Table 4.4 - Site 2: Borehole Installation Details

BH ID	BH Type	Northing	Easting	BH Ground level (mAOD)	Standpipe level (mAOD)	Casing Height	Static Water Level *	Water Elevation (mAOD)	Drilling Method	Drill Date	Total depth (mbgl)	Blank pipe interval (mbgl)	Slotted Pipe Interval (mbgl)	Screened Geology
ONSITE														
LG01	Combined gas/leachate	723643.326	718221.9	83.758	84.16	34	4.21	80.0	Rotary	21/01/2016	16.0	0-1	1-5	Waste
LG02	Combined gas/leachate	723692.634	718261.4	83.185	83.408	31	8.48	74.9	Cable Percussive & Rotary	17/02/2016	12.0	0-1	1-9	Waste
LG03	Combined gas/leachate	723751.153	718307.3	82.248	82.525	23	14.89	67.6	Rotary	21/01/2016	29.0	0-1	1-18	Waste
LG04	Combined gas/leachate	723728.763	718362.2	81.883	82.044	19	12.45	69.9	Cable Percussive & Rotary	17/02/2016	18.0	0-1	1-15	Waste
LG05	Combined gas/leachate	723786.907	718340.6	80.14	80.199	38	13.74	66.5	Rotary	19/01/2016	25.5	0-1	1-14	Waste
LG06	Combined gas/leachate	723716.541	718432.1	82.678	83.119	40	6.56	76.6	Rotary	20/01/2016	17.5	0-1	1-6.4	Waste
LG07	Combined gas/leachate	723798.501	718404.3	74.868	75.126	27	11.46	63.7	Cable Percussive & Rotary	15/02/2016	17.1	0-1	1-16.1	Waste (base of waste not reached)
LG08	Combined gas/leachate	723855.048	718376.5	70.767	70.938	26	7.65	63.3	Rotary	01/02/2016	19.5	0-1	1-8	Waste
LG09	Combined gas/leachate	723827.321	718410.7	71.057	71.236	26	11.11	60.1	Rotary	02/02/2016	25.5	0-1	1-17	Waste
LG10	Combined gas/leachate	723905.291	718400.6	66.373	66.623	49	17.46	49.2	Cable Percussive & Rotary	11/02/2016	21.0	0-1	1-18	Waste
OFFSITE														
BH01	Groundwater	723751.86	718464.1	79.222	79.464	28	14.82	64.6	Rotary	05/02/2016	21	0-5	5-21	Clay with boulder content/ clayey sand/ clay gravel/ clay
BH03	Groundwater	723834.106	718313.2	78.651	78.796	33	Dry	59.3	Rotary	10/02/2016	19.5	0-2	2-19.5	Sand/ sandy gravel
BH04	Groundwater	723658.785	718159.8	84.409	84.532	42	Dry	59.0	Rotary	19/02/2016	25.5	0-13.5	13.5-25.5	Clayey gravel/ sandy gravel/ sand
BH11	Groundwater	723802.675	718269.4	82.653	82.826	42	Dry	49.8	Rotary	24/02/2016	33	0-1	1-33	Sandy clay/ sandy gravel/ gravel/ sand
BH13	Groundwater	723633.902	718448	87.985	87.990	30	Dry	68.5	Rotary	03/02/2016	19.5	0-4.5	4.5-19.5	Sandy clayey gravel/ sand/ sandy gravel/ gravel/ silty sandy clay
G01	Offsite gas	723757.346	718233.3	84.991	85.397	43	Dry	68.3	Rotary	23/02/2016	19.5	0-1	1-17.5	sandy gravel/ gravel
G02	Offsite gas	723906.485	718311.7	72.662	72.638	36	Dry	53.1	Rotary	10/02/2016	19.5	0-1	1-19.5	Clay/ sand/ gravel/ sandy gravel
G03	Offsite gas	723984.285	718343.9	69.504	69.626	45	Dry	50.1	Rotary	09/02/2016	19.5	0-1	1-19.5	Clay/ gravel/ sandy gravel/ gravel with boulder content/ sand
G04	Offsite gas	723640.86	718282.2	85.617	85.971	36	8.23	77.7	Rotary	22/02/2016	20	0-3	3-17	Sandy gravel/ sandy clayey gravel/ gravel
G05	Offsite gas	723638.096	718344.7	86.723	86.857	37	16.46	70.4	Rotary	25/01/2016	20	0-1	1-20	Sandy clayey gravel/ sandy gravel/ sand
G13	Offsite gas	724005.712	718058.5	75.822	76.001	44	Dry	56.0	Rotary	26/02/2016	20	0-1	1-20	Sandy clay/ sandy gravel/ sand
G20	Offsite gas	723622.08	718199.8	85.551	85.826	45	14.57	71.3	Rotary	02/02/2016	27	0-1	1-20	Sandy clayey gravel/ gravel/ sand
G21	Offsite gas	723750.429	718164.1	86.662	87.003	43	Dry	`70.0	Rotary	24/02/2106	19	0-1	1-17	Sandy clay/ sandy gravel/ sand
G22	Offsite gas	724131.346	717889.4	63.675	63.85	34	9.42	54.4	Rotary	30/02/2016	20	0-1	1-15	Sandy clay/ sandy gravel/ sand
G23	Offsite gas	723934.096	717921.8	78.954	78.943	42	17.24	61.7	Rotary	29/02/2016	20	0-1	1-20	Sandy silty clay gravel/ sand
G24	Offsite gas	723786.073	718048.2	86.831	86.835	22	Dry	66.8	Rotary	25/02/2016	20.5	0-1.5	1.5-20.5	Sandy gravel/ gravel/ sand
G25	Offsite gas	723664.356	718398.6	85.635	86.027	49	Dry	66.0	Rotary	04/02/2016	34	0-1	1-20	Sandy clay/ sandy clayey gravel/ gravel/ sandy gravel/ sand

* Static water level is taken as metres below top of standpipe as measured following construction on 26.04.2016. All groundwater level data provided in Table 4.15.

Table 4.5 - Site 3A: Borehole Installation Details

BH ID	BH type	Northing	Easting	BH Ground level (mAOD)	Standpipe level (mAOD)	Casing Height	Static Water Level *	Water Elevation (mAOD)	Drilling Method	Drill Date	Total depth (mbgl)	Blank pipe interval (mbgl)	Slotted Pipe Interval (mbgl)	Screened Geology
ONSITE														
LG15	Combined gas/leachate	722726.6	718288.1	103.972	104.13	33	6.85	97.3	Cable Percussive & Rotary	19/02/2016	19.0	0-1	1-8	Waste
LG19	Combined gas/leachate	722742.6	718394.3	103.897	104.179	27	14.58	89.6	Cable Percussive & Rotary	18/02/2016	26.0	0-1	1-15	Waste
LG20	Combined gas/leachate	722760.5	718333.9	103.823	104.354	51	Dry	92.4	Rotary	10/02/2016	23.0	0-1	1-12	Waste
MW3	Combined gas/leachate **(25mm)**	722773.2	718362.3	103.105	104.254	115	10.44	93.8	Rotary	03/09/2012	11	0-3	3-11	Waste
	Combined gas/leachate (50mm)						16.55	87.7			18.1	0-14.1	14.1-18.1	Gravel & sand
MW4	Combined gas/leachate	722728.3	718355.6	104.543	105.587	108	7.72	97.9	Rotary	06/09/2012	13.3	0-2	2-10	Waste
OFFSITE														
BH07	Groundwater	722641.5	718220.4	106.107	106.371	38	14.13	92.2	Rotary	09/02/2016	21	0-11	11-21	Sandy clayey gravel/ gravel/ sandy gravelly clay silt
BH09	Groundwater	722746.2	718179.4	97.969	98.140	32	6.96	91.2	Rotary	09/02/2016	12	0-2	2-12	Sandy clayey gravel/ gravelly sand/ sandy gravel
BH10	Groundwater	722791.5	718278.6	99.305	99.505	17	8.73	90.8	Rotary	11/02/2016	14	0-4	4-14	Sand/ sandy gravel/ sandy clayey gravel
G12	Offsite gas	722830.1	718346	98.913	99.016	21	10.75	88.3	Rotary	12/02/2016	14	0-1	1-14	Sandy clayey gravel/ sandy gravel
G14	Offsite gas	722814.8	718240.5	98.624	98.834	25.5	7.94	90.9	Rotary	11/02/2016	14	0-1	1-14	Sandy clay gravel/ wet gravel/ dry silty sandy clay

* Static water level is taken as metres below top of standpipe as measured following construction on 26.04.2016. All groundwater level data provided in Table 4.15.

Table 4.6 - Site 3B: Borehole Installation Details

BH ID	BH type	Northing	Easting	BH Ground level (mAOD)	Standpipe level (mAOD)	Casing Height	Static Water Level*	Water Elevation (mAOD)	Drilling Method	Drill Date	Total depth (mbgl)	Blank pipe interval (mbgl)	Slotted Pipe Interval (mbgl)	Screened Geology
ONSITE														
LG16	Combined gas/leachate	722748.1	718100.4	99.516	99.725	33	3.34	96.4	Rotary	05/02/2016	16.0	0-1	1-2.5	Waste
LG17	Combined gas/leachate	722707.2	718058.9	100.506	100.874	38	3.61	97.3	Cable Percussive	18/02/2016	5.40	0-1	1-3.9	Waste
LG21	Combined gas/leachate	722746.5	718045.7	100.58	100.849	28	Dry	96.8	Cable Percussive	18/02/2016	5.75	0-1	01-Apr	Waste
OFFSITE														
BH08	Groundwater	722752.2	718129.7	98.801	98.950	14	7.62	91.3	Rotary	10/02/2016	13.5	0-1	1-4.5	Sandy gravel/ sand
G15	Offsite gas	722795.2	718080.3	99.172	99.509	35	Dry	93.5	Rotary	08/02/2016	6	0-1	1-6	Gravel
G16	Offsite gas	722652.6	718073.7	100.38	100.762	41	4.35	96.4	Rotary	08/02/2016	6	0-1	1-6	Sandy clay/ sandy clay gravel
G17	Offsite gas	722714.9	718133.7	98.415	98.764	27	Dry	91.3	Rotary	08/02/2016	6	0-1	1-6	Sandy clay/ sandy clay gravel

* Static water level is taken as metres below top of standpipe as measured following construction on 26.04.2016. All groundwater level data provided in Table 4.15.

Table 4.7 - Site 3C: Borehole Installation Details

BH ID	BH type	Northing	Easting	BH Ground level (mAOD)	Standpipe level (mAOD)	Casing Height	Static Water Level*	Water Elevation (mAOD)	Drilling Method	Drill Date	Total depth (mbgl)	Blank pipe interval (mbgl)	Slotted Pipe Interval (mbgl)	Screened Geology
ONSITE														
LG14	Combined gas/leachate	723040.4	718343.2	93.44	93.873	45	5.21	83.7	Cable Percussive & Rotary	16/02/2016	23.0	0-1	1-12	Waste
LG18	Combined gas/leachate	723040	718381.3	92.417	92.854	45	10.21	82.9	Rotary	16/02/2016	22.0	0-1	1-10	Waste
MW2	Combined gas/leachate	723033.7	718362.9	93.398	94.222	92	9.99	89.0	Rotary	31/08/2012	8.1	0-2	2-5	Waste
OFFSITE														
BH06	Groundwater	723028.4	718310.6	95.273	95.396	38	12.78	89.6	Rotary	17/02/2016	14	0-2	2-14	Sandy gravel/ silty sandy gravel
G09	Offsite gas	723094.1	718349.4	93.562	93.875	29	10.18	81.1	Rotary	17/02/2016	14	0-1	1-14	Sandy clay/ gravelly sand/ sandy clay gravel
G11	Offsite gas	722976.7	718343.4	97.207	97.395	32	5.78	87.2	Rotary	18/02/2016	15	0-1	1-15	Sandy clay/ sandy gravel/ sand/ gravel

* Static water level is taken as metres below top of standpipe as measured following construction on 26.04.2016. All groundwater level data provided in Table 4.15.

4.4 SAMPLING PROCEDURES & CHEMICAL ANALYSES

4.4.1 Soils/Waste

4.4.1.1 Trial Pits

All environmental samples taken between 7th and 10th December 2015 were collected in laboratory sample containers by Priority Geotechnical Ltd and shipped to Chemtest (UKAS Accredited) in Newmarket, Suffolk, England for analysis.

The collection and analysis soil/waste samples from the trial pits was based on the requirement to characterise the waste and determine the base of waste where possible.

Environmental samples were obtained from 25 trial pits excavated in December 2015, with samples taken from the waste and soils beneath where encountered. A total of 28 samples were obtained from the 25 trial pits excavated (22 No. from the waste and 6 No. from soils) as outlined in **Table 4.8**.

Table 4.8 - Trial Pits Sampled

Site ID	TP ID
Site 1	TP12,TP13,TP14,TP15
Site 2	TP1,TP2,TP3,TP4,TP5,TP6,TP7,TP8,TP9,TP10,TP11
Site 3A	TP20,TP21,TP22,TP23,TP24
Site 3B	TP25,TP26,TP27,TP28
Site 3C	TP16,TP17,TP18,TP19

4.4.1.2 Boreholes

All environmental samples taken between 8th and 19th February 2016 were collected by RPS staff in laboratory sample containers and shipped to Chemtest (UKAS Accredited) in Newmarket, Suffolk, England.

The collection and analysis of waste/ soil samples from the boreholes was based on the requirement to characterise material encountered during investigative works in terms of environmental contamination. A total of 46 soil/ waste samples (11 from capping material, 25 from waste and 10 from subsoil) were collected from 11 boreholes in February 2016.

Table 4.9 - Boreholes Sampled

Site ID	BH ID
Site 1	LG11,LG13
Site 2	LG2,LG4,LG7,LG10
Site 3A	LG15,LG19
Site 3B	LG17,LG21
Site 3C	LG14

4.4.2 Leachate

Three rounds of leachate sampling and analysis have been undertaken on the Fassaroe site:

- Round 1 (High Groundwater Level) - 15th - 23rd of March 2016;
- Round 2 (Low Groundwater Level) – 30th August – 1st September 2016; and
- Round 3 (High Groundwater Level) - 15th March 2018.

All leachate samples were collected by RPS staff in laboratory supplied sample containers and shipped to ALS Environmental Ltd. (UKAS Accredited), Torrington Avenue, Coventry, CV4 9GU, England.

To minimise cross contamination between sampling locations new sampling equipment was used to collect each discrete sample. Sufficient sample volume could not be recovered from all installed leachate monitoring boreholes. A total of 12 leachate samples were collected from the 5 sites in Round 1, including from historic boreholes MW2 (Site 3C) and MW4 (Site 3A). A total of 11 leachate samples Round 2. A total of 10 leachate samples were taken in Round 3.

Leachate levels measured in each monitoring well during each round is summarised in **Table 4.1**.

Historic leachate monitoring wells are in existence across Sites 1 and 2 however borehole logs were not available therefore the integrity of existing monitoring infrastructure could not be established and were not utilised during the monitoring regime.

Table 4.10 - Leachate Monitoring Boreholes Sampled

Site ID		Round 1 – March 2016 (leachate depth in m)	Round 2 – August 2016 (leachate depth in m)	Round 3 – March 2018 (leachate depth in m)
Site 1	Sampled	LG11 (1-3)	LG11 (0.88)	LG11 (6.29)
	Not Sampled	*LG12 (dry), LG13 (dry)*	*LG12 (dry), LG13 (dry)*	*LG12, LG13*
Site 2	Sampled	LG01 (<1), LG03 (5.0), LG07 (7.0), LG09 (6.7), LG10 (1-3)	LG03 (0.43), LG07 (5.5), LG09 (9.95), LG10 (5.0)	LG07 (10.65), LG09 (12.6), LG10 (4.0)
	Not Sampled	*LG02, LG04, LG05 (dry), LG06 (<40cm of leachate), LG08 (dry)*	*LG01 (dry), LG02 (dry), LG04 (dry), LG05 (dry), LG06 (<40cm leachate), LG08 (dry)*	*LG01, LG02, LG03, LG04, LG05, LG06, LG08)*
Site 3A	Sampled	LG15 (1-3), MW4 (<1), LG19 (<1)	LG15 (1.0), MW4, LG19 (0.5)	LG15 (1.4), MW4, LG19 (4.5)
	Not Sampled	*LG20 (dry), MW3*	*LG20 (dry), MW3*	*LG20, MW3*
Site 3B	Sampled	LG17 (<1)	LG17 (0.33)	LG17 (0.48)
	Not Sampled	*LG16 (<15cm of leachate), LG21 (<20cm of leachate)*	*LG16 (<15cm of leachate), LG21 (<20cm of leachate)*	*LG16, LG21*
Site 3C	Sampled	LG14 (<1), MW2 (<1.0)	LG14 (0.8), MW2 (nk)	LG14 (1.2), MW2 (1.0)
	Not Sampled	*LG18 (dry)*	*LG18 (dry)*	*LG18*

4.4.3 Groundwater

Three rounds of groundwater sampling and analysis have been undertaken on the Fassaroe site:

- Round 1 (High Groundwater Level) - 15th to 23rd of March 2016;
- Round 2 (Low Groundwater Level) – 30th August to 1st September 2016; and
- Round 3 (High Groundwater Level) – 14th and 15th March 2018

Groundwater samples were taken from up to 8 newly installed groundwater monitoring boreholes (including one gas borehole G20), targeting both up-gradient and down-gradient locations where possible. The groundwater locations sampled in each round are summarised in **Table 4.11**. All groundwater samples were taken by RPS staff in laboratory supplied sample containers.

Groundwater samples were obtained following purging a minimum of three well volumes prior to sample collection. To minimise cross contamination between sampling locations dedicated sampling equipment was used to collect each sample. Field parameters were also recorded during sampling, including pH, electrical conductivity, oxidation-reduction potential (ORP) and temperature.

Table 4.11 - Groundwater Monitoring Boreholes Sampled

Site ID	Sampled / Not Sampled *(Position in groundwater flow field)*	Round 1 – March 2016	Round 2 – August 2016	Round 3 – March 2018
Site 1	Sampled (Up gradient)	BH05	BH05	none
	Not Sampled	none	None	*None*
Site 2	Sampled (Up gradient)	G20 (gas well)	G20 (gas well)	G20 (gas well)
	Sampled (Down gradient)	BH01	BH01	BH01
	Not Sampled	*Up gradient: BH03 (dry); BH04(dry); BH11(dry); BH13(dry)*	*Up gradient: BH03 (dry); BH04(dry); BH11(dry); BH13(dry)*	*Up gradient: BH03; BH04; BH11; BH13*
Site 3A	Sampled (Up Gradient / Lateral)	BH07, BH09, BH10(d)	BH07, BH09, BH10(d)	BH07, BH09, BH10(d)
	Not Sampled	none	None	none
Site 3B	Sampled (Down Gradient)	BH08	none	none
	Not Sampled	none	*Down gradient:* BH08(dry)	*Down gradient:* BH08
Site 3C	Sampled (Up-gradient)	BH06	BH06	BH06
	Not Sampled	none	None	none

SITE INVESTIGATION CO-ORDINATES		
ID	X Co-ordinate	Y Co-ordinate
Surface Water Monitoring Locations		
SW1	724137.00	718407.00
SW2	723733.00	718594.00
SW3	723598.00	718560.00
SW4	722837.00	718475.00
SW5	722609.00	718667.00

SITE INVESTIGATION CO-ORDINATES		
ID	X Co-ordinate	Y Co-ordinate
Spring Locations		
Spring 1	724052.00	718436.00
Spring 2	723554.00	718552.00
Spring 3	723365.00	718567.00
Spring 4	723200.00	718486.00
Spring 5	723100.00	718489.00
Spring 6	723038.00	718488.00
Spring 7	722982.00	718476.00
Spring 8	722842.00	718471.00
Spring 9	722780.00	718489.00
Spring 10	722783.12	718446.41

LEGEND

- ESB Overhead (38 kv)
- ESB Overhead (110kv)
- ESB Overhead (220kv)
- ESB Overhead (400kv)
- ESB Overhead (LV)
- ESB Overhead (MV)
- ESB Underground (38kv)
- ESB Underground (MV & LV)
- ESB Underground (Spare)
- Extent of Waste
- Special Areas of Conservation (SAC's)

Site Investigation

- MW1 — Existing Boreholes
- G01 — Gas Monitoring Borehole
- LG01 — Combined Gas/Leachate Monitoring Boreholes (Rotary)
- LG02 — Combined Gas/Leachate Monitoring Boreholes (Cable Percussive)
- Combined Gas/Leachate Monitoring Boreholes (Cable Percussive with Rotary follow on)
- BH01 — Combined Groundwater/Gas Monitoring Boreholes
- SW1 — Surface Water Monitoring Location
- Spring 1 — Spring Location
- SP1 — Spring Sampling Location

Client

Comhairle Contae Chill Mhantáin

General Notes

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(ii) All Levels refer to Ordnance Survey Datum, Malin Head.

(iii) DO NOT SCALE, use figured dimensions only, if in doubt ask.

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No.	Date	Drn. / Chk.	Amendment / Issue	App
F02	04.05.18	DN / KG	COA APPLICATION	CC
F01	May'16	RH / LD	FINAL ISSUE	CC

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Drawn	RH
Checked	LD
Approved	CC
Date	May 2016
Scale	1:2500 @ A1
	1:5000 @ A3
Job No.	MDR1206

Project: **FASSAROE HISTORIC LANDFILL**

Title: PLAN SHOWING MONITORING LOCATIONS

File Ref. MDR1206FG0015F02.dwg | Drg. No. Figure 15 | Rev. F02

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4.4.4 Surface Water

Surface water sampling was completed at 10 locations including 5 springs and 5 targeted locations along the County Brook River (Fassaroe Stream). Monitoring locations of surface water locations are presented in **Figure 15**. The position of the springs relative to the waste bodies is identified in **Table 4.12.**

Table 4.12 – Spring Monitoring Locations

Site ID	Round 1 March 2016	Round 2 August 2016	Round 3 March 2018	Location
Spring 1	SP1	SP1	SP1	60m down gradient of Site 2
Spring 2	SP2	SP2	SP2	85m down gradient of Site 1
Spring 3	-	-	-	85m down gradient of Site 1
Spring 4	SP3	SP3	SP3	140m down gradient of Site 3C
Spring 5	-	-	-	80m down gradient of Site 3C
Spring 6	-	-	-	75m down gradient of Site 3C
Spring 7	-	-	-	75m up gradient of Site 3C
Spring 8	SP5	SP5	SP5	60m down gradient of Site 3A
Spring 9	-	-		55m down gradient of Site 3A
Spring 10	SP4	SP4	SP4	25m down gradient of Site 3A

All surface water grab samples were obtained by placing the dedicated laboratory sampling bottles directly into the surface water body. Samples were obtained from areas where river level and flow was observed to ensure samples were representative. The sample inlet was placed below the surface flow while care was taken not to disturb the base/bed of the surface water body.

Indicative field parameters of electrical conductivity, oxidation-reduction potential (ORP) and temperature were also taken for each sampling locations.

4.4.5 Laboratory Analysis

Surface water, spring water, leachate and groundwater have been analysed for the following suite of parameters:

- Metals (including Al, As, Ba, B, Cd, Ca, Cr, Cu, Fe, Pb, Mn, Hg, Ni, K, Na, V, Zn);
- Biochemical Oxygen Demand (BOD);
- Chemical Oxygen Demand (COD);
- pH;
- Electrical Conductivity (EC);
- Alkalinity as CaCO3
- Ammonical Nitrogen as N
- Chloride as Cl
- Cyanide

- Extractable Petroleum Hydrocarbons
- Fluoride
- Nitrite as N
- Nitrogen, Total Oxidised as N
- Phenols
- Phosphate, Ortho as P
- Polycyclic aromatic Hydrocarbons (PAHs)
- Semi-Volatile Organic Compound (SVOCs)
- Sulphate as SO4
- Total Dissolved Solids
- Total Suspended Solids
- Total Organic Carbon
- Volatile Organic Compounds (VOCs)

In addition during the second monitoring round in August 2016, leachate and groundwater samples were also scheduled for the analysis of dissolved gases that include: methane, oxygen and carbon dioxide.

