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Your Ref:

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For the attn. of Mr Darren Rhys Thomas

DETAILED GROUND GAS RISK ASSESSMENT: SWANSEA BAY TECHNOLOGY CENTRE

1.0 Introduction

Terra Firma Wales Ltd. Have been retained by Morgan Sindall Construction & Infrastructure Ltd. (the Client) to prepare a detailed ground gas risk assessment for their development site at Swansea Bay Technology Park.

Between December 2019 and January 2020 site investigation works were undertaken at the site by the author to investigate any geotechnical and geoenvironmental liabilities, to facilitate the construction of the proposed commercial development. Three boreholes were drilled as part of the investigation and installed with dual purpose monitoring wells. A programme of ground gas and groundwater monitoring followed site works for a period of three months, with visits approximately every two weeks.

An initial ground gas risk assessment was prepared based on the results of the first two rounds of ground gas monitoring data. It was evident that borehole BH03 was producing high levels of methane gas at elevated flow rates. However, it was noted that the screened section of the well was flooded which is likely to influence the actual gas concentration. Where the screened section of well was not wholly flooded in borehole BH01 and BH02, negligible levels of hazardous gas were recorded. It was also suggested that elevated flow rates may be attributed to tidal changes. Based on the measured results a gas screening value of 2.73l/hr was prepared, classifying the site as 'Gas Characteristic Situation 3' (CS3).

This letter report is to be read in conjunction with Terra Firma Wales Ltd. Geotechnical and Geoenvironmental Report, referenced 15773, dated February 2020.

2.0 Ground Gas Monitoring Results

Three monitoring wells were installed in boreholes BH01, BH02 and BH03 as part of Terra Firma Wales Ltd initial investigation.

Six rounds of gas monitoring have been carried out to date. The installations were tested for carbon dioxide, methane, oxygen, carbon monoxide and hydrogen sulphide using a Gas Analyser

GA2000. On occasion the installations were also monitored for volatile organic compounds (VOC) using a photo-ionisation detector with a 10.6eV lamp.

Ground gas monitoring results are tabulated in **Table 2.1** along with approximate tide heights (tidetimes.co.uk) and barometric pressure at time of visit.

Table 2.1 Ground Gas Monitoring Results									
Date & Time	Borehole	Methane (%)	Oxygen (%)	Carbon Dioxide (%)	Flow (l/hr)	Ground-Water (m)	Tide (m)	VOC (ppm)	Barometric Pressure (mb)
24/01/20 16:00	BH01	0	10.6	0	0	1.5	5.1		1021
04/02/20 11:30	BH01	0.1	2.3	0.1	0	1.63	5.3	0.9	1027
18/02/20 15:00	BH01	0.1	8.6	0.1	0	1.5	7.2		1017
02/03/20 12:00	BH01	0.5	5.5	0	2	1.3	7.2		995
31/03/20 15:00	BH01	0	14.6	0.1	0	1.7	3		1031
20/04/20 11:30	BH01	0	18.8	0	0	1.9	1.7	0	1016
24/01/20 16:00	BH02	0	2.7	0	0	2.4	5.1		1021
04/02/20 11:30	BH02	0.6	0.8	0.1	0	2.33	5.3	0.6	1027
18/02/20 15:00	BH02	0.2	0.8	0	0.2	2.1	7.2		1017
02/03/20 12:00	BH02	0.1	0.4	0.1	7.8	2	7.2		995
31/03/20 15:00	BH02	0	19.9	0.1	0	2.4	3		1031
20/04/20 11:30	BH02	0	18.3	0.1	0	2.6	1.7	0	1016
24/01/20 16:00	BH03	29.8	3.8	0	0	1.6	5.1		1021
04/02/20 11:30	BH03	35.9	19.1	7.3	7.6	1.5	5.3	1.3	1027
18/02/20 15:00	BH03	39.8	5.5	0	8	1.45	7.2		1017
02/03/20 12:00	BH03	45.8	4.7	0	12.5	1.4	7.2		995
31/03/20 15:00	BH03	3.1	17.7	0	7.2	1.7	3		1031
20/04/20 11:30	BH03	9.8	14.1	0	0	1.9	1.7	0	1016

Carbon monoxide and hydrogen sulphide were not detected during monitoring of the borehole installations.

