See section 6.1.2 for soil exceedances from human health assessment. The monitoring dataset for landfill gas (Source S4) 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 with variable flow rates of between -6.2 l/hr to +7.6 l/hr.

5.1.4.2 Pathways

Most of the waste mass at Site 2 is located above the water-table with an unsaturated zone thickness of greater than 5m. The unsaturated sand and gravel deposits provide both lateral and vertical migration pathways via pore spaces for landfill gas generated at the site (Pathway P5 and Pathway P7 respectively).

The vertical pathway for leachate generation is driven by direct rainfall percolating through the waste body. A discrete leachate body has been identified in the waste mass (e.g. LG03 and LG10). The pathway for leachate migration is expected to be complex, as leachate will percolate through more permeable areas of the perching layer at the base of the waste mass, through the underlying unsaturated zone to the saturated sand gravel deposits at depth where it will mix with groundwater.

The low elevation of the waste body in the north of Site 2 suggests that leachate and groundwater may be in hydraulic continuity. This indicates a potential lateral pathway for soluble gases in groundwater (Pathway P6), although clay layers identified between the base of the waste and the deeper gravels may act as a confining layer causing the leachate to be perched above groundwater. It appears that the clay layers are largely absent to the north, with the leachate levels and groundwater head coincident as indicated by LG10. Leachate from the landfill site may also contain dissolved gases or may potentially degrade during migration to produce methane and carbon dioxide. Dissolved gas concentrations measured during Round 2 did identify elevated carbon dioxide (30 mg/l in BH1) but the absence of methane.

Upon reaching the water-table, the sand and gravel aquifer system provides both lateral and vertical migration pathways for leachate through groundwater (Pathway P2). The groundwater flow within the saturated sand and gravel aquifer is in a north-easterly direction towards the County Brook River (Fassaroe Stream) and SAC.

Multiple springs and seepages have been mapped along the river valley. Springs are often associated with tufa type deposition. Spring flows are relatively small and often occur as diffuse up-wellings which coalesce downstream to form a more defined channel. Ochre staining was observed in some springs situated in close proximity to Site 2, most notably Spring SP1. These springs represent the point of emergence from the groundwater pathway at surface and then discharge to the drainage system within the SAC that ultimately reaches Country Brook River (Fassaroe Stream). Spring 1 is characterised by the absence of tufa, ochre staining, sheening and elevated concentrations of certain contaminants of concern, principally in Round 1.

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 2.

Site 2 is currently in agricultural use and utilised for grazing. The site is therefore in use by animals, farmers and walkers. Potential pathways for dermal contact and inhalation are considered likely (Pathway P4). The proposed development proposes a road alignment through the southern margin of Site 2 which may result in the potential development of additional pathways for landfill gas migration through the road structure and associated service/utility routings (Pathway P8).

5.1.4.3 Receptors

The receptors for Site 2 include: the County Brook River (Fassaroe Stream) (Receptor R1); the Ballyman Glen SAC (Receptor R4 / R2); the underlying sand and gravel aquifer (Receptor R5); current and future site users (Receptor R7); and existing and proposed offsite buildings and structures (Receptor R9). No private or public groundwater supply sources are present down-hydraulic gradient from Site (Receptor R3 and R6).

5.1.5 Site 3A

The section (C-C') represented in **Figure 22** traverses Sites 3A and 3B from south to north. The section extends beyond 3A site boundary through boreholes BH08 and BH09 and Site 3A up to the County Brook River (Fassaroe Stream).

5.1.5.1 Source

The waste mass at Site 3A (Source S2) has been 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 16mbgl and an estimated area of 1.9Ha. An estimated c.120,000 tonnes of waste is present at Site 3A (based on a conversion factor for metres cubed to tonnes of 0.4 for compacted household waste[4]).

