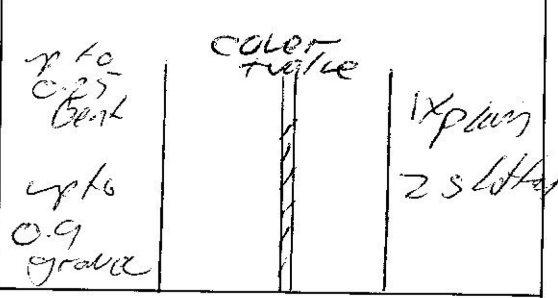
Backfilling Details

Borehole Depth =

Maximum Drilling Diameter =

Backfill material = Arisings / Bento /Gravel

Installation Details (diagram)



Water level at start of shift =	Water Record Strike/s = 2.2	Rest Levels after 20min=	
Driller (print name) D Iceo		Driller Signature	[signature]
Client (print name) James Jackson		Client Signature	

SFR33 - Duplicate - log - issue 1 12-10-09

Site :	Tree Hamlet Border Rd Upton	Ws/Dp N° 11	TOR

Day & Date	M / T / W / (T) / F / S / S / 28 : 3 : 13	A daily log sheet must be completed for each Day/Date/BH
Concrete Coring	Yes / (No) Diameter =	Please ensure that these logs are fully completed & a copy
Vac- Excavation	Yes / (No) By Tor / By Others	should be issued in clean condition to the site engineer
Dig pit	(Yes) / No Depth = 1.2	Rig / System Used = Tracked Unit / Jackhammer System

Depths of change in Geology	Drillers Geology Description
	Pit to 1.2 Fill 1.2 natural sandy clay

ID N°	Sample/Test Depth	Sample Type	Casing Depth	In- Situ Test Results or Sample Recovery %
11	0-1.2	ws	1	
	1.2-2	ws	2	
	2-3	ws	3	

Test / Sample key: S = Spt / C = Cpt / Ws = Window sample / Bs = Bulk-Bag sample / Ds = Disturbed / T = Tub J = Jar / W = water

Dayworks & Standing Records (please note total hrs and a brief reason)

Dynamic Probing Count Chart (Heavy / Super Heavy) delete as appropriate

	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10
0.0 m										
1.0 m										
2.0 m										
3.0 m										
4.0 m										
5.0 m										
6.0 m										
7.0 m										
8.0 m										
9.0 m										
10.0 m										
11.0 m										
12.0 m										

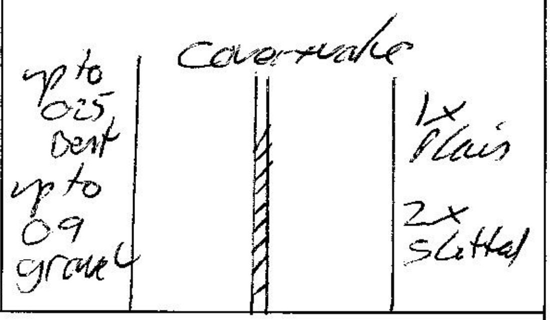
Backfilling Details

Borehole Depth =

Maximum Drilling Diameter =

Backfill material = Arisings / Bento /Gravel

Installation Details (diagram)



Water level at start of shift = Water Record Strike/s = — Rest Levels after 20min=

Driller (print name) D. Ites	Driller Signature
Client (print name) James Lawson	Client Signature

SFR33 - Duplicate - log - issue 1 12-10-09

Site :	Tree Hamlet Border Rd Upton	Ws/Dp N° 12	TOR

Day & Date	M / T / W / (T) / F / S / S / 28 : 3 : 17	A daily log sheet must be completed for each Day/Date/BH
Concrete Coring	Yes / (No) Diameter =	Please ensure that these logs are fully completed & a copy
Vac- Excavation	Yes / (No) By Tor / By Others	should be issued in clean condition to the site engineer
Dig pit	(Yes) / No Depth = 1.2	Rig / System Used = Tracked Unit / Jackhammer System

Depths of change in Geology	Drillers Geology Description
	Fill all cased to 1.5 refused barrel drilled to 2m with 2nd barrel no recovery 1.5 - 2m

ID N°	Sample/Test Depth	Sample Type	Casing Depth	In- Situ Test Results or Sample Recovery %
	0-1.2	Pit	1	
	1.2-1.6	ws	1.6	casing refusal
	1.6-2	ws	—	2nd barrel

Test / Sample key: S = Spt / C = Cpt / Ws = Window sample / Bs = Bulk-Bag sample / Ds = Disturbed / T = Tub J = Jar / W = water

Dayworks & Standing Records (please note total hrs and a brief reason)

Dynamic Probing Count Chart (Heavy / Super Heavy) delete as appropriate

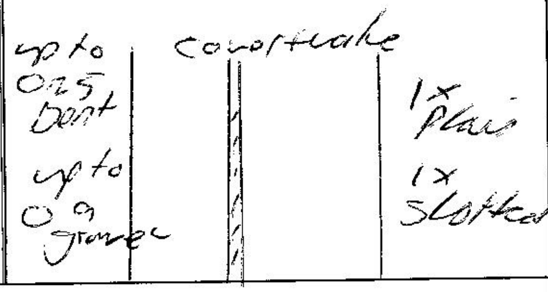
	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10
0.0 m										
1.0 m										
2.0 m										
3.0 m										
4.0 m										
5.0 m										
6.0 m										
7.0 m										
8.0 m										
9.0 m										
10.0 m										
11.0 m										
12.0 m										

Backfilling Details

Borehole Depth =
Maximum Drilling Diameter =
Backfill material = Arisings / Bento /Gravel

Installation Details (diagram)

2m



Water level at start of shift = Water Record Strike/s = — Rest Levels after 20min=

Driller (print name) D. Isley	Driller Signature
Client (print name) Sam Wilson	Client Signature

SFR33 - Duplicate - log - issue 1 12-10-09

Site :	Tree hamlet Border Rd Upton	Ws/Dp N° 13	TOR

Day & Date	M / T / (W) / T / F / S / S / 27 : 3 : 13	A daily log sheet must be completed for each Day/Date/BH
Concrete Coring	Yes / (No) Diameter =	Please ensure that these logs are fully completed & a copy
Vac- Excavation	Yes / (No) By Tor / By Others	should be issued in clean condition to the site engineer
Dig pit	(Yes) / No Depth = 1.2	Rig / System Used = Tracked Unit / Jackhammer System

Depths of change in Geology	Drillers Geology Description	ID N°	Sample/Test Depth	Sample Type	Casing Depth	In- Situ Test Results or Sample Recovery %
	Pit to 1.2 Fill 1.6 Natural sandy clay	13	0 - 1.2	Pit	1	
			1.2 - 2	ws	2	
			2 - 3	ws	3	

Test / Sample key: S = Spt / C = Cpt / Ws = Window sample / Bs = Bulk-Bag sample / Ds = Disturbed / T = Tub J = Jar / W = water

Dayworks & Standing Records (please note total hrs and a brief reason)

Dynamic Probing Count Chart (Heavy / Super Heavy) delete as appropriate

	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10
0.0 m										
1.0 m										
2.0 m										
3.0 m										
4.0 m										
5.0 m										
6.0 m										
7.0 m										
8.0 m										
9.0 m										
10.0 m										
11.0 m										
12.0 m										

Backfilling Details

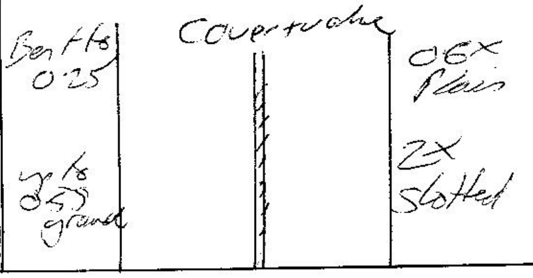
Borehole Depth =

Maximum Drilling Diameter =

Backfill material = Arisings / Bento /Gravel

Installation Details (diagram)

2.6



Water level at start of shift = Water Record Strike/s = 1.4 Rest Levels after 20min=

Driller (print name) D. Tees Driller Signature

Client (print name) Client Signature

Site :	Tree Hamlet Border Rd Upton	Ws/Dp Nº 14	TOR

Day & Date	M / T / (W) / T / F / S / S / 27 : 3 : 13	**A daily log sheet must be completed for each Day/Date/BH**
Concrete Coring	Yes / (No) Diameter =	Please ensure that these logs are fully completed & a copy
Vac- Excavation	Yes / (No) By Tor / By Others	should be issued in clean condition to the site engineer
Dig pit	(Yes) / No Depth = 1.2	Rig / System Used = Tracked Unit / Jackhammer System

Depths of change in Geology	Drillers Geology Description	ID Nº	Sample/Test Depth	Sample Type	Casing Depth	In- Situ Test Results or Sample Recovery %
	pit to 1.2 Fill 0.6 Natural gravel – gravelly sand	16	0-1.2	Pit	1	
			1.2-2	ws	2	
			2-3	ws	3	

Test / Sample key: S = Spt / C = Cpt / Ws = Window sample / Bs = Bulk-Bag sample / Ds = Disturbed / T = Tub J = Jar / W = water

Dayworks & Standing Records (please note total hrs and a brief reason)

Dynamic Probing Count Chart (Heavy / Super Heavy) delete as appropriate

	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10
0.0 m										
1.0 m										
2.0 m										
3.0 m										
4.0 m										
5.0 m										
6.0 m										
7.0 m										
8.0 m										
9.0 m										
10.0 m										
11.0 m										
12.0 m										

Backfilling Details

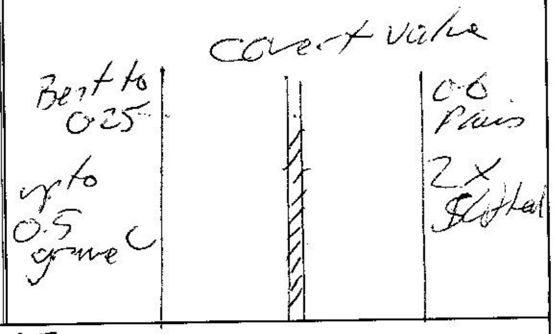
Borehole Depth =

Maximum Drilling Diameter =

Backfill material = Arisings / Bento /Gravel

Installation Details (diagram)

2.7



Water level at start of shift = Water Record Strike/s = 0.62 Rest Levels after 20min=

Driller (print name) O. Ices Driller Signature [signature]

Client (print name) James Wilson Client Signature [signature]

SFR33 - Duplicate - log - issue 1 12-10-09

Site :	Tree Hamlet Border Rd UPTON	Ws/Dp Nº 15	TOR

Day & Date	M / T / (W) / T / F / S / S / 27 : 3 : 17	A daily log sheet must be completed for each Day/Date/BH
Concrete Coring	Yes / (No) Diameter =	Please ensure that these logs are fully completed & a copy
Vac- Excavation	Yes / (No) By Tor / By Others	should be issued in clean condition to the site engineer
Dig pit	(Yes) / No Depth = 1.2	Rig / System Used = Tracked Unit / Jackhammer System

Depths of change in Geology	Drillers Geology Description	ID Nº	Sample/Test Depth	Sample Type	Casing Depth	In- Situ Test Results or Sample Recovery %
	Pit to 1.2 Fill 1.5 Natural Sandy clay	15	0-1.2	Pit	1	
			1.2-2	WS	2	
			2-3	WS	3	

Test / Sample key: S = Spt / C = Cpt / Ws = Window sample / Bs = Bulk-Bag sample / Ds = Disturbed / T = Tub J = Jar / W = water

Dayworks & Standing Records (please note total hrs and a brief reason)

Dynamic Probing Count Chart (Heavy / Super Heavy) delete as appropriate

	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10
0.0 m										
1.0 m										
2.0 m										
3.0 m										
4.0 m										
5.0 m										
6.0 m										
7.0 m										
8.0 m										
9.0 m										
10.0 m										
11.0 m										
12.0 m										

Backfilling Details

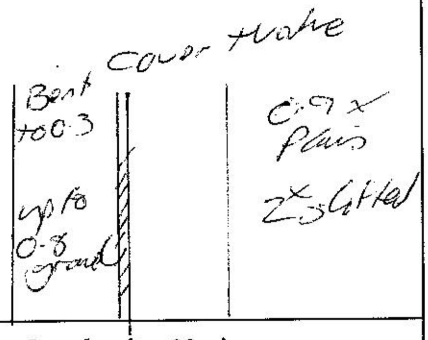
Borehole Depth =

Maximum Drilling Diameter =

Backfill material = Arisings / Bento /Gravel

Installation Details (diagram)

3m



Water level at start of shift = Water Record Strike/s = 0.75 Rest Levels after 20min=

Driller (print name)	D. ICE	Driller Signature	[signature]
Client (print name)	D. [illegible]	Client Signature	[signature]

SFR33 - Duplicate - log - issue 1 12-10-09

APPENDIX B

GROUND GAS MONITORING

BU Borehole Code	Date Taken	Barometric Pressure	Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV	
BH102	17-Apr-13	1014	0	4.1	13.5	0	0	0.3	0	-1.9	0.00	0.00	0.00	
BH102	14-May-13	1008	0	3.5	16	0	0		-0.1	-0.1	0.00	0.00	0.00	
BH102	23-May-13	1019	0	5.4	11.9	0	0		0	0	0.00	0.00	0.00	CO2 increaseing slowly over 5 minute peri
BH102	12-Jun-13	1016	0	3.8	18.3	0	0		-0.3	-0.3	0.00	0.01	0.00	
BH102	26-Jun-13	1034	0	4.6	11.9	0	0	0.3	-0.2	-0.2	0.00	0.01	0.00	
BH102	09-Jul-13	1027	0	3.1	16.6	0	0	0.5	-0.2	-0.2	0.00	0.01	0.00	GA2000 2 min, VOC 2min
	Count		6	6	6	6	6	3	6	6	6.00	6.00	6.00	
	Min		0.0	3.1	6.0	0	0	0.3	-0.3	-1.9	0.00	0.00	0.00	
	Mean Average		0.0	4.1	12.5	0	0	0.4	-0.1	-0.5	0.00	0.01	0.00	
	Max		0.0	5.4	18.3	0	0	0.5	0.0	0.0	0.00	0.01	0.00	
	Range		0	2.3	12.3	0	0	0.2	0.3	1.9	0.00	0.01	0.00	

BU Borehole Code	Date Taken		Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV	
BH104	17-Apr-13	1014	2.8	6.9	0.3	0	0	0	-0.1	-0.3	0.00	0.01	0.00	CH4 and CO2 dropping over time
BH104	14-May-13	1008	0	2.4	16.3	0	0		0.1	0	0.00	0.00	0.00	CO2 dropping slowly over 5 minutes
BH104	23-May-13	1019	3.2	7.7	0.6	0	0		0	0	0.00	0.00	0.00	
BH104	12-Jun-13	1016	5.4	8.3	0.2	0	0		0.6	0	0.03	0.05	0.00	
BH104	26-Jun-13	1034	3.2	7.5	1.2	0	0	0	0	0	0.00	0.00	0.00	
BH104	09-Jul-13	1027	2.6	7.7	0.8	1	0	0.6	-0.2	-0.2	0.01	0.02	0.00	GA2000 1.5 min, VOC, 1.5 min
	Count		6	6	6	6	6	3	6	6	6.00	6.00	6.00	
	Min		0.0	2.4	0.2	0	0	0.0	-0.2	-0.3	0.00	0.00	0.00	
	Mean Average		2.9	6.8	3.2	0	0	0.2	0.1	-0.1	0.00	0.00	0.00	
	Max		5.4	8.3	16.3	1	0	0.6	0.6	0.0	0.00	0.00	0.00	
	Range		5.4	5.9	16.1	1	0	0.6	0.8	0.3	0.00	0.00	0.00	

BU Borehole Code	Date Taken		Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV	
BH211	17-Apr-13	1014	0.1	0.6	20.2	0	0	0	0	0	0.00	0.00	0.00	High CO2 to start then decreased over 5 m
BH211	14-May-13	1008	0.4	1.9	19	0	0		0.1	0.1	0.00	0.00	0.00	
BH211	23-May-13	1019	0	1.3	19.7	0	0		0	0	0.00	0.00	0.00	CO2 decreasing v.gradualy over 5 minutes
BH211	12-Jun-13	1016	0	3.8	18.3	0	0		-0.1	-0.1	0.00	0.00	0.00	
BH211	26-Jun-13	1034	0.3	10.8	9.1	0	0	1.9	-0.4	-0.4	0.00	0.04	0.00	Recently cut grass.
BH211	09-Jul-13	1027	0	0	19.8	0	0	1.9	0	0	0.00	0.00	0.00	GA2000 1.5 min, VOC 1.5 min
	Count		6	6	6	6	6	3	6	6	6.00	6.00	6.00	
	Min		0.0	0.0	9.1	0	0	0.0	-0.4	-0.4	0.00	0.00	0.00	
	Mean Average		0.1	3.1	17.7	0	0	1.3	-0.1	-0.1	0.00	0.01	0.00	
	Max		0.4	10.8	20.2	0	0	1.9	0.1	0.1	0.00	0.04	0.00	
	Range		0.4	10.8	11.1	0	0	1.9	0.5	0.5	0.00	0.04	0.00	

BU Borehole Code	Date Taken		Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV	
BH212	17-Apr-13	1014	1.5	1.3	8.1	0	2	1.9	-0.2	-0.2	0.00	0.00	0.00	VOC's gradualy increasing over 5 minutes.
BH212	14-May-13	1008	3	2.9	1.2	0	0	0	0.1	0.1	0.00	0.00	0.00	Issue with PID switched self off and failed t
BH212	23-May-13	1019	3.9	3.1	0.6	0	0		0	-0.1	0.00	0.00	0.00	CH4 increasing v.slightly over time.
BH212	12-Jun-13	1016	6.1	3.5	0.6	0	0		0	0	0.00	0.00	0.00	
BH212	26-Jun-13	1034	3.7	4.1	0.8	0	0	4.8	-0.1	0	0.00	0.00	0.00	VOC concnetration creeping up over 5 min
BH212	09-Jul-13	1027	3.8	4	1.7	1	0	4.7	0	0	0.00	0.00	0.00	GA2000 1.5 min, VOC 5 min
	Count		6	6	6	6	6	4	6	6	6.00	6.00	6.00	
	Min		1.5	1.3	0.6	0	0	0.0	-0.2	-0.2	0.00	0.00	0.00	
	Mean Average		3.7	3.2	2.2	0	0	2.9	0.0	0.0	0.00	0.00	0.00	
	Max		6.1	4.1	8.1	1	2	4.8	0.1	0.1	0.00	0.00	0.00	
	Range		4.6	2.8	7.5	1	2	4.8	0.3	0.3	0.00	0.00	0.00	

BU Borehole Code	Date Taken		Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV	
BH213	17-Apr-13	1014	0	1.7	18.8	0	0	0.9	0	0	0.00	0.00	0.00	Very stable values
BH213	14-May-13	1008	0	2.8	18.6	0	0	0	0.1	0.1	0.00	0.00	0.00	
BH213	23-May-13	1019	0	3.5	17.1	0	0		-0.7	-0.7	0.00	0.02	0.00	
BH213	12-Jun-13	1016	0	2.9	19.6	0	0		0.1	-0.1	0.00	0.00	0.00	
BH213	26-Jun-13	1034	0	2.8	17.5	0	0	0	0	-0.1	0.00	0.00	0.00	
BH213	09-Jul-13	1027	0	2.7	16.8	0	0	0.2	0	0	0.00	0.00	0.00	VOCs 1 min, GA2000 5 min
	Count		6	6	6	6	6	4	6	6	6.00	6.00	6.00	
	Min		0.0	1.7	16.8	0	0	0.0	-0.7	-0.7	0.00	0.00	0.00	
	Mean Average		0.0	2.7	18.1	0	0	0.3	-0.1	-0.1	0.00	0.01	0.00	
	Max		0.0	3.5	19.6	0	0	0.9	0.1	0.1	0.00	0.02	0.00	
	Range		0	1.8	2.8	0	0	0.9	0.8	0.8	0.00	0.02	0.00	