All surface water, spring water, leachate and groundwater samples were collected by RPS staff in laboratory supplied sample containers and shipped in cooler boxes including ice packs on the same day. The following UKAS Accredited laboratories were used for analysis:

- Round 1 (March 2016) – ALS Environmental Ltd. (Torrington Avenue, Coventry, England, UK);
- Round 2 (August 2016) – Chemtest Ltd. (Depot Road, Newmarket, CB8 0AL, England, UK); and
- Round 3 (March 2018) – ALS Environmental Ltd. (Torrington Avenue, Coventry, England, UK);

Confirmation of receipt was received the following day that all three batches of samples arrived in good condition.

4.4.6 Landfill Gas

Historical guidance generally suggest that a minimum of 6 to 10 readings are required to make decisions regarding a gas regime (Harries et al 1995 and Environment Agency et al 2000) however of utmost importance is that the monitoring period covers the 'worst case' scenario which occurs during falling atmospheric pressure and particular weather events including rainfall, frost and dry weather. Gas sampling has been undertaken in accordance with published guidance *Evaluation Of Development Proposals On Sites Where Methane And Carbon Dioxide Are Present* (Rpt. Ed. No. 4), which recommends that gas monitoring covers varying climatic conditions (including falling atmospheric pressure and after heavy rainfall)in accordance with CIRIA Guidance (R150).

A total of eighteen gas monitoring rounds have been undertaken on the Fassaroe site and includes the following:

- 8 No. weekly gas monitoring rounds between 7th March and 27th April 2016; and

- 10 No. monthly gas monitoring round (May 2016 to February 2017).

The monitoring undertaken generally conforms to the recommendations of Wilson et al (2005) and CIRIA Guidance C665 present typical/idealised periods and frequencies of monitoring, which suggest a 12-24 period of monitoring on a fortnightly or monthly frequency for sites with a high sensitivity of development (i.e. houses with gardens) and a high to very high source potential (i.e. landfill gas).

The gas monitoring network is summarised in **Table 4.13**. The majority of these boreholes were monitored in each of each of the 18 No. monitoring rounds (see gas monitoring sheets provided in Appendix J)

Table 4.13 - Gas Monitoring Boreholes

Site ID		BH ID
Site 1	Onsite	LG11,LG12,LG13
	Offsite	BH05,G06,G07,G08,G10,G18,G19
Site 2	Onsite	LG01,LG02,LG03,LG04,LG05,LG06, LG07,LG08,LG09,LG10
	Offsite	BH01,BH03,BH04,BH11,BH13,G01,G02,G03,G04,G05,G13,G20,G21,G22,G23,G24,G25
Site 3A	Onsite	LG15,LG19,LG20,MW3,MW4
	Offsite	BH07,BH09,BH10,G12,G14
Site 3B	Onsite	LG16,LG17,LG21
	Offsite	BH08,G15,G16,G17
Site 3C	Onsite	LG14,LG18,MW2
	Offsite	BH06,G09,G11

4.4.7 Investigation Limitations

All new monitoring borehole locations were installed on lands within the ownership of Cosgrave Developments which combined with the proximity to the SAC and access/slope stability constraints restricted the siting and availability of down gradient groundwater monitoring locations although this is mitigated by the location of spring sampling locations within the river valley.

Ownership and access constraints combined with the presence of existing services and associated wayleaves and hazard working zones also restricted the siting of up-gradient groundwater monitoring locations.

The thickness of the gravels and depth to bedrock was not established at any location during the drilling programme as it extended below the maximum reach of the drilling rig (30m).

Sufficient sample volume could not be recovered from all installed leachate monitoring boreholes.

Limitations associated with laboratory analysis are summarised in **Appendix E.**

4.5 OBSERVED GROUND CONDITIONS

4.5.1 Made Ground

Waste visually identified during the excavation of trial pits and borehole drilling was generally consistent across all five sites with the exception of Site 1 which recorded a high proportion of C&D waste. A summary of the depth and nature of waste encountered is presented in **Table 4.14**. For a full list of waste encountered see trial pit and borehole logs in the Priority Geotechnical Factual Report included in **Appendix D**.

Table 4.14 - Maximum Depth of Waste

Site ID	Maximum Depth of Waste (mbgl) (from BHs)	Location of Maximum Depth of Waste (BH ID)	Geophysical Interpretation of Waste Depth (mbgl)	Waste Type
Site 1	14.7	LG13	c. 16	Mixed municipal and C&D
Site2	19	LG03	c. 26	Mixed municipal
Site 3A	16	LG19	c. 20	Mixed municipal
Site3B	3.7	LG17 & LG21	c. 8.5	Mixed municipal
Site3C	12.5	LG14	c. 20.5	Mixed municipal

Waste encountered at Site 2, Site 3A, Site 3B and Site 3C was generally composed of mixed municipal waste that comprises plastic, paper, textiles, glass, timber, metals and glass. Visual characterisation of waste within Site 1 indicated a predominantly C&D waste that comprises concrete, bricks, rebar, tarmac and timber. Large plastic syringes assumed to be of agricultural origin were noted in TP13.

Evidence of waste dating back to the 1970s was noted during the trial pitting in Site 1, 1980s in Site 2 and 1990s in Sites 3B and 3C.

Waste was encountered in all combined gas/leachate monitoring boreholes (LG01-LG21) with waste varying in depth from 13-15mgbl (Site 1); 6-19mbgl (Site 2); 9-16mbgl (Site 3A); 4-4.5mgbl (Site 3B) and 11-12.5mbgl (Site 3C).

No waste was noted in TP05 (Site 1) and TP27 (Site 3B) and potential natural ground was noted in TP15 (at 3mbgl).

Malodours were detected across all five sites. There was slight olfactory evidence of hydrocarbons noted in TP13 in site 1.

4.5.2 Natural Ground

Undisturbed natural ground was encountered in TP05 (Site 1) and TP27 (Site 3B) which comprised topsoil (0.4-0.5m) underlain by slightly sandy, slightly gravelly SILT and slightly sandy gravelly CLAY at Site 1 and sandy GRAVEL and gravelly SAND at Site 3B.

The area is underlain by a thick sequence of up to 30m of unsaturated sand and gravels. The waste is overlain by a clay cap which is approximately 1 to 2m thick. The condition of the cap varies between the sites but is considered generally to be moderately poor at the sites.

The thickness of the sand and gravel unit was not established during the drilling programme as it extended below the maximum reach of the drilling rig on site (30m below ground level). However, bedrock outcrop was noted in the river bed to the north of the Site 1 at the County Brook River (Fassaroe Stream) at an elevation of 55maod.

See borehole logs included in Priority Geotechnical's Factual Report (Appendix D) for detailed depths and descriptions of the unconsolidated sand and gravel deposits.

4.5.3 Land Stability

Evidence of landslide/slip material is suggested from the geophysical survey on the northern/north eastern slopes of Sites 2, 3A and 3C. Due to access and slope stability constraints, the installation of directly down-gradient groundwater boreholes was unfeasible with the exception of BH1 at Site 2 and BH8 at Site 3B.

Site surveys were undertaken by Atkins Consulting Engineers for the purposes of a recent planning application (Wicklow County Council Reg. Ref. 16/999) prepared in respect of development lands at Fassaroe (including landfill Site 1, Site 2 and Site 3B). The site surveys identified four areas where landslips have previously occurred or where they might potentially occur in the future to the north of Site 2. Site visits for geophysical surveys undertaken at all landfill sites identified areas of possible previous slippage on the northern sides of Sites 3A and 3C also. Slope stabilisation works will be required in these areas. This will involve physical works within /adjacent to the edge of the Ballyman Glen SAC which are considered in the NIS prepared to accompany the Certificate of Authorisation application by Wicklow County Council.

4.5.4 Surface Water Drainage System

Observations made during the intrusive investigations and subsequent monitoring rounds have confirmed the absence of any formal surface water drainage system in the vicinity of the five landfill sites. This precludes a direct connection with the Ballyman Glen SAC and/or County Brook River therein.

4.5.5 Groundwater Observations

Groundwater was identified in 17 boreholes (both groundwater and gas monitoring boreholes) completed in the sands and gravel deposits, both onsite and offsite of the former landfills in March monitoring rounds (2016). 19 boreholes, most of which were gas monitoring boreholes, were dry.

Groundwater levels have been recorded during all 18 No. gas monitoring rounds and on a single occasion for Round 2 (August 2016) and Round 3 (March 2018). A summary of groundwater water levels is presented in **Table 4.16**.

The groundwater level dataset (29th of March 2016) demonstrates that the flow direction in all sites does follow topography being orientated towards the river to the north and northeast. The hydraulic gradient steepens towards the valleys and is flatter on the plateau. As a result there is a steeper hydraulic gradient underlying Sites 1 and 2 than Sites 3A, B and C.

4.5.6 Leachate Observations

In the absence of surface water drainage in the vicinity of the landfill sites there is no evidence of leachate breakout, although some evidence of vegetation die back has been recorded around Site 2 and Site 3B which is attributed to the generation of landfill gas.

There are no instances of leachate emergences at the foot of the waste body that directly link via overland drainage to the down-gradient stream, although at Site 2 there is possible seepage from exposed waste at a collapsed river bank. There are a number of spring flows emerging as diffuse seepages with some showing ochre staining, particularly those found close to Site 2 (Spring SP1) and Site 3A (Spring SP4). Spring monitoring has confirmed visual evidence of contamination at several points of groundwater emergence with the Ballyman Glen SAC principally in the form of orange / red ochre deposition and/or sheening. Visual observations are summarised in **Table 4.15.**

Table 4.15 – Field Observation for Springs

Spring Ref.	Round 1 (March 2016)	Round 2 (August 2016)	Round 3 (March 2016)
SP1	Ochre staining and hydrocarbon sheening	Ochre, red discoloration & hydrocarbon sheen	Tufa Deposition
SP2	Not recorded	Calcite Deposits / Tufa	Tufa Deposition
SP3	Not recorded	Calcite Deposits / Tufa	Tufa Deposition
SP4	Not recorded	Ochre Deposition.	Ochre Deposition.
SP5	Not recorded	Calcite Deposits / Tufa	Tufa Deposition

Table 4.16 – Summary of water levels for March and April 2016

BH ID	Type	Site	Installation depth (mbgl)	Standpipe Level (mOD)	15/03/2016		22/03/2016		29/03/2016		05/04/2016		14/04/2016		20/04/2016		26/04/2016					
					mbtoc	mAOD	mbtoc	mAOD	mbtoc	mAOD	mbtoc	mAOD	mbtoc	mAOD	mbtoc	mAOD	mbtoc	mAOD				
G19	Gas	1	14.0	98.39	7.94	90.45	7.97	90.42	dry	<84.4	8.03	90.36	7.93	90.46	7.9	90.49	7.92	90.47				
G08	Gas	1	14.0	94.6	dry	<80.6	dry	<80.6	dry	<80.6	dry	<80.6	dry	<80.6	dry	<80.6	dry	<80.6				
G07	Gas	1	14.0	93.236	dry	na	dry	na	dry	<79.2	dry	<79.2	19.99	73.246	dry	73.246	dry	73.246				
BH05	GW	1	29.0	96.32	20.43	75.89	20.07	76.25	20.1	76.22	20.06	76.26	dry	76.26	19.95	76.37	20	76.32				
G18	Gas	1	14.0	93.83	dry	<79.8	dry	<79.8	dry	<79.8	dry	<79.8	dry	<79.8	dry	<79.8	dry	<79.8				
G06	Gas	1	11.0	91.303	dry	<80.3	dry	<80.3	dry	<80.3	dry	<80.3	dry	<80.3	dry	<80.3	dry	<80.3				
BH04	GW	2	25.5	84.53	dry	<59.9	dry	<59.9	dry	<59.9	dry	<59.9	dry	<59.9	dry	<59.9	dry	<59.9				
G04	Gas	2	20.0	85.97	8.76	77.21	9.05	76.92	9.48	76.49	7.75	78.22	2.19	83.78	6.46	79.51	8.23	77.74				
G05	Gas	2	20.0	86.86	16.06	70.8	16.16	70.7	16.23	70.63	16.36	70.5	16.45	70.41	16.46	70.4	16.46	70.4				
G25	Gas	2	20.0	86.027	dry	<66.86	dry	<66.86	dry	<66.86	dry	<66.86	dry	<66.86	dry	<66.86	dry	<66.86				
BH13	GW	2	19.5	87.99	dry	<68.5	dry	<68.5	dry	<68.5	dry	<68.5	dry	<68.5	dry	<68.5	dry	<68.5				
BH01	GW	2	21.0	79.46	14.38	65.08	14.14	65.32	14.49	64.97	14.65	64.81	14.71	64.75	14.86	64.6	14.82	64.64				
G03	Gas	2	19.5	69.63	dry	<50.1	dry	<50.1	dry	<50.1	dry	<50.1	dry	<50.1	dry	<50.1	dry	<50.1				
G02	Gas	2	19.5	72.64	dry	<53.1	dry	<53.1	dry	<53.1	dry	<53.1	dry	<53.1	dry	<53.1	dry	<53.1				
G13	Gas	2	20.0	99.87	dry	<79.9	dry	<79.9	dry	<79.9	dry	<79.9	dry	<79.9	dry	<79.9	dry	<79.9				
G22	Gas	2	20.0	63.85					~9.38	54.47			9.27	54.58	9.38	54.47	9.42	54.43				
G23	Gas	2	20.0	78.94					dry	<58.94	17	61.94	17.05	61.89	dry	61.89	17.24	61.7				
G24	Gas	2	20.0	86.84	dry	<66.8	dry	<66.8	dry	<66.8	dry	<66.8	dry	<66.8	dry	<66.8	dry	<66.8				
BH03	GW	2	19.5	78.8	dry	<66.8	dry	<66.8	dry	<66.8	dry	<66.8	dry	<66.8	dry	<66.8	dry	<66.8				
G20	Gas	2	20.0	85.826	14.43	71.396	14.41	71.416	14.45	71.376	14.49	71.336	14.53	71.336	16.57	69.256	14.57	71.256				
G21	Gas	2	17.0	87	dry	<70.0	dry	<70.0	dry	<70.0	dry	<70.0	dry	<70.0	dry	<70.0	dry	<70.0				
G01	Gas	2	17.5	85.4	dry	<67.9	dry	<67.9	dry	<67.9	dry	<67.9	dry	<67.9	dry	<67.9	dry	<67.9				
BH11	GW	2	33.0	82.83	dry	<49.8	dry	<49.8	dry	<49.8	dry	<49.8	dry	<49.8	dry	<49.8	dry	<49.8				
G10	Gas	2	18.0	98.95	9.22	89.73	9.24	89.71	9.27	89.68	9.32	89.63	9.23	89.72	9.24	89.71	9.26	89.69				
G12	Gas	3A	14.0	99.02	10.13	88.89	10.29	88.73	10.44	88.58	10.55	88.47	10.64	88.38	10.73	88.29	10.75	88.27				
BH10	GW	3A	14.0	99.51	8.43	91.08	8.5	91.01	8.61	90.9	8.63	90.88	8.71	90.8	8.7	90.81	8.73	90.78				
G14	Gas	3A	14.0	98.83	7.53	91.3	7.63	91.2	7.75	91.08	7.81	91.02	7.87	90.96	7.91	90.92	7.94	90.89				
BH09	GW	3B	12.0	98.14	6.43	91.71	6.57	91.57	6.75	91.39	6.85	91.29	6.88	91.26	6.94	91.2	6.96	91.18				
G17	Gas	3B	6.0	98.76	dry	<92.8	dry	<92.8	dry	<92.8	dry	<92.8	4.4	94.36	dry	94.36	dry	94.36				
BH08	GW	3B	13.5	98.95	6.61	92.34	6.92	92.03	7.09	91.86	7.26	91.69	7.35	91.6	7.47	91.48	7.62	91.33				
G15	Gas	3B	6.0	99.51	5.41	94.1	dry	<93.5	dry	<93.5	dry	<93.5	dry	<93.5	dry	<93.5	dry	<93.5				
G16	Gas	3B	6.0	100.76	4.08	96.68	4.11	96.65	4.18	96.58	4.27	96.49	4.27	96.49	4.31	96.45	4.35	96.41				
BH07	GW	3B	21.0	106.37	13.71	92.66	13.76	92.61	13.81	92.56	13.88	92.49	13.97	92.4	14.09	92.28	14.13	92.24				
G11	Gas	3C	15.0	97.4	9.83	87.57	9.87	87.53	10	87.4	10.05	87.35	10.13	87.27	10.17	87.23	10.18	87.22				
BH06	GW	3C	14.0	95.4	5.53	89.87	5.57	89.83	5.65	89.75	5.74	89.66	5.7	89.7	5.75	89.65	5.78	89.62				
G09	Gas	3C	14.0	98.14	12.3	85.84	12.38	85.76	12.47	85.67	12.6	85.54	12.65	85.49	12.74	85.4	12.78	85.36				

Table 4.16 – Summary of water levels for March and April 2016 (Continued)

BH ID	Type	Site	Installation depth (mbgl)	Standpipe Level (mOD)																	
G19	Gas	1	14.0	98.39																	
G08	Gas	1	14.0	94.6																	
G07	Gas	1	14.0	93.236																	
BH05	GW	1	29.0	96.32																	
G18	Gas	1	14.0	93.83																	
G06	Gas	1	11.0	91.303																	
BH04	GW	2	25.5	84.53																	
G04	Gas	2	20.0	85.97																	
G05	Gas	2	20.0	86.86																	
G25	Gas	2	20.0	86.027																	
BH13	GW	2	19.5	87.99																	
BH01	GW	2	21.0	79.46																	
G03	Gas	2	19.5	69.63																	
G02	Gas	2	19.5	72.64																	
G13	Gas	2	20.0	99.87																	
G22	Gas	2	20.0	63.85																	
G23	Gas	2	20.0	78.94																	
G24	Gas	2	20.0	86.84																	
BH03	GW	2	19.5	78.8																	
G20	Gas	2	20.0	85.826																	
G21	Gas	2	17.0	87																	
G01	Gas	2	17.5	85.4																	
BH11	GW	2	33.0	82.83																	
G10	Gas	2	18.0	98.95																	
G12	Gas	3A	14.0	99.02																	
BH10	GW	3A	14.0	99.51																	
G14	Gas	3A	14.0	98.83																	
BH09	GW	3B	12.0	98.14																	
G17	Gas	3B	6.0	98.76																	
BH08	GW	3B	13.5	98.95																	
G15	Gas	3B	6.0	99.51																	
G16	Gas	3B	6.0	100.76																	
BH07	GW	3B	21.0	106.37																	
G11	Gas	3C	15.0	97.4																	
BH06	GW	3C	14.0	95.4																	
G09	Gas	3C	14.0	98.14																	

4.6 RESULTS OF LABORATORY ANALYSIS

4.6.1 Waste Characterisation

Of the 28 No. trial pits excavated and 21 No. combined gas/leachate boreholes installed across the five sites, waste was encountered at all locations with the exception of TP05 (Site 1) and TP27 (Site 3B).

EU Council Decision 2003/33/EC (*establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC*) establishes criteria and procedures for the testing and classification of waste for acceptance at inert, non-hazardous and hazardous landfills throughout Europe.

Analysis of waste acceptance criteria (WAC) was conducted on all waste and subsoil samples recovered from the trial pits and exceedances of the inert, non-hazardous and hazardous waste acceptance criteria are summarised below.

A detailed summary of the waste characterisation analysis is presented in **Appendix F**. The result of the assessment of the nature of the waste and its classification is presented below in Table 4.16.

4.6.1.1 Site 1

Elevated concentrations of pH, total organic carbon, antimony, total PCBs (7 congeners) and sulphate were noted in Site 1.

pH ranged from 7.4 to 8.4 with the WAC for non-hazardous landfills (>6).

Exceedances of Total Organic Carbon (TP13 and TP15) were noted above the WAC limit for inert landfills.

There are two elevated concentrations of Antimony 0.08mg/kg at TP15 (exceeding the inert limit of 0.06mg/kg) and 1.0mg/kg at TP13 (exceeding the non-hazardous limit of 0.7mg/kg).

One sample exceeds the inert limit for sulphate of 1000mg/kg. The maximum concentration of 2,700mg/kg was recorded in TP14.

4.6.1.2 Site 2

Elevated concentrations of pH, TOC, antimony, sulphate, molybdenum and Total Dissolved Solids (TDS) were noted in Site 2.

pH ranged from 8.0 to 8.7 with the WAC for non-hazardous landfills (>6).

Exceedances of Total Organic Carbon (TP03 and TP06) were noted above the WAC limit for inert landfills.

Antimony concentrations exceed the WAC limit for inert landfills at TP02 and TP07.

Sulphate concentrations exceeded the WAC limit for inert landfills at TP01, TP03 and TP08 with a maximum concentration of 5,100mg/kg being recorded at TP03.

Exceedances of Molybdenum above the WAC for inert landfills were recorded at TP01, TP02 and TP07 with a maximum concentration of 0.55mg/kg noted in TP02.

TP02 and TP08 recorded exceedances of TDS above the WAC for inert landfills (4,000mg/kg) with a maximum concentration of 6,500mg/kg recorded at TP03.

4.6.1.3 Site 3A

Elevated concentrations of pH, TOC, antimony, sulphate, molybdenum, TDS, Loss on Ignition (LoI), lead and TPH were noted at Site 3A.

All five samples exceeded the WAC for non-hazardous landfills for pH with a maximum concentration of 8.7 recorded at TP24.

TOC exceeded the WAC for inert landfills (3%) at TP23 (4.5%).

Exceedances of antimony above the WAC for inert landfills were noted at TP21 and TP23 with the maximum concentration recorded at TP23 (0.42mg/kg).

One sample exceeded the inert limit for sulphate. This occurred at TP24 with a reading of 3,000mg/kg at a depth of 2mbgl.

The WAC for inert landfills was exceed for molybdenum (TP21 – 0.71mg/kg), TDS (TP24 – 5,300mg/kg), lead (TP23 – 0.59mg/kg) and TPH (TP24 – 1,200mg/kg).

LoI exceeded the WAC for non-hazardous landfills at TP23 (13mg/kg).

4.6.1.4 Site 3B

Elevated concentrations of pH, TOC, antimony, molybdenum and TPH were noted at Site 3B.

All four samples (TP25, TP26, TP27 and TP28) exceeded the WAC for non-hazardous landfills with a maximum concentration of 8.7 noted at TP27.

The WAC for inert landfills was exceeded for TOC (TP25 – 3.2%), antimony (TP25 and TP26), molybdenum (TP26 – 0.5mg/kg) and TPH (Tp25 and TP26).

4.6.1.5 Site 3C

Elevated concentrations of pH, TOC, antimony, molybdenum, TDS, lead, TPH, mercury, nickel, selenium and chloride were recorded at Site 3C.

All four samples (TP16, TP17, TP18 and TP19) exceeded the WAC for non-hazardous landfills for pH with a maximum concentration of 8.2 recorded at TP19.

The WAC for inert landfills was exceeded for TOC (TP17 – 3.1%), antimony (TP17 and TP19), molybdenum (TP16 and TP18), TDS (TP18 – 15,000mg/kg), lead (TP18 – 1.8 mg/kg), TPH (TP17 and TP18), mercury (TP18- 0.028mg/kg), nickel (TP18 – 1.3mg/kg), selenium (TP18 – 0.13mg/kg) and chloride (TP18 – 3,000mg/kg).