Borehole BH03 installation well, unlike BH01 and BH02, was completed flooded throughout monitoring. Monitored gas concentration are therefore only reflective of the trapped gasses in the top of the well. It is contentious how the effect of preferential partitioning of dissolved gasses

within groundwater into the well top will influence the result. Furthermore, flooded wells in combination with variable groundwater levels will confine pressures within the well top, significantly influencing flow rates. It is considered that borehole BH03 results are not representative of the actual gas risk and should be used with extreme caution.

3.0 Gas Risk Characterisation

3.1 Gas Source

Borehole BH03 installation well is entirely situated below the made ground material therefore ruling out this material as the methane source. Apart from rare timber fragments found within the made ground material, no other potential gas producing, organic rich components were identified.

Soft to firm dark grey peaty clay was encountered between 3.00m and 3.50m in borehole BH03. Oxidation of peat would produce methane at concentrations observed during monitoring. It should be noted that peat deposits of any volume are finite reservoirs of very limited amounts of interstitial gas and moreover do not have the capacity to de-gas at significant rates. Elevated flow rate recorded during monitoring are therefore attributed to other driving forces.

Borehole BH01 and BH02 encountered similar dark grey clay without the significant peat content, which may account for the variation in methane concentrations recorded between wells.

3.2 Gas Migration Pathways

Due to the vary nature of peat deposits, the lamination of thin horizontal alluvial clay beds, interbedded with organic rich peat, precludes the vertical movement of gasses or fluids at elevated rates. Typically, peaty clay deposits have a permeability in the order of 1×10^{-07} m/s, whereas permeabilities $< 1 \times 10^{-04}$ m/s are required for adequate gas flow (Technical Paper: Risk and Reliability in Gas Protection Design – 20 Year on. Parts 1 and 2:2019).

Made ground encountered above the peaty clay deposits have a permeability at best of 1×10^{-05} , based on previously undertaken soakage tests at shallow depth.

The fact that shallow soils are completely saturated to a depth of between 1.4-2.6m will also inhibit migration of gasses.

Existing borehole are considered the only feasible gas migration pathway to surface. It is recommended that borehole be decommissioned prior to development, utilising a bentonite clay plug.

The underlying ground conditions precludes the use of traditional foundation for the proposed structure therefore a piled foundation solution is to be adopted. Although it is considered unlikely due to the re-sealing effect of saturated clays, the annulus between the pile and in-situ materials is considered a potential gas migration pathway.

It is likely the proposed building will include a lift pit, constructed at depth, possibly within or through the peaty clay deposits. The drainage layer between the structure and soil is a potential gas migration pathway.

3.3 Potential Receptors

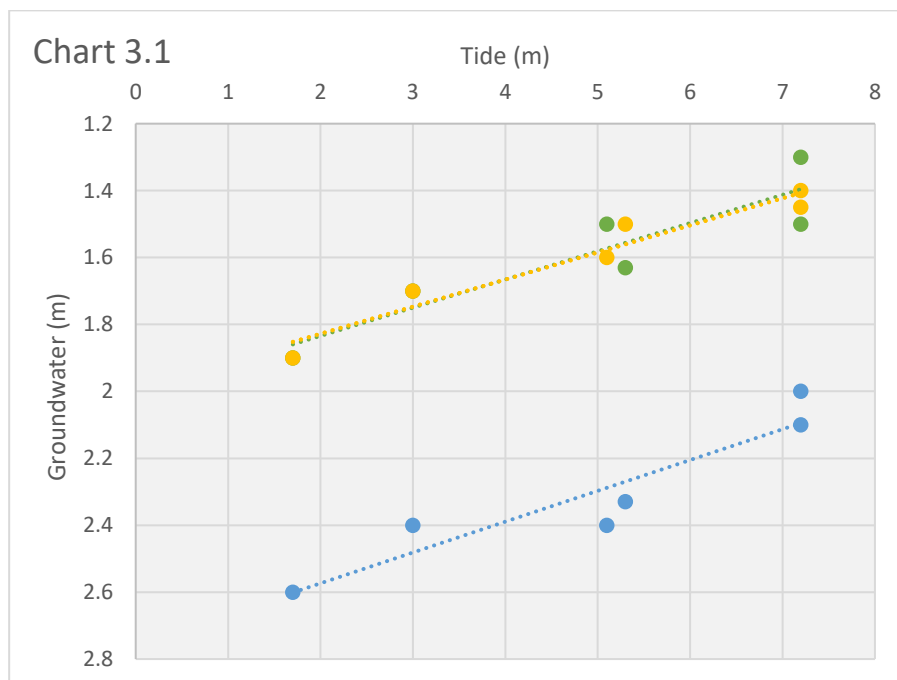
Potential receptors included all staff and visitor to the commercial structure, as well as the structure itself. Although methane gas itself is nontoxic, significant displacement of oxygen within a confined space can cause asphyxiation. Methane is also explosive at concentrations between 5-15%.