BU Borehole Code	Date Taken		Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV	
BH214	17-Apr-13	1014	0	1	18.7	0	0	0.6	0.1	-0.1	0.00	0.00	0.00	CO2 elevated at start and dropping steadil
BH214	14-May-13	1008	0	3.4	18.8	0	0	0	0.7	0.7	0.00	0.02	0.00	CO2 dropping slowly over 5 minutes
BH214	23-May-13	1019	0	3.2	16.9	0	0		-0.2	-0.3	0.00	0.01	0.00	Flow decreasing after 5 minutes.
BH214	12-Jun-13	1016	0	0.9	20.6	0	0		0	0	0.00	0.00	0.00	CO2 droppping slowly to 0.9 at 5 minutes.
BH214	26-Jun-13	1034	0	0.7	19.7	0	0	0.2	-0.2	-0.2	0.00	0.00	0.00	CO2 concnetration dropping steadily over t
BH214	09-Jul-13	1027	0	3.6	15.4	1	0	0.2	0	0	0.00	0.00	0.00	GA2000 5 min
	Count		6	6	6	6	6	4	6	6	6.00	6.00	6.00	
	Min		0.0	0.7	15.4	0	0	0.0	-0.2	-0.3	0.00	0.00	0.00	
	Mean Average		0.0	2.1	18.4	0	0	0.3	0.1	0.0	0.00	0.01	0.00	
	Max		0.0	3.6	20.6	1	0	0.6	0.7	0.7	0.00	0.02	0.00	
	Range		0	2.9	5.2	1	0	0.6	0.9	1	0.00	0.02	0.00	

Appendix B
Table 1 - Borehole Results Tables

BU Borehole Code	Date Taken		Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV	
BH215	17-Apr-13	1014	0.2	11.3	17	0	85	0.9	5.1	2.3	0.01	0.26	0.00	High flow but negligable rel. pressure. Res
BH215	14-May-13	1008	0.1	6.1	18.6	0	13	0.2	-2	-0.1	0.00	0.12	0.00	Flow dropped rapidly stabilising at -0.1, suc
BH215	23-May-13	1019	0	2.3	19.7	0	0		-0.8	-4.6	0.00	0.02	0.00	Steady change towards -0.5 l/hr flow over 5
BH215	12-Jun-13	1016	0	0.9	20.6	0	0		7.7	-9.9	0.00	0.07	0.00	Pressure very negative then rapidly decrea
BH215	26-Jun-13	1034	0	1.4	20	0	0	2.3	-4	-18.8	0.00	0.06	0.00	Flow dropping rapidly over 5 minutes from
BH215	09-Jul-13	1027	0	3.5	15.4	7	0	2.1	-1	-5	0.00	0.04	0.00	Flow started at -2.7 dropped rapidly to -5 th
	Count		6	6	6	6	6	4	6	6	6.00	6.00	6.00	
	Min		0.0	0.9	15.4	0	0	0.2	-4.0	-18.8	0.00	0.02	0.00	
	Mean Average		0.1	4.3	18.6	1	16	1.4	0.8	-6.0	0.00	0.09	0.00	
	Max		0.2	11.3	20.6	7	85	2.3	7.7	2.3	0.01	0.26	0.00	
	Range		0.2	10.4	5.2	7	85	2.1	11.7	21.1	0.01	0.24	0.00	

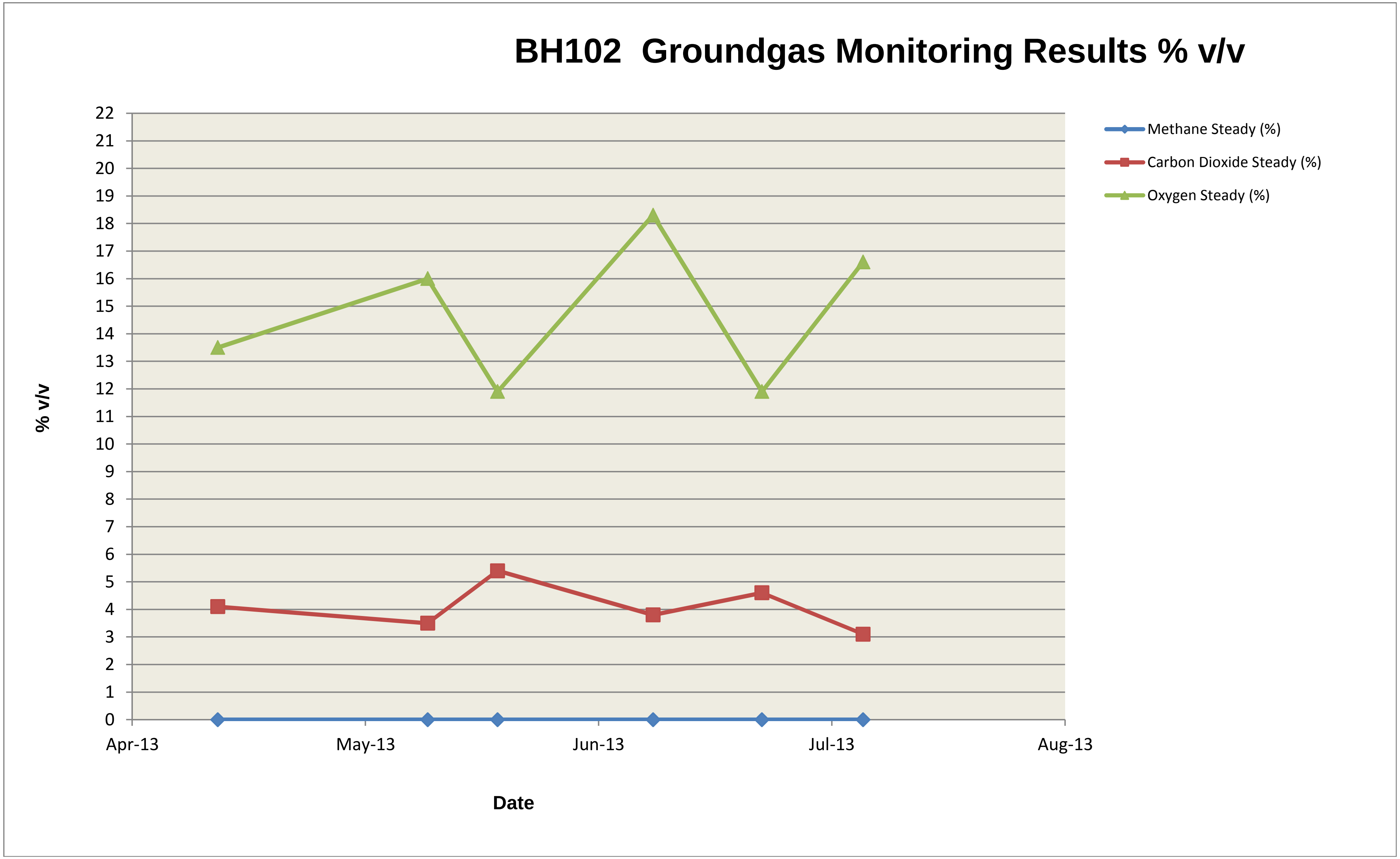
BU Borehole Code	Date Taken		Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV	
BH216	17-Apr-13	1014	47.5	4.3	1.3	0	7	0	2.04	0.5	0.97	0.09	0.00	Flow decreasing steadily over 3 minutes.
BH216	14-May-13	1008	80.4	12.7	0.2	0	0		-0.1	-0.1	0.08	0.01	0.00	
BH216	23-May-13	1019	80.3	11.7	0.2	0	0		0	0	0.00	0.00	0.00	
BH216	12-Jun-13	1016	77.6	13.6	0.2	0	0		0	0	0.00	0.00	0.00	
BH216	26-Jun-13	1034	59.3	11	2.7	0	0	0	0	0	0.00	0.00	0.00	Recently cut grass.
BH216	09-Jul-13	1027	60.1	12.9	0.4	2	0	0	0	0	0.00	0.00	0.00	Vent left open from last week to see effect
	Count		6	6	6	6	6	3	6	6	6.00	6.00	6.00	
	Min		47.5	4.3	0.2	0	0	0.0	-0.1	-0.1	0.00	0.00	0.00	
	Mean Average		67.5	11.0	0.8	0	1	0.0	0.3	0.1	0.17	0.02	0.00	
	Max		80.4	13.6	2.7	2	7	0.0	2.0	0.5	0.97	0.09	0.00	
	Range		32.9	9.3	2.5	2	7	0	2.14	0.6	0.97	0.09	0.00	

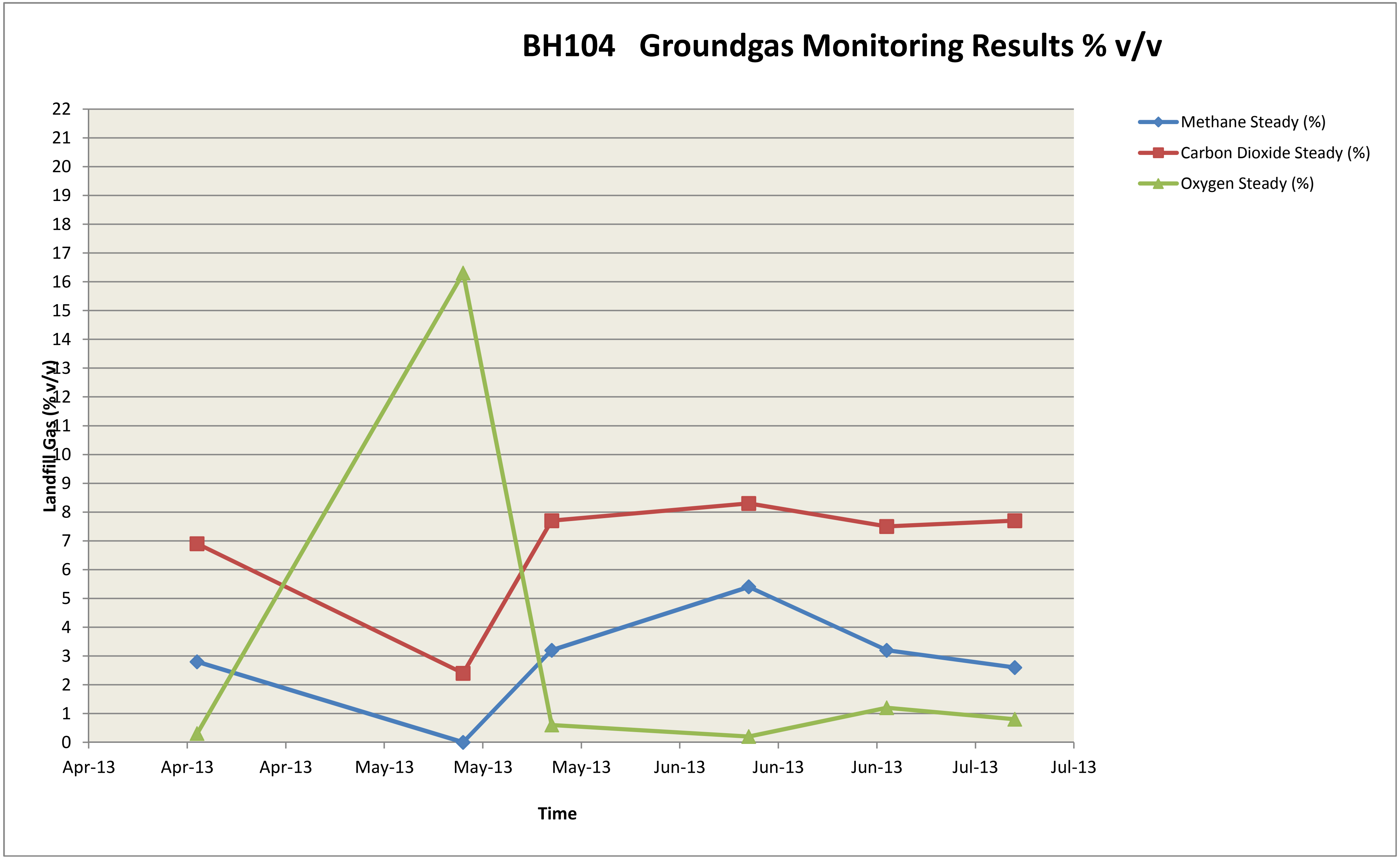
BU Borehole Code	Date Taken		Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV
											0.00	0.00	0.00
											0.00	0.00	0.00
											0.00	0.00	0.00
	Count		0	0	0	0	0	0	0	0	3.00	3.00	3.00
	Min		0.0	0.0	0.0	0	0	0.0	0.0	0.0	0.00	0.00	0.00
	Mean Average										0.00	0.00	0.00
	Max		0.0	0.0	0.0	0	0	0.0	0.0	0.0	0.00	0.00	0.00
	Range		0	0	0	0	0	0	0	0	0.00	0.00	0.00

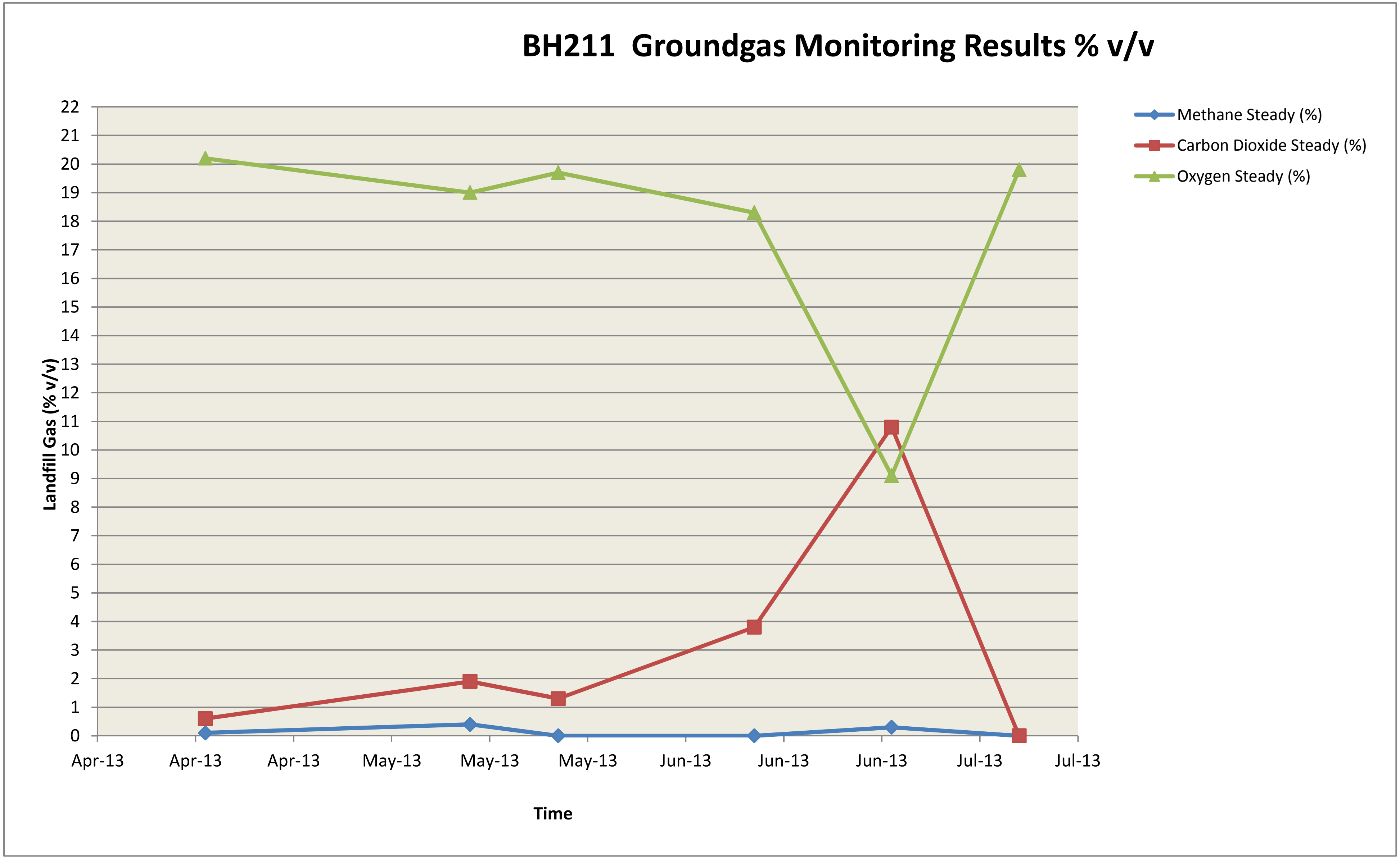
Appendix B
Table 1 - Borehole Results Tables