The WAC for hazardous landfills was exceeded for TOC at TP18 (8.6mg/kg) with the WAC for non-hazardous landfills also being exceed at TP18 for antimony (0.88mg/kg).

Table 4.17 - Summary Analysis Results from WAC samples

Contaminant	No. of samples	No. of Exceedances	Range (mg/kg)	No. of samples below detection limit	WAC (mg/kg)		No. of samples exceeding WAC	Site ID	Location and Depth (mbgl)
pH	28	5	7.4 - 8.7	0	Non- hazardous	>6	28	Site 1	TP12 (2.5); TP13 (2.5); TP14 (3); TP15 (2); TP15 (4.5)
		10						Site 2	TP1 (2.7); TP2 (3.5); TP3 (2); TP3 (4.2); TP5 (3); TP6 (2); TP7 (3); TP8 (2); TP10 (2.5); TP10 (4)
		5						Site 3A	TP20 (4); TP21 (3); TP22 (1.5); TP23 (2.5); TP24 (2)
		4						Site 3B	TP25 (2.5); TP26 (2.5); TP27 (2.5); TP28 (2)
		4						Site 3C	TP16 (3); TP17 (2.5); TP18 (1.5); TP19 (2)
Total Organic Carbon	28	5	<0.2 - 8.6	20	Inert	3	7	Site 1	TP13 (2.5); TP15 (2)
		10						Site 2	TP3 (2); TP6 (2)
		5						Site 3A	TP23 (2.5)
		4						Site 3B	TP25 (2.5)
		4						Site 3C	TP17 (2.5)
		4		27	Hazardous	6	1	Site 3C	TP18 (1.5)
Antimony	28	5	<0.01 - 1.0	17	Inert	0.06	9	Site 1	TP15 (4.5)
		10						Site 2	TP2 (3.5); TP7 (3)
		5						Site 3A	TP21 (3); TP23 (2.5)
		4						Site 3B	TP25 (2.5); TP26 (2.5)
		4						Site 3C	TP17 (2.5); TP19 (2.5)
		5		26	Non- hazardous	0.7	2	Site 1	TP13 (2.5)
		4						Site 3C	TP18 (1.5)
Total PCBs (7 Congeners)	28	5	<0.10 - 1.9	27	Inert	1	1	Site 1	TP14 (3)

Contaminant	No. of samples	No. of Exceedances	Range (mg/kg)	No. of samples below detection limit	WAC (mg/kg)		No. of samples exceeding WAC	Site ID	Location and Depth (mbgl)
Sulphate	28	5	10 - 5900	23	Inert	1000	5	Site 1	TP14 (3)
		10						Site 2	TP1 (2.7); TP3 (2); TP8 (2)
		5						Site 3A	TP24 (2)
Molybdenum	28	10	<0.05 - 0.71	21	Inert	0.5	7	Site 2	TP1 (2.7); TP2 (3.5); TP7 (3)
		5						Site 3A	TP21 (3)
		4						Site 3B	TP26 (2.5)
		4						Site 3C	TP16 (3); TP18 (1.5)
Total Dissolved Solids	28	10	610 - 15,000	23	Inert	4000	4	Site 2	TP3 (2); TP8 (2)
		5						Site 3A	TP24 (2)
		4						Site 3C	TP18 (1.5)
Loss on Ignition	28	5	0.93 - 13	27	Hazardous	10	1	Site 3A	TP23 (2.5)
Lead	28	5	<0.010 - 1.8	26	Inert	0.5	2	Site 3A	TP23 (2.5)
		4						Site 3C	TP18 (1.5)
TPH Total WAC (Mineral Oil)	28	5	<10 - 1,200	23	Inert	500	5	Site 3A	TP24 (2)
		4						Site 3B	TP25 (2.5); TP26 (2.5)
		4						Site 3C	TP17 (2.5); TP18 (1.5)
Mercury	28	4	<0.005 - 0.028	27	Inert	0.01	1	Site 3C	TP18 (1.5)
Nickel	28	4	<0.05 - 1.3	27	Inert	0.4	1	Site 3C	TP18 (1.5)
Selenium	28	4	<0.01 - 0.13	27	Inert	0.1	1	Site 3C	TP18 (1.5)
Chloride	28	4	<10 - 3,000	27	Inert	800	1	Site 3C	TP18 (1.5)

4.6.2 Leachate Characterisation

Field measurements of electrical conductivity, temperature, total dissolved solids and oxidation-reduction potential (ORP) for leachate samples taken at each of the sites are used as indicators of generic leachate properties.

Waste leachate concentrations obtained from chemical laboratory analysis have been compared to the most recent water quality criteria for groundwater as presented in European Union Environmental Objectives (Groundwater) (Amendment) Regulations 2016 (Statutory Instruments No. 366 of 2016) (GW Regs 2016). Other possible water quality assessment criteria include: Interim Guideline Values (IGV) for Groundwater as presented in EPA interim report "Towards Setting Guideline Values for the Protection of Groundwater in Ireland" 2002; and Groundwater Threshold Values (GTV) in the Groundwater Regulations (SI 9 of 2010). All the above water quality assessments are applicable to groundwater and are therefore extremely conservative when applied to leachate data. See **Appendix G** for tabulated summary of leachate quality results for Sites 1-3C.

Table 4.18 – Leachate Quality Comparison with Typical Data for Methanogenic Landfills

Parameter	Min	Mean	Max	Site 1	Site 2	Site 3A	Site 3B	Site 3C
pH-value	6.8	**7.52**	8.2	6.9	7.0	6.9	6.9	6.8
EC (µS/cm)	5,990	**11,502**	19,300	1,680	5,407	6,277	11,600	7,253
alkalinity	3,000	**5,376**	9,130	1,880	2,332	3,387	4,640	3,525
COD	622	**2,307**	8,000	2,790	707	1852	8,140	3,544
BOD5	97	**374**	1,770	188	64	234	4,851	1,727
TOC	184	**733**	2,270	22	248	133	2,500	922
Ammoniacal-N	283	**889**	4,040	32	342	385	893	525
nitrate-N	0.2	**0.86**	2.1	0.35	0.35	0.50	0.35	0.35
nitrite-N	0.005	**0.17**	1.3	0.04	0.04	0.04	0.04	0.04
Sulphate	2.5	**67**	322	119	68	6	2	2
phosphate	0.3	**4.3**	18.4	0.3	2.8	1.1	0.3	0.6
Chloride	570	**2,074**	4,710	57	706	703	978	679
Sodium	474	**1,480**	3,650	14	285	428	566	333
potassium	100	**854**	1,580	20	188	254	567	297
Calcium	23	**151**	501	954	162	480	336	461
chromium	0.015	**0.09**	0.56	0.13	0.03	0.07	0.04	0.06
manganese	0.04	**0.46**	3.59	10.20	1.91	6.87	10.30	8.61
Iron	1.6	**27.4**	160	190	134	101	87	120
Nickel	0.015	**0.17**	0.6	0.20	0.07	0.20	0.20	0.21
Copper	0.01	**0.13**	0.62	0.14	0.08	0.12	0.02	0.07
Zinc	0.03	**1.14**	6.7	9.97	0.43	5.04	0.83	2.97
Arsenic	0.0005	**0.034**	0.485	0.17	0.15	0.11	0.49	0.89
Cadmium	0.005	**0.015**	0.08	0.02	0.003	0.009	0.001	0.009
Mercury	<0.00005	**0.0002**	0.0008	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Lead	0.02	**0.2**	1.9	2.46	0.19	1.07	0.12	0.62

Results in mg/l except pH-value and conductivity (µS/cm)

The average leachate quality for each site in Round 1 (March 2016) has been screened against the typical values for methanogenic leachate from large landfills as presented in the EPA Landfill Manual (Table 7.2) as summarised in **Table 4.18**. The data screening is generally consistent with methanogenic conditions in landfill sites, most notably SA, SB and 3C. Notable features of the dataset include elevated arsenic and manganese in the landfill sites and generally elevated metals in Site 1.

4.6.2.1 Site 1

Field parameters for the leachate samples taken from Site 1 during each monitoring round are summarised in Table 4.19.

Table 4.19 – Site 1 Field Parameters for Leachate

Borehole ID	Round	Ph	Temp (deg C)	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
LG11	1	-	12.6	1,924	964	-92	black/ dark brown turbid sample, foul odour, traces of hydrocarbons
	2	7.01	15.7	2,473	-	-	Dark grey, very turbid, slight foul odour
	3	5.86	11.5	2,100	1,050	-180	-

Leachate samples from Site 1 showed concentrations above relevant water quality assessment criteria (i.e. GW Regs 2016, IGV or GTV) for the parameters listed in **Table 4.20**.

Table 4.20 – Leachate Sample LG11 Exceedances

Round 1	Round 2	Round 3
Inorganics		
Electrical Conductivity	Electrical Conductivity	Electrical Conductivity
Total Dissolved Solids	Total Dissolved Solids	Total Dissolved Solids
Ammoniacal Nitrogen	Ammoniacal Nitrogen, Nitrite	Ammoniacal Nitrogen, Orthophosphate
Chloride	Chloride	Chloride
Calcium		Calcium
Metals* including: Aluminium, Arsenic, Cadmium, Copper, Iron, Lead, Nickel, Zinc	Metals** including: Chromium, Iron	Metals* including: Aluminium, Arsenic, Iron, Lead, Zinc
Manganese, Potassium	Manganese, Potassium	Manganese, Potassium
Barium	Barium, Boron	Barium
Cyanide		Sulphate
Organics		
Total Polycyclic Aromatic Hydrocarbons (PAHs) including Fluoranthene, Benzo (a) pyrene, Benzo (b) fluoranthene.	None	Total Polycyclic Aromatic Hydrocarbons (PAHs
Total Petroleum Hydrocarbons		Benzene***

* Metals measured as totals; ** Metal measured as dissolved. *** TPH not measured in R3;

A small number of trace organics were detected above the laboratory Limit of Detection (LoD) for which there are currently no water quality criterial appropriate for a screening exercise.

4.6.2.2 Site 2

Field parameters for the leachate samples taken from Site 2 during each monitoring round are summarised in **Table 4.20.** It is evident that leachate from Site 2 is typically characterised by high EC, TDS and low ORP, indicating a concentrated leachate and strongly reducing conditions.

Table 4.21 – Site 2 Field Parameters for Leachate

Borehole ID	Round	pH	Temp (deg C)	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
LG01	R1	-	9.9	938	472	-8.4	black colour, foul odour
	R2	-	-	-	-	-	dry
	R3	-	-	-	-	-	Dry
LG03	R1	-	10.5	>3,999	>2,000	-77	brown turbid, foamy; foul odour
	R2	6.99	15.3	>3,999	-	-	-
	R3	-	-	-	-	-	Not enough water to purge / bail
LG07	R1	-	11.7	>3,999	>2,000	-127	dark brown, turbid sample, foul odour
	R2	7.18	15	>3,999	-	-	Brown/grey, speckles of hydrocarbon sheen, strong foul odour.
	R3	5.34	11.2	>3,999	>2,000	-122	Dark grey/black, turbid with flecks of hydrocarbon. Strongly reducing smell & hydrocarbon odour.
LG09	R1	-	11.6	>3,999	>2,000	-113	red/brown, turbid sample
	R2	7.19	14.2	>3,999	-	-	Dark brown, speckles of hydrocarbon sheen, strong foul odour.
	R3	5.72	11.7	>3,999	>2,000	-140	-
LG10	R1	-	13.2	>3,999	>2,000	-127	light brown, cloudy sample
	R2	7.17	15	>3,999	-	-	Dark brown, speckles of hydrocarbon sheen, strong foul odour.
	R3	4.17	10	1,908	954	-86	Dark grey/black, turbid with flecks of hydrocarbon. Strongly reducing smell & hydrocarbon odour

Leachate samples at Site 2 showed concentrations above relevant water quality assessment criteria (i.e. GW Regs 2016, IGV or GTV) for the parameters listed in **Table 4.22**.

Table 4.22 – Site 2 Leachate Quality Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
Electrical Conductivity, Total Dissolved Solids	Electrical Conductivity, Total Dissolved Solids	Electrical Conductivity, Total Dissolved Solids
Ammoniacal Nitrogen, Orthophosphate	Ammoniacal Nitrogen, Orthophosphate	Ammoniacal Nitrogen, Total phosphate
Chloride	Chloride	Chloride
Metals* including: Aluminium, Arsenic, Copper, Iron, Lead, Nickel, Zinc	Metals** including: Arsenic, Chromium, Copper, Iron, Mercury, Nickel	Metals* including: Aluminium, Arsenic, Copper, Iron, Lead, Nickel, Zinc
Manganese, Potassium, Sodium	Manganese, Potassium, Sodium	Manganese, Potassium, Sodium
Sodium	Sodium	Sodium
Barium, Boron	Barium, Boron	Barium, Boron
Organics		
Total PAHs including Naphthalene		Total PAHs including Naphthalene
Total Petroleum Hydrocarbons	Total Petroleum Hydrocarbons	Benzene***

* Metals measured as totals; ** Metal measured as dissolved; *** TPH not measured in R3.

A small number of other trace organics were detected above the LoD for which there are currently no water quality criterial appropriate for a screening exercise.

4.6.2.3 Site 3A

Field parameters for the leachate samples taken from Site 3A during each monitoring round are summarised in **Table 4.23**.

Table 4.23 – Site 3A Field Parameters (Leachate)

Borehole ID	Round	Temp (deg C)	pH	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
MW4	Round 1	10.5	-	>3,999	>2,000	-136	brown, cloudy sample, foul odour
	Round 2	-	-	-	-	-	-
	Round 3	9.7	5.74	>3,999	>2,000	-97	Pale brown & fizzing at the top. Very strong reducing / detergent/ bitter odour
LG15	Round 1	9.0	-	1,993	996	-77	brown, turbid sample, foul odour
	Round 2	19	6.82	3,467	-	-	Black colour, strong foul odour
	Round 3	8.5	5.31	1,464	731	-95	Light grey, not cloudy but turbid, hydrocarbon/reducing odour
LG19	Round 1	9.5	-	>3,999	>2,000	-157	brown, cloudy sample, foul odour
	Round 2	14	7.2	>3,999	-	-	Slight black colour, strong foul odour
	Round 3	-	-	-	-	-	-

Leachate samples taken from Site 3A showed concentrations above relevant water quality assessment criteria (i.e. GW Regs 2016, IGV or GTV) for the parameters listed in **Table 4.24**.

Table 4.24 – Site 3A Leachate Quality Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
Electrical Conductivity, Total Dissolved Solids	Electrical Conductivity, Total Dissolved Solids	Electrical Conductivity, Total Dissolved Solids
Ammoniacal Nitrogen, Orthophosphate	Ammoniacal Nitrogen, Orthophosphate	Ammoniacal Nitrogen
Chloride	Chloride	Chloride
Calcium	Calcium	Calcium
Metals* including Aluminium, Arsenic, Cadmium, Copper, Iron, Lead, Nickel, Zinc	Metals** including Arsenic, Chromium, Copper, Iron, Lead, Nickel, Zinc	Metals* including Aluminium, Arsenic, Iron, Lead, Nickel, Zinc
Manganese, Potassium, Sodium	Manganese, Sodium	Manganese, Potassium, Sodium
Barium, Boron	Barium, Boron	Barium, Boron
*Organics***		
Total Polycyclic Aromatic Hydrocarbons (PAH) including Naphthalene	Total Polycyclic Aromatic Hydrocarbons (PAH) including Naphthalene	Total Polycyclic Aromatic Hydrocarbons (PAH) including Naphthalene
Total Petroleum Hydrocarbons including Toluene, Ethyl Benzene, MTBE	Total Petroleum Hydrocarbons including Benzene, Toluene	Benzene, Toluene, xylene
Phenol		
Trans-1,2-dichloroethene, Vinyl chloride	Vinyl chloride	Vinyl chloride

* Metals measured as totals; ** Metal measured as dissolved; *** TPH not measured in R3.

A small number of other trace organics were detected above the laboratory LoD for which there are currently no water quality criterial appropriate for a screening exercise.

4.6.2.4 Site 3B

Field parameters for the leachate samples taken from Site 3B during each monitoring round are summarised in **Table 4.25**.

Table 4.25 – Site 3B Field Parameters (Leachate)

Borehole ID	Temp (deg C)	pH	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
LG17	11.0	-	>3,999	>2,000	-126	black colour, foul odour
	16.2	7.23	>3,999	-	-	Dark grey cloudy, strong foul odour
	10.1	5.93	1,220	610	-78	-

Leachate samples taken from Site 3B showed concentrations above relevant water quality assessment criteria (i.e. GW Regs 2016, IGV or GTV) for the parameters listed in **Table 4.26**.

Table 4.26 – Site 3B Leachate Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
Electrical Conductivity, Total Dissolved Solids	Electrical Conductivity, Total Dissolved Solids	Electrical Conductivity
Ammoniacal Nitrogen	Ammoniacal Nitrogen, Orthophosphate	Ammoniacal Nitrogen, Total Phosphate
Chloride	Chloride	Chloride
Calcium		
Barium, Boron	Barium, Boron	Barium
Metals* including Aluminium, Arsenic, Iron, Lead, Nickel, Zinc	Metals** including Arsenic, Chromium, Copper, Iron, Lead, Nickel	Metals* including Aluminium, Arsenic, Iron, Lead, Nickel, Zinc
Manganese, Potassium, Sodium	Manganese, Potassium, Sodium	Manganese, Potassium
*Organics****		
Total Polycyclic Aromatic Hydrocarbons (PAH)		Total Polycyclic Aromatic Hydrocarbons (PAH)
Total Petroleum Hydrocarbons	Total Petroleum Hydrocarbons including Benzene, Toluene	Toluene
Phenol (Note elevated concentration of 3+4-Methylphenol & 3,5-Dimethylphenol)	Phenol	
	Vinyl Chloride	

* Metals measured as totals; ** Metal measured as dissolved; *** TPH not measured in R3.

A small number of other trace organics were detected above the laboratory LoD for which there are currently no water quality criterial appropriate for a screening exercise.

Leachate data for Site 3B (LG17) is characterised by the presence of short chain TPH including BTEX hydrocarbons and a larger range of VOCs and SVOCs than seen at the other sites. The dataset for Site 3B is also considerably more dilute in Round 3 relative to the two previous rounds.

4.6.2.5 Site 3C

Field parameters for the leachate samples taken from Site 3C during each monitoring round are summarised in **Table 4.27**.

Table 4.27 – Site 3C Field Parameters (Leachate)

Borehole ID	Round	pH	Temp (deg C)	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
MW2	R1	-	10.3	1,139	620	-109	black/dark brown colour, high levels of suspended solids
	R2	-	-	-	-	-	-
	R3	6.55	7.4	733	382	-102	Light grey tint, specs of black, strong reducing odour
LG14	R1	-	11.6	>3,999	>2,000	-175	black/dark brown colour, high levels of suspended solids
	R2	7.34	17	>3,999	-	-	Dark grey, very turbid, strong foul odour
	R2	5.47	11.6	>3,999	>2,000	-118	-

Leachate samples taken from Site 3C showed concentrations above relevant water quality assessment criteria (i.e. GW Regs 2016, IGV or GTV) for the parameters listed in **Table 4.27**.

Table 4.28 – Site 3C Leachate Quality Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
Electrical Conductivity, Total Dissolved Solids	Electrical Conductivity, Total Dissolved Solids	Electrical Conductivity, Total Dissolved Solids
Ammoniacal Nitrogen, Orthophosphate	Ammoniacal Nitrogen, Orthophosphate	Ammoniacal Nitrogen, Total Phosphate
Chloride	Chloride	Chloride
Calcium	Calcium	Calcium
Metals* including Aluminium, Arsenic, Cadmium, Copper, Iron , Lead , Nickel , Zinc	Metals** including Arsenic, Chromium, Copper, Iron , Lead , Nickel	Metals* including Aluminium, Arsenic, Cadmium, Copper, Iron , Lead , Nickel , Zinc
Barium	Barium, Boron	Barium, Boron
Manganese, Potassium, Sodium	Manganese, Potassium, Sodium	Manganese, Potassium, Sodium
*Organics***		
Polycyclic Aromatic Hydrocarbons (PAH) including Naphthalene	Naphthalene	Polycyclic Aromatic Hydrocarbons (PAH) including Naphthalene
Total Petroleum Hydrocarbons	Total Petroleum Hydrocarbons	
Phenol		

A small number of other trace organics were detected above the laboratory LoD for which there are currently no water quality criterial appropriate for a screening exercise.

4.6.3 Soil Characterisation

See section 6.1.2 for human health risk assessment results.

4.6.4 Groundwater Quality Characterisation

The tabulated and screened groundwater quality dataset for all 5 landfill sites is presented in **Appendix H**. Field measurements of electrical conductivity, temperature, total dissolved solids and oxidation-reduction potential (ORP) for groundwater samples taken at each of the sites are used as indicators of generic groundwater properties.

The groundwater quality dataset collected for each landfill site has been compared with the most relevant water quality assessment criteria available for groundwater. The most relevant water quality criteria are Schedule 5 Groundwater Threshold Values (GTV) as presented in the Environmental Objectives (Groundwater) (Amendment) Regulations 2016 (Statutory Instruments No. 366 of 2016) which update the Schedule 5 GTV's presented in Environmental Objectives (Groundwater) Regulations 2010 (SI No. 9, 2010).

Interim Guideline Values (IGV) for Groundwater as presented in EPA interim report "Towards Setting Guideline Values for the Protection of Groundwater in Ireland" (EPA, 2003) also represent potential groundwater quality assessment criteria and have been included in the assessment presented herein. There are currently no published generic assessment criteria for groundwater derived specifically to be protective of human health via direct contact. However it can be assumed that if water is considered safe for human consumption then there are no risks from direct contact.

Due to access and slope stability constraints, the installation of directly down-gradient groundwater boreholes was unfeasible with the exception of BH1 at Site 2 and BH8 at Site 3B. Sampling from springs down-gradient of the sites were used to indicate the down A comparison between up-gradient and down-gradient groundwater quality for each site is made for each Site where applicable.

4.6.4.1 Site 1

Field parameters for groundwater sample taken during each monitoring on Site 1 are summarised in **Table 4.28**. It should be noted that borehole BH5 appears to be located in an up-gradient location relative to the Landfill Site 1 based on the local groundwater flow direction in the area, however the water quality indicates there the groundwater at this location is potentially impacted by the leachate.

Table 4.29 – Site 1 Field Parameters (Groundwater)

Borehole ID	Round	pH	Temp (deg C)	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
BH5 (up-gradient)	R1	-	10.0	886	443	221	brown turbid colour
	R2	7.12	13.3	972	-	-	Slight brown colour, very silty
	R3	-	-	-	-	-	Well silted up

Groundwater samples taken from Site 1 (i.e. BH5) demonstrated groundwater concentrations in excess of the relevant GTV or IGV for the parameters summarised in **Table 4.30**.

Table 4.30 – Site 1 Groundwater Quality Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
Ammoniacal Nitrogen	Ammoniacal Nitrogen	No Sample
Calcium	Calcium	
Metals* including Aluminium, Arsenic, Cadmium, Iron, Lead, Nickel, Zinc	Metals** including chromium	
Barium	Boron	
Manganese		
*Organics****		
Total Petroleum Hydrocarbons	None	No Sample
[No PAHs, VOCs or SVOCs above LoD]		

* Metals measured as totals; ** Metal measured as dissolved;

There are a number of exceedances of IGV and GTV thresholds for heavy metals, ammonia and total hydrocarbons at the up-gradient borehole (BH5) at Site 1.