3.4 Driving Forces

It has been demonstrated that driving forces are accountable for the elevated flow rates recorded, as the gas source is not favourable to such high degassing conditions.

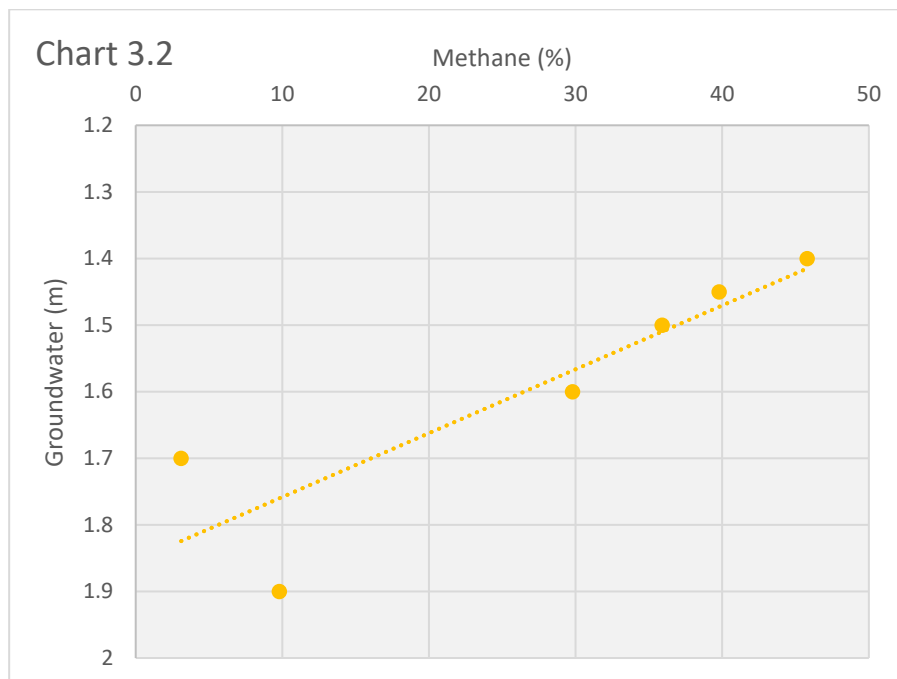
3.4.1 Groundwater

Over the investigation and monitoring period groundwater was shown to fluctuate over a range of between 0.5-0.6m. Previous assessments undertaken by the author have alluded to a correlation between tidal patterns and groundwater levels. The following chart **Chart 3.1** illustrates a positive correlation between the two variables for each of the boreholes.