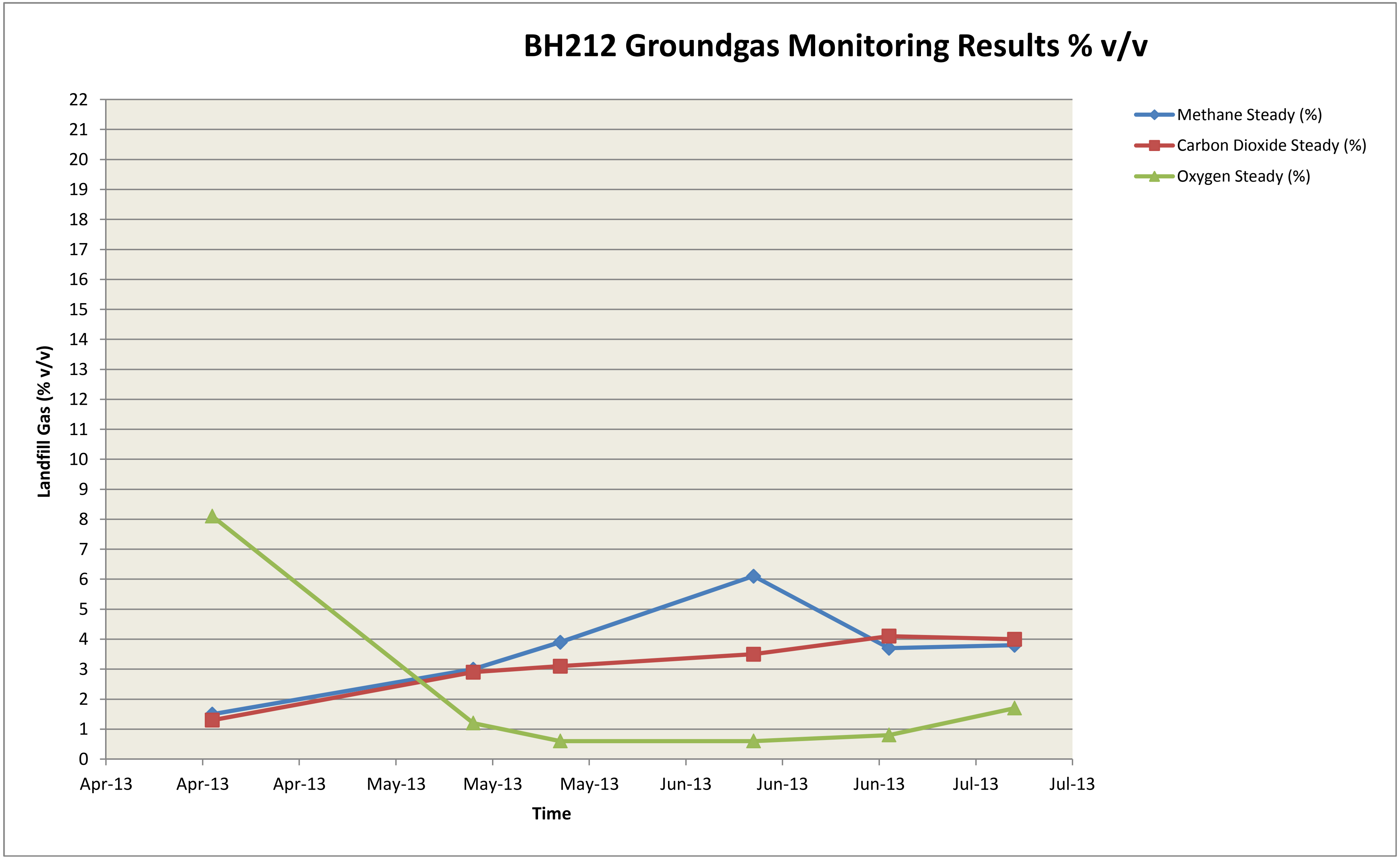
BU Borehole Code	Date Taken		Methane Steady (%)	Carbon Dioxide Steady	Oxygen Steady (%)	Hydrogen Sulphide Steady (ppm)	Carbon Monoxide Steady (ppm)	VOC Steady (ppm)	Max Flow Rate	Min Flow Rate	Methane GSV	Carbon Dioxide GSV	VOC GSV	
											0.00	0.00	0.00	
											0.00	0.00	0.00	
											0.00	0.00	0.00	
	Count		0	0	0	0	0	0	0	0	3.00	3.00	3.00	
	Min		0.0	0.0	0.0	0	0	0.0	0.0	0.0	0.00	0.00	0.00	
	Mean Average										0.00	0.00	0.00	
	Max		0.0	0.0	0.0	0	0	0.0	0.0	0.0	0.00	0.00	0.00	
	Range		0	0	0	0	0	0	0	0	0.00	0.00	0.00	

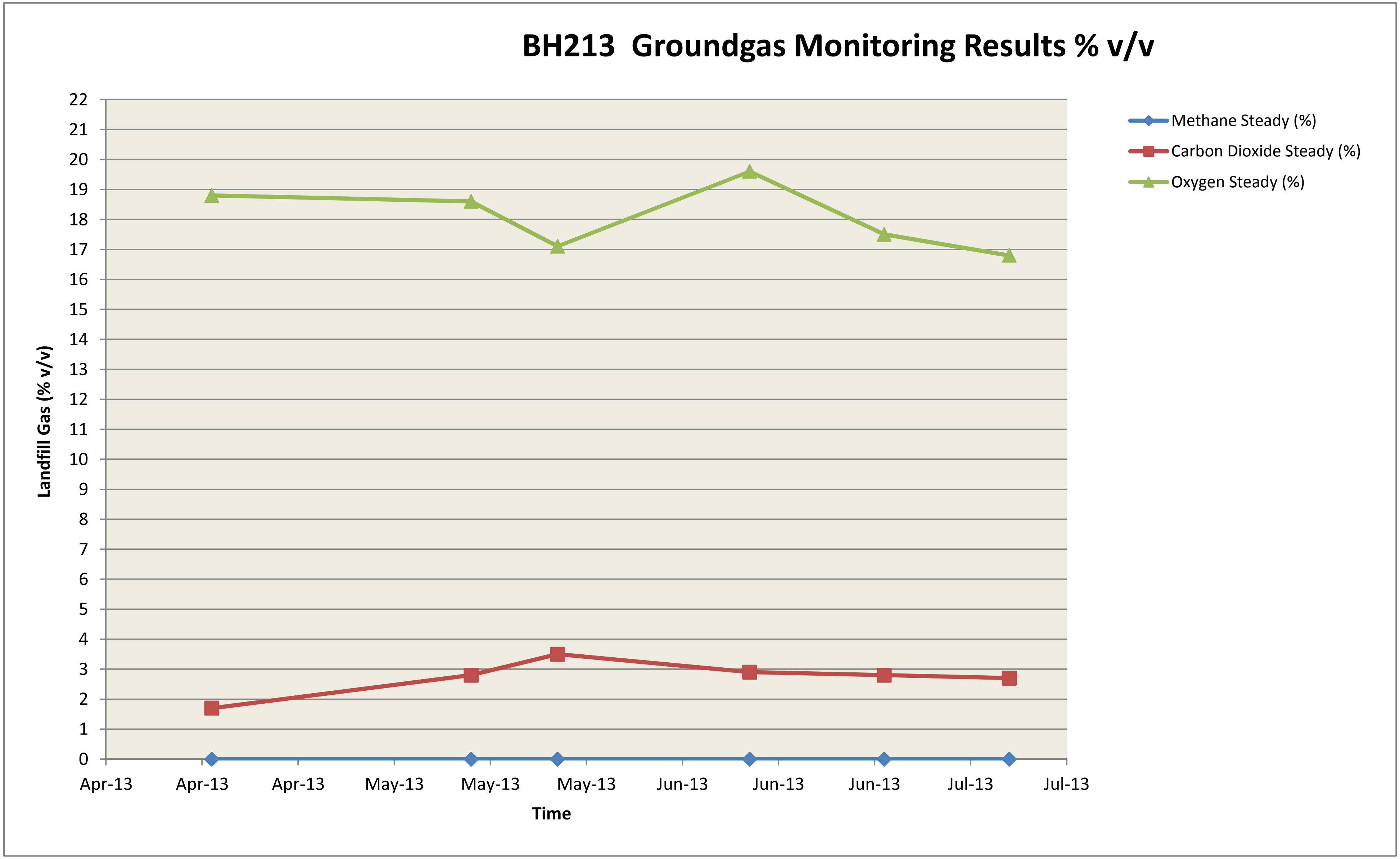
Appendix B
Table 1 - Borehole Results Tables

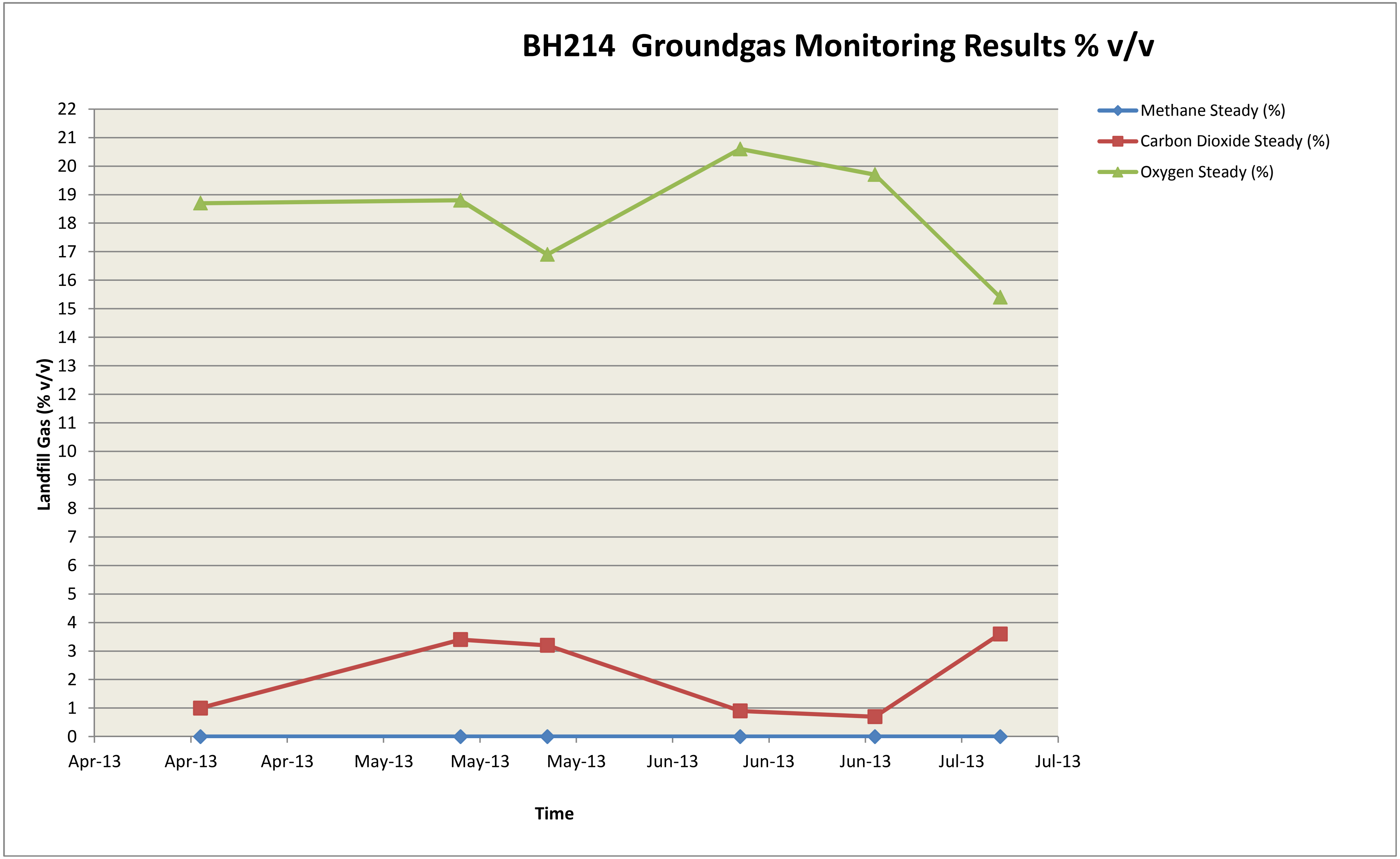

BH102 Groundgas Monitoring Results % v/v
% v/v
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Date
Methane Steady (%)
Carbon Dioxide Steady (%)
Oxygen Steady (%)

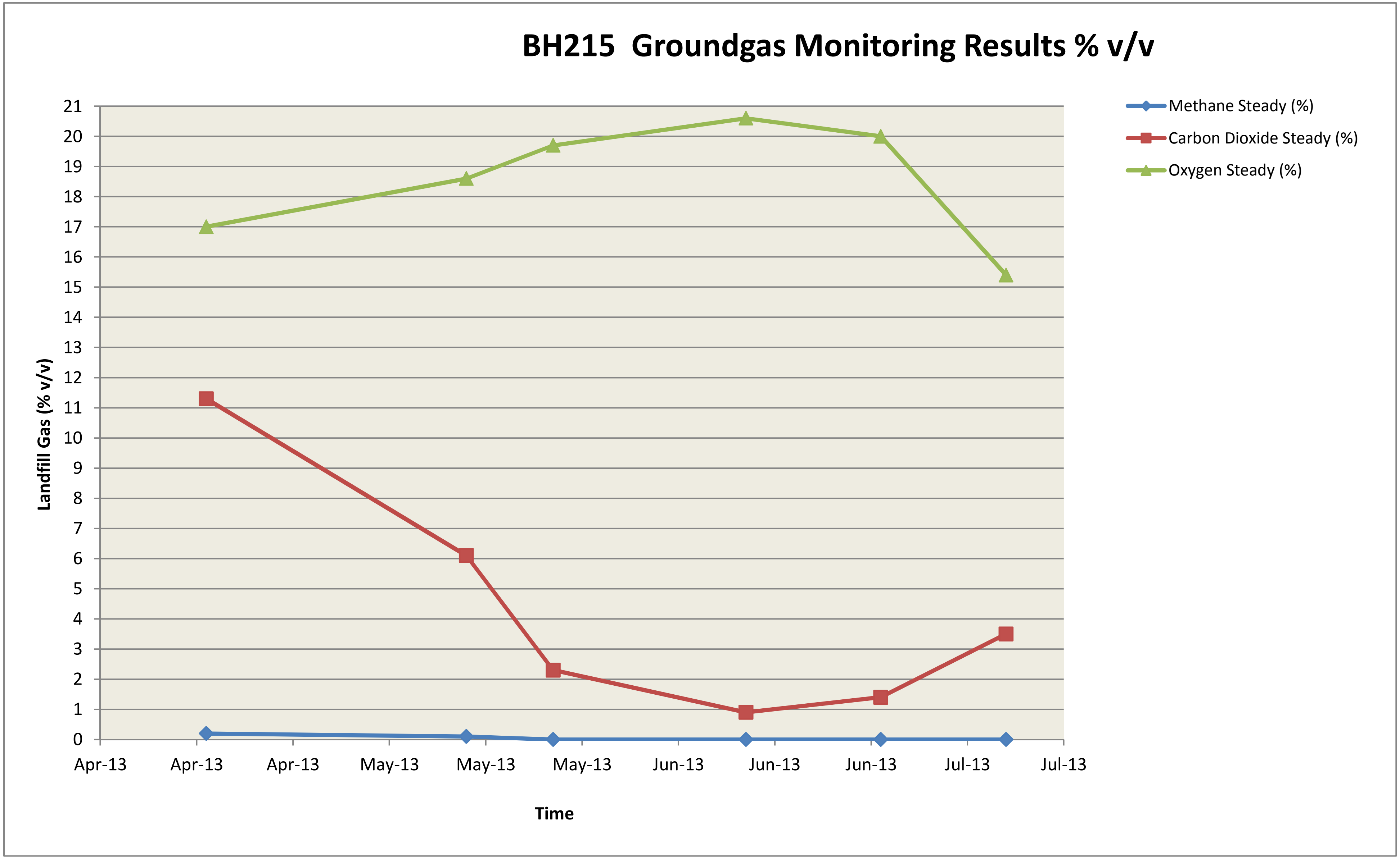

BH104 Groundgas Monitoring Results % v/v
Landfill Gas (% v/v)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Methane Steady (%)
Carbon Dioxide Steady (%)
Oxygen Steady (%)

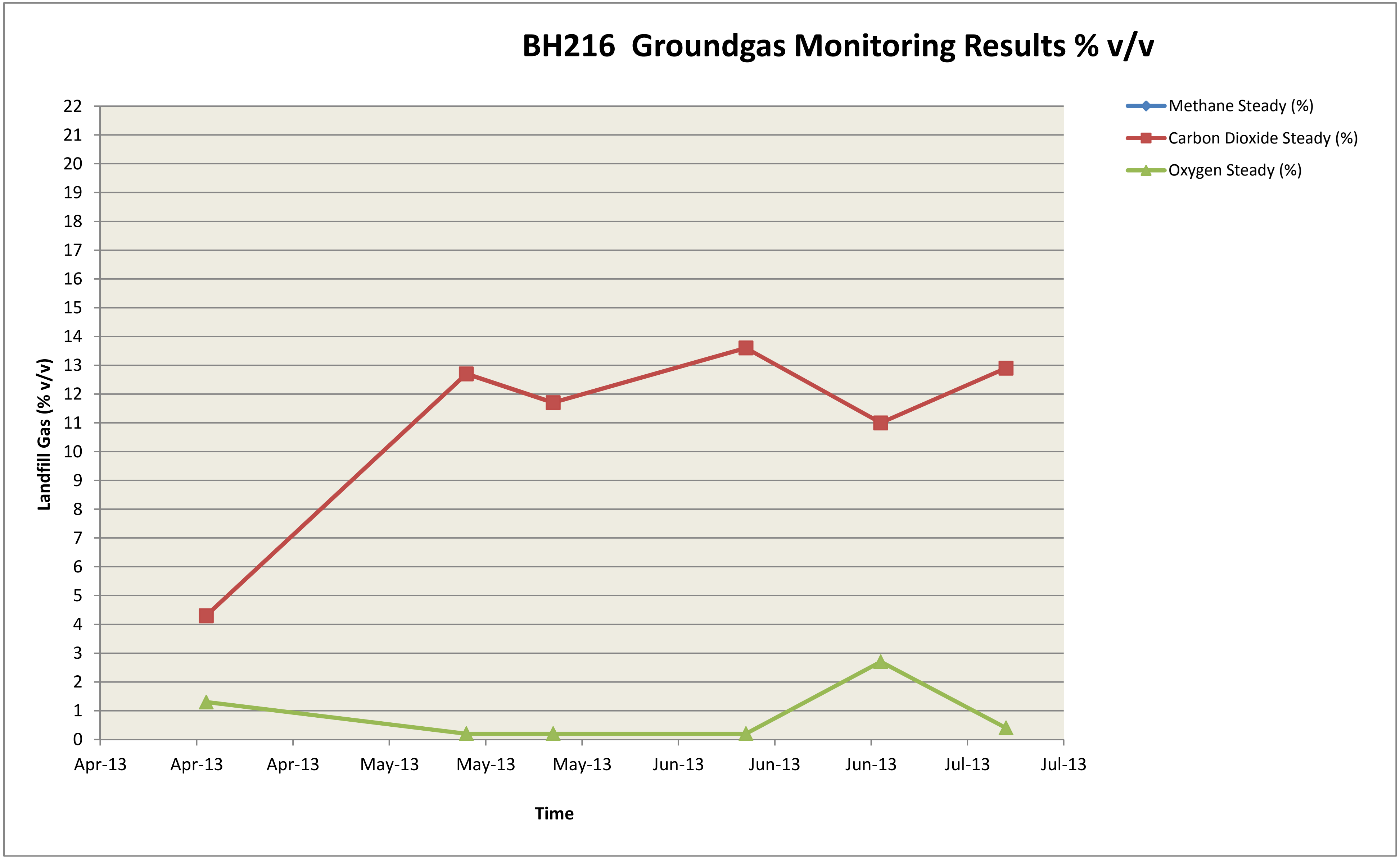

BH211 Groundgas Monitoring Results % v/v
Landfill Gas (% v/v)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Methane Steady (%)
Carbon Dioxide Steady (%)
Oxygen Steady (%)