4.6.4.2 Site 2

Field parameters for groundwater sample taken during each monitoring on Site 2 are summarised in **Table 4.31.**

Table 4.31 – Site 2 Field Parameters (Groundwater)

Borehole ID	Round	pH	Temp (deg C)	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
G20 (up-gradient)	R1	-	10.0	585	294	194	brown colour, silty sample
	R2	7.76	14	523	-	-	Brown, very silty
	R3	5.52	10.4	735	288	-15	Light brown, very silty, no odour
BH1 (down-gradient)	R1		10.7	921	461	268	brown colour, silty sample
	R2	6.68	12.1	927	-	-	Brown, turbid, very silty
	R3	-	-	-	-	-	Tubing lodged down well, irretrievable, well blocked

Groundwater samples taken from Site 2 demonstrated groundwater concentrations in excess of the relevant GTV or IGV for the parameters summarised in Table 4.32.

Table 4.32 – Site 2 Groundwater Quality Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
Ammoniacal Nitrogen	Ammoniacal Nitrogen	
Calcium		Calcium
Metals* including Aluminium, Arsenic, Iron, Lead, Nickel, Zinc	Metals** including Iron	Metals* including Aluminium, Cadmium, Nickel, Zinc
Barium	Boron	Barium
Manganese		Manganese, Potassium
*Organics****		
None	None	None

* Metals measured as totals; ** Metal measured as dissolved; *** TPH not measured in R3

As expected, concentrations of heavy metals in up-gradient borehole G20 are generally slightly lower than those measured in BH1. Furthermore, down-gradient borehole BH1 shows exceedances above GTV for parameters of lead and ammonia which are not observed in up-gradient borehole G20.

There are no detections of trace organic compounds in either of the groundwater at Site 2.

4.6.4.3 Site 3A

Field parameters for groundwater sample taken during each monitoring on Site 3A are summarised in **Table 4.33**.

Table 4.33 – Site 3A Field Parameters (Groundwater)

Borehole ID	Round	pH	Temp (deg C)	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
BH7 (up-gradient)	R1	-	8.9	676	339	148	Very silty
	R2	7.43	16.5	709	-	-	Brown, very silty
	R3	6.42	10.4	660	330	-33	Brown, silty, no odour
BH9 (up-gradient)	R1	-	9.8	572	267	182	Silty
	R2	7.06	13.8	740	-	-	Silty brown
	R3	5.38	9.5	668	336	94	Brown, silty, no odour
BH10 (down gradient / lateral)	R1	-	10.6	606	346	314	Silty
	R2	7.35	13.6	727	-	-	Brown, very silty
	R3	5.5	8.6	738	336	92	Brown, very silty, ammonium odour

Groundwater samples taken from Site 3A demonstrated groundwater concentrations in excess of the relevant GTV or IGV for the parameters summarised in **Table 4.34**.

Table 4.34 – Site 3A Groundwater Quality Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
	Ammoniacal Nitrogen	Total Phosphates
Calcium		Calcium
Metals* including Aluminium, Arsenic, Cadmium, Iron, Lead, Nickel, Zinc	Metals** including Chromium, Iron	Metals* including Aluminium, Arsenic, Cadmium, Copper, Iron, Lead, Nickel, Zinc
Manganese	Manganese, Potassium	Manganese, Potassium
Barium, Boron	Boron	Barium,
*Organics****		
None	None	None

* Metals measured as totals; ** Metal measured as dissolved; *** TPH not measured in R3

A number of metal concentrations in up-gradient borehole BH9 are slightly lower than concentrations in down-gradient borehole BH10, however this is not the case for all heavy metals (e.g. aluminium and iron concentrations are slightly lower in the down-gradient groundwater). Note BH9 is up-gradient of Site 3A but also downgradient of 3B and as such, may not be representative of local groundwater quality (background) concentrations. Furthermore, while BH10 is considered to be down-gradient of Site 3A it is not located within the direct path of leachate migration as indicated by geophysical surveys.

There are no detections of trace organic compounds any of the groundwater boreholes at Site 3A.

4.6.4.4 Site 3B

Field parameters for groundwater sample taken during each monitoring on Site 3B are summarised in **Table 4.35**.

Table 4.35 – Site 3B Field Parameters (Groundwater)

Borehole ID	Round	pH	Temp (deg C)	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
BH8 (down-gradient)	R1	-	10.9	900	509	252	Very silty
	R2	-	-	-	-	-	Dry
	R3	-	-	-	-	-	-

Groundwater samples taken from Site 3B (i.e. BH8) demonstrated groundwater concentrations in excess of the relevant GTV or IGV for the parameters summarised in **Table 4.36**.

Table 4.36 – Site 3B Groundwater Quality Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
Calcium	-	-
Metals* including Aluminium, Cadmium, Iron, Lead, Nickel, Zinc	-	-
Manganese, Potassium	-	-
*Inorganics***		
none	-	-

* Metals measured as totals; ** Metal measured as dissolved; *** TPH not measured in R3

There are no detections of ammonia or trace organic compounds in groundwater at Site 3B.

4.6.4.5 Site 3C

Field parameters for groundwater sample taken during each monitoring on Site 3C are summarised in **Table 4.37**.

Table 4.37 – Site 3C Field Parameters (Groundwater)

Borehole ID	Round	pH	Temp (deg C)	EC (µS/cm)	TDS (ppm)	ORP (mV)	Comment
BH6 (up-gradient)	R1	-	10.3	664	333	298	Brown turbid colour
	R2	6.88	14.5	867	-	-	Silty brown
	R3	5.36	9	735	360	96	-

Groundwater samples taken from Site 3C (i.e. BH6) demonstrated groundwater concentrations in excess of the relevant GTV or IGV for the parameters summarised in **Table 4.38**.

Table 4.38 – Site 3C Groundwater Quality Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
	Ammoniacal Nitrogen	
Metals* including Aluminium, Arsenic, Cadmium, Copper, Iron, Lead, Nickel, Zinc	Metals** including Chromium, Iron	Metals* including Aluminium, Arsenic, Copper, Iron, Lead, Nickel, Zinc
Calcium		Calcium
Potassium, Manganese	Potassium	Potassium, Manganese
Barium, Boron	Boron	Barium
Chloride		
*Organics****		
None	None	None

* Metals measured as totals; ** Metal measured as dissolved; *** TPH not measured in R3

There are no detections of trace organic compounds in groundwater at Site 3C.

4.6.5 Surface Water Characterisation

Water samples were collected from 5 springs and 5 locations along the County Brook River (Fassaroe Stream). Sampling locations are illustrated in **Figure 15**. The samples were analysed for the broad suite of parameters as presented in Appendix I. The analytical suite was selected to be consistent with the parameters analysed in the waste, leachate and groundwater samples to allow comparison across the results..

Surface water samples were compared to Environmental Quality Standards (EQS) protective of Freshwater bodies as presented in Environmental Objectives (Surface Waters) (Amendment) Regulations 2015 (S.I. No. 386 of 2015) which update the Surface Water Regulations (SI 327 of 2012). These standards are considered to be the most appropriate generic assessment criteria for assessing the risk to surface water courses.

There are no instances of leachate emergences at the foot of the waste body that directly link via overland drainage system to the down-gradient stream. However, there a number of spring flows emerging as diffuse upwellings with some showing ochre staining, particularly those found close to Site 3A and Site 2.

4.6.5.1 River Water Samples

Field parameters for the 5 surface water sampling locations along the County Brook River (Fassaroe Stream) are summarised in **Table 4.39**. Monitoring location SW1 is the most downstream sampling location and SW5 is the most up-stream sampling location along the County Brook River (Fassaroe Stream).

Table 4.39 – Surface Water Field Parameters

Surface water ID	Location	Round	Temp (deg C)	EC (µS/cm)	pH (-)	Comment
SW1	Down-gradient of Site 2	R1	5.5	515	6.5	Clear
		R2	12.9	547	8.28	Clear
		R3	5.5	442	7.81	Clear
SW2	Down-Gradient of Site 1	R1	5.3	570	7.6	Clear
		R2	12.5	539	8.52	Clear
		R3	6.5	436	8.07	Clear
SW3	Down-gradient of site 1	R1	5.3	475	7.93	Cloudy
		R2	12.4	558	8.61	Clear
		R3	6.5	421	7.69	Clear
SW4	Down-gradient of Site 3A	R1	5.3	538	7.97	Cloudy
		R2	12.1	550	8.47	Clear
		R3	7.7	531	6.95	Clear
SW5	Up-gradient of all sites	R1	5.8	425	8.09	Cloudy
		R2	11.8	548	8.18	Clear
		R3	8.0	405	7.01	Clear

Surface water quality samples showed exceedances above EQS for the parameters summarised in **Table 4.40**.

Table 4.40 – Surface Water Quality Parameter Exceedances

Round 1	Round 2	Round 3
Inorganics		
Biochemical Oxygen Demand		Biochemical Oxygen Demand
Metals* including Copper, Chromium, Lead, Nickel, Vanadium.	Mercury**	
Ammoniacal Nitrogen, Orthophosphate	Ammoniacal Nitrogen	Orthophosphate
*Organics****		
Polycyclic Aromatic Hydrocarbons including Benzo(a) pyrene, Fluorine		

* Metals measured as totals; ** Metal measured as dissolved; *** TPH not measured in R3

In Round 1, the water quality exceedances correspond primarily to sampling location SW3, SW4 and SW5 (upstream of Site 1, close to Site 3A and up-gradient of all sites respectively). Similarly, detection of hydrocarbons are observed in SW3, SW4 and SW5 in Round 1. In Round 1 There are no exceedances observed at SW1 and SW2, suggesting that Sites 2 is not having a measurable effect on water quality in County Brook River (Fassaroe Stream) despite the leachate quality on the site and water quality observed at Spring 1.

It is evident that in Round 2 and Round 3, relevant EQSs were not generally exceeded. However a variety of VOCs and SVOCs were identified in surface water at concentrations above the analytical LoD at multiple locations in Round 3 and Round 1, most notably at location SW3. These included 2-chlorophenol, 2-methylphenol, 2,4-dichlorophenol, 2,4-dimethylphenol, 2,4,6-tichlorophenol and a variety of other PAHs

4.6.5.2 Spring Water Samples

Field parameters for the 5 spring sampling locations along the County Brook River (Fassaroe Stream) are summarised in **Table 4.41**.

Table 4.41 – Spring Field Parameters

Spring ID	Round	Temp (deg C)	EC (µS/cm)	pH	Comment	Approx. Location
SP1	R1	2.7	1330	6.6	Ochre staining	Down-gradient of Site 2
	R2	14.8	1,379	7.67	Ochre, red discolouration & hydrocarbon sheen	
	R3	3.4	614	7.53	Tufa, clear	
SP2	R1	2.9	615	7.9	Calcite deposits present	Down-gradient of Site 1
	R2	14.1	660	8.51	Calcite deposits present	
	R3	5.8	843	7.73	Tufa, clear	
SP3	R1	3.3	490	8.0	Calcite deposits present	Down-gradient of Site 3C
	R2	15.2	607	7.77	Calcite deposits present	
	R3	7.3	531	6.95	Tufa, clear	
SP4	R1	7.4	750	7.5	Ochre staining	Down-gradient of Site 3A
	R2	15.6	976	7.49	Ochre deposits present	
	R3	8.9	966	6.53	Ochre	
SP5	R1	4.1	572	7.9	Calcite deposits present	Down-gradient of Site 3A
	R2	15.2	646	7.95	Calcite deposits present	
	R3	9.2	453	6.5	Tufa clear (note redox potential negative)	

Water quality samples showed exceedances above EQS for the parameters summarised in **Table 4.42**.

Table 4.42 – Spring Water Quality Parameter Exceedances

Round 1	Round 2	Round 3~
Inorganics		
Biochemical Oxygen Demand	Biochemical Oxygen Demand	Biochemical Oxygen Demand
Ammoniacal Nitrogen	Ammoniacal Nitrogen	
Metals* including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel and Zinc	Metals** including Nickel and Zinc	Metals* including copper, Lead, Nickel and Zinc.
Organics **		
None	None	None

* Metals measured as totals; ** Metal measured as dissolved; *** TPH not measured in R3; ~ SP5 not sampled in R3

The spring quality is variable between the 5 different spring locations sampled and between successive rounds at each spring. This in part relates to the analytical approaches adopted as identified in Table 4.42 but does imply a variable water quality in subsequent rounds.

In Round 1, the poorest water quality was observed at Spring SP1 (down-gradient of Site 2) and is characterised by the highest concentration of ammoniacal nitrogen and heavy metals. Spring SP1 was the only spring sampling location where petroleum hydrocarbons (and di-n-Butylphthalate) were detected above the analytical Limit of Detection. The water quality observed at Spring 3 (down-gradient/lateral of Site 3C) in Round 1 included exceedances above the EQS for multiple heavy metals and BOD. Spring SP4 (down-gradient of Site 3A) shows exceedances above EQS for

arsenic, nickel, BOD and ammonia and SP2 (down-gradient of Site 1) shows exceedances above EQS for lead, nickel, zinc and BOD. Spring SP5 shows an exceedance of the EQS for lead and orthophosphate in Round 1. In comparison to water quality of up-gradient groundwater, which showed elevated concentrations of ammonia and heavy metals, SP5 water quality is likely to be affected by a component some overland flow. Note the sampling was undertaken on a relatively wet period in March (2016). There is no detection of any other trace organic contaminants, hydrocarbons contaminants in the spring water samples with the exception of SP1.

The analytical results for Round 2 and Round 3 are characterised lower concentrations for potential contaminants of concern with fewer exceedances, most notably for heavy metals and absence of petroleum hydrocarbons. In Round 3 ammoniacal nitrogen concentrations did not exceed the analytical limit of detection.

The results for Round 1 provided some supporting evidence to suggest that springs characterised by the absence of tufa formation, the presence of in-channel ochre deposition and potential sheening were associated with spring water characterised by a of low pH and elevated heavy metal / ammoniacal nitrogen concentrations. However this relationship was not seen in subsequent monitoring rounds, with no systematic relationship between pH, contamination status and tufa formation observed.

4.6.6 Landfill Gas Monitoring Results

Gas monitoring was carried out on eighteen occasions between 7th March 2016 and 21st February 2017. The gas monitoring dataset is summarised on a site by site basis in the follow tables and time series charts. Atmospheric pressure during the monitoring events ranged from 983 to 1020mbar. Gas monitoring data is presented in Appendix J.

4.6.6.1 Site 1

In total ten boreholes were monitored for gas at Site 1, three onsite combined gas/leachate boreholes and seven offsite boreholes including six gas boreholes and one groundwater borehole.

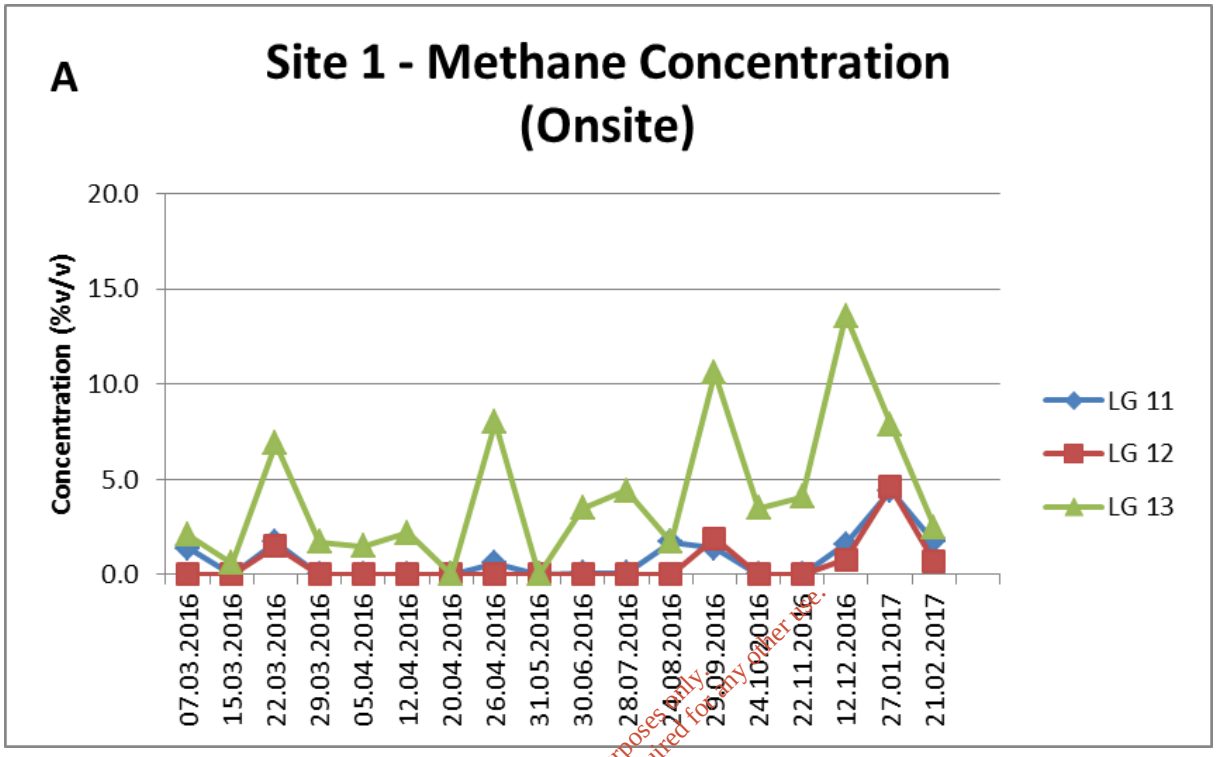
A summary of gas monitoring data for Site 1 is presented in **Table 4.35** below.

Table 4.43 – Site 1: Summary of Landfill Gas Monitoring Data

Borehole	Evidence of contamination	No. of monitoring occasions	Methane (%)	Carbon Dioxide (%)	Flow * (l/hr)	Water level (mbgl)	Range of atmospheric pressure (mbar)
Site 1							
Onsite							
LG11	In waste	18	0-4.4	0.1-11.7	0 – 0.4	dry -12.2	983-1020
LG12	In waste	18	0-1.5	0.1 - 18.9	0 – 2.8	dry	983-1020
LG13	In waste	18	0-13.6	2.0 – 18.7	0 = 4.0	8.7 - 9.5	983-1020
Offsite							
G06	No	18	11.0 – 23.9	3.2 - 8.1	0 - 3.5	dry	983-1020
G07	No	18	0	0 - 3.3	-3.2 - 6.9	dry	983-1020
G08	No	18	0	0 - 2.8	-3.7 – 6.3	dry	983-1020
G10	No	18	0	0.3 - 1.9	-1.5 – 3.1	dry - 9.2	983-1020
G18	No	18	0	0 – 2.5	-3.2 - 0.3	dry – 8.0	983-1020
G19	No	18	0	0.2 - 2.0	-0.1 – 0.6	dry - 7.9	983-1020
BH05	No	18	0	0 - 5.9	0 - 9.0	dry - 20.7	983-1020
* only 7 monitoring rounds for flow as flow tube damaged for monitoring on 7-8th March							

The gas monitoring data is presented graphically in Chart 4.1 and Chart 4.2.

Chart 4.1 – Site 1 Methane Concentrations



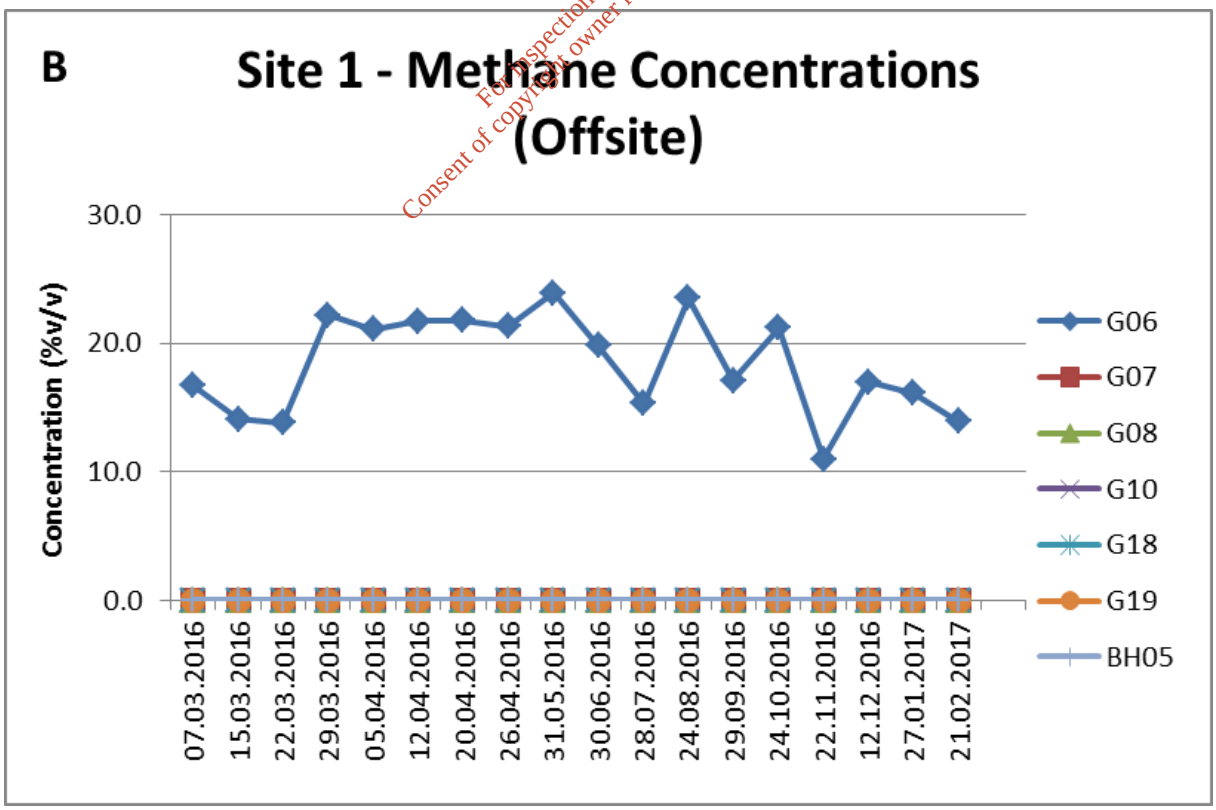
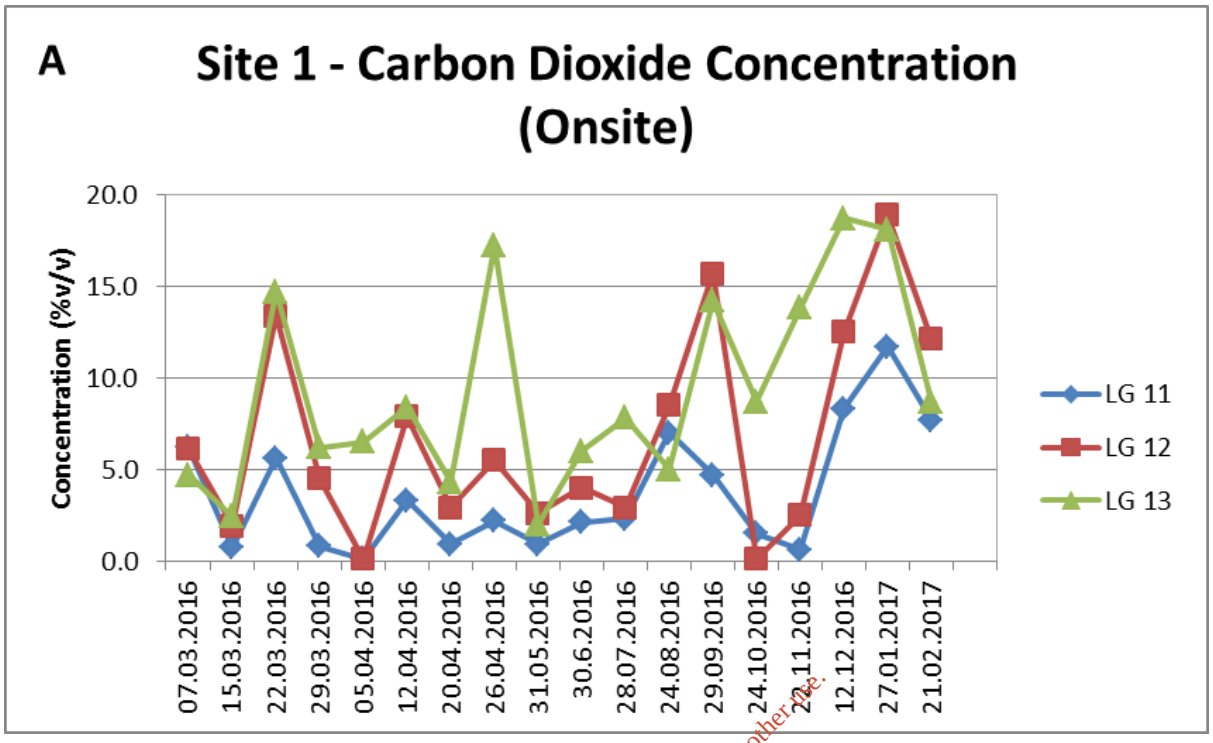
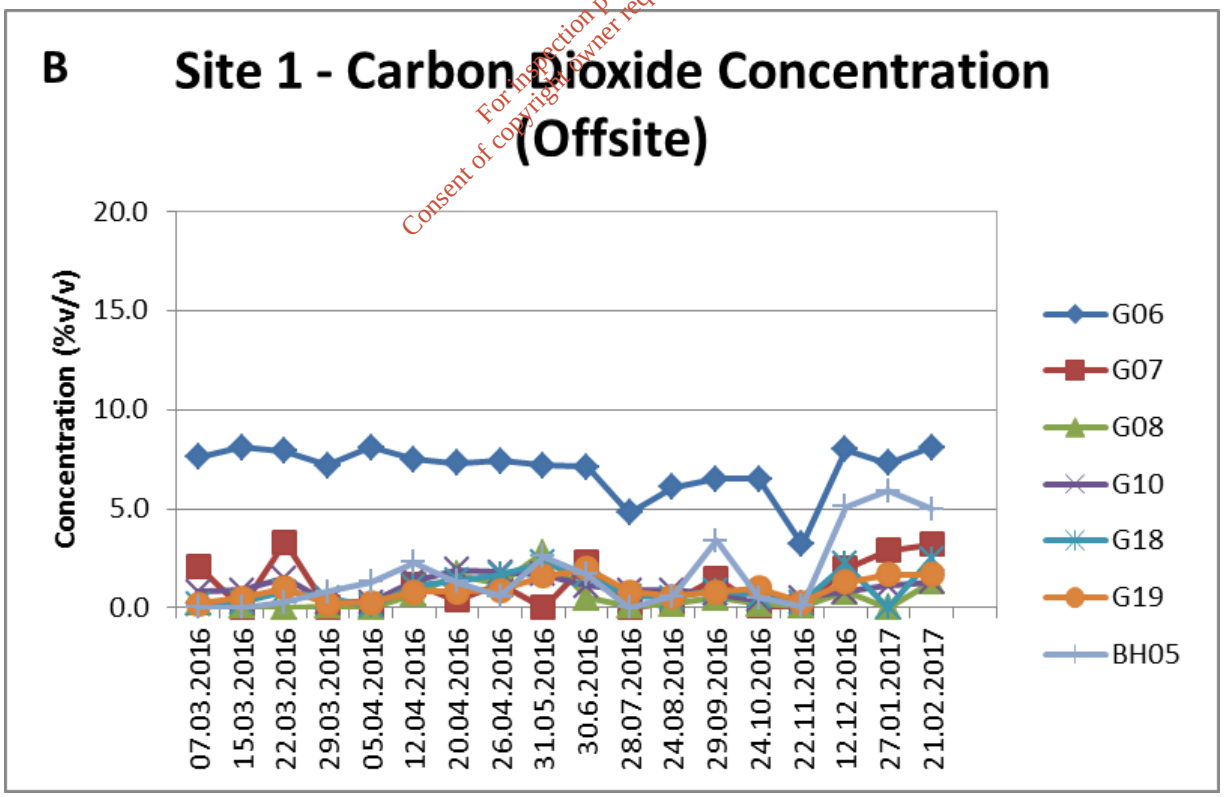