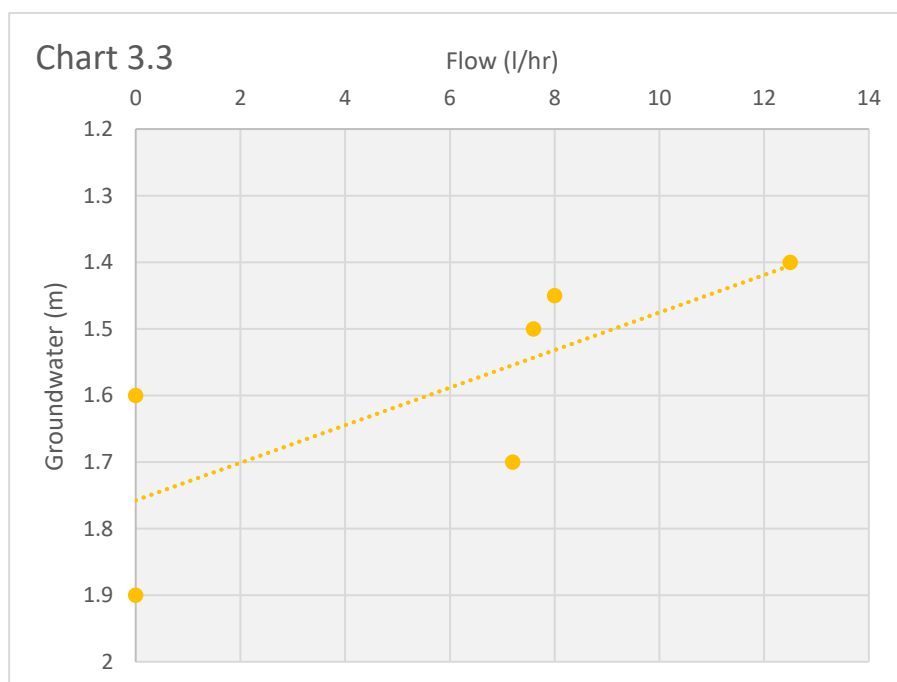
Notes: Green – BH01; Blue – BH02; Yellow – BH03. Trendlines are linear.

Chart 3.2 demonstrates the relationship between methane concentration and groundwater levels for borehole BH03. The chart shows a clear correlation between rising groundwater levels and rising methane levels.



Notes: Yellow – BH03. Trendline is linear.

Similarly, a positive but weak relationship is shown in **Chart 3.3**, which illustrates the correlation between increasing flow rates and rising groundwater level in borehole BH03.



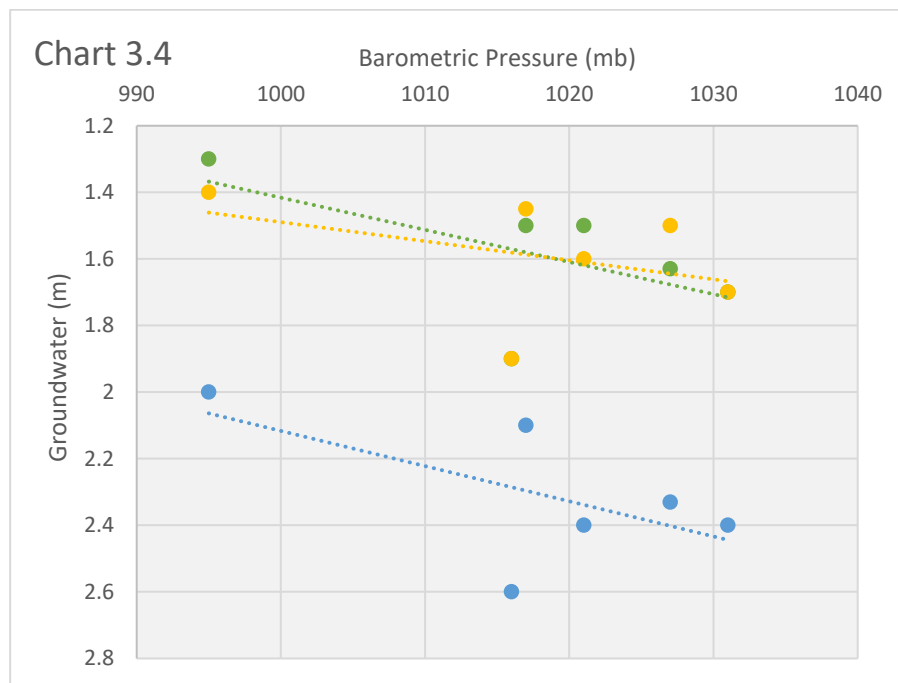
Notes: Yellow – BH03. Trendline is linear.