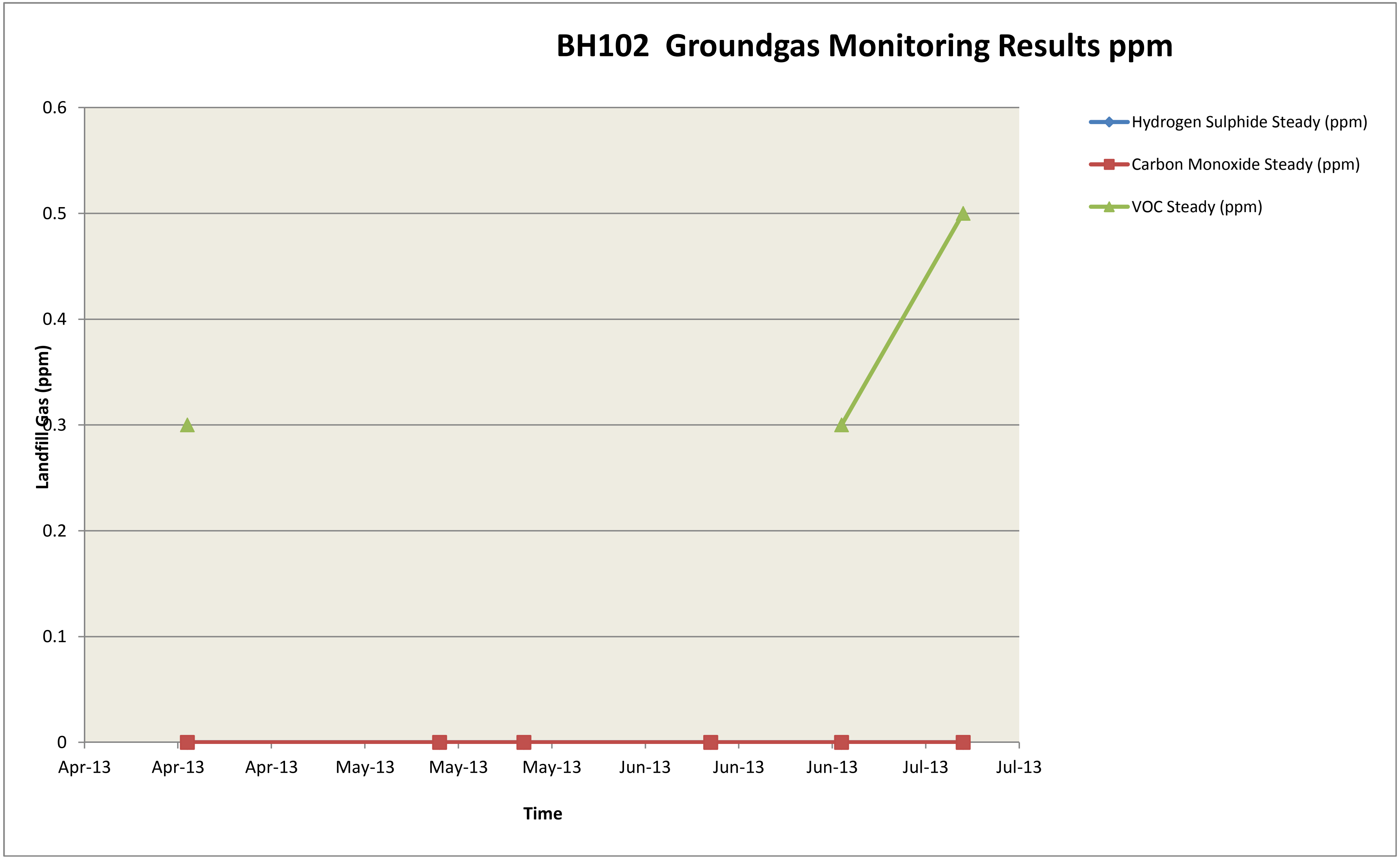

BH212 Groundgas Monitoring Results % v/v
Landfill Gas (% v/v)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Methane Steady (%)
Carbon Dioxide Steady (%)
Oxygen Steady (%)

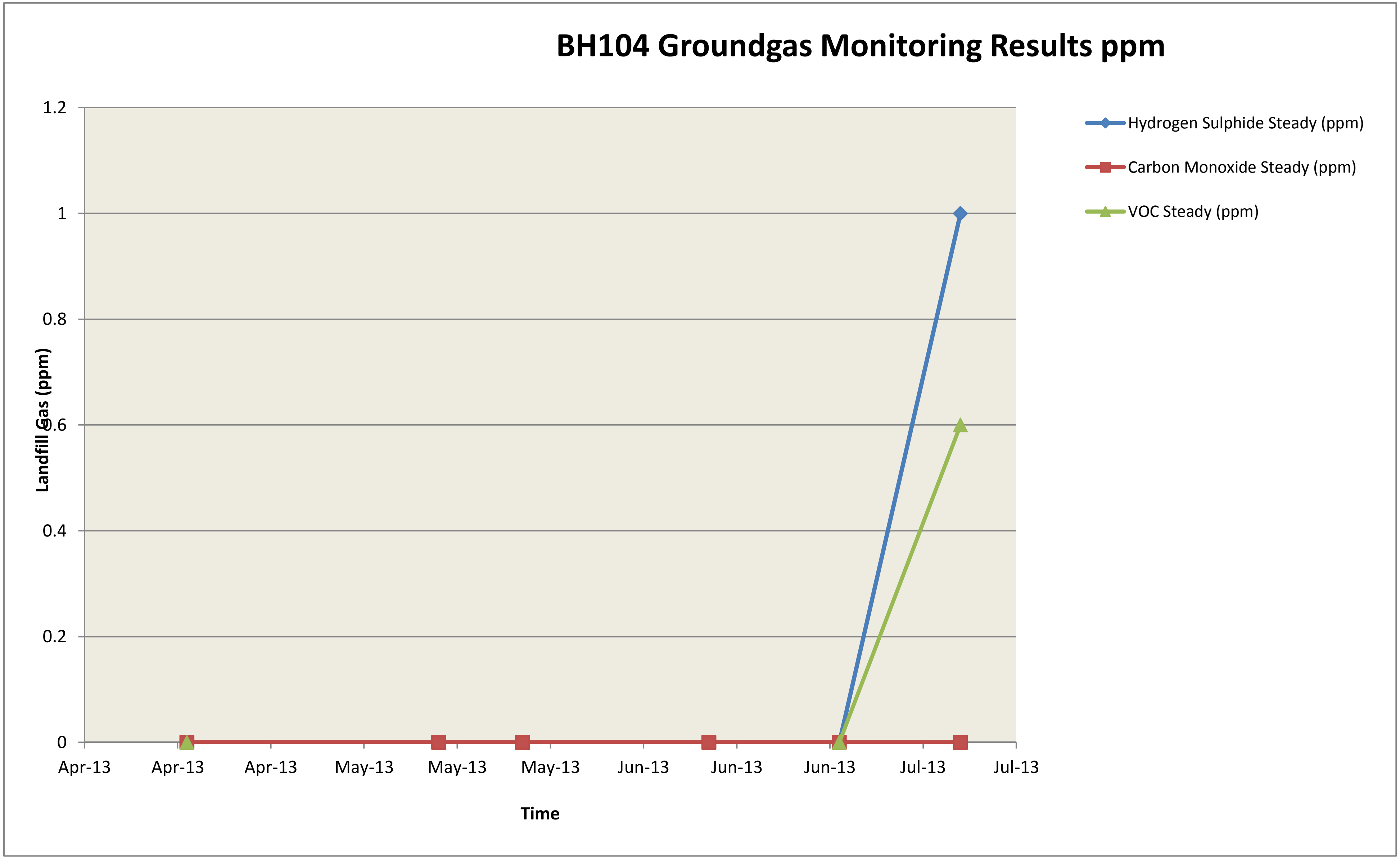

BH213 Groundgas Monitoring Results % v/v
Landfill Gas (% v/v)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Methane Steady (%)
Carbon Dioxide Steady (%)
Oxygen Steady (%)

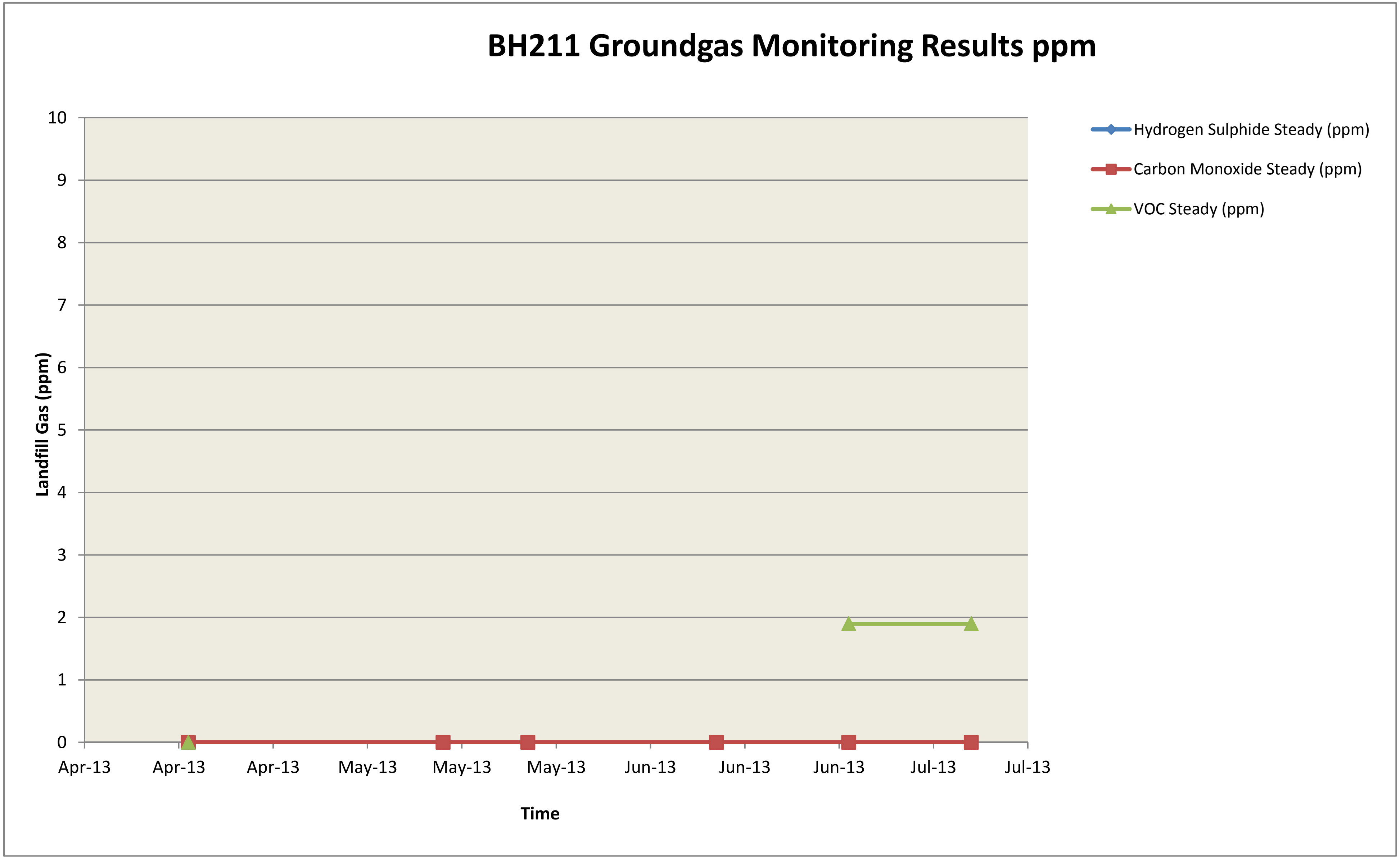

BH214 Groundgas Monitoring Results % v/v
Landfill Gas (% v/v)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Methane Steady (%)
Carbon Dioxide Steady (%)
Oxygen Steady (%)

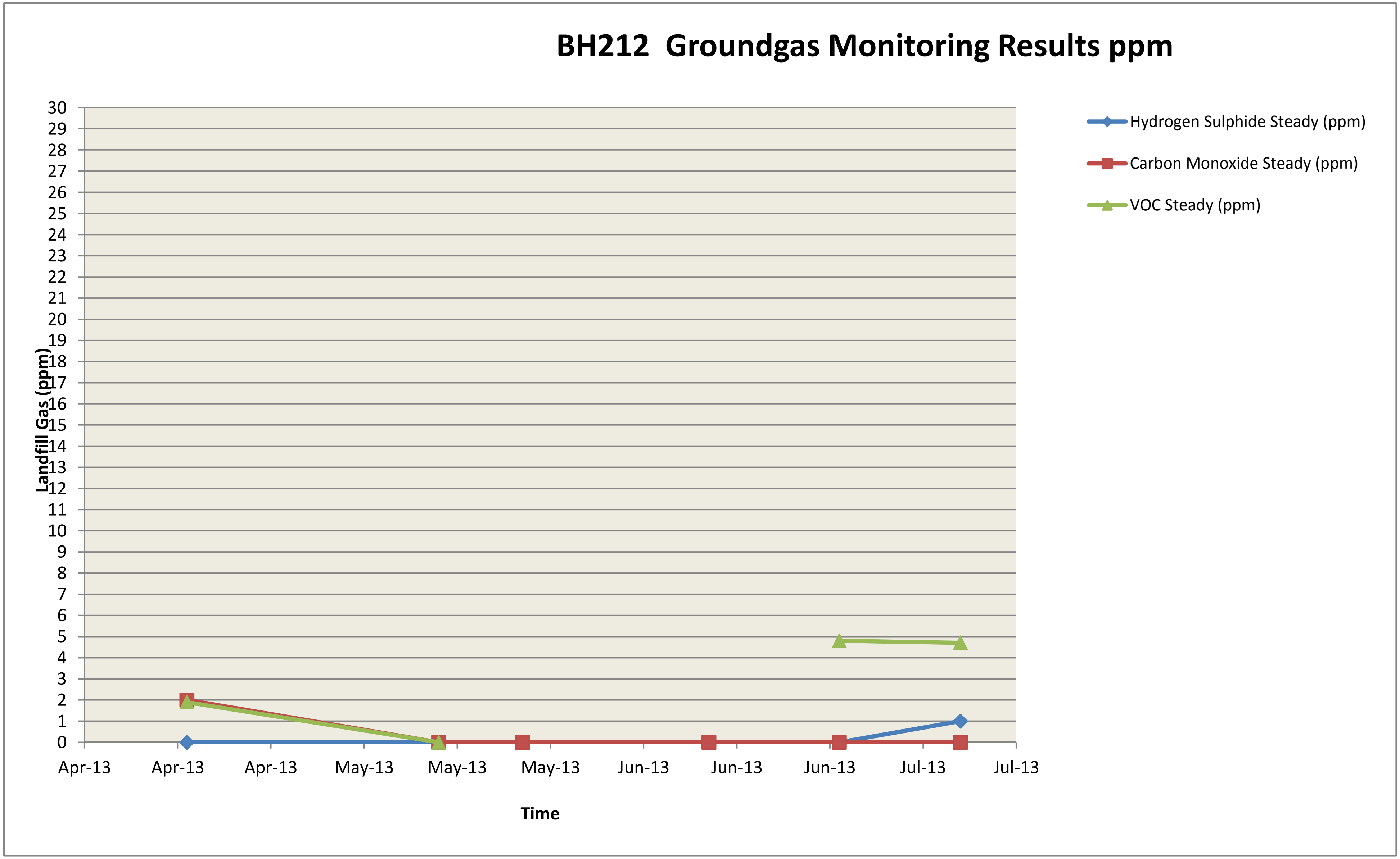

BH215 Groundgas Monitoring Results % v/v
Landfill Gas (% v/v)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Methane Steady (%)
Carbon Dioxide Steady (%)
Oxygen Steady (%)

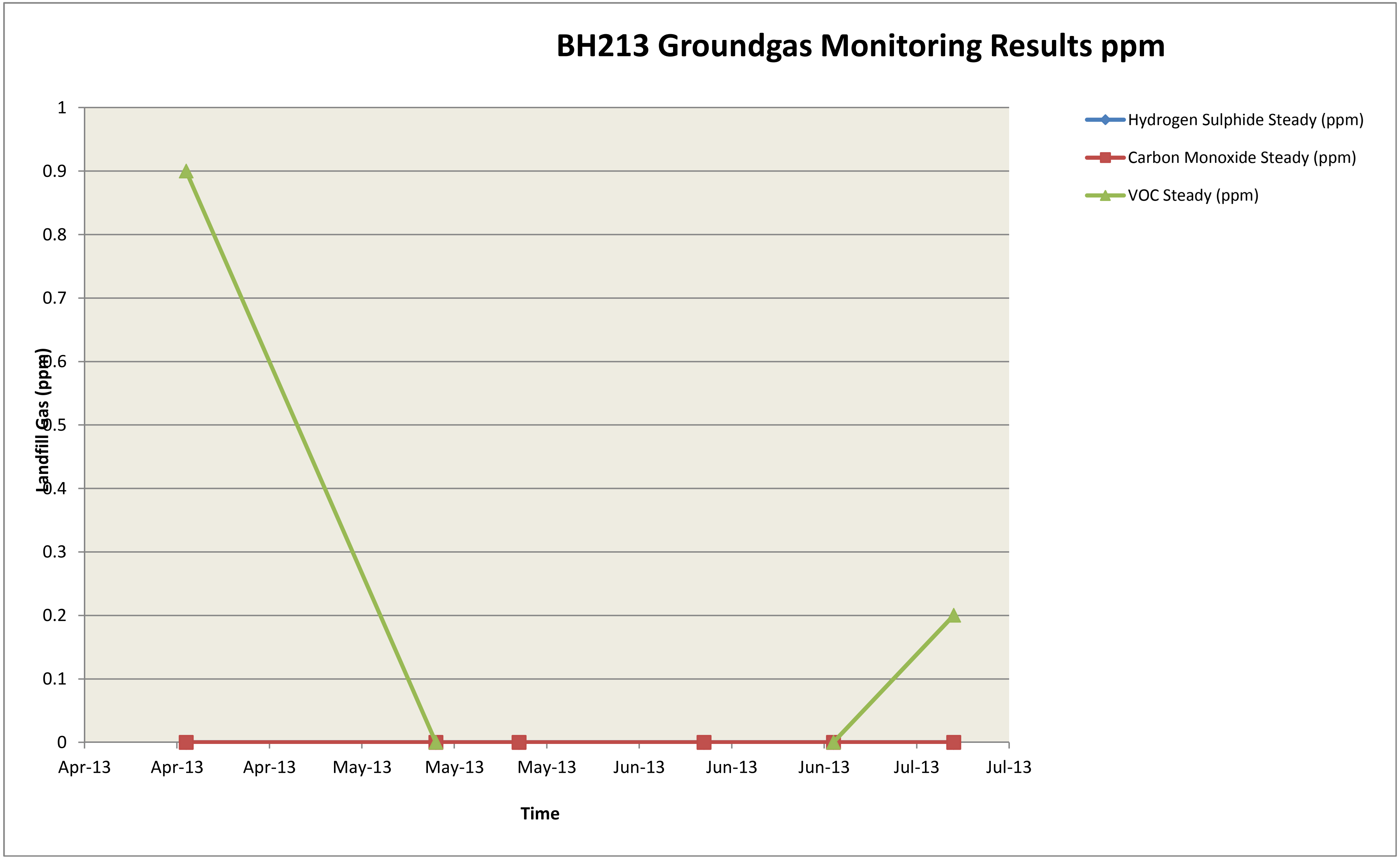

BH216 Groundgas Monitoring Results % v/v
Landfill Gas (% v/v)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Methane Steady (%)
Carbon Dioxide Steady (%)
Oxygen Steady (%)