Chart 4.2 – Site 1 Carbon Dioxide Concentrations





Summary of Site 1 Gas Conditions Onsite

The gas monitoring data collected from onsite monitoring boreholes at Site 1 recorded methane concentrations up to 13.6% v/v and carbon dioxide concentrations up to 18.9% v/v. The observed conditions encountered during site investigation indicate Site 1 predominantly comprises construction and demolition (C&D) waste with some municipal waste.

There is some suggestion of possible increasing methane and carbon dioxide concentrations within the waste mass on Site 1. Flows are typically very low and do not exceed 4.0 l/hr in any borehole suggesting low surface emission rates.

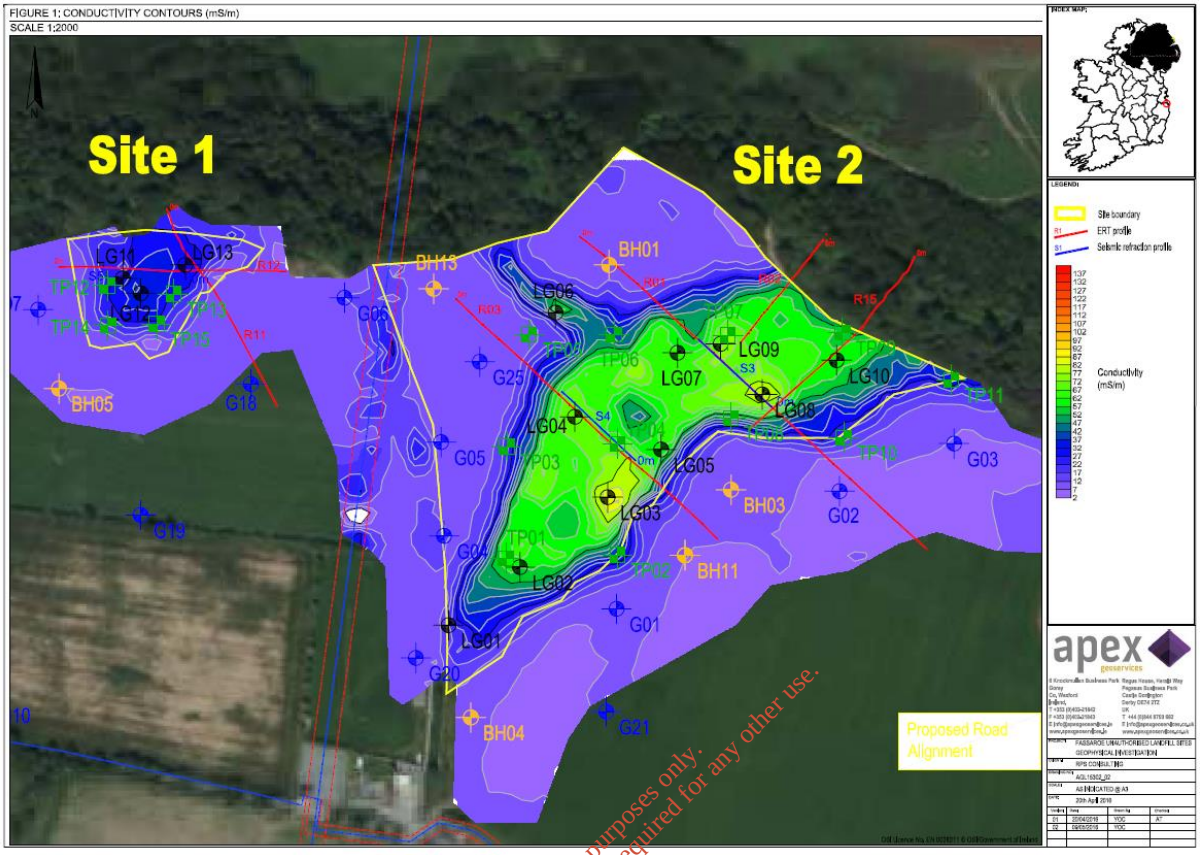
Summary of Site 1 Gas Conditions Offsite

With the exception of G06 methane concentrations in off-site boreholes are zero and carbon dioxide concentrations low, typically below 3.0 % v.v. In contrast G06 has elevated methane concentrations of 11 to 23.9% v/v and carbon dioxide concentration of 3.2 to 8.1 % v.v. Monitoring point G06 is located immediately to the west of the existing 33" water main which runs in a north south direction.

On review of site investigation data it is noted that elevated Electrical Conductivity (EC) has been recorded within the vicinity of G06. This appears to correspond to the backfilling activities associated with the water main routing in this area, as shown in **Figure 16** below taken from the geophysical survey (Appendix C).

The methane concentrations recorded at G06 are significantly higher than those recorded at the initially perceived source (worst case) location i.e. within Site 1, and may therefore be reflective of a separate gassing regime associated with the made ground/backfill surrounding the water main.

Figure 16 Site 1 and 2 Conductivity Contours (extract from Apex Geophysical Survey)



4.6.6.2 Site 2

A total of twenty seven (27) boreholes were monitored for gas at Site 2 which included ten (10) onsite combined gas/leachate boreholes, seventeen (17) offsite boreholes comprising twelve (12) gas boreholes and five (5) groundwater monitoring boreholes.

A summary of gas monitoring data collected during the monitoring period is presented in **Table 4.36** below.

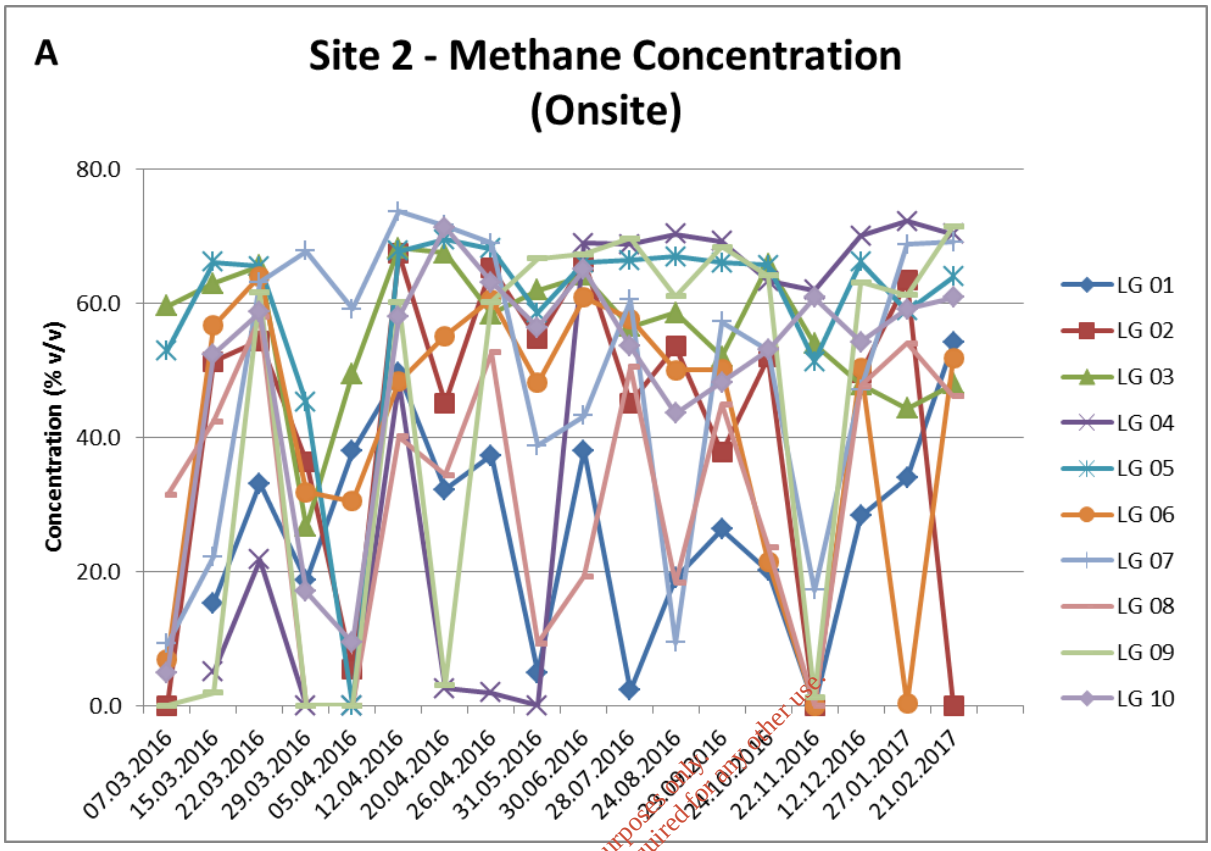
Table 4.44 – Site 2: Summary of Landfill Gas Monitoring Data

Borehole	Evidence of contamination	No. of monitoring occasions	Methane (%)	Carbon Dioxide (%)	Flow * (l/hr)	Water level***(mbgl)	Range of atmospheric pressure (mbar)
Site 2							
Onsite							
LG01	In waste	17	0.0-54.1	0.4-22.0	-0.6 to 2.5	3.7-3.95	983-1020
LG02	In waste	18	0-67.4	0-29.8	-2.5 to 7.0	7.95-8.33	983-1020
LG03	In waste	18	26.6-68.2	11.7-29.7	-1 to 4.3	12.65-15.67	983-1020
LG04	In waste	18	0-72.2	0-27.7	-5.2 to 7.6	11.76-12.29	983-1020
LG05	In waste	18	0-69.5	0-36.1	-6.2 to 7	12.56-13.85	983-1020
LG06	In waste	18	0-64	0.3-30.3	0-3.3	6.11-6.18^	983-1020
LG07	In waste	18	9.4-73.7	2.2-26.6	-0.3 to 3.9	1.95-11.20	983-1020
LG08	In waste	18	0-57.9	0-36.6	-3.1 to 4.6	dry-7.65	983-1020
LG09	In waste	18	0-71.5	0-24.4	-6.6 to 6.0	9.26-11.36	983-1020
LG10	In waste	18	4.8-71.3	2.3-27.9	-1.2-4.8	11.95-17.25	983-1020
Offsite							
G01	No	18	0-8.0~	0-4.9~~	-15.9 to 3.8	dry	983-1020
G02	No	18	0-0.1	0-9.5	-3.3 to 5.0	dry	983-1020
G03	No	18	0-4.9	0-17.2	-5.3 to 4.7	dry^	983-1020
G04	No	18	0	0-2.6	-0.3 to 0.1	1.84 - 9.13	983-1020
G05	No	18	0-55.7	0-8.1	-4.2-6.3	15.93 - 16.33	983-1020
G13	No	18	0	0-1.4	-8.2 to 6.4	dry	983-1020
G20	No	18	0-0.1	0-1.1	-10.9 to 13.6	14.14 - 16.3	983-1020
G21	No	18	0	0.1-2.2	-7.6 to 5.8	dry	983-1020
G22	No	18	0	0-2.5	-2.7 to 19.8	9.09 - 9.24^^	983-1020
G23	No	18	0	0-1.5	-10.3 to 3.4	dry to 17.25^^^	983-1020
G24	No	18	0	0-1.6	-15.9 to 10.5	dry	983-1020
G25	No	18	0-55.3	0-11.6	-0.3 to 9.0	dry	983-1020
BH01	No	18	0	0-4.8	-0.4 to 3.4	13.9 - 14.62	983-1020
BH03	No	18	0-8.6	0-15.4	-9.3 to 10.2	dry	983-1020
BH04	No	18	0	0-2.0	-18.6 to 10.8	dry	983-1020
BH11	No	18	0-16.3	0-16.5	-14.1 to 7.2	dry	983-1020
BH13	No	18	0-21.7	0.1-9.5	-0.2 to 4.7	dry	983-1020

~ Single reading of 45.4
~~ Single reading of 25.5

The gas monitoring data is presented graphically in Chart 4.3 and Chart 4.4.

Chart 4.3 – Site 2 Methane Concentrations



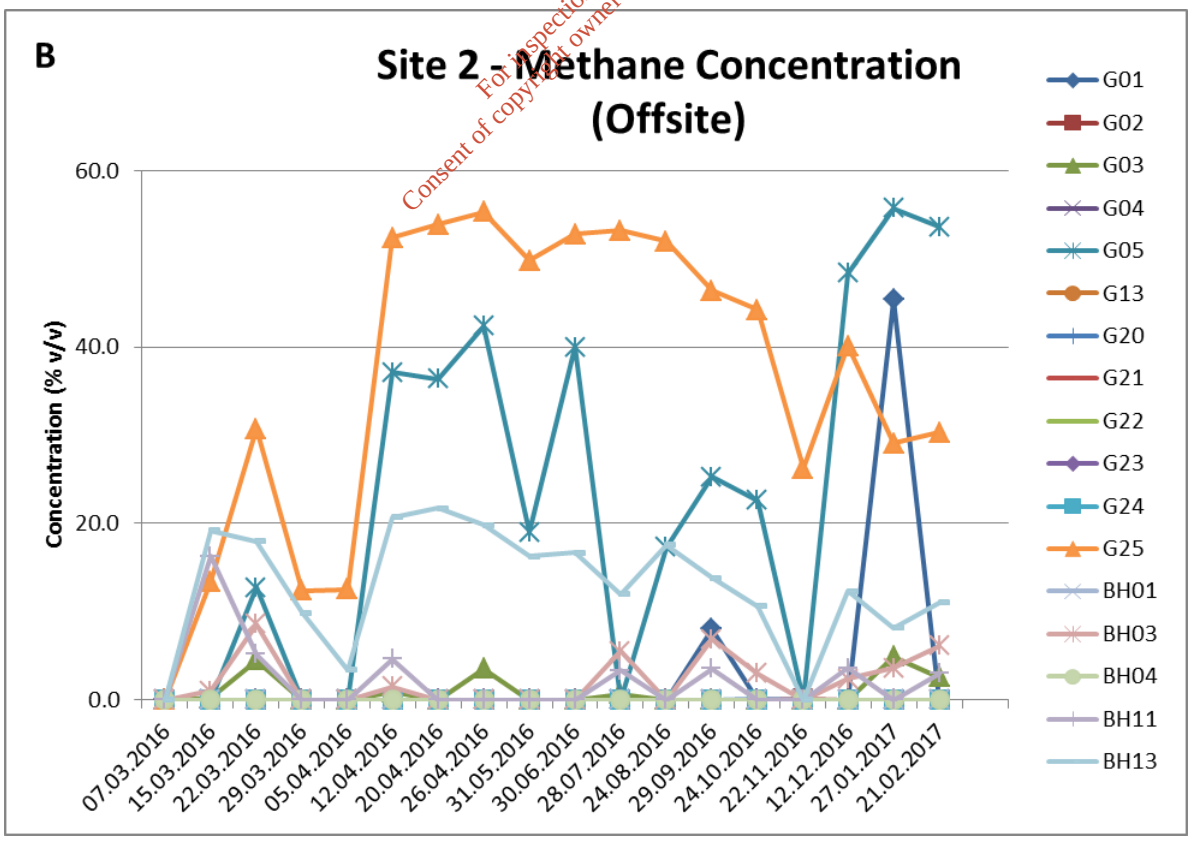
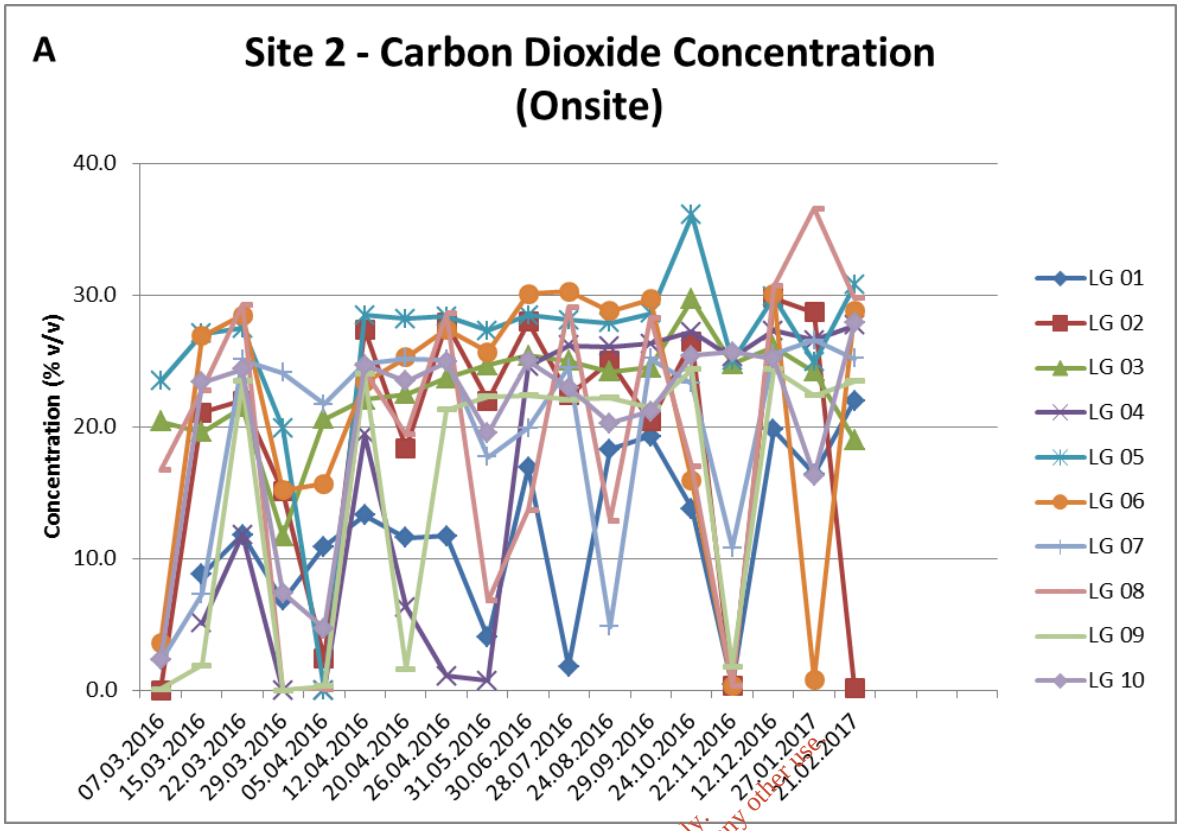
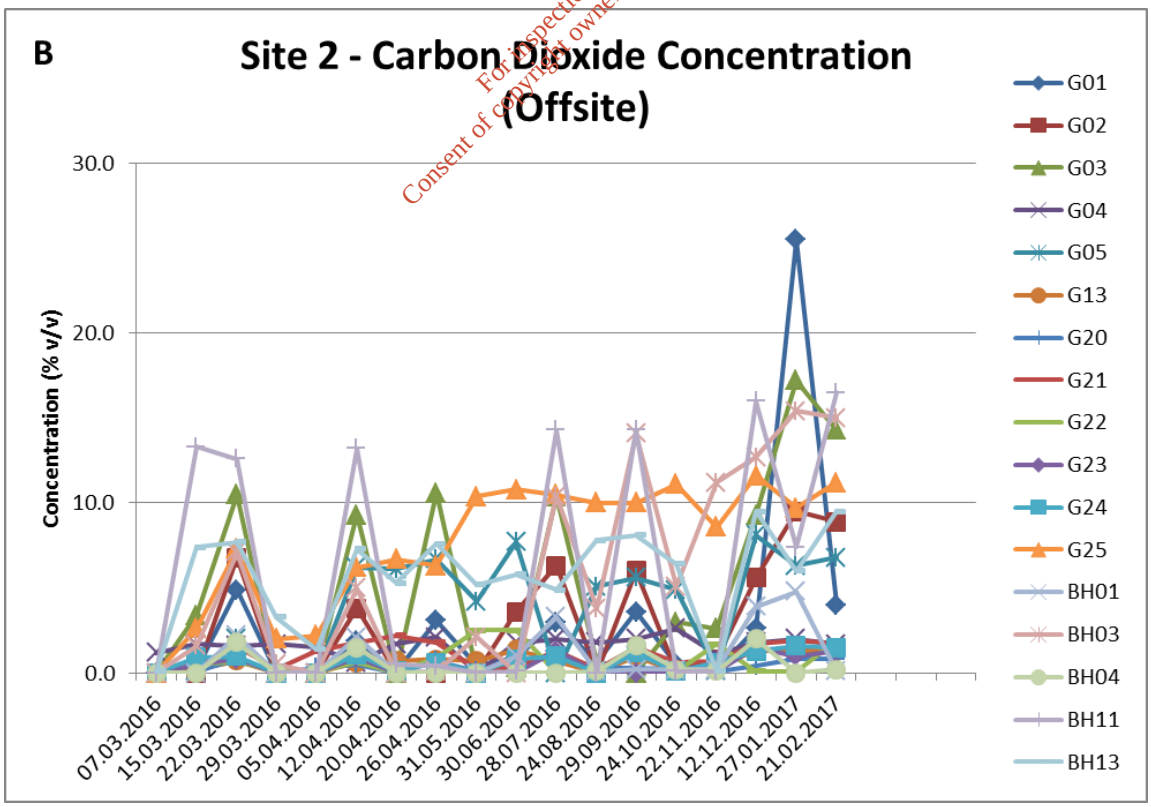


Chart 4.4 – Site 2 Carbon Dioxide Concentrations





Summary of Site 2 Gas Conditions Onsite

The gas monitoring data collected for onsite monitoring locations within Site 2 over the complete monitoring period recorded methane concentrations ranging from no detections to 73.7% v/v and carbon dioxide concentrations ranging from no detection to 36.6% v/v. Methane concentrations are consistently elevated with peak readings in excess of 60% v/v in LG02, LG03, LG05, LG06, LG07, LG09 and LG10. Flow rates are extremely variable ranging from -6.2 to +7.6 l/hr.