3.4.2 Barometric Pressure

Barometric pressure is also considered another driving force for consideration. Typically, low atmospheric pressure give rise to elevated gas flow rates due to resulting differential pressures

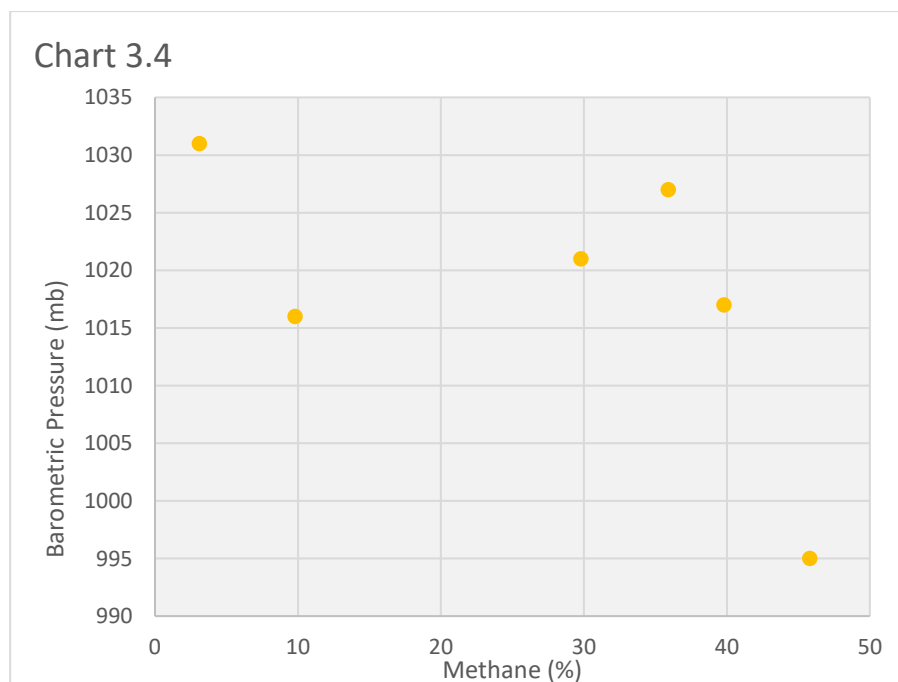
between the well and atmosphere. However, analysis of the results shows no discernible relationship between the two variables.

The following chart **Chart 3.4** illustrates a correlation, albeit weak, between barometric pressure and groundwater levels.



Notes: Green – BH01; Blue – BH02; Yellow – BH03. Trendlines are linear.

The relationship between methane concentration and barometric pressure is also analysed in **Chart 3.4** for borehole BH03, it is considered there to be little correlation. Similar results were seen for borehole BH02.



Notes: Yellow – BH03.

It is therefore considered that rising groundwater, predominantly attributed to tidal changes with lesser influence from barometric pressure, is the main driving force for gas flow.

3.5 Volatile Gasses

Boreholes were monitored for volatile organic compounds on two occasions during monitoring, no significant volatiles were recorded. The risk from volatile gasses is considered negligible.

4.0 Ground Gas Risk Assessment

4.1 Conceptual Site Model

Based on the geological data an illustrative conceptual site model has been prepared, **Figure 4.0**, detailing the gas source, potential gas migration pathways and receptors.