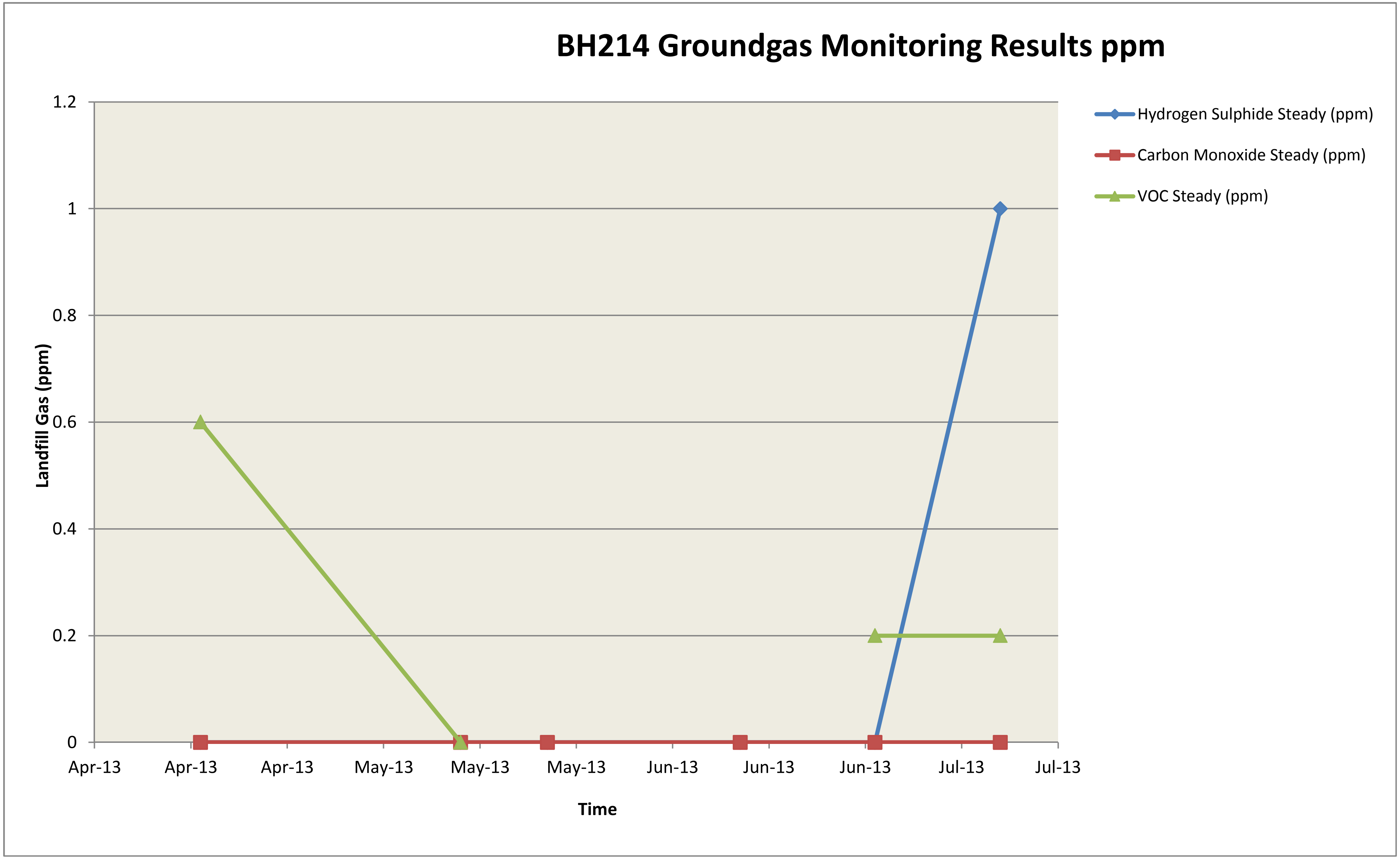

BH102 Groundgas Monitoring Results ppm
0.6
0.5
0.4
0.3
0.2
0.1
0
Landfill Gas (ppm)
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Hydrogen Sulphide Steady (ppm)
Carbon Monoxide Steady (ppm)
VOC Steady (ppm)

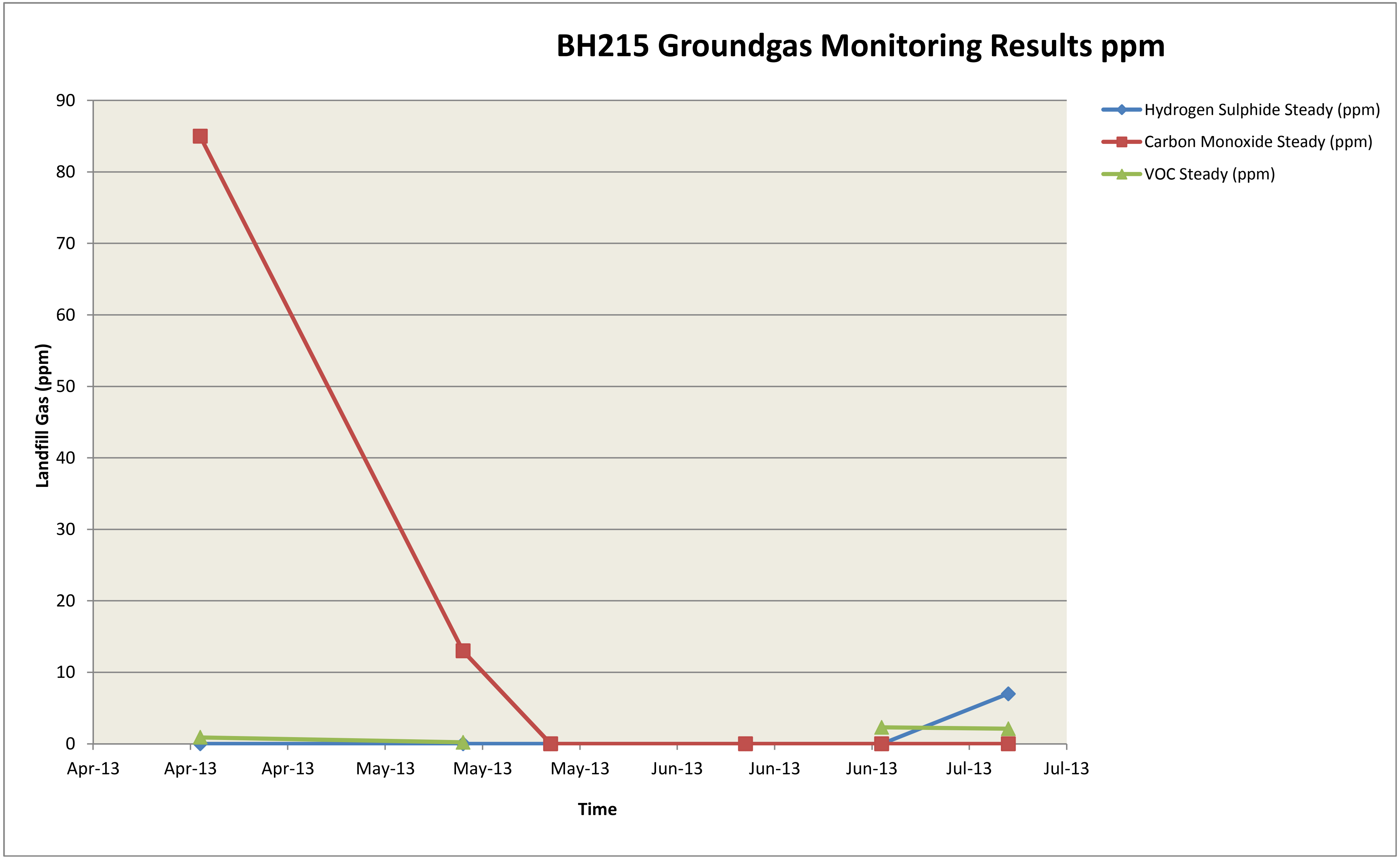

BH104 Groundgas Monitoring Results ppm
Landfill Gas (ppm)
1.2
1
0.8
0.6
0.4
0.2
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Hydrogen Sulphide Steady (ppm)
Carbon Monoxide Steady (ppm)
VOC Steady (ppm)

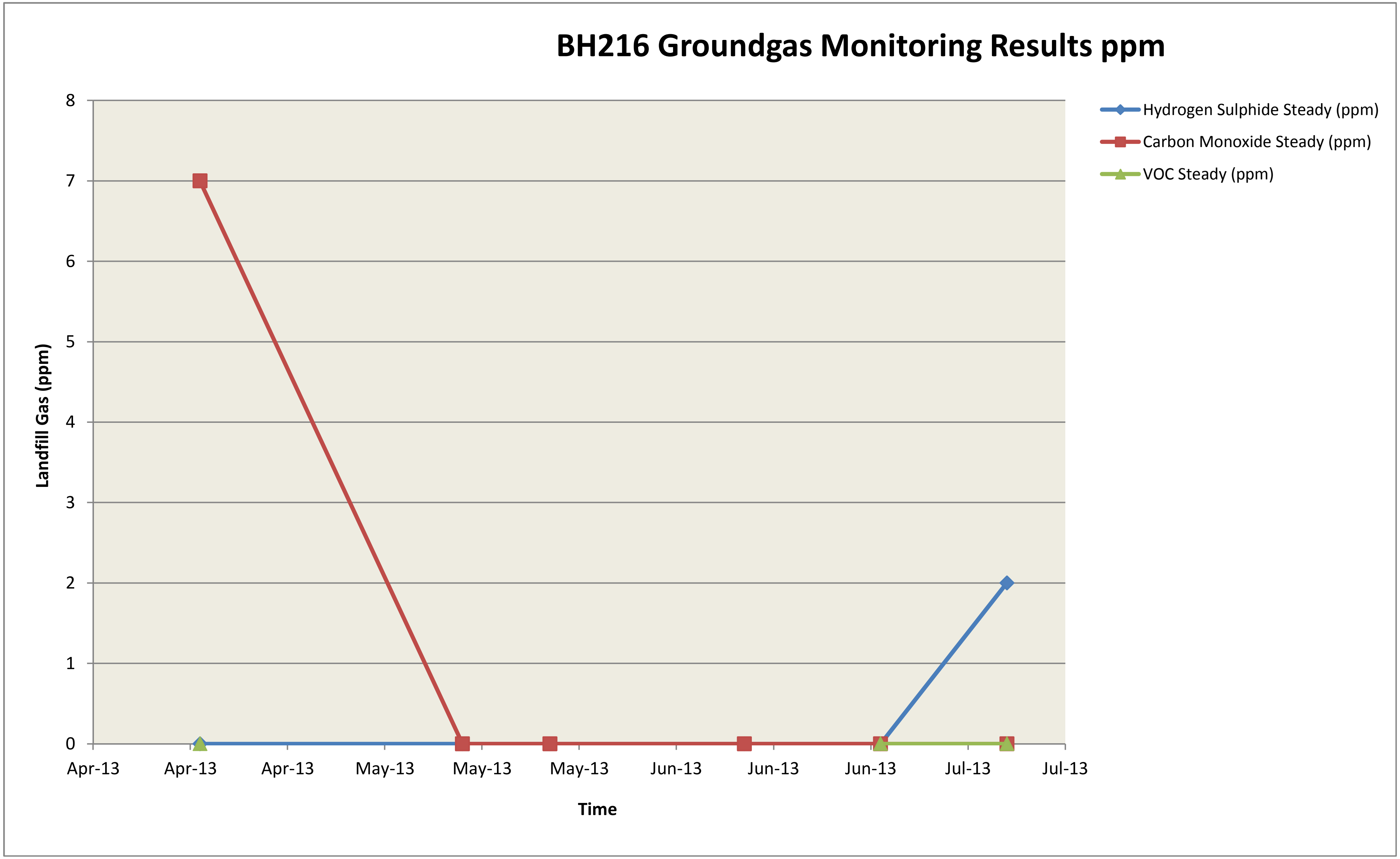

BH211 Groundgas Monitoring Results ppm
10
9
8
7
6
5
4
3
2
1
0
Landfill Gas (ppm)
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Hydrogen Sulphide Steady (ppm)
Carbon Monoxide Steady (ppm)
VOC Steady (ppm)


BH212 Groundgas Monitoring Results ppm
Landfill Gas (ppm)
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Hydrogen Sulphide Steady (ppm)
Carbon Monoxide Steady (ppm)
VOC Steady (ppm)


BH213 Groundgas Monitoring Results ppm
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Landfill Gas (ppm)
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Hydrogen Sulphide Steady (ppm)
Carbon Monoxide Steady (ppm)
VOC Steady (ppm)


BH214 Groundgas Monitoring Results ppm
1.2
1
0.8
0.6
0.4
0.2
0
Landfill Gas (ppm)
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Hydrogen Sulphide Steady (ppm)
Carbon Monoxide Steady (ppm)
VOC Steady (ppm)


BH215 Groundgas Monitoring Results ppm
Landfill Gas (ppm)
90
80
70
60
50
40
30
20
10
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Hydrogen Sulphide Steady (ppm)
Carbon Monoxide Steady (ppm)
VOC Steady (ppm)

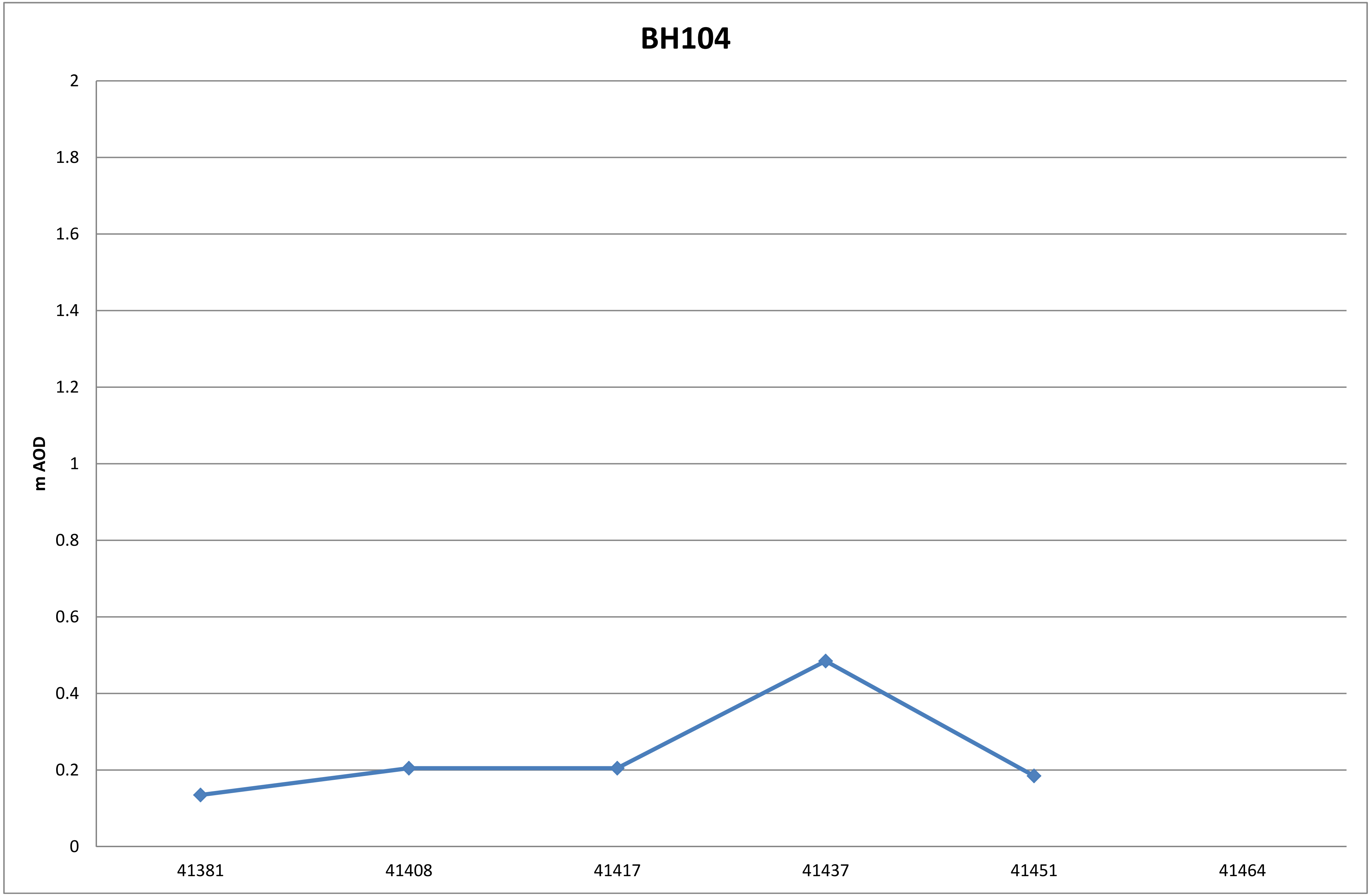

BH216 Groundgas Monitoring Results ppm
Landfill Gas (ppm)
8
7
6
5
4
3
2
1
0
Apr-13
Apr-13
Apr-13
May-13
May-13
May-13
Jun-13
Jun-13
Jun-13
Jul-13
Jul-13
Time
Hydrogen Sulphide Steady (ppm)
Carbon Monoxide Steady (ppm)
VOC Steady (ppm)