Summary of Site 2 Gas Conditions Offsite

The gas monitoring data collected for offsite monitoring locations generally recorded no detections or very low methane concentrations in the majority of monitoring locations (G02, G04, G13, G20-24, BH01 and BH04). The notable exceptions are G25, G05 and BH13 where methane concentrations range from zero up to 55.3, 55.7 and 21.7 % respectively. It notable that methane concentrations recorded at the 3 location typically increase after 5th April 2016.

Offsite carbon dioxide concentrations are extremely variable ranging from 0 to 16.5 % v/v, but are elevated on occasions at most offsite monitoring locations. Sustained elevated concentrations are characteristic of G25 and BH13 (the latter located between the existing 33" water main and Site 2).

Flow rates are correspondingly variable, ranging between -16 l/hr to +19.8 l/hr.

4.6.6.3 Site 3A

A total of ten (10) boreholes were monitored for gas at Site 3A; five onsite comprising three combined gas/leachate boreholes and two existing boreholes, five offsite comprising two gas boreholes and three groundwater boreholes.

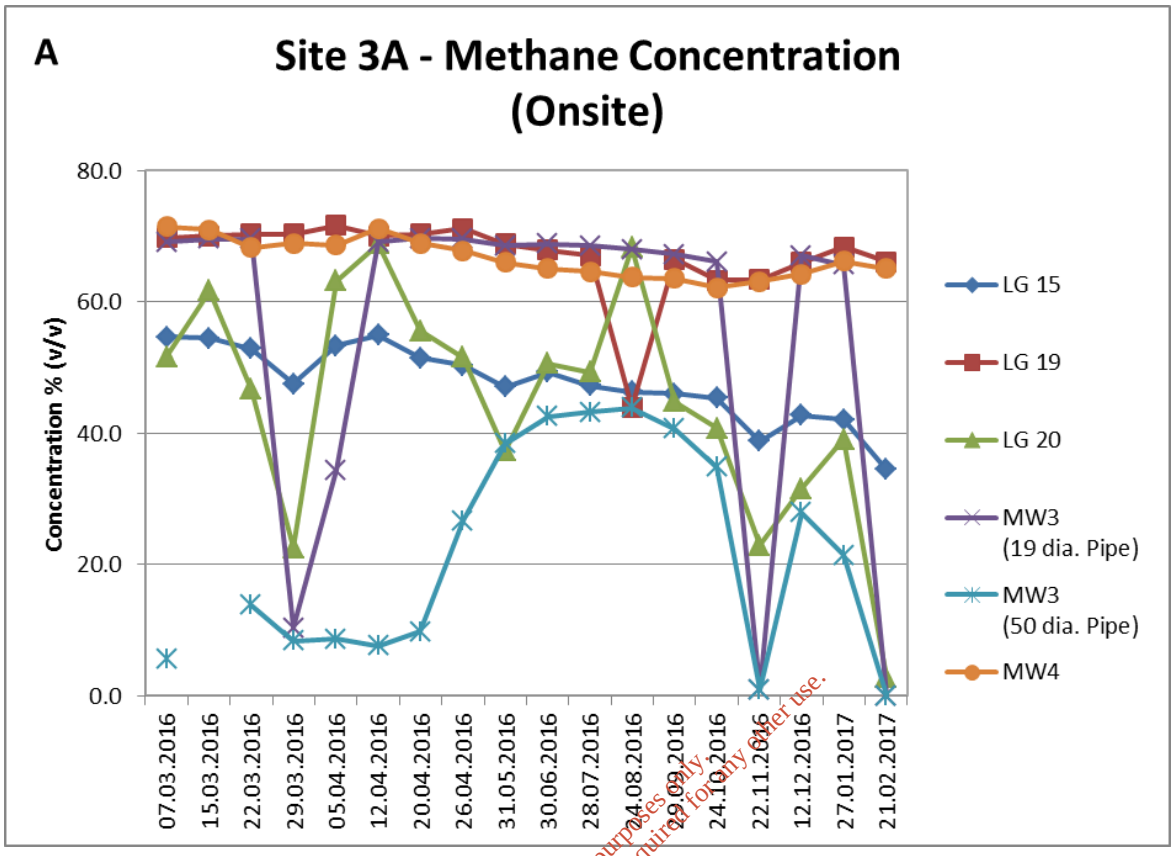
A summary of gas monitoring data is presented in **Table 4.37** below.

Table 4.45 – Site 3A: Summary of Landfill Gas Monitoring Data – Onsite & Offsite

Borehole	Evidence of contamination	No. of monitoring occasions	Methane (%)	Carbon Dioxide (%)	Flow * (l/hr)	Water level (mbgl)	Range of atmospheric pressure (mbar)
Site 3A							
Onsite							
LG15	In waste	18	34.5 - 55	19.4-26.8	0-5.8	6.47-6.97^	983-1020
LG19	In waste	18	44.0 - 71.7	21.7-35.9	0-45	6.19-14.3^	983-1020
LG20	In waste	18	2.8 - 68.9	4.3-33.1	-1.3 to 26.5	dry	983-1020
MW3 (19mm) **MW3 (50mm)**	In waste	18	0-69.7 0-43.9	0-32.9 0.1-14.4	0-1.5 -0.3 to 4.9	5.95-15.31	983-1020
MW4	In waste	18	62.2-71.5	28.5-37.0	-0.8-43.0	5.9-6.65^	983-1020
Offsite							
G12	No	18	0	0-1.9	0-1.4	10.03-10.65^	983-1020
G14	No	18	0	0.8-2.1	0-1.3	7.32-7.73^	983-1020
BH07	No	18	0	0.1-4	-0.1 to 1.6	13.45-13.87^	983-1020
BH09	No	18	0	0.1-2.3	-0.2 to 1.6	6.26-6.79^	983-1020
BH10	No	18	0	0.1-3.2	-0.3 to 1.6	8.23-8.53^	983-1020

The gas monitoring data is presented graphically in Chart 4.5 and Chart 4.6.

Chart 4.5 – Site 3A Methane Concentrations



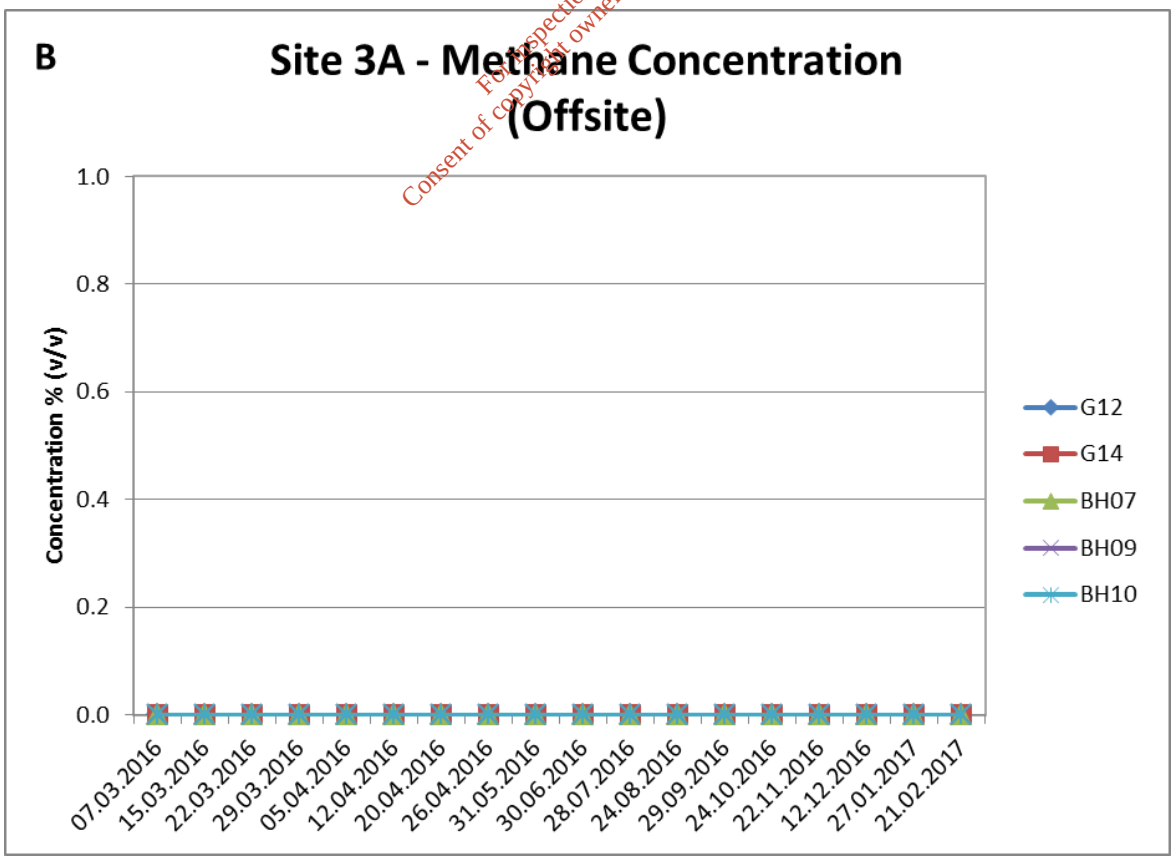
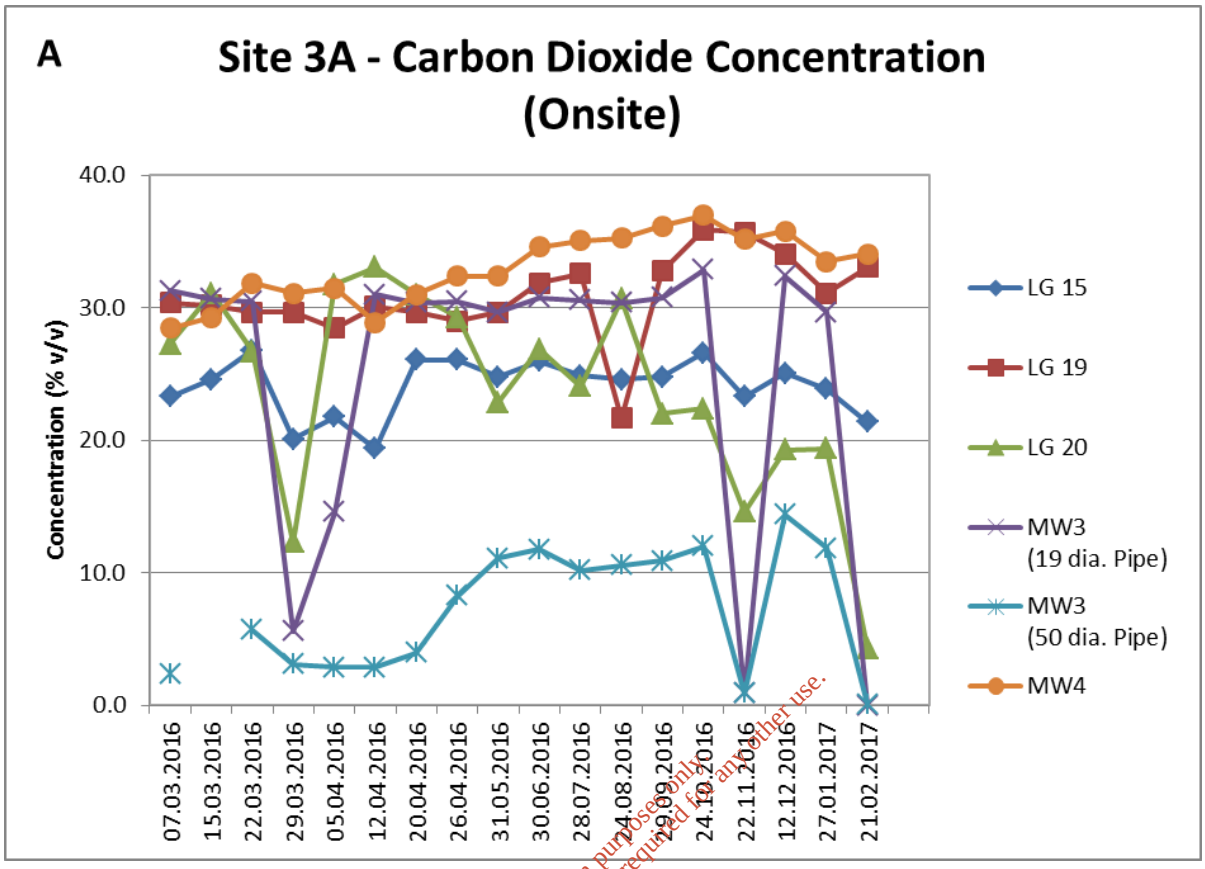
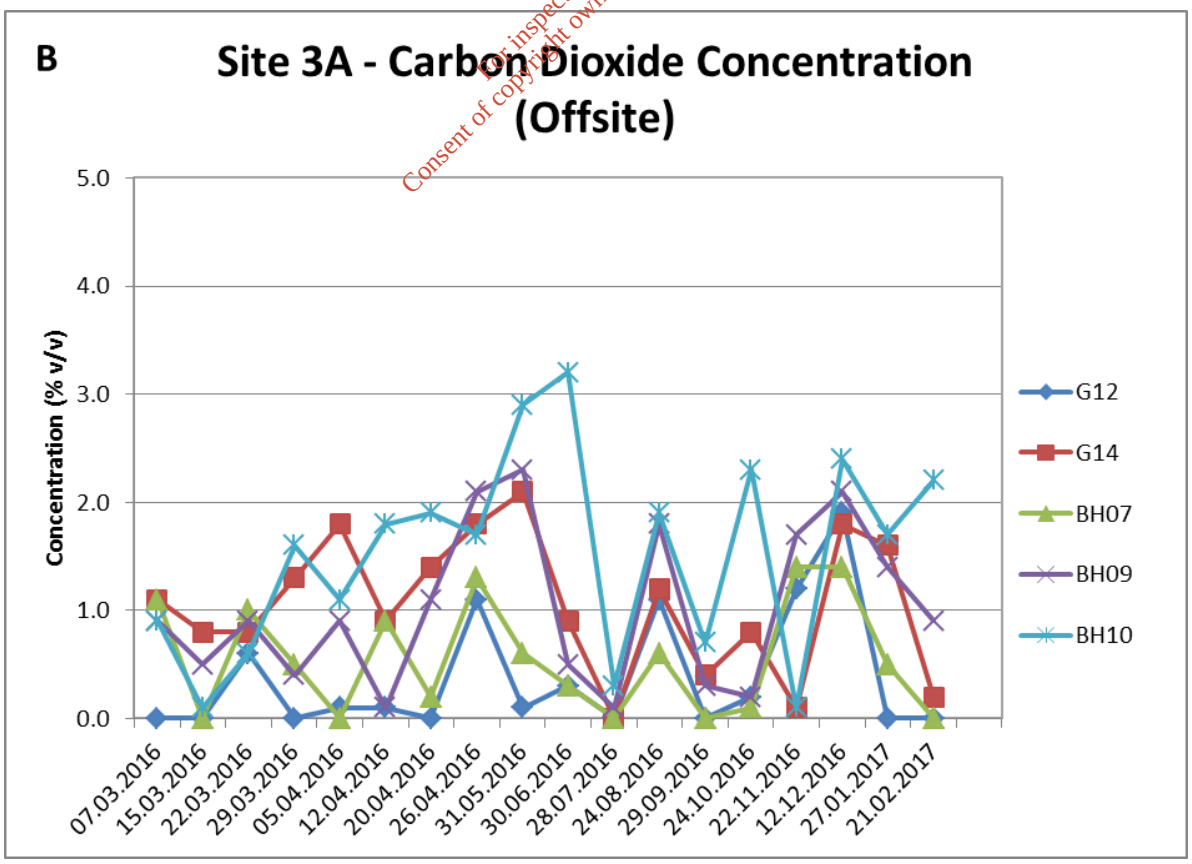


Chart 4.6 – Site 3A Carbon Dioxide Concentrations





Summary of Site 3A Gas Conditions Onsite

The gas monitoring data collected at onsite monitoring boreholes recorded methane concentrations ranging from 0% v/v to 71.7% v/v with carbon dioxide concentrations ranging from 0% v/v to 37% v/v. The lowest gas concentrations were observed at the dual installation within MW3. All other in-waste boreholes demonstrate methane and carbon dioxide concentrations above zero. MW3 is a 19 or 25mm diameter historic standpipe installed within the waste horizon, with the 50mm standpipe is installed within the underlying sands and gravels. Removing MW3 from the dataset provides a more consistent range of results with methane concentrations between. Typically methane concentrations are elevated between 30 and 70 % v/v. Similarly carbon dioxide concentrations are continuously elevated between 20 and 30 % v/v.

Flow rates are extremely variable, although high flow rates typically in excess of 30l/hr have been recorded at all in-waste boreholes. The results of the flow readings are considered to be consistent with a waste mass that is still degrading in pockets or 'hot spots' of the landfill. This is producing large volumes of gas under pressure driven, advective flow conditions.

Summary of Site 3A Gas Conditions Offsite

The gas monitoring data collected at offsite monitoring locations did not record any methane detections during the course of the monitoring period and carbon dioxide concentrations ranging from no detection to 3.2% v/v.

Flow rates in boreholes located outside the landfill body have remained consistently low, typically below 1.6 l/hr.

4.6.6.4 Site 3B

A total of seven (7) boreholes were monitored for gas at Site 3B; three (3) onsite combined gas/leachate boreholes and four (4) offsite boreholes comprising three gas boreholes and one groundwater borehole.

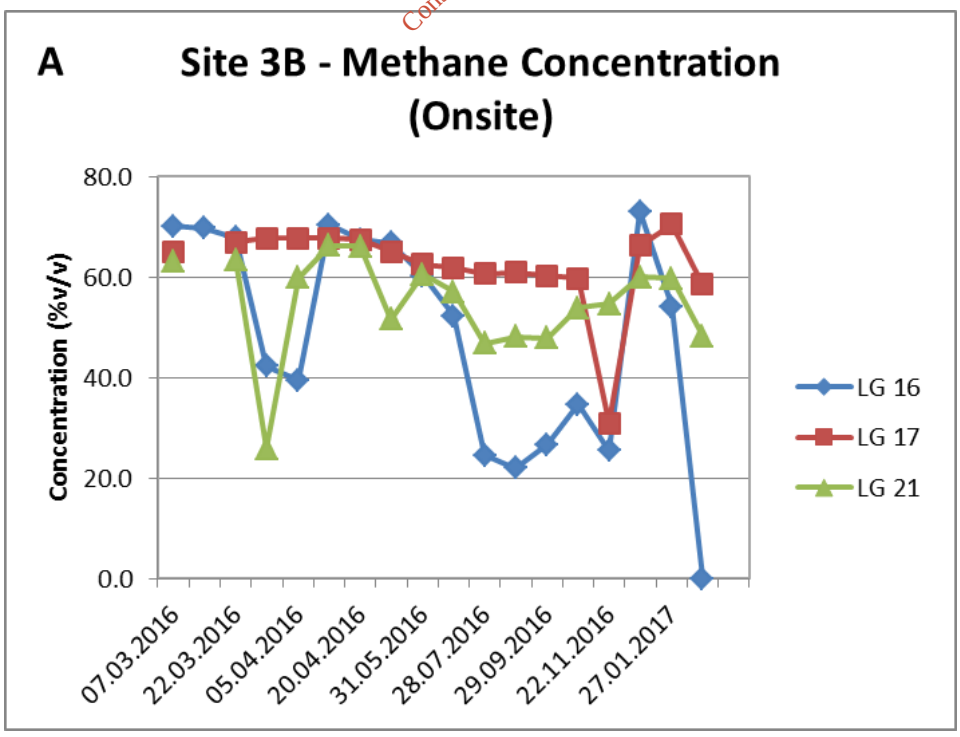
A summary of gas monitoring data is presented in **Table 4.38** below.