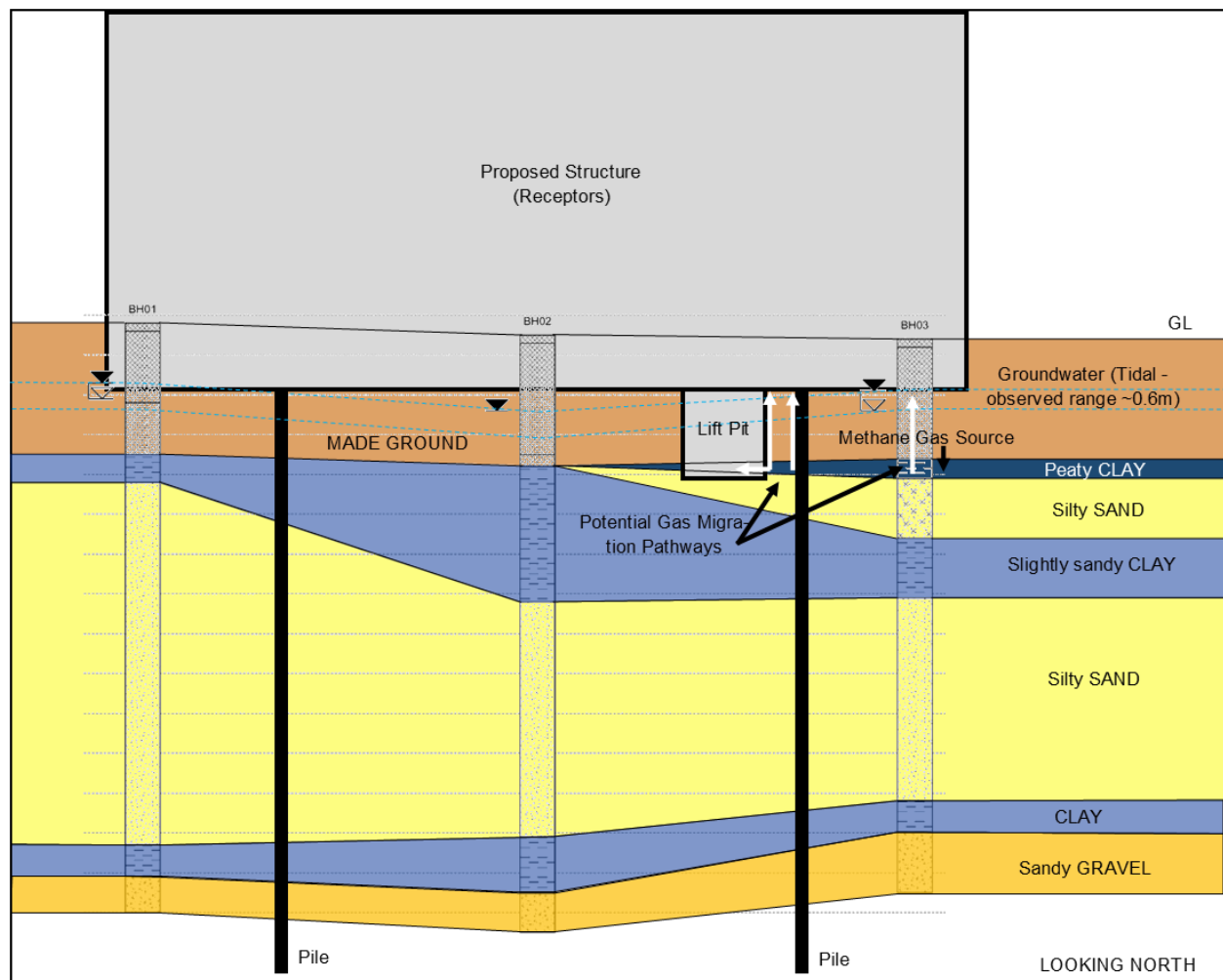


Figure 4.0 – Conceptual Site Model (not to scale).

4.2 Gas Screening Value

Based on the data and analysis of risk a gas screening value of $<0.7\text{l/hr}$ is considered appropriate for the development (CIRIA C665:2007) and remains conservative for peat derived gas. It is considered that borehole BH03 gas concentration and flow results are not representative of the actual gas risk at the site and should be not used in this assessment. Flow rates and gas concentrations in borehole BH03 are a product of a flooded well in combination with tidal derived pressure and to a lesser extent barometric pressure, affecting flow rates. The very presence of the well has created a preferential pathway through the ordinarily impermeable clay, allowing for the concentration of gasses in the well top.

When this gas screening value is compared with Table 8.5 of CIRIA report C665, the site is classified as 'Gas Characteristic Situation 2' (CS2).

5.0 Recommended Protection Measures

The ground gas protection system should be designed, verified, installed and validated in accordance with the British Standard 8485:2015+A1:2019 and CIRIA guidance C735:2014.

It is recommended that a specialist consultant is retained to prepare a risk assessed ground gas protection system Verification Plan for the proposed development. The Verification Plan will detail the required protection measures based on the perceived risk associated with the complexity of design, experience of the installer, scale of the development and gas characteristic situation. The Verification Plan also details the step by step process and requirements to allow for the completion of a Validation Report. Terra Firma (Wales) Ltd offer Verification and Validation services.

Validation of installed ground gas protection systems by an independent third party will be required upon completion of the development. Validation may only be achieved if processes prescribed in the Verification Plan are undertaken.