APPENDIX C

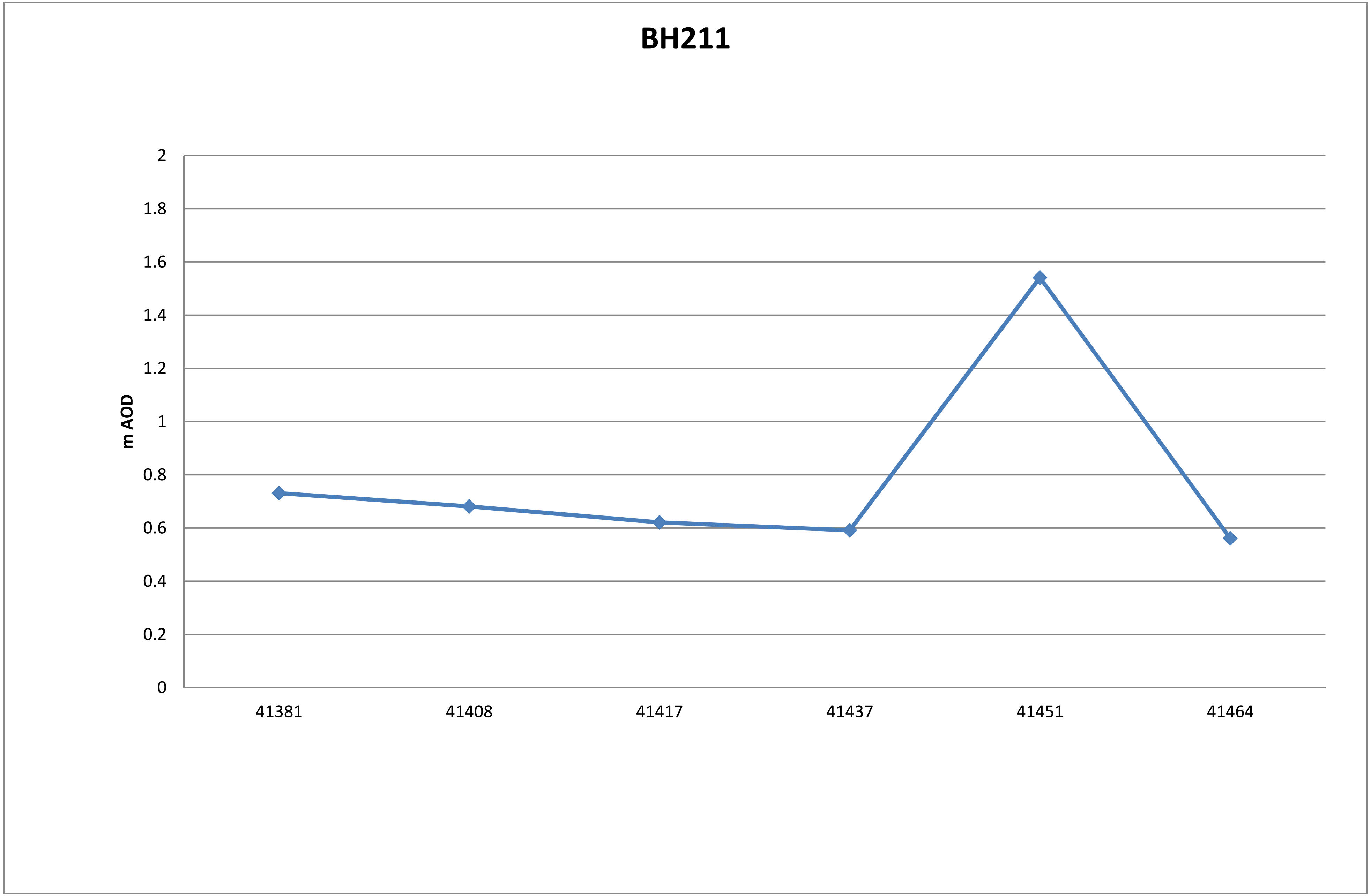
GROUND WATER LEVELS

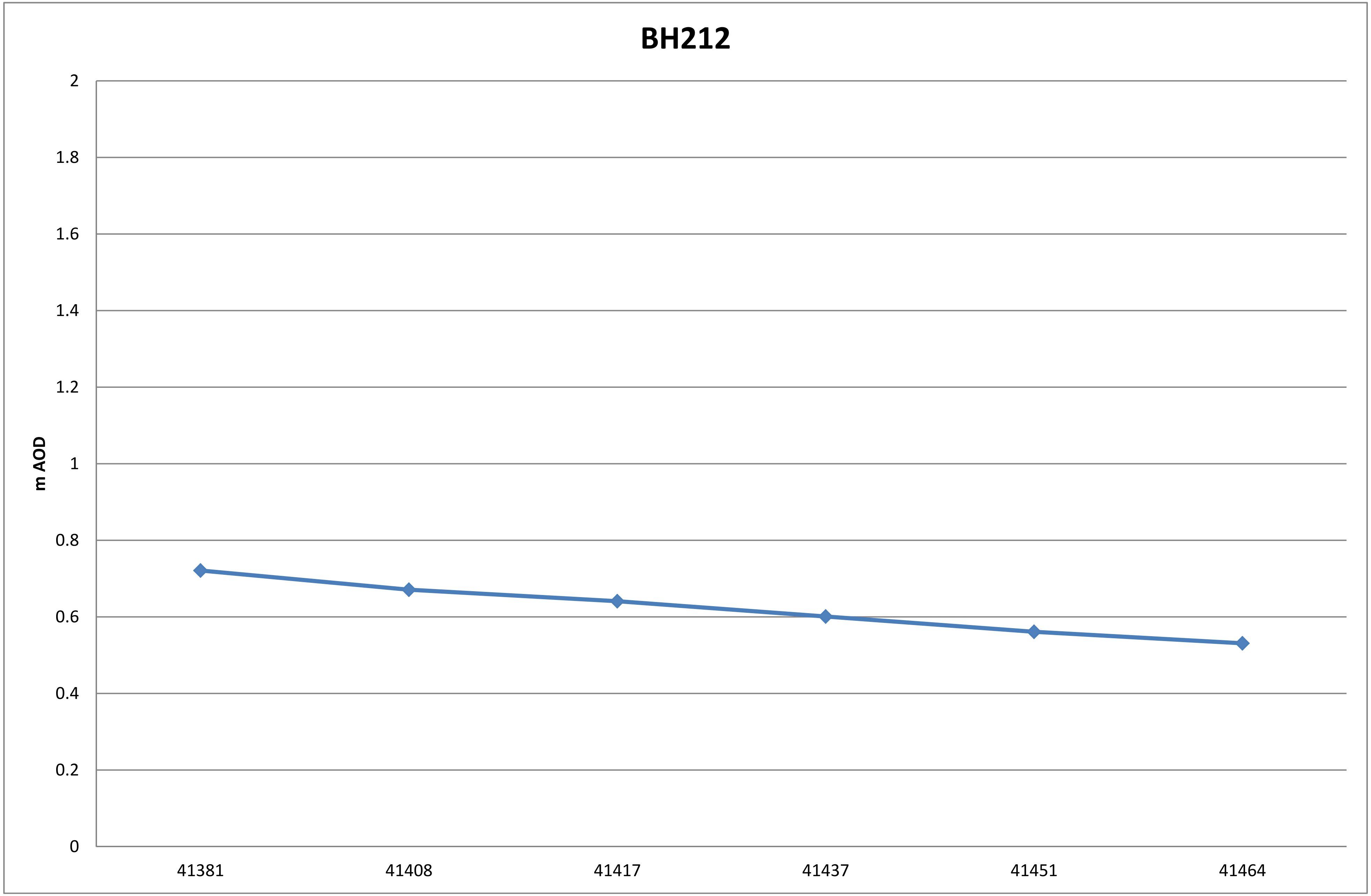
Appendix C
Ground Water Levels

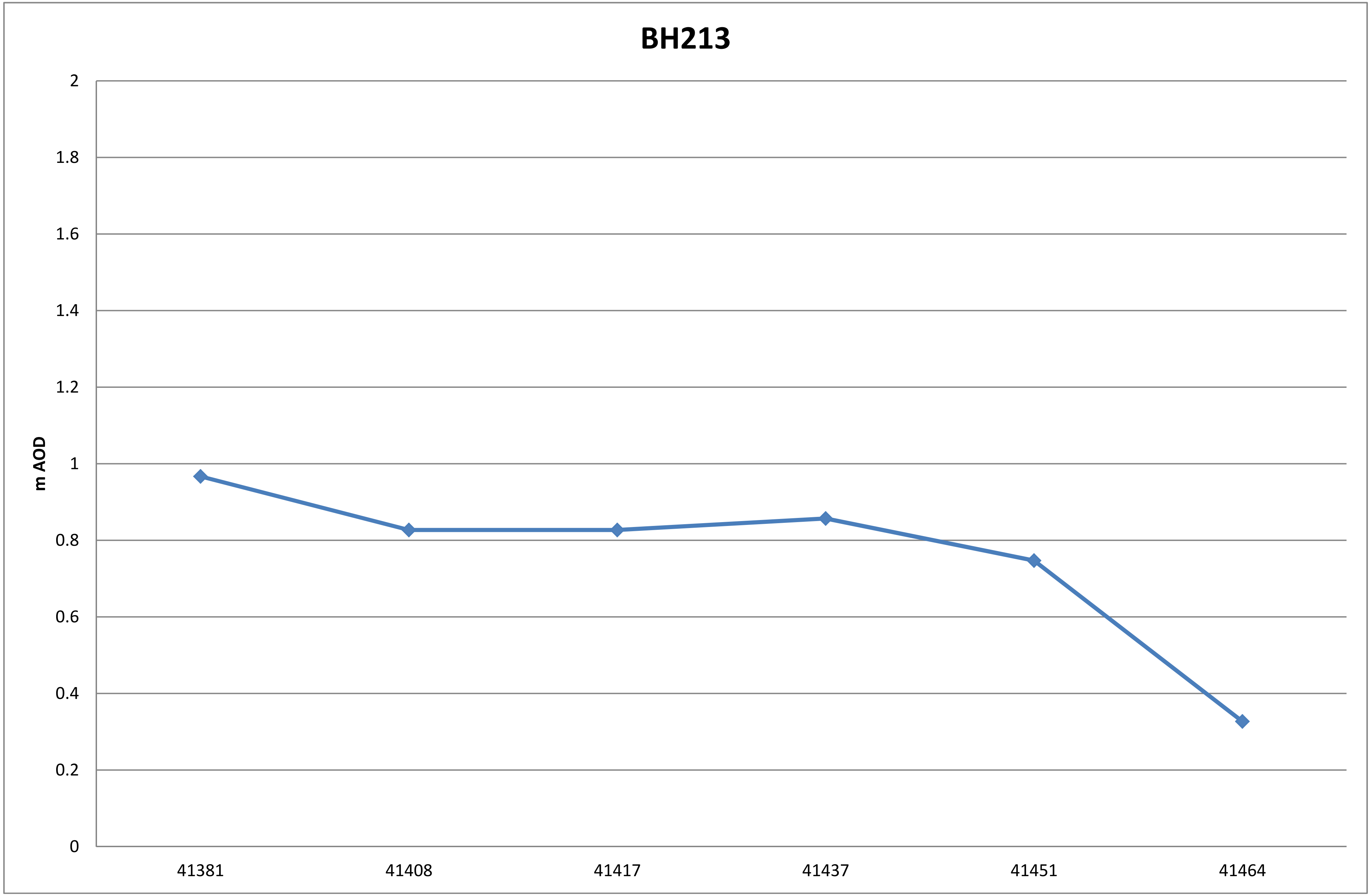
Borehole Code	Date Taken	Water Level m AOD	Water Level (m bgl)	Summary	
BH102	17/4/13	0.856	1.45	Max	0.856
BH102	14/5/13	0.346	1.96	Min	-1.674
BH102	23/5/13	-1.674	3.98	Average	0.084333
BH102	12/6/13	0.316	1.99		
BH102	26/6/13	0.336	1.97		
BH102	9/7/13	0.326	1.98		
BH104	17/4/13	0.1347	1.6	Max	0.4847
BH104	14/5/13	0.2047	1.53	Min	0.1347
BH104	23/5/13	0.2047	1.53	Average	0.2427
BH104	12/6/13	0.4847	1.25		
BH104	26/6/13	0.1847	1.55		
BH104	9/7/13	failed to record			
BH211	17/4/13	0.731	1.9	Max	1.541
BH211	14/5/13	0.681	1.95	Min	0.561
BH211	23/5/13	0.621	2.01	Average	0.787667
BH211	12/6/13	0.591	2.04		
BH211	26/6/13	1.541	1.09		
BH211	9/7/13	0.561	2.07		
BH212	17/4/13	0.721	1.63	Max	0.721
BH212	14/5/13	0.671	1.68	Min	0.531
BH212	23/5/13	0.641	1.71	Average	0.621
BH212	12/6/13	0.601	1.75		
BH212	26/6/13	0.561	1.79		
BH212	9/7/13	0.531	1.82		
BH213	17/4/13	0.967	1.18	Max	0.967
BH213	14/5/13	0.827	1.32	Min	0.327
BH213	23/5/13	0.827	1.32	Average	0.758667
BH213	12/6/13	0.857	1.29		
BH213	26/6/13	0.747	1.4		
BH213	9/7/13	0.327	1.82		
BH214	17/4/13	1.355	0.87	Max	1.355
BH214	14/5/13	0.975	1.25	Min	0.585
BH214	23/5/13	0.915	1.31	Average	0.873333
BH214	12/6/13	0.775	1.45		
BH214	26/6/13	0.635	1.59		
BH214	9/7/13	0.585	1.64		
BH215	17/4/13	1.761	0.46	Max	1.771
BH215	14/5/13	1.771	0.45	Min	1.271
BH215	23/5/13	1.731	0.49	Average	1.612667
BH215	12/6/13	1.681	0.54		
BH215	26/6/13	1.461	0.76		
BH215	9/7/13	1.271	0.95		
BH216	17/4/13	1.0385	1.2905	Max	1.0385
BH216	14/5/13	0.829	1.5	Min	0.689
BH216	23/5/13	0.759	1.57	Average	0.80225
BH216	12/6/13	0.749	1.58		
BH216	26/6/13	0.689	1.64		
BH216	9/7/13	0.749	1.58		

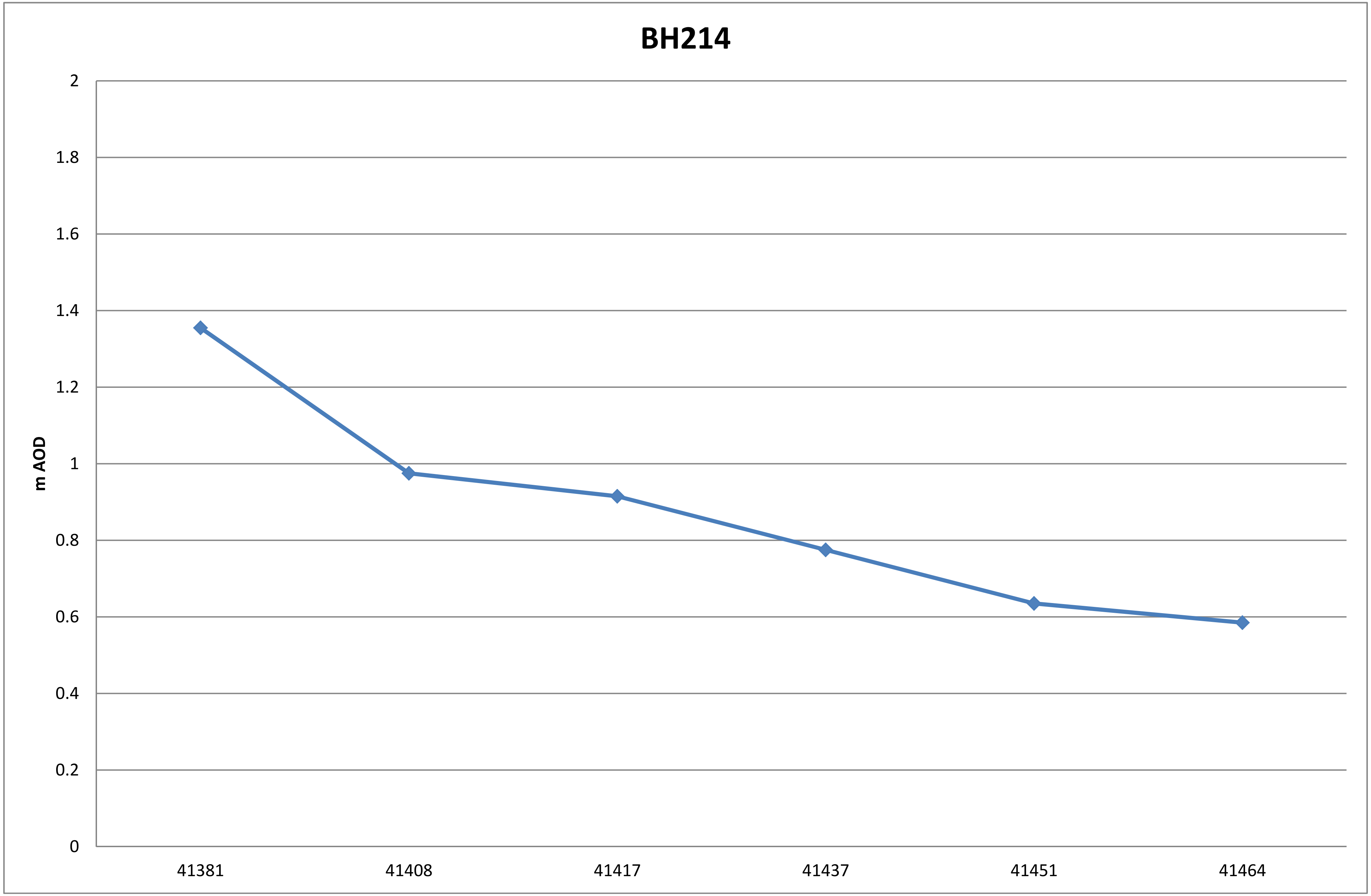


BH104
m AOD
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
41381
41408
41417
41437
41451
41464

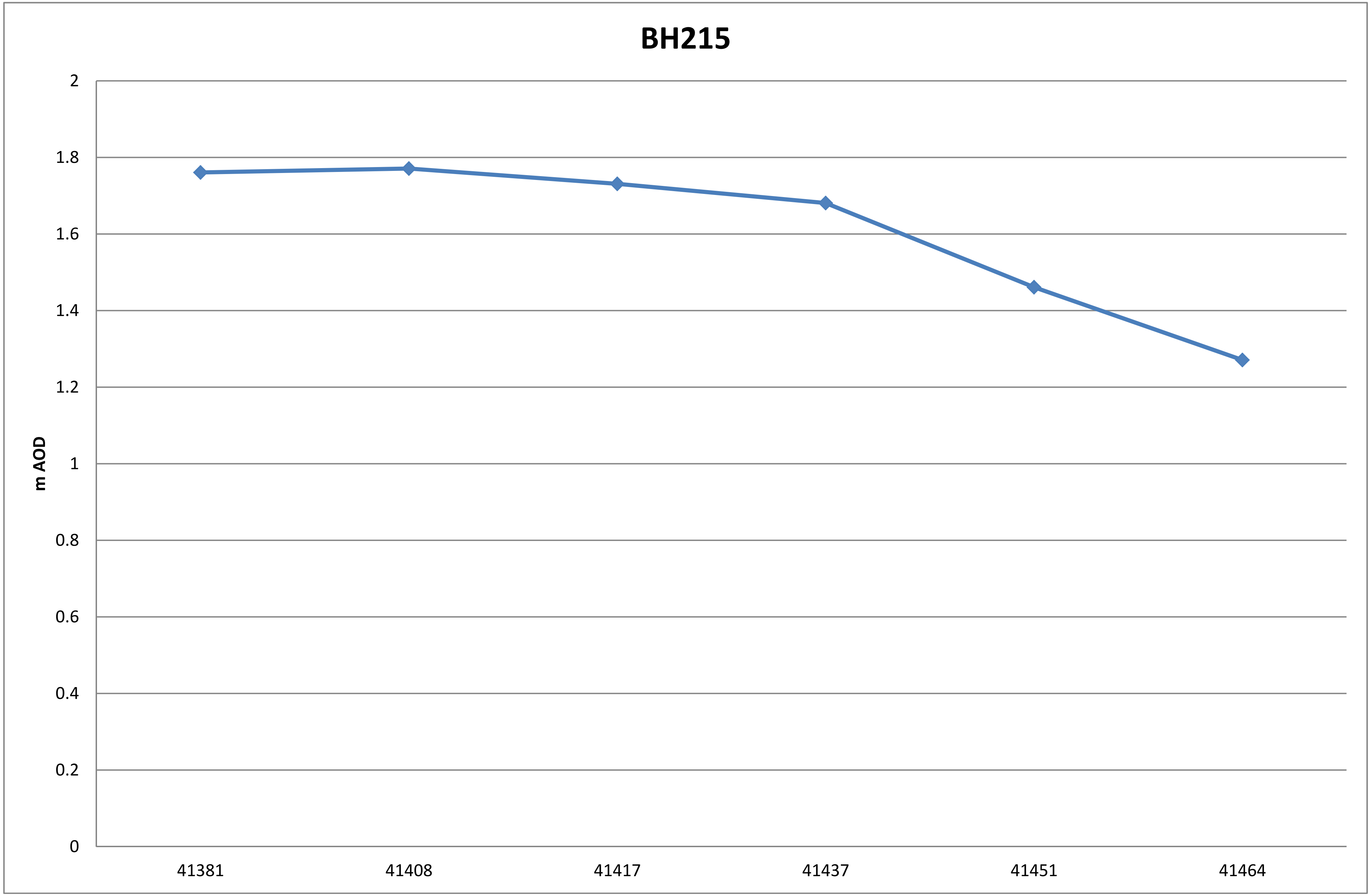

BH211
m AOD
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
41381
41408
41417
41437
41451
41464


BH212
m AOD
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
41381
41408
41417
41437
41451
41464