Table 4.46 – Site 3B: Summary of Landfill Gas Monitoring Data – Onsite & Offsite

Borehole	Evidence of contamination	No. of monitoring occasions	Methane (%)	Carbon Dioxide (%)	Flow * (l/hr)	Water level (mbgl)	Range of atmospheric pressure (mbar)
Site 3B							
Onsite							
LG16	In waste	18	22.0-73.1~	19.5-34.7~	0 to 3.3	3.11-3.19	983-1020
LG17	In waste	18	30.9-70.5	19.9-39.4	-0.1 to 6.2	3.14-3.29***	983-1020
LG21	In waste	18	25.8-66.2	17.2-37.4	0 to 2.5	dry***	983-1020
Offsite							
G15	No	18	0	0.8-3.6	0 to 1.3	dry - 5.07	983-1020
G16	No	18	0-2.1	0.7-3.3	-0.5 to 0.1	3.7-3.97	983-1020
G17	No	18	0	0.1-3.2	0 to 2.2	dry-4.05	983-1020
BH08	No	18	0	0.0-4.2	-1 to 1.4	6.46-7.47	983-1020
~ single anomalous reading of zero in final round							

The gas monitoring data is presented graphically below:

Chart 4.7- Site 3B Methane Concentrations



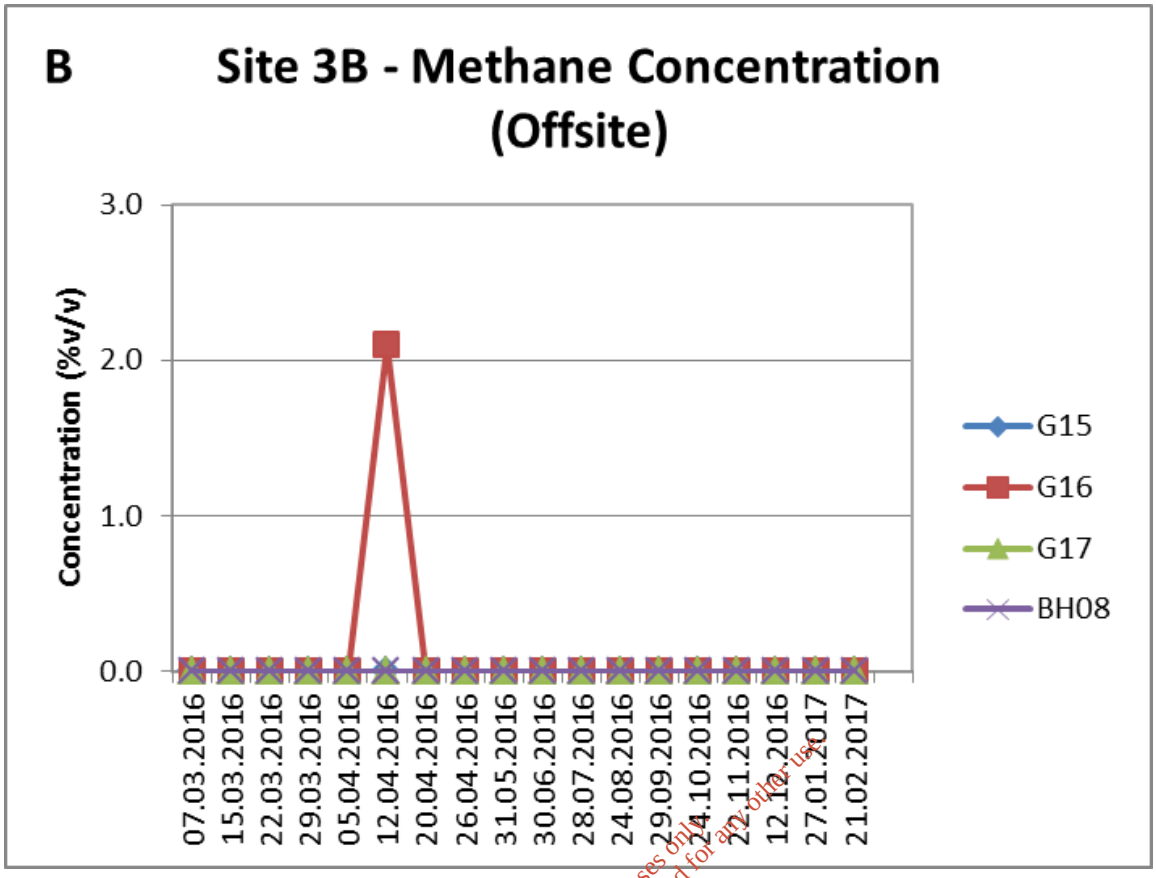
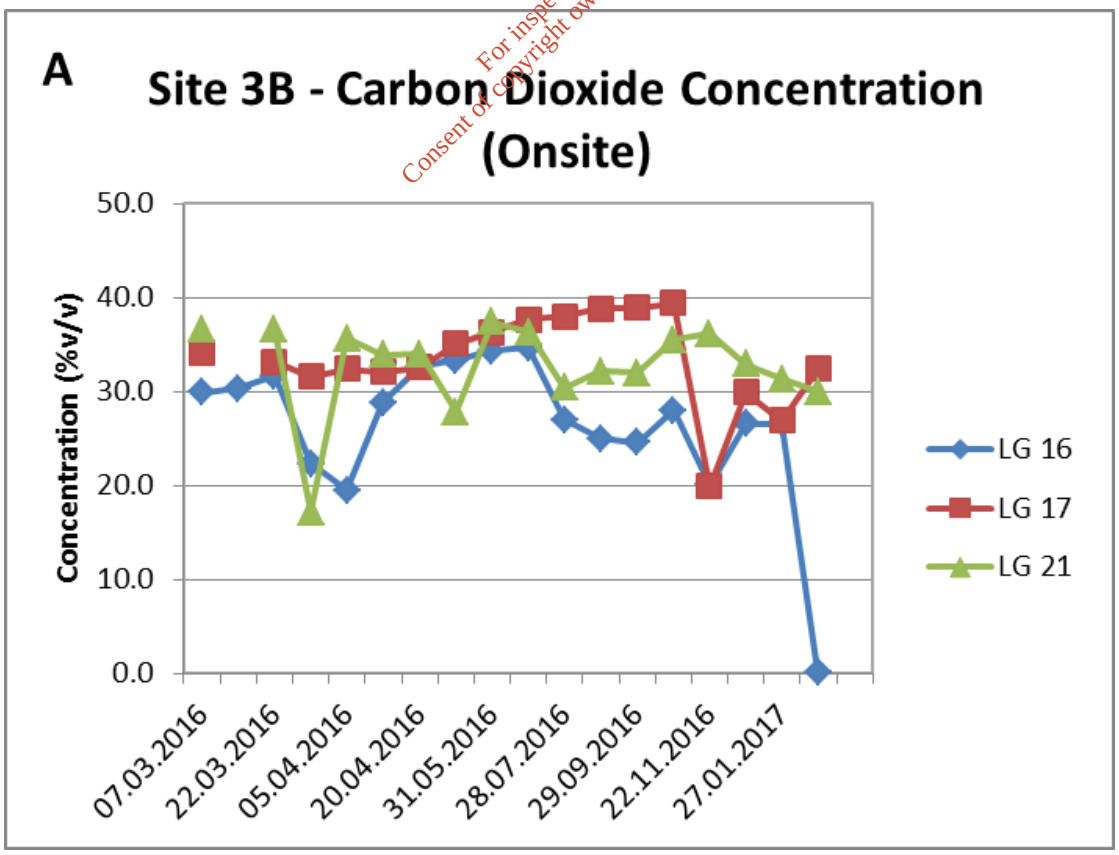
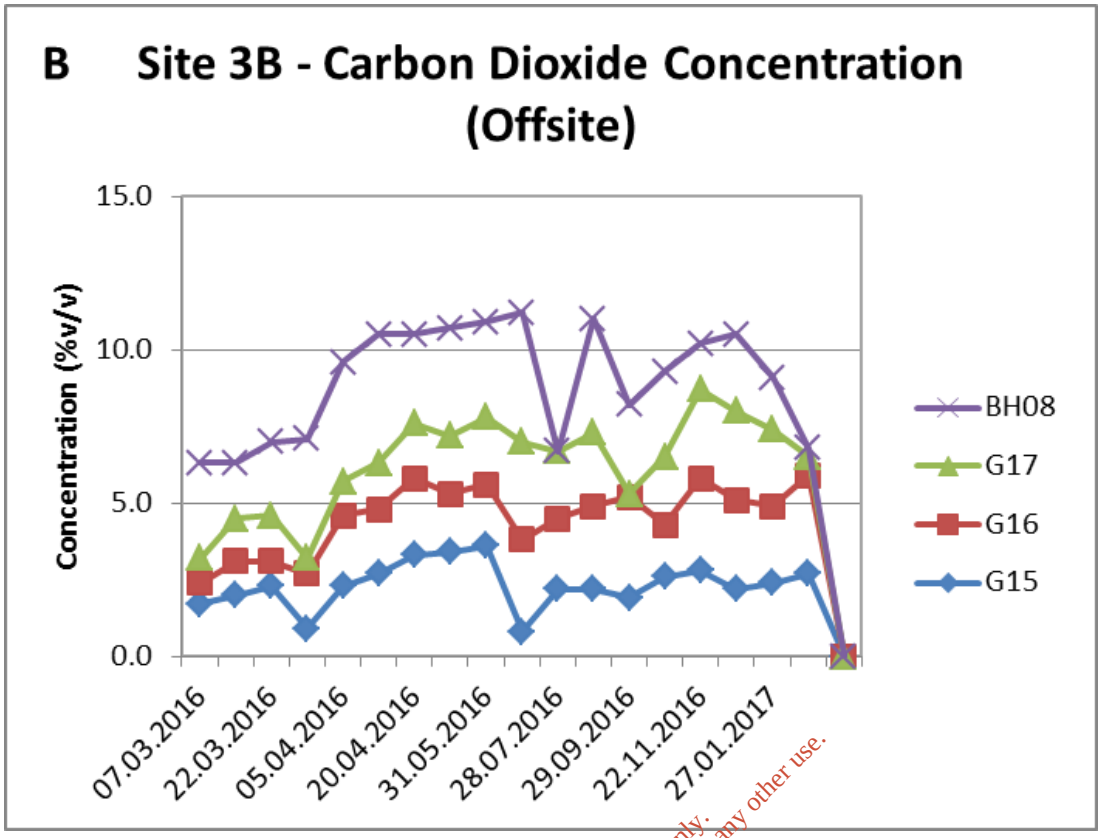


Chart 4.8 – Site 3B Carbon Dioxide Concentrations





Summary of Site 3B Gas Conditions Onsite

The gas monitoring data collected at onsite monitoring locations recorded consistently elevated methane concentrations ranging from 22.0% v/v to 73.1% v/v and carbon dioxide ranging from 17.2% v/v and 39.3% v/v. No measureable flow rate was recorded during several monitoring periods with peak reading of 3.3l/hr, 6.2l/hr and 2.5l/hr recorded at LG16, LG17 and LG21 respectively.

Summary of Site 3B Gas Conditions Offsite

The gas monitoring data collected at offsite monitoring locations recorded no methane detections with the exception of one monitoring period at G16 (2.1% v/v on the 12/4/2016). Carbon dioxide concentrations ranged from 0.5% v/v to 4.2% v/v. Flow rates are typically low, albeit variable ranging from -0.5 l/hr to 2.2 l/hr.

4.6.6.5 Site 3C

A total of six boreholes were monitored for gas at site 3C; three onsite boreholes comprising two combined gas/leachate boreholes and one historic borehole and three (3) offsite boreholes comprising two gas boreholes and one groundwater borehole.

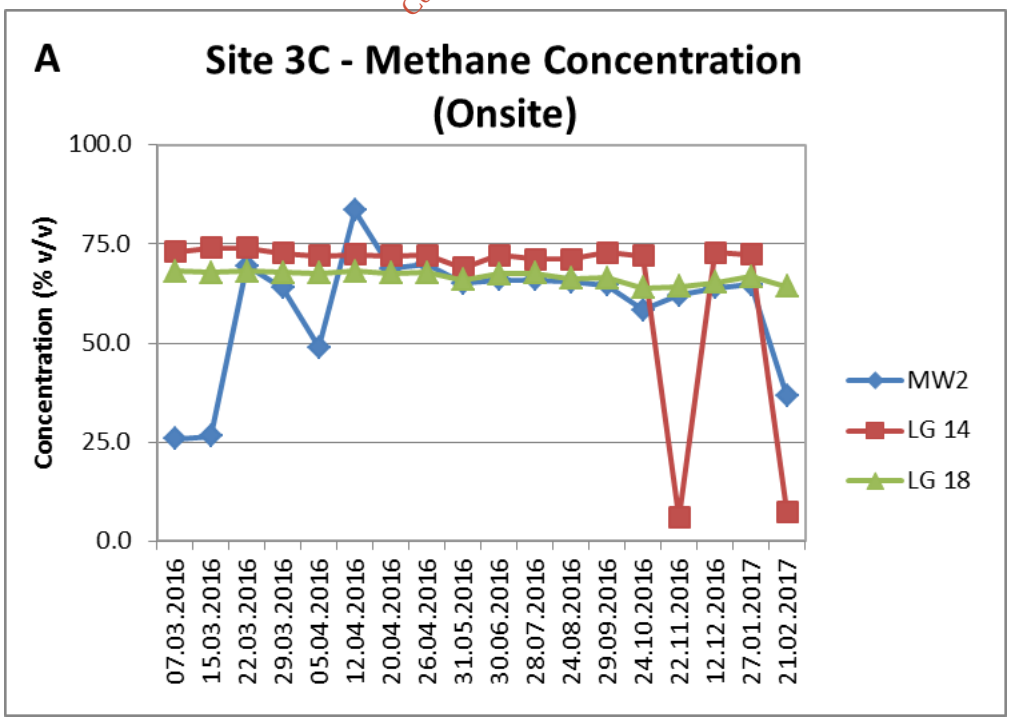
A summary of gas monitoring data is presented in **Table 4.39**.

Table 4.47 – Site 3C: Summary of Landfill Gas Monitoring Data – Onsite & Offsite

Borehole	Evidence of contamination	No. of monitoring occasions	Methane (%)	Carbon Dioxide (%)	Flow * (l/hr)	Water level**(mbgl)	Range of atmospheric pressure (mbar)
Site 3C							
Onsite							
MW2	In waste	18	25.8-83.5	7.3-37.2	-2.2 to 11.7~	3.31-4.34	983-1020
LG14	In waste	18	5.9-74.1	4.1-28.2	-0.1 to 1.9	9.11-10.07	983-1020
LG18	In waste	18	63.9-68.2	31.7-35.3	0.0 to 1.2	9.44-9.58	983-1020
Offsite							
G09	No	18	0.0-18.6	0-14.8	0 to 3.1	11.99-12.47	983-1020
G11	No	18	0.0 – 0.1	0-2.7	-0.1 to 1.2	9.64-9.99	983-1020
BH06	No	18	0.0-22.2	0.3-19.6	0 to 0.9	5.41-5.66	983-1020
~ single anomalously high reading of 11.7							

The gas monitoring data is presented graphically in Chart 4.9 and Chart 4.10.

Chart 4.9 – Site 3C Methane Concentrations



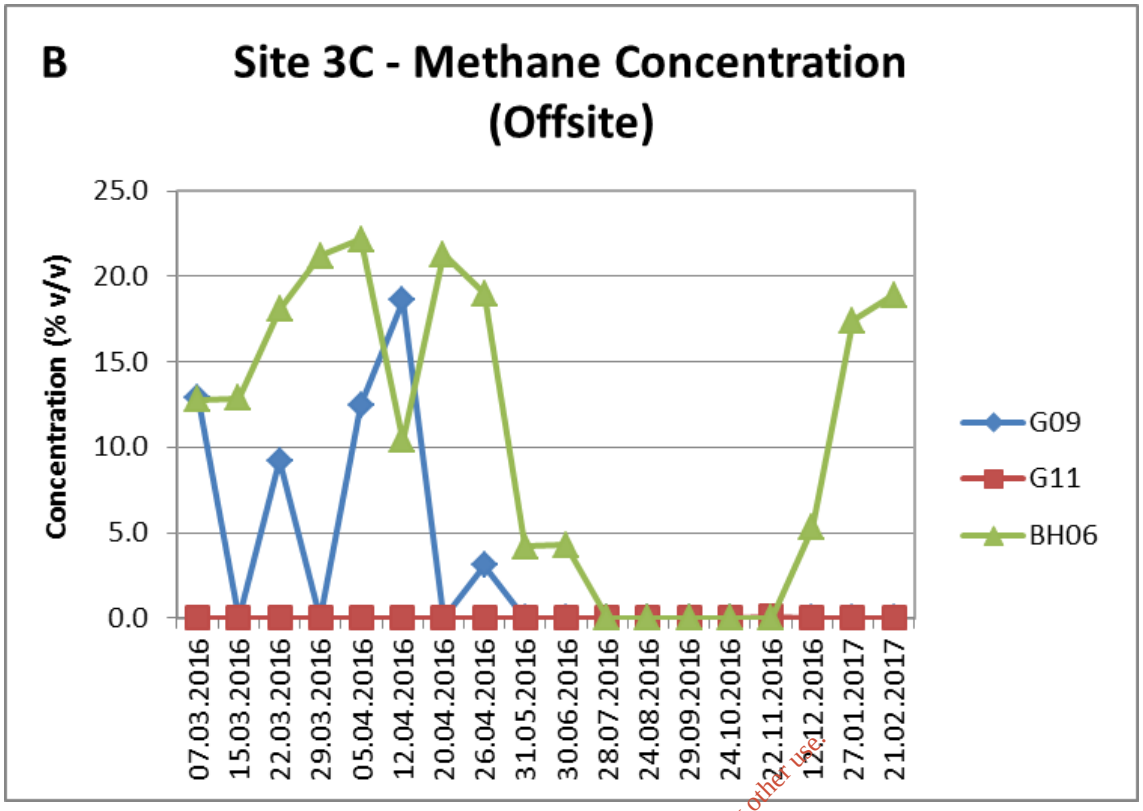
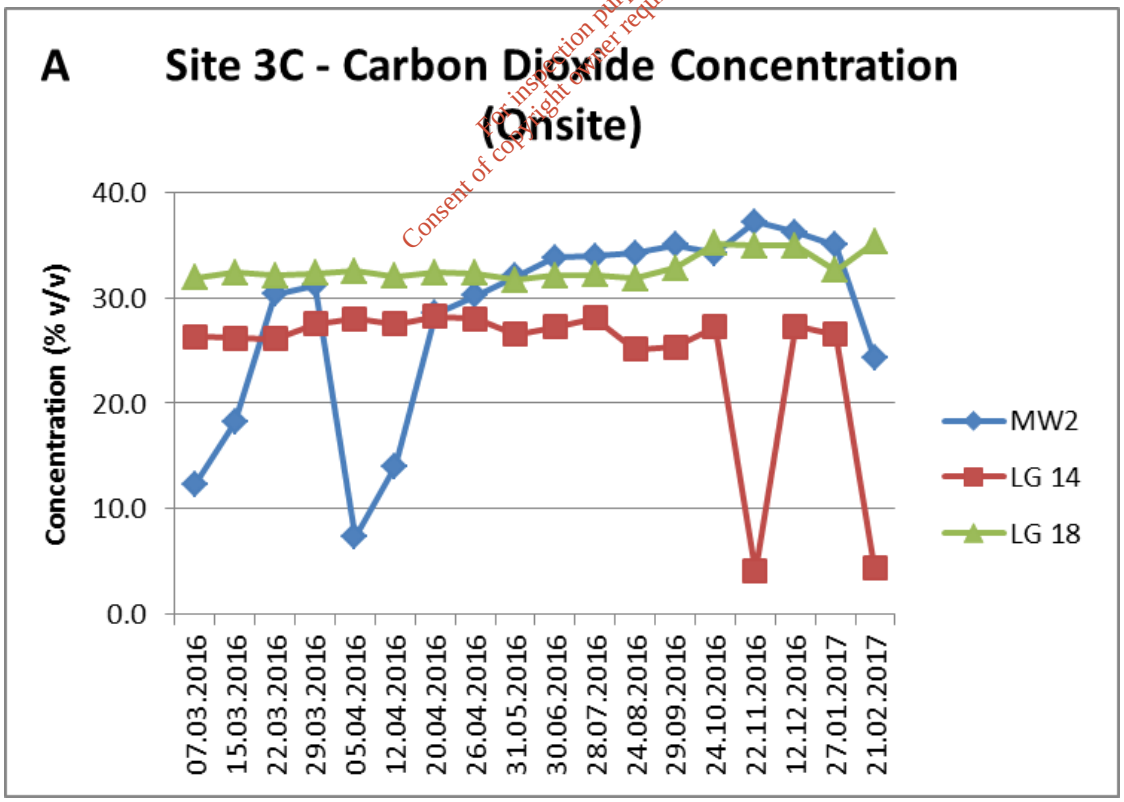
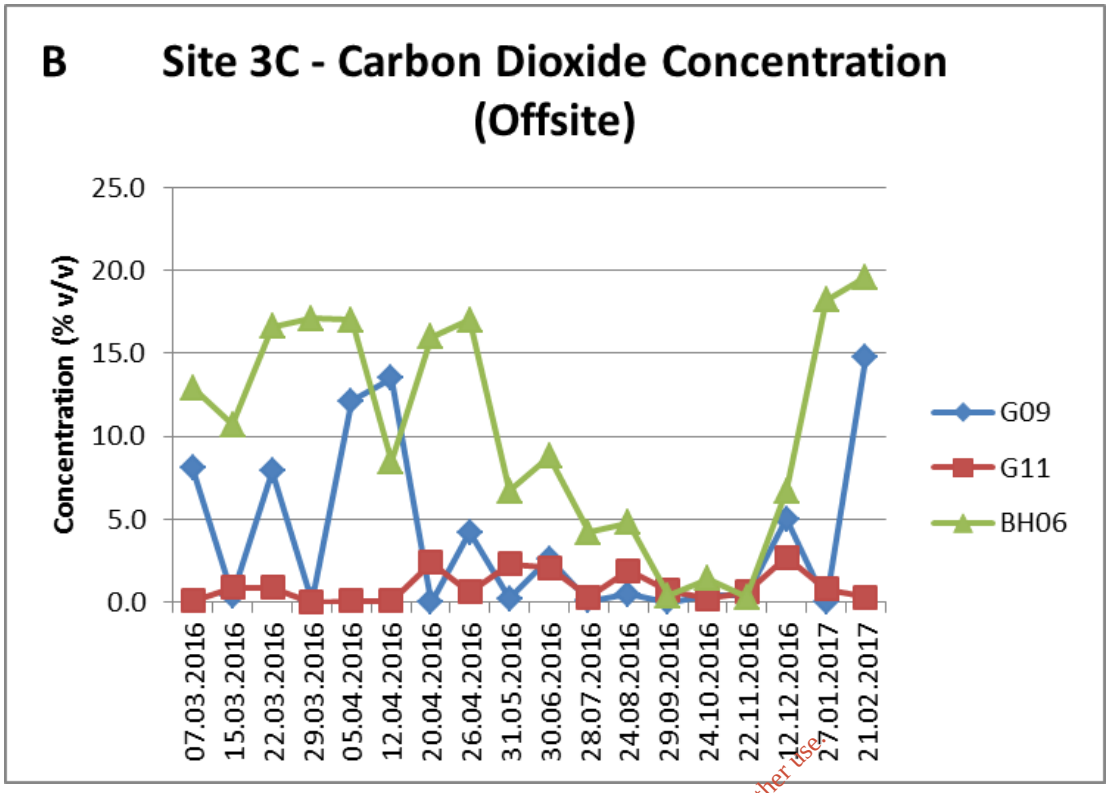


Chart 4.10- Site 3C Carbon Dioxide Concentrations





Summary of Site 3C Gas Conditions Onsite

The gas monitoring data collected from onsite monitoring locations recorded methane concentrations ranging from 5.9% v/v to 83.5% v/v with carbon dioxide concentrations ranging from 4.1% v/v to 37.2% v/v. Methane concentrations are typically stable with a concentration between 60% v/v and 75% v/v. Similarly the carbon dioxide concentrations typically exceeds 25%. Flow readings are typically low (i.e. below 2 L/hr) with the exception of 11.7l/hr recorded at MW2 on 12/04/2016. The elevated gas concentrations are consistent with an actively gassing municipal landfill.

Summary of Site 3C Gas Conditions Offsite

The monitoring of offsite monitoring locations recorded methane concentrations ranging from no detectable concentration to of 22.2% v/v and carbon dioxide concentrations ranging from no detectable concentration to 19.6% v/v. Methane concentrations show significant variability with absence of methane at all locations between July and November 2016. This variability is also seen with carbon dioxide, although non-zero concentrations are typically observed over this period. No measureable flow was recorded with the exception of 0.4l/hr in G09 and 0.3l/hr in BH06 on 05.04.2016.