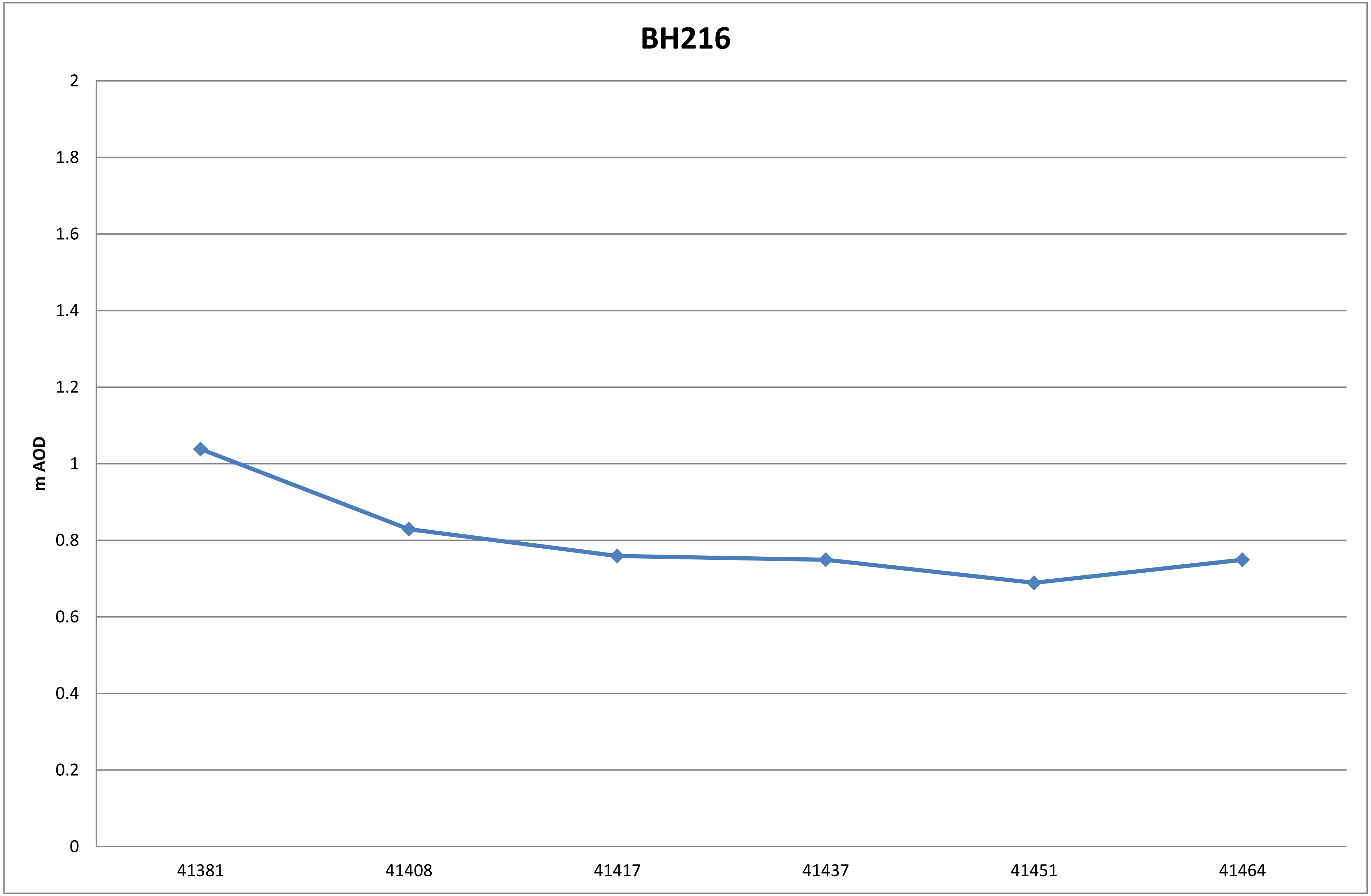

BH213
m AOD
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
41381
41408
41417
41437
41451
41464



BH214
m AOD
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
41381
41408
41417
41437
41451
41464



BH215
m AOD
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
41381
41408
41417
41437
41451
41464



BH216
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
m AOD
41381
41408
41417
41437
41451
41464

APPENDIX D

GAS INGRESS CALCULATION SPREADSHEETS

$Q_{soil} = 2\prod \Delta P K_v X_{crack} / \mu 1n(2Z_{crack}/R_{crack})$ 0.0002

Q_{soil} is volumetric flow rate of soil gas entering the building cm^3/s
$\prod$ = 3.14159
ΔP is pressure differential between the soil surface and enclosed space g/cm/s/s or mb — Field measurement — Stack effect of 2.5kpa from CLEA UK Handbook
K_v is Soil vapour permeability cm^2 7.58E-08
X_{crack} is perimeter of floor/wall seam cm — Building specific - extension perimeter slabs, length of extension for rafts
μ is viscocity of air, g/cm/s 0.0175 g/cms
Z_{crack} is Crack Depth below grade cm 15 0.15 m derived from CLEA Report SR3
R_{crack} is equivalent crack radius — Calculated using Equation 16 USEPA (2003) Users Guide for evaluating subsurface intrusion into building

$R_{crack} = n(A_B/X_{crack)}$
$n = A_{crack}/AB$ — Acrack is total area of cracks, assumed width of 0.2 cm from CLEA Handbook
A_B = Area of enclosed space below grade cm^2

$K_i = K_s U_w$ based on USEPA (2003) Eq. 26 = 9.87E-08 cm^2
K_i is soil intrinsic permeability (cm^2)
K_s is soil saturated hydraulic conductivity (cm/s) 0.007 cm/s
U_w is Dynamic viscosity of water (g/cm/s) 0.01307 at 10oC
P_w is density of water (g/cm^3) 0.999 c/cm^3
g is acceleration due to gravity (cm/s^2) 980.665 cm/s^2

Kv = Ki x I Krg is relative air permeability

$K_{rg} = (1-S_{te})^{1/2}(1$
K_{rg} is relative ao
S_{te} is Effective fl
M is van Genucl
M =

Site Worst Case Gas and Flow		
CH4 %	80.4	
CO2 %	13.6	
VOC %	0.0002544	0.0005
Correction factor Isobutylene to Benzene		0.53

73.68
73.12
93.2576
132.124
89.7888

Dilution Factor
DF=q/(Q+q)

To calculate equilibrium concentration
$C_u = DF \times C_g$
Cu = The equilibrium concnetration of a specific soil gas in the void
Cg = the concentration of a specific soil gas in the ground beneath the property.
DF = Dilution Factor

Consideration of dilution affect fr

Q = Clean air flow

Q = Extension Length (m) x Extensi

Height per Level	
Numer of Levels	
Air Change Rate	

ppm to mg/m
1ppm =
= Less than actio
= Exceeds assess

							Building Parameters														Consideration of Dilution affect from I			
	Property	ΔP measured in field	ΔP CLEA SR3	Q_{soil} cm^3/s	Flux (q) l/hr		Strip, Slab or Unkown Foundation	Maximum Length m	Maximum Length cm	Maximum Width m	Maximum Width cm	Measured Surface Area m2	Building Height m	Building Height cm	Building Height Ratio	Building Plan Ratio	Perimeter/X_{crack} cm	Area (A_B) cm^2	A_{crack} cm^2	n	R_{crack}	Clean Air Flow into Property (Q) m3/hr	Clean Air Flow into Property (Q) L/hr	Dilution Factor (DF)	Methane % v/v
NS	Generic Flat 1	3.14	0.03	0.059	0.213	Flat	slab	8.00	800.00	9.21	921.00	73.68	4.90	490.00	0.53	0.01	3442.00	#######	688.40	0.0009	0.200	180.5	180516	1.17996E-06	9.49E-05
NS	Generic Flat 2	3.14	0.03	0.059	0.212	Flat	Slab	8.00	800.00	9.14	914.00	53.48	4.90	490.00	0.54	0.88	3428.00	#######	685.60	0.0009	0.200	131.0	131026	1.61904E-06	1.30E-04
NS	Generic Flat 3	3.14	0.03	0.068	0.245	Flat	Slab	7.72	772.00	12.08	1208.00	61.82	4.90	490.00	0.41	0.64	3960.00	#######	792.00	0.0008	0.200	151.5	151459	1.61798E-06	1.30E-04
NS	Generic Flat 4	3.14	0.03	0.079	0.285	Flat	Slab	11.39	1139.00	11.60	1160.00	63.06	4.90	490.00	0.42	0.98	4598.00	#######	919.60	0.0007	0.200	154.5	154497	1.84171E-06	1.48E-04
NS	Generic Flat 5	3.14	0.03	0.066	0.238	Flat	Slab	7.96	796.00	11.28	1128.00	77.62	4.90	490.00	0.43	0.71	3848.00	#######	769.60	0.0009	0.200	190.2	190169	1.25219E-06	1.01E-04
																								Maximum	1.48E-04

$Q_{soil} = 2\prod \Delta P K_v X_{crack} / \mu 1n(2Z_{crack}/R_{crack})$

Q_{soil} is volumetric flow rate of soil gas entering the building cm^3/s

$\prod$ = 3.14159

ΔP is pressure differential between the soil surface and enclosed space g/cm/s/s or mb — Field measurement

K_v is Soil vapour permeability cm^2 7.58E-08

X_{crack} is perimeter of floor/wall seam cm — Building sp

μ is viscocity of air, g/cm/s 0.0175 g/cms

Z_{crack} is Crack Depth below grade cm 15 0.15 m derived

R_{crack} is equivalent crack radius — Calculated

$R_{crack} = n(A_B/X_{crack)}$

$n = A_{crack}/AB$

Acrack is total area of cracks, assumed width of 0.2 cm from CLEA Handbook

A_B = Area of enclosed space below grade cm^2

$-S_{te}^{1/M})^{2M}$ 0.768

r permeability unitless

luid saturation, unitless

hten parameter unitless 0.3509

$S_{te} = (\theta_w - \theta_r)/(n-\theta_r)$

S_{te} is Effective fluid saturation, unitless 0.3617

θ_w is soil water filled porosity cm^3/cm^3 0.24

θ_r Is Residual soil water content cm^3/cm^3 0.07

n is Soil Total Porosity cm^3/cm^3 0.54

om property passive ventilation

on Width (m) x Height Per Level (m) x Number Of Levels x Air Change Rate (dimension less)

2.45 m assumed as half height to eaves
2
0.5

3 = (#ppm)(molecular wt.)/24.45 — 24.45 Volumne of 1 mole of gas at 25 degrees c

3.190184049 mg/m3

n level or assessment criteria

ment criteria or action level

	Property	ΔP measured in field	ΔP CLEA SR3	Q_{soil} cm^3/s	Flux (q) l/hr		Strip, Slab or Unkown Foundation	Propertys Passive Ventilation Equillibrium Concentration Carbon Dioxide % v/v	VOCs % v/v	VOCs in ug/m3
NS	Generic Flat 1	3.14	0.03	0.059	0.213	Flat	slab	1.60E-05	3.00E-10	0.010
NS	Generic Flat 2	3.14	0.03	0.059	0.212	Flat	Slab	2.20E-05	4.12E-10	0.013
NS	Generic Flat 3	3.14	0.03	0.068	0.245	Flat	Slab	2.20E-05	4.12E-10	0.013
NS	Generic Flat 4	3.14	0.03	0.079	0.285	Flat	Slab	2.50E-05	4.69E-10	0.015
NS	Generic Flat 5	3.14	0.03	0.066	0.238	Flat	Slab	1.70E-05	3.19E-10	0.010
								2.50E-05	4.69E-10	1.49E-02

$Q_{soil} = 2\prod\Delta PK_vX_{crack} / \mu 1n(2Z_{crack}/R_{crack})$ 0.0002

Q_{soil} is volumetric flow rate of soil gas entering the building cm^3/s

$\prod$ = 3.14159

ΔP is pressure differential between the soil surface and enclosed space g/cm/s/s or mb — Field measurement — Stack effect of 2.5kpa from CLEA UK Handbook

K_v is Soil vapour permeability cm^2 7.58E-08

X_{crack} is perimeter of floor/wall seam cm — Building specific - extension perimeter slabs, length of extension for rafts

μ is viscocity of air, g/cm/s 0.0175 g/cms

Z_{crack} is Crack Depth below grade cm 15 0.15 m derived from CLEA Report SR3

R_{crack} is equivalent crack radius — Calculated using Equation 16 USEPA (2003) Users Guide for evaluating subsurface intrusion into building

$R_{crack} = n(A_B/X_{crack})$

$n = A_{crack}/AB$ — Acrack is total area of cracks, assumed width of 0.2 cm from CLEA Handbook

A_B = Area of enclosed space below grade cm^2

73.68
73.12
93.2576
132.124
89.7888

Dilution Factor
DF=q/(Q+q)

								Building Parameters									
	Property	**ΔP measured in field**	**ΔP CLEA SR3**	**Q_{soil} cm^3/s**	**Flux (q) l/hr**		**Strip, Slab or Unkown**	**Maximum Length m**	**Maximum Length cm**	**Maximum Width m**	**Maximum Width cm**	**Measured Surface Area m2**	**Building Height m**	**Building Height cm**	**Building Height Ratio**	**Building Plan Ratio**
NS	Generic Flat 1	0.16	0.03	0.003	0.013	Flat	slab	8.00	800.00	9.21	921.00	73.68	4.90	490.00	0.53	0.01
NS	Generic Flat 2	0.16	0.03	0.003	0.013	Flat	Slab	8.00	800.00	9.14	914.00	53.48	4.90	490.00	0.54	0.88
NS	Generic Flat 3	0.16	0.03	0.004	0.014	Flat	Slab	7.72	772.00	12.08	1208.00	61.82	4.90	490.00	0.41	0.64
NS	Generic Flat 4	0.16	0.03	0.005	0.017	Flat	Slab	11.39	1139.00	11.60	1160.00	63.06	4.90	490.00	0.42	0.98
NS	Generic Flat 5	0.16	0.03	0.004	0.014	Flat	Slab	7.96	796.00	11.28	1128.00	77.62	4.90	490.00	0.43	0.71

$K_i = K_s U_w$ based on USEPA (2003) Eq. 26 = 9.87E-08 cm^2
K_i is soil intrinsic permeability (cm^2)
K_s is soil saturated hydraulic conductivity (cm/s) 0.007 cm/s
U_w is Dynamic viscosity of water (g/cm/s) 0.01307 at 10oC
P_w is density of water (g/cm^3) 0.999 c/cm^3
g is acceleration due to gravity (cm/s^2) 980.665 cm/s^2

Kv = Ki x I Krg is relative air permeability

$K_{rg} = (1-S_{te})^{1/2}(1-S_{te}^{1/M})^{2M}$ 0.768
K_{rg} is relative aor permeability unitless
S_{te} is Effective fluid saturation, unitless

M is van Genuchten parameter unitless
M = 0.3509

$S_{te} = (\theta_w - \theta_r)/(n-\theta_r)$
S_{te} is Effective fluid saturation, unitless 0.3617
θ_w is soil water filled porosity cm^3/cm^3 0.24
θ_r Is Residual soil water content cm^3/cm^3 0.07
n is Soil Total Porosity cm^3/cm^3 0.54

Site Worst Case Gas and Flow

CH4 %	**80.4**	
CO2 %	**13.6**	
VOC %	**0.0002544**	0.0005
Correction factor Isobutylene to Benzen		0.53

Consideration of dilution affect from property passive ventilation

Q = Clean air flow

Q = Extension Length (m) x Extension Width (m) x Height Per Level (m) x Number Of Levels x Air Change Rate (dimension less)

Height per Level	2.45	m assumed as half height to eaves
Numer of Levels	2	
Air Change Rate	0.5	

To calculate equilibrium concentration
$C_u = DF \times C_g$
Cu = The equilibrium concnetration of a specific soil gas in the void
Cg = the concentration of a specific soil gas in the ground beneath the property.
DF = Dilution Factor

ppm to mg/m3 = (#ppm)(molecular wt.)/24.45 24.45 Volumne of 1 mole of gas at 25 degrees c
1ppm = 3.190184049 mg/m3

= Less than action level or assessment criteria (green)
= Exceeds assessment criteria or action level (amber)

Perimeter/X$_{crack}$ cm	Area (A_B) cm^2	A_{crack} cm^2	n	R_{crack}	Clean Air Flow into Property	Clean Air Flow into Property	Dilution Factor (DF)	Methane % v/v	Carbon Dioxide % v/v	VOCs % v/v	VOCs in ug/m3
					Consideration of Dilution affect from Propertys Passive Ventilation			Equillibrium Concentration			
3442.00	#######	688.40	0.0009	0.200	180.5	180516	6.97167E-08	5.61E-06	9.48E-07	1.77E-11	0.001
3428.00	#######	685.60	0.0009	0.200	131.0	131026	9.56589E-08	7.69E-06	1.30E-06	2.43E-11	0.001
3960.00	#######	792.00	0.0008	0.200	151.5	151459	9.55965E-08	7.69E-06	1.30E-06	2.43E-11	0.001
4598.00	#######	919.60	0.0007	0.200	154.5	154497	1.08816E-07	8.75E-06	1.48E-06	2.77E-11	0.001
3848.00	#######	769.60	0.0009	0.200	190.2	190169	7.39839E-08	5.95E-06	1.01E-06	1.88E-11	0.001
							Maximum	8.75E-06	1.48E-06	2.77E-11	8.83E-04

$Q_{soil} = 2\prod \Delta P K_v X_{crack} / \mu 1n(2Z_{crack}/R_{crack})$ 0.0002

Q_{soil} is volumetric flow rate of soil gas entering the building cm^3/s

∏ = 3.14159

ΔP is pressure differential between the soil surface and enclosed space g/cm/s/s or mb — Field measurement — Stack effect of 2.5kpa from CLEA UK Handbook

K_v is Soil vapour permeability cm^2 7.58E-08

X_{crack} is perimeter of floor/wall seam cm — Building specific - extension perimeter slabs, length of extension for rafts

μ is viscocity of air, g/cm/s 0.0175 g/cms

Z_{crack} is Crack Depth below grade cm 15 0.15 m derived from CLEA Report SR3

R_{crack} is equivalent crack radius — Calculated using Equation 16 USEPA (2003) Users Guide for evaluating subsurface intrusion into building

$R_{crack} = n(A_B/X_{crack})$

$n = A_{crack}/AB$ — Acrack is total area of cracks, assumed width of 0.2 cm from CLEA Handbook

A_B = Area of enclosed space below grade cm^2

73.68
73.12
93.2576
132.124
89.7888

Dilution Factor
DF=q/(Q+q)

								Building Parameters								
	Property	**ΔP measured in field**	**ΔP CLEA SR3**	**Q_{soil} cm^3/s**	**Flux (q) l/hr**		**Strip, Slab or Unkown**	**Maximum Length m**	**Maximum Length cm**	**Maximum Width m**	**Maximum Width cm**	**Measured Surface Area m2**	**Building Height m**	**Building Height cm**	**Building Height Ratio**	**Building Plan Ratio**
NS	Generic Flat 1	0.37	0.03	0.007	0.026	Flat	slab	8.00	800.00	9.21	921.00	73.68	4.90	490.00	0.53	0.01
NS	Generic Flat 2	0.37	0.03	0.007	0.026	Flat	Slab	8.00	800.00	9.14	914.00	53.48	4.90	490.00	0.54	0.88
NS	Generic Flat 3	0.37	0.03	0.008	0.030	Flat	Slab	7.72	772.00	12.08	1208.00	61.82	4.90	490.00	0.41	0.64
NS	Generic Flat 4	0.37	0.03	0.010	0.035	Flat	Slab	11.39	1139.00	11.60	1160.00	63.06	4.90	490.00	0.42	0.98
NS	Generic Flat 5	0.37	0.03	0.008	0.029	Flat	Slab	7.96	796.00	11.28	1128.00	77.62	4.90	490.00	0.43	0.71