G11 located to the west of the site did not record any detectable concentrations of methane for the duration of the monitoring period. G09 and BH06 are located to the east and south of the historic landfill however it should be noted that they are located in close proximity to the lateral extent of the waste body and not c.20m from the waste extent as proposed by best practice. Access was restricted within these locations due to ownership restrictions and minimisation of impact to local crops. Borehole logs for G09 and BH06 did not record the presence of any waste however these monitoring locations could be considered peripheral rather than offsite perimeter locations.

5 TIER 3 REFINEMENT OF CSM AND QUANTITATIVE RISK ASSESSMENT

5.1 REFINEMENT OF CONCEPTUAL SITE MODEL

Following the completion of the Tier 2 Investigation and Testing, a refined CSM was prepared for each site and is summarised in the cross sections provided in **Figure 20** to **23**, with the position of each conceptual cross section shown in **Figure 17**. The refined CSM is based on the Tier 1 information (i.e. regional geological and hydrogeological data from the GSI) and results of the site investigation and associated environmental monitoring (i.e. dataset for trial pits, boreholes, geophysical survey, quality data and groundwater levels).

5.1.1 Local Hydrogeological Setting

All five waste bodies are situated within a thick sequence of sand and gravel deposits that form the principal aquifer unit in the local area. Each waste body is overlain by a clay cap which is approximately 1 to 2m thick although its integrity is questioned following observations with respect to landfill gas emissions.

The sands and gravels are a glacial outwash deposits that comprise glaciofluvial and glaciolacustrine sediments formed as part of the Fassaroe Delta. The sediments are arranged in the typical delta sequence: topset gravels composed of up to 2m depth of horizontally bedded gravels on top; foreset gravels which are steeply dipping and well bedded deposited at the front of the delta; and bottomset, finer sediments of sands and silts, usually underlying the foresets and representing sediment that was originally deposited beyond the steep delta front on the sea floor. The thickness of the sand and gravel unit was not established during the drilling programme as it extended below the maximum reach of the drilling rig on site (35m below ground level). However, bedrock outcrop was noted in the river bed to the north of the site, the County Brook River (Fassaroe Stream) at an elevation of approximately 55mAOD.

The underlying bedrock consists of Ordovician Metasediments of the Maulin Bedrock Formation which are characteristically composed of dark blue-grey slate, phyllite & schist. The Maulin Formation is classified by the GSI as a locally important, moderately productive bedrock aquifer in local zones (Ll).

A significant depth of unsaturated sand and gravel deposits is characteristic of the areas surrounding each for the former landfill sites. The position of the waste mass with respect to groundwater levels is as follows:

- Site 1: Unsaturated sand and gravel deposits beneath waste mass;
- Site 2: Majority of waste body underlain by unsaturated sand and gravel deposits with the exception of most northerly parts of waste mass possibly intercept groundwater table;
- Site 3A: Majority of waste body underlain by unsaturated sand and gravel deposits with the exception of most northerly parts of waste mass possibly intercept groundwater table;
- Site 3B: Unsaturated sand and gravel deposits beneath waste mass;
- Site 3C: Base of the waste mass appears to intercept the top of the groundwater table across the majority of the site.

The unconsolidated sand and gravel deposits are principally composed of limestone from the Irish Midlands. The sand and gravel deposits form part of the Enniskerry gravel aquifer body, which is designated a locally important gravel aquifer with a WFD status of "Good".

The bedrock is characterised by a significantly lower transmissivity than the overlying sand and gravel deposits. It is therefore assumed that the contact bedrock constitutes the hydraulic base to the overlying granular sand and gravel aquifer system.

The groundwater flow regime at Fassaroe is that of a shallow, unconfined, largely granular aquifer system with groundwater flow directions generally reflecting the surface topography. A groundwater contour map for the local system is presented in **Figure 18**, based on water levels measured on the 29th of March 2016. This figure confirms that a water-table is present within the sand and gravel deposits, and groundwater flow direction at all sites is ultimately towards the County Brook River (Fassaroe Stream) to the north and northeast. The hydraulic gradient steepens towards the valleys and is flatter on the plateau. Groundwater underlying the site constitutes an important water environment receptor, although no private or public or private water supplies situated down-hydraulic gradient from the former landfill sites.

The nearest surface water receptor is the County Brook River (Fassaroe Stream) which cuts a steep gorge (up to 40m deep) through the gravel deposits. Flow in the river is estimated to be approximately 20L/s based on the river catchment area and proportional weighting from adjacent flow monitoring locations on the River Dargle. The river is a tributary of the River Dargle, which it joins approximately 1km downstream of the site and ultimately flows into the Irish Sea at Bray, a further 2km downstream.

The nearest sensitive site is the Ballyman Glen SAC (Site Code: 000713), adjacent to the County Brook River (Fassaroe Stream), selected for petrifying springs with tufa formation and alkaline fens. Lateral groundwater flow emerges as springs and/or seepages that feed the channels in which tufa deposition occurs and cross the alkaline fen. This confirms that the Ballyman Glen constitutes a Groundwater Dependant Terrestrial Ecosystems (GWDTE) under the WFD.

5.1.2 Current and Future Development of the Fassaroe Site

The general location and setting is characterised by one off housing developments in a predominantly agricultural setting. One off housing and commercial/agricultural buildings are located within the vicinity of Sites 2 and 3C. A sports ground and associated facilities are located in lands immediately to the east of Site 3B.

The five landfill sites are located within the area of Fassaroe, Bray, Co. Wicklow which is zoned for major new development under the Draft Bray Municipal District Local Area Plan 2018. The lands are zoned for residential high density (R-HD) new development with existing residential (RE), open space (OS1 and OS2), active open space (AOS), and neighbourhood centre (NC)[1].

It is anticipated that development of infrastructure would be undertaken outside of the landfill areas which would be incorporated into the overall development proposal as open space/amenity use.

[1] Bray Municipal District Local Area Plan 2017 Land Use Zoning Map, Map No. 2 DRAFT.

SITE INVESTIGATION CO-ORDINATES		
ID	X Co-ordinate	Y Co-ordinate
Surface Water Monitoring Locations		
SW1	724137.00	718407.00
SW2	723733.00	718594.00
SW3	723598.00	718560.00
SW4	722837.00	718475.00
SW5	722609.00	718667.00

SITE INVESTIGATION CO-ORDINATES		
ID	X Co-ordinate	Y Co-ordinate
Spring Locations		
Spring 1	724052.00	718436.00
Spring 2	723554.00	718552.00
Spring 3	723365.00	718567.00
Spring 4	723200.00	718486.00
Spring 5	723100.00	718489.00
Spring 6	723038.00	718488.00
Spring 7	722982.00	718476.00
Spring 8	722842.00	718471.00
Spring 9	722780.00	718489.00
Spring 10	722783.12	718446.41

LEGEND

- ESB Overhead (38 kv)
- ESB Overhead (110kv)
- ESB Overhead (220kv)
- ESB Overhead (400kv)
- ESB Overhead (LV)
- ESB Overhead (MV)
- ESB Underground (38kv)
- ESB Underground (MV & LV)
- ESB Underground (Spare)
- Extent of Waste
- Special Areas of Conservation (SAC's)
- Watermain

Site Investigation

- MW1 Existing Boreholes
- G01 Gas Monitoring Borehole
- LG01 Combined Gas/Leachate Monitoring Boreholes (Rotary)
- LG02 Combined Gas/Leachate Monitoring Boreholes (Cable Percussive)
- Combined Gas/Leachate Monitoring Boreholes (Cable Percussive with Rotary follow on)
- BH01 Combined Groundwater/Gas Monitoring Boreholes
- SW1 Surface Water Monitoring Location
- Spring 1 Spring Location
- SP1 Spring Sampling Location

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F01	May'16	RH / LD	FINAL ISSUE	CC

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Date	May 2016
Scale	1:2500 @ A1 1:5000 @ A3
Job No.	MDR1206

Project: **FASSAROE HISTORIC LANDFILL**

Title: PLAN SHOWING CROSS SECTION LOCATIONS SPRINGS, & MONITORING LOCATIONS

File Ref. MDR1206FG0017F02.dwg | Drg. No. Figure 17 | Rev. F02

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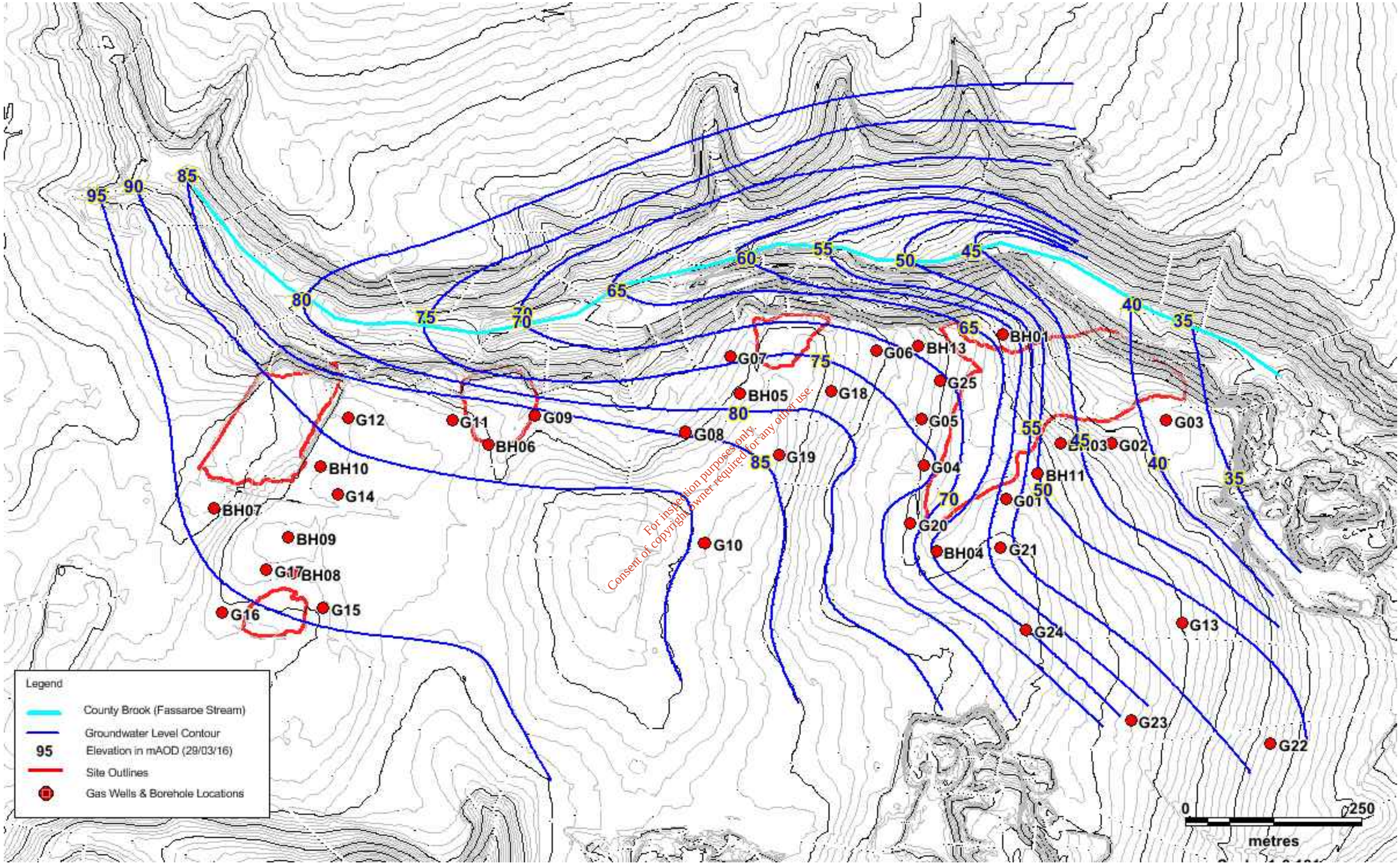

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Date	May 2016
Scale	NTS @ A1 NTS @ A3

Project
FASSAROE HISTORIC LANDFILL

Title
GROUNDWATER CONTOUR MAP

Job No.	File Ref.	Drg. No.	Rev.
MDR1206	MDR1206FG0018F02.dwg	Figure 18	F02

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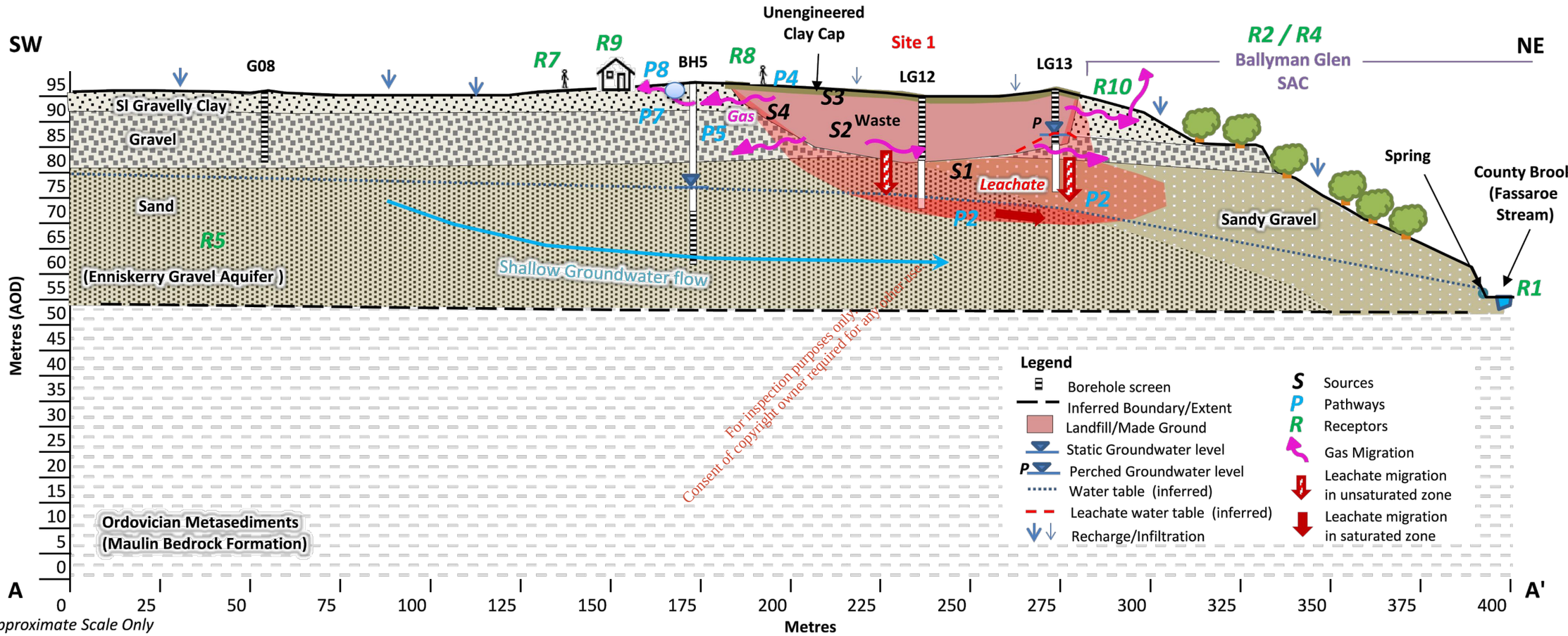
5.1.3 Site 1

The section (A-A') represented in **Figure 20** traverses the site from southwest to northeast. The section extends beyond the site boundary from the up-gradient boreholes G08 and BH5 to the County Brook River (Fassaroe Stream).

5.1.3.1 Source

The waste mass at Site 1 (Source S2) has been well defined though a series of site investigations including the site walk-over, trial pits, boreholes and geophysical surveys. The waste material is dominantly comprised of C&D waste with pockets of municipal waste. The maximum measured depth of waste is 14mbgl with an estimated area of 0.53 Ha. There may be a locally perched leachate towards the northern extent of the waste body (Source S1) as indicated by LG13.



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Scale	NTS @ A1 NTS @ A3
Job No.	MDR1206

Project: FASSAROE HISTORIC LANDFILL

Title: CONCEPTUAL SITE MODEL SITE 1

File Ref.	Drg. No.	Rev.
MDR1206FG0020F02.dwg	Figure 19	F02

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Based on lateral and vertical extent as defined by site investigations, an estimated 110,000 tonnes of waste is present at Site 1 (using a conversion factor for metres cubed to tonnes of 1.5 for inactive or inert waste (comprising sand, subsoil, concrete, bricks, fiberglass etc.)[2]).

WAC test analyses for samples from Site 1 recorded elevated concentration of pH, total organic carbon, antimony, total PCBs (7 congeners) and sulphate (see Section 4.7.1 for further details).

Geophysical survey results suggest that lower levels of the leachate plume have reached as far as 10 metres below the depth of waste at Site 1. Leachate samples from borehole LG11 highlighted the exceedances above the Groundwater Threshold Values (GTV) (S.I. 9 of 2010) and/or the Interim Guidelines Values (IGV) (EPA 2003) for several metals and major ions, as well as the detection of hydrocarbons and small number of trace organic compounds. The list of all contaminants of potential concern for the site is summarised in Section 6.1.3.

Analysis for the potential presence of Asbestos Containing Materials (ACMs) was completed at Site 1 with one fragment of asbestos cement encountered within the waste mass (Source S3).

See Section 6.1.2 for source contaminants from human health assessment.

Landfill gas (Source S4) was recorded at Site 1 methane concentrations up to 13.6% v/v and carbon dioxide concentrations up to 18.9% v/v.

5.1.3.2 Pathways

The waste mass at Site 1 is located above the water-table with an unsaturated zone thickness of over 5 m. The unsaturated sand and gravel deposits provide both a lateral (Pathway P5) and vertical migration pathway (Pathway P7) for landfill gas generated at the source.

The vertical pathway for leachate generation is driven by direct rainfall percolating through the waste body. The infiltrating water is considered likely to travel to the north-east through higher permeability horizons within the waste mass. Leachate then pools within the base of the waste mass in the north-eastern portion of Site 1 (LG13) from where it percolates into the underlying unsaturated and sand gravel deposits.

Upon reaching the water table, leachate mixes with groundwater in the sand and gravel aquifer. The saturated aquifer then provides both lateral and vertical (downward) migration pathways for leachate mixed with groundwater (Pathway P2). No evidence of free phase contamination has been identified during the works. The groundwater flow within the sand and gravel deposits is orientated in a north-easterly direction towards the County Brook River (Fassaroe Stream) and associated drainage system within the SAC.

Multiple springs and seepages have been mapped along the river valley. The spring flows are relatively small and often emerge as diffuse up-wellings which then coalesce downstream to form more defined riparian drains. Spring 2 (SP2) is situated in a position that is likely to be down-hydraulic gradient from Site 1. Spring 2 is characterised by clear water, tufa formation and high (mildly-alkaline) pH above 7.0 with little evidence of impact on chemical quality.

[2] S.I. No. 189/2015 – Waste Management (landfill Levy) Regulations 2015

There is considered to be a general absence of a formal surface water drainage system that directly connects Site 1 with the County Brook River (Fassaroe Stream) and the SAC in the river valley, hence Pathway P1 and Pathway P3 are not considered relevant to Site 1.

The existing 33" water main runs in a north south direction to the east of the waste infill area and could provide a potential pathway for landfill gas (Pathway P8).

The site currently comprises scrub and debris and is not in regular use therefore dermal contact, ingestion and inhalation pathways (Pathway P4) are considered unlikely.

5.1.3.3 Receptors

The receptors for Site 1 include: the County Brook River (Fassaroe Stream) (Receptor R1); the Ballyman Glen SAC (Receptor R4 / R2); the underlying sand and gravel aquifer system (Receptor R5); existing and future site users (Receptor R7); and existing, and any future off site buildings and structures (Receptor R9). No private or public groundwater supply sources are present down-hydraulic gradient from Site (Receptor R3 and R6).

5.1.4 Site 2

The section (B-B') represented in **Figure 21** traverses Site 2 from southwest to northeast. The section extends beyond the site boundary from the up-gradient borehole G20 to the County Brook River (Fassaroe Stream).

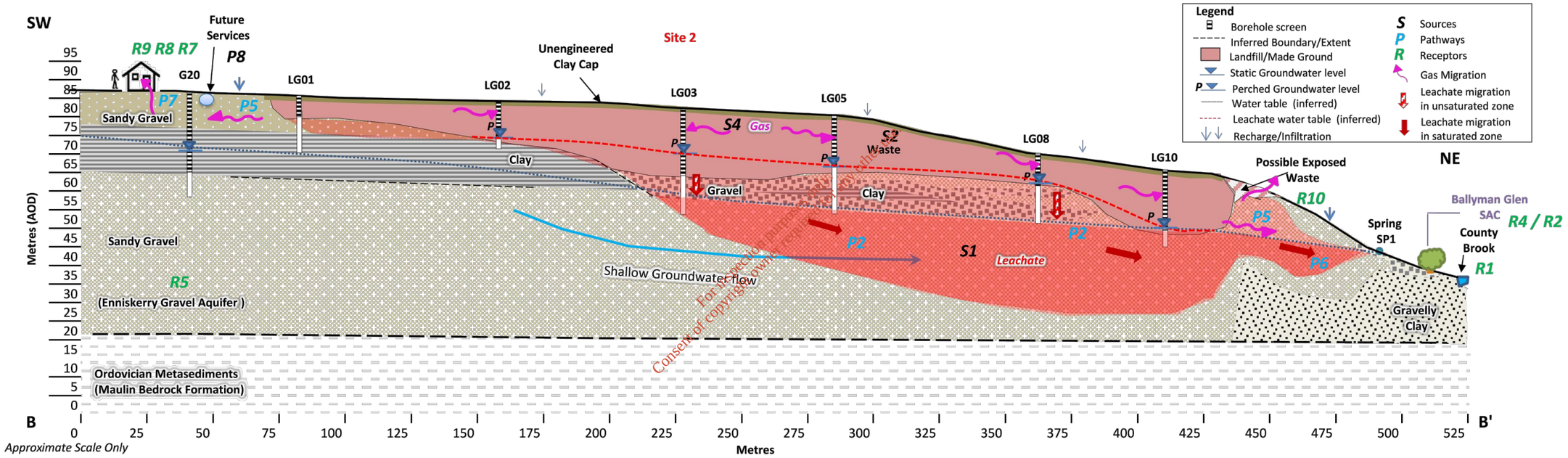
5.1.4.1 Source

The waste mass at Site 2 (Source S2) has been well defined though a series of site investigations including the site walk-over, trial pits, boreholes and geophysical surveys. The waste material is dominantly comprised of municipal waste with a maximum measured depth of 19mbgl and an estimated area of 4.5 Ha. An estimated c.340,000 tonnes of waste is present at Site 2 (based on a conversion factor for metres cubed to tonnes of 0.4 for compacted household waste[3]).

WAC test analyses from waste samples recorded exceedances of pH, TOC, antimony, sulphate, molybdenum and Total Dissolved Solids (TDS) (see Section 4.6.1 for further detail).

A discrete leachate body has been identified in the waste mass (e.g. LG03 and LG10) and geophysical survey results suggest that the leachate plume (Source S1) has reached as far as 40 metres below the depth of waste, particularly to the north-east at Site 2. Leachate samples taken at 5 leachate boreholes (LG01, LG03, LG7, LG09 and LG10) highlighted the exceedances above the GTVs and/ or the IGVs for several metals and major ions, as well as the detections of hydrocarbons and small number of trace organic compounds. The list of all contaminants of potential concern for the site is summarised in Section 6.1.3.

[3] S.I. No. 189/2015 – Waste Management (landfill Levy) Regulations 2015



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Date	May 2016
Scale	NTS @ A1 NTS @ A3
Job No.	MDR1206

Project: FASSAROE HISTORIC LANDFILL

Title: CONCEPTUAL SITE MODEL SITE 2

File Ref.	Drg. No.	Rev.
MDR1206FG0020F02.dwg	Figure 20	F02

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