$K_i = K_s U_w$ based on USEPA (2003) Eq. 26 = 9.87E-08 cm^2
K_i is soil intrinsic permeability (cm^2)
K_s is soil saturated hydraulic conductivity (cm/s) 0.007 cm/s
U_w is Dynamic viscosity of water (g/cm/s) 0.01307 at 10oC
P_w is density of water (g/cm^3) 0.999 c/cm^3
g is acceleration due to gravity (cm/s^2) 980.665 cm/s^2

Kv = Ki x l Krg is relative air permeability

$K_{rg} = (1-S_{te})^{1/2}(1-S_{te}^{1/M})^{2M}$ 0.768
K_{rg} is relative aor permeability unitless
S_{te} is Effective fluid saturation, unitless

M is van Genuchten parameter unitless
M = 0.3509

$S_{te} = (\theta_w - \theta_r)/(n-\theta_r)$
S_{te} is Effective fluid saturation, unitless 0.3617
θ_w is soil water filled porosity cm^3/cm^3 0.24
θ_r Is Residual soil water content cm^3/cm^3 0.07
n is Soil Total Porosity cm^3/cm^3 0.54

Site Worst Case Gas and Flow		
CH4 %	**80.4**	
CO2 %	**13.6**	
VOC %	**0.0002544**	0.0005
Correction factor Isobutylene to Benzen		0.53

Consideration of dilution affect from property passive ventilation

Q = Clean air flow

Q = Extension Length (m) x Extension Width (m) x Height Per Level (m) x Number Of Levels x Air Change Rate (dimension less)

Height per Level	2.45	m assumed as half height to eaves
Numer of Levels	2	
Air Change Rate	0.5	

To calculate equilibrium concentration
$C_u = DF \times C_g$
Cu = The equilibrium concnetration of a specific soil gas in the void
Cg = the concentration of a specific soil gas in the ground beneath the property.
DF = Dilution Factor

ppm to mg/m3 = (#ppm)(molecular wt.)/24.45 24.45 Volumne of 1 mole of gas at 25 degrees c
1ppm = 3.190184049 mg/m3

(green) = Less than action level or assessment criteria
(orange) = Exceeds assessment criteria or action level

Perimeter/X$_{crack}$ cm	Area (A_B) cm^2	A_{crack} cm^2	n	R_{crack}	Clean Air Flow into Property	Clean Air Flow into Property	Dilution Factor (DF)	Methane % v/v	Carbon Dioxide % v/v	VOCs % v/v	VOCs in ug/m3
					Consideration of Dilution affect from Propertys Passive Ventilation			Equillibrium Concentration			
3442.00	#######	688.40	0.0009	0.200	180.5	180516	1.45399E-07	1.17E-05	1.98E-06	3.70E-11	0.001
3428.00	#######	685.60	0.0009	0.200	131.0	131026	1.99502E-07	1.60E-05	2.71E-06	5.08E-11	0.002
3960.00	#######	792.00	0.0008	0.200	151.5	151459	1.99372E-07	1.60E-05	2.71E-06	5.07E-11	0.002
4598.00	#######	919.60	0.0007	0.200	154.5	154497	2.26941E-07	1.82E-05	3.09E-06	5.77E-11	0.002
3848.00	#######	769.60	0.0009	0.200	190.2	190169	1.54298E-07	1.24E-05	2.10E-06	3.93E-11	0.001
							Maximum	1.82E-05	3.09E-06	5.77E-11	1.84E-03

APPENDIX E

FAULT TREE ANALYSIS

FAULT TREE ANALYSIS OF GAS INGRESS RISK:

PROPERTY ADJACENT TO FORMER BROOKS TIP, BORDER ROAD

WPA CONSULTANTS LTD

FOR

WEYMOUTH & PORTLAND BOROUGH COUNCIL

J. Wilson

ISSUED 29/11/2013

Contents

Appendices

1.0 GAS RISK ESTIMATION

1.1 Introduction

The following describes the process undertaken to calculate the probability of an incident of one person being injured by a methane or benzene explosion while living in a house built near or on a site such as a gassing landfill. The assessment considers the potential for such explosion to take place due to an occupier switching on an ignition source in a poorly ventilated cupboard.

The risk assessment is based on the framework proposed in CIRIA report 152 and reiterated in CIRIA C665. The explosive limits for methane are 5-15%.

The above scenario was assessed by assuming that the gas flow into a 0.8m^3 cupboard would not exceed the volumetric flow rate of ground gas entering the building. This approach is described in the following reference document Developing A Risk Assessment Framework for Landfill Gas: Calculating the Probability of a Landfill Gas Explosion (2004) construction scenario to be considered as part of this explosivity assessment is a house with no under floor ventilation.

The properties at the site are generally small and therefore it is considered unlikely that they will contain a large cupboard with an ignition source.

A screening level assessment has been carried out using a the Site Worse Case methane fluxes based on the highest flow rate and gas concentrations as detailed within the main report.

1.2 Methodology

A fault tree analysis is used to determine the likelihood of a hazardous final event following a source, pathway and target approach. Fault tree analysis systematically identifies all the individual failure combinations, which are necessary for the top event to occur. Starting at the top of the tree, the failure combinations are set down in progressively more details. The general fault tree in this case is:

1.2.1 Top Event

The top event in this case is serious or fatal injury to people due to a methane or VOC explosion. The minimal cut set is found to be the mathematical product of the following failures.

1.2.2 Failure to Prevent Occupation

This is to estimate the probability that part of the development or property susceptible to a methane or VOC explosion is occupied. The occupation level for residential houses is estimated to be 80% of the year based on the default value in CIRIA 152. Therefore the probability that a person is present is **0.8.**

1.2.3 Failure to prevent gas cloud Ignition

Ignition can be the direct results of occupation but can also be independent of occupation. Manual switching of electrical supplies, lighting cigarettes and sparks from static electricity are common examples of manual ignition source. Automatic electrical timers, which are independent of occupation, are an example of remote ignition sources.

Continuous sources of ignition such as open fires and pilot lights are not considered as ignition sources as they will burn methane in a controlled manner when it is present in small quantities, assuming that there will very rarely be a sudden inrush and that methane from the ground will infiltrate slowly.

Considering the light being switched on over the period of year, the CIRIA assumption is the light will be switched on 50 times per year on average. Therefore the probability that it will not be turned on for a whole year is very small and the probability that the light will be turned on at least once in a week is relatively high and can be considered to be **0.63.** This is based on guidance from CIRIA 152.

1.2.4 Failure to Detect a Gas Cloud

Methane is explosive in concentrations in air of between 5 and 15%. It is unlikely that any of the properties will have methane detection equipment and the probability of failure to detect is **1.0.**

1.2.5 Failure to Ventilate Adequately

Failure of Void Ventilation

The property has no underfloor void therefore it is consider that the probability of it's failure is ***1.0.***

Failure to House Ventilation

If gas does penetrate the floor then we can assume that it might build up in confined places such as closed cupboards. Such places are likely to be ventilated albeit to a small degree. CIRIA Report 152 assumed a cupboard ventilation rate of 1 air change per day.

The Site Worse Case gas flow rate for the subject site is measured to be 0.5 l/h with a maximum recorded relative pressure of 3.19, mean relative pressure of 0.162 and 95th percentile relative pressure of 0.365. The rate of gas diffusion into the property through the underlying floor slab has been calculated using these 3 different relative pressures using the equations detailed in section 3.2 of the Gas Ingress Modelling Report presented in Appendix H. The assessment assumes that this maximum flow rate is present at the house location and that the methane lower explosive limits pass to the cupboard at the maximum flow rate. Based on the above the lower explosive limit of the ground gas of interest in a 0.8m^3 cupboard volume will be reached in the number of days calculated from the following equation;

Time (hours)= Volume (L) x LEL % gas / dilution factor of gas L/h x gas concentration %

The same methodology was followed for methane. With one air change per day, the probability that a methane cloud exists in the cupboard at a concentration of 5% for the different relative pressures is therefore:

Circumstances	Relative pressure	Likelihood	Probability
Worst Case Recorded	3.19	1 in 460	0.00217
Mean Average	1.62	1 in 7721	0.000122952
95th Percentile	0.365	1 in 3750	0.0002667

In other words, the methane would have to arrive between 460 to 7721 times faster than calculated in order for 5% methane levels to be achieved with one air change per day in the cupboard.

1.2.6 Failure to prevent gas from Entry to the development

The properties surrounding the site have not been demonstrated to contain gas membranes that meet the required standard therefore there presence has been discounted in this assessment. As such the probability of gas entry into the property is considered to be **1.** This is based on guidance from CIRIA 152.

1.2.7 Failure to prevent gas Migration to the development

The migration of gas from a source to the development is principally controlled by the three parameters, the pressure gradient, the distance and the soil permeability. Methane and VOCs were detected in all of the boreholes at the site. Based on their occurrences the probability of methane and VOCs migration is considered to be **1**. This is assuming that the surface geology will fail to prevent sufficient gas from migrating to the surface at the locations of the residential properties or that piles act as a preferential pathway.

1.2.8 Potential

The landfill is known to be gassing and hence the probability that there is a potential for gas is **1.0**.

1.2.9 Conditions

As above the site is known to be gassing and hence the probability that the conditions for benzene or methane exists must also be **1.0**.

1.3 Probability of an Explosion

Based on the factors considered in the above sections the probability of explosion has been calculated. This is presented in Table 2.

Table 2
Probability of an explosion Worst Case Relative Pressure

Event	VOCs	Methane
Potential		1
Condition		1
Failure to prevent migration		1
Failure of barrier		1
Entry of gas into builidng		1
Failure of void ventilation		1
Failure to detect gas		1
Failure of house ventilation		0.00217143
Igniton source		0.63
Occupant present		0.8
Probability of Explosion		1.09E-03
Probability of Explosion		1:1009

Mean Average Relative Pressure

Event	VOCs	Methane
Potential		1
Condition		1
Failure to prevent migration		1
Failure of barrier		1
Entry of gas into builidng		1
Failure of void ventilation		1
Failure to detect gas		1
Failure of house ventilation		0.00012952
Igniton source		0.63
Occupant present		0.8
Probability of Explosion		6.53E-05
Probability of Explosion		1:65000

95th Percentile Relative Pressure

Event	VOCs	Methane
Potential		1
Condition		1
Failure to prevent migration		1
Failure of barrier		1
Entry of gas into builidng		1
Failure of void ventilation		1
Failure to detect gas		1
Failure of house ventilation		0.00026667
Igniton source		0.63
Occupant present		0.8
Probability of Explosion		1.34E-04
Probability of Explosion		1:34000

As the scenario detailed above is dependent on a relative pressure that is present for a reasonable period of time WPA consider the use of the gas ingress rate based on a mean average scenario as most representative of the site.

The above tables indicate that the risk of explosion presented by methane based on the Site Worse Case concentrations and flow rates generates a frequency of explosion of once in 65,000 years. As previously stated the use of the Site Worst Case concentrations is highly conservative and the probability is likely to be considerably lower.

The spreadsheets used to model the risk estimation are presented in Appendix A.

Appendix A

Potential		**1**	beacause gas is present
Condition		**1**	beacasue methane is present
Maximum Methane Concentration			80 %
Maximum Borehole Flow Rate			2 l/hr
Diffusion through floor slab 1 m2			0.285 l/hr

Failure of cover layer to prevent gas movement probability	**1**	
Failure to prevent migration	**1**	
Entry of gas into cupboard	**1**	0.003619 l/hr
Probabilty of membrane failure	**1**	

Faliure of void ventilation:
First considering ventilation

Area	0.8	m
Void Depth	1	m
Volumne	0.8	m3
Airchange	1	airchange per day
Ventilation Volume	800	l/hr
Methane concentration	9.66E-05	
Methane concentration %		
Lower Explosive Limit	5	%

the entry rate has to increase by	92.10526	to reach the unaceptable level of 1%
it has to increase by	460.5263	to reach the exposive level of 5%

Second consider periods of zero ventilation

Concetrations after:	4 hours	0.00181	%
	10 hours	0.004524	%
	24 hours	0.010857	%
	100 hours	0.045238	%
	200 hours	0.090476	%
	500 hours	0.22619	%
	1000 hours	0.452381	%
	2000 hours	0.904762	%
	4000 hours	1.809524	%

to achieve and explosive level of	5 %
time required is:	11052.63 hours
	460.5263 days

Therefore we suggest probability of **0.002171**

Failure to detect gas **1**

Event	Methane
Potential	1
Condition	1
Failure to prevent migration	1
Failure of barrier	1
Entry of gas into builidng	1
Failure of void ventilation	1
Failure to detect gas	1
Failure of house ventilation	0.00217143
Igniton source	0.63
Occupant present	0.8
Probability of Explosion	0.0010944
Probability of Explosion	913.74269

Event	VOCs	Methane
Potential		1
Condition		1
Failure to prevent migration		1
Failure of barrier		1
Entry of gas into builidng		1
Failure of void ventilation		1
Failure to detect gas		1
Failure of house ventilation		0.00217143
Igniton source		0.63
Occupant present		0.8
Probability of Explosion		1.09E-03
Probability of Explosion		1:1009

1 in 1009 years

Potential	**1** beacause gas is present	
Condition	**1** beacasue methane is present	
Maximum Methane Concentration		80 %
Maximum Borehole Flow Rate		2 l/hr
Diffusion through floor slab		0.285 l/hr

Failure of cover layer to prevent gas movement probability	**1**	

Failure to prevent migration	**1**	

Entry of gas into builidng	**1**	0.228 l/hr
Probabilty of membrane failure	**1**	

Faliure of void ventilation:
First considering ventilation

Area	0.8	m
Void Depth	1	m
Volumne	0.8	m3
Airchange	1	airchange per day
Ventilation Volume	800	l/hr
Methane concentration	9.66E-05	
Methane concentration %		
Lower Explosive Limit	5	%

the entry rate has to increase by	1.461988	to reach the unaceptable level of 1%
it has to increase by	7.309942	to reach the exposive level of 5%

Second consider periods of zero ventilation

Concetrations after:	4 hours	0.114 %
	10 hours	0.285 %
	24 hours	0.684 %
	100 hours	2.85 %
	200 hours	5.7 %
	500 hours	14.25 %
	1000 hours	28.5 %
	2000 hours	57 %
	4000 hours	114 %

to achieve and explosive level of	5 %
time required is:	175.4386 hours
	7.309942 days

Therefore we suggest probability of **0.1368**

Failure to detect gas	**1**

Event	Methane
Potential	1
Condition	1
Failure to prevent migration	1
Failure of barrier	1
Entry of gas into builidng	1
Failure of void ventilation	1
Failure to detect gas	1
Failure of house ventilation	0.1368
Igniton source	0.63
Occupant present	0.8
Probability of Explosion	0.0689472
Probability of Explosion	14.5038522

Event	VOCs	Methane
Potential		1
Condition		1
Failure to prevent migration		1
Failure of barrier		1
Entry of gas into builidng		1
Failure of void ventilation		1
Failure to detect gas		1
Failure of house ventilation		0.1368
Igniton source		0.63
Occupant present		0.8
Probability of Explosion		6.89E-02
Probability of Explosion		0.00

1 in 14.5

Potential	**1** beacause gas is present		
Condition	**1** beacasue methane is present		
Maximum Methane Concentration		80	%
Maximum Borehole Flow Rate		2	l/hr
Diffusion through floor slab 1 m2		0.017	l/hr

Failure of cover layer to prevent gas movement probability	**1**

Failure to prevent migration	**1**

Entry of gas into cupboard	**1**	0.000215873 l/hr
Probabilty of membrane failure	**1**	

Faliure of void ventilation:
First considering ventilation

Area	0.8	m
Void Depth	1	m
Volumne	0.8	m3
Airchange	1	airchange per day
Ventilation Volume	800	l/hr
Methane concentration	9.66E-05	
Methane concentration %		
Lower Explosive Limit	5	%

the entry rate has to increase by 1544.118 to reach the unaceptable level of 1%
it has to increase by 7720.588 to reach the exposive level of 5%

Second consider periods of zero ventilation

Concetrations after:	4 hours	0.000108	%
	10 hours	0.00027	%
	24 hours	0.000648	%
	100 hours	0.002698	%
	200 hours	0.005397	%
	500 hours	0.013492	%
	1000 hours	0.026984	%
	2000 hours	0.053968	%
	4000 hours	0.107937	%

to achieve and explosive level of 5 %
time required is: 185294.1 hours
7720.588 days

Therefore we suggest probability of **1.30E-04**

Failure to detect gas	**1**

Event	**Methane**
Potential	1
Condition	1
Failure to prevent migration	1
Failure of barrier	1
Entry of gas into builidng	1
Failure of void ventilation	1
Failure to detect gas	1
Failure of house ventilation	0.00012952
Igniton source	0.63
Occupant present	0.8
Probability of Explosion	0.00006528
Probability of Explosion	15318.6275

Event	VOCs	Methane
Potential		1
Condition		1
Failure to prevent migration		1
Failure of barrier		1
Entry of gas into builidng		1
Failure of void ventilation		1
Failure to detect gas		1
Failure of house ventilation		0.00012952
Igniton source		0.63
Occupant present		0.8
Probability of Explosion		6.53E-05
Probability of Explosion		1:65000

1 in 650000 years

10	1.00E+01
100	1.00E+02
1000	1.00E+03
10000	1.00E+04
100000	1.00E+05
10000000	1.00E+07

Potential		**1**	beacause gas is present
Condition		**1**	beacasue methane is present
Maximum Methane Concentration			80 %
Maximum Borehole Flow Rate			2 l/hr
Diffusion through floor slab 1 m2			0.035 l/hr
Failure of cover layer to prevent gas movement probability		**1**	
Failure to prevent migration		**1**	
Entry of gas into cupboard		**1**	0.000444 l/hr
Probabilty of membrane failure		**1**	

Faliure of void ventilation:			
First considering ventilation			
Area		0.8 m	
Void Depth		1 m	
Volumne		0.8 m3	
Airchange		1 airchange per day	
Ventilation Volume		800 l/hr	
Methane concentration		9.66E-05	
Methane concentration %			
Lower Explosive Limit			5 %
the entry rate has to increase by			750 to reach the unaceptable level of 1%
it has to increase by			3750 to reach the exposive level of 5%
Second consider periods of zero ventilation			
Concetrations after:	4 hours	0.000222 %	
	10 hours	0.000556 %	
	24 hours	0.001333 %	
	100 hours	0.005556 %	
	200 hours	0.011111 %	
	500 hours	0.027778 %	
	1000 hours	0.055556 %	
	2000 hours	0.111111 %	
	4000 hours	0.222222 %	
to achieve and explosive level of	5 %		
time required is:	90000 hours		
	3750 days		
Therefore we suggest probability of			**2.67E-04**
Failure to detect gas			**1**

Event	**Methane**
Potential	1
Condition	1
Failure to prevent migration	1
Failure of barrier	1
Entry of gas into builidng	1
Failure of void ventilation	1
Failure to detect gas	1
Failure of house ventilation	0.00026667
Igniton source	0.63
Occupant present	0.8
Probability of Explosion	0.0001344
Probability of Explosion	7440.47619

Event	**VOCs**	**Methane**	
Potential		1	
Condition		1	
Failure to prevent migration		1	
Failure of barrier		1	
Entry of gas into builidng		1	
Failure of void ventilation		1	
Failure to detect gas		1	
Failure of house ventilation		0.00026667	
Igniton source		0.63	
Occupant present		0.8	
Probability of Explosion		1.34E-04	
Probability of Explosion		1:34000	1 in 13400 years