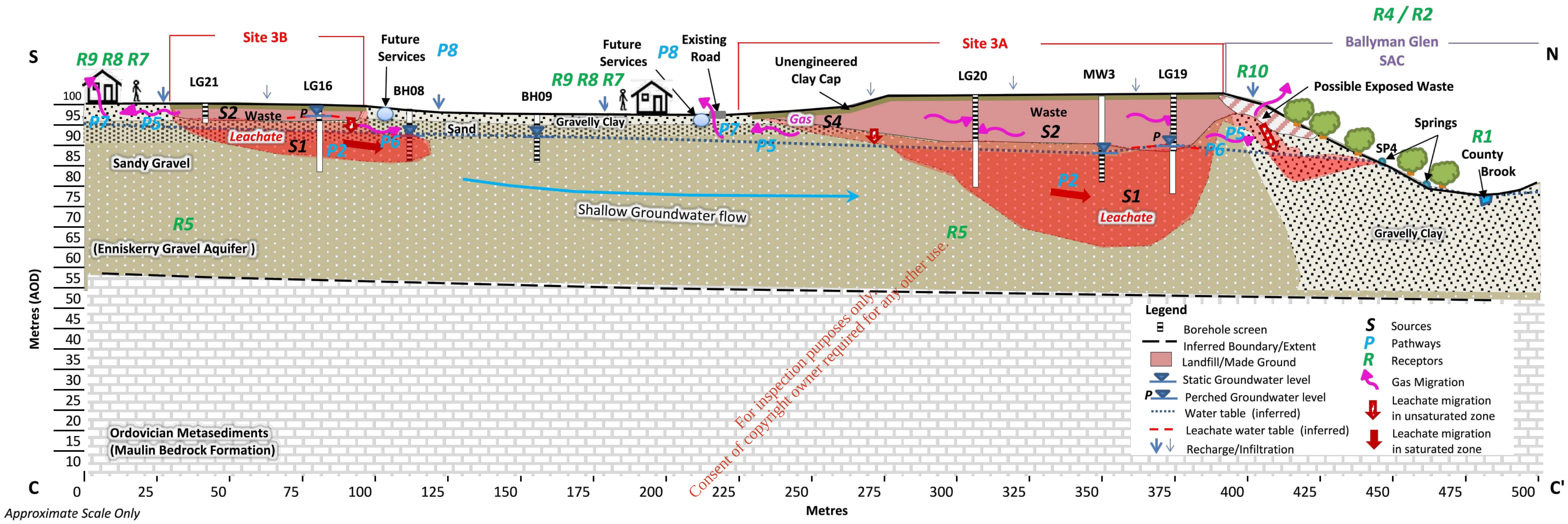
WAC test analyses recorded exceedances of pH, TOC, antimony, molybdenum and TPH (see Section 4.6.1 for further detail).

See Section 6.1.2 for soil exceedances from human health assessment.

The monitoring dataset for Landfill Gas for Site 3A (excluding MW3) identifies methane concentrations between 30 and 70 % v/v and carbon dioxide concentrations 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. These results are considered to be consistent with a waste mass which is still degrading and producing large volumes of gas under pressure driven conditions (Source S4).

The waste body at Site 3A generally appears to be unsaturated with leachate restricted to the north of the site. This suggests the downward migration of leachate and mixing with groundwater at the water table. Geophysical survey results suggest that the leachate plume (Source S1) has reached as far as 20 metres below the depth of waste at Site 3A. Leachate samples taken at 3 leachate boreholes (MW4, LG15 and LG19) at Site 3A highlighted the exceedances above the GTVs and/ or IGVs for several metals and major ions, as well as the detections of hydrocarbons and several trace organic compounds. The list of all contaminants of potential concern for the site is summarised in Section 6.1.3.

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



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

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

Project

FASSAROE HISTORIC LANDFILL

Title

CONCEPTUAL SITE MODEL
SITES 3A & 3B

File Ref.	Drg. No.	Rev.
MDR1206FG0021F02.dwg	Figure 21	F02

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5.1.5.2 Pathways

The waste body at Site 3A generally appears to be unsaturated with leachate restricted to the north of the site. Groundwater appears to be located immediately beneath the landfill site, although a thin unsaturated zone may be present, with leachate mixing with groundwater at the water table. An unsaturated zone within the sand and gravel would provide both lateral and vertical migration pathways via pore spaces for the landfill gas generated at the site (Pathway P5 and P7). In the north of Site 3A, leachate and groundwater may be in hydraulic continuity. This indicates a potential lateral pathway for soluble gases in groundwater (Pathway P6). Dissolved gas analysis undertaken in Round 2 did not identify dissolved gases in groundwater although the dataset is limited (i.e. BH7, BH9 and BH10).

The vertical pathway for leachate generation is driven by the direct percolation of rainfall through the waste body. Infiltrating water is considered to travel northwards through the higher permeability sections of the waste mass. The leachate then pools within the base of the waste in the northern portion of Site 3A (LG19), and from there percolates into the underlying unsaturated sand and gravel deposits where it mixes with groundwater. Upon reaching the water-table, the sand and gravel aquifer provides both vertical (downward) and lateral migration pathway for leachate through groundwater (Pathway P2).

The general groundwater flow within the sand and gravel aquifer is to the north-easterly direction towards County Brook River (Fassaroe Stream) and the SAC. Multiple springs and seepages have been mapped along the river valley. The springs are often associated with tufa deposits. Spring flows are relatively small and often occur as diffuse up-wellings which coalesce downstream to form a more defined channel. Ochre staining was observed in some springs close to Site 3A, most notably Spring SP4 although spring SP4 is characterised by clear waters, low EC and tufa formation.

There is considered to be a general absence of a formal surface water drainage system that directly connects Site 3A 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 3A.

The site is currently not in use and generally comprises scrub therefore dermal contact, ingestion and inhalation pathways (Pathway P4) are considered unlikely, although waste is exposed in the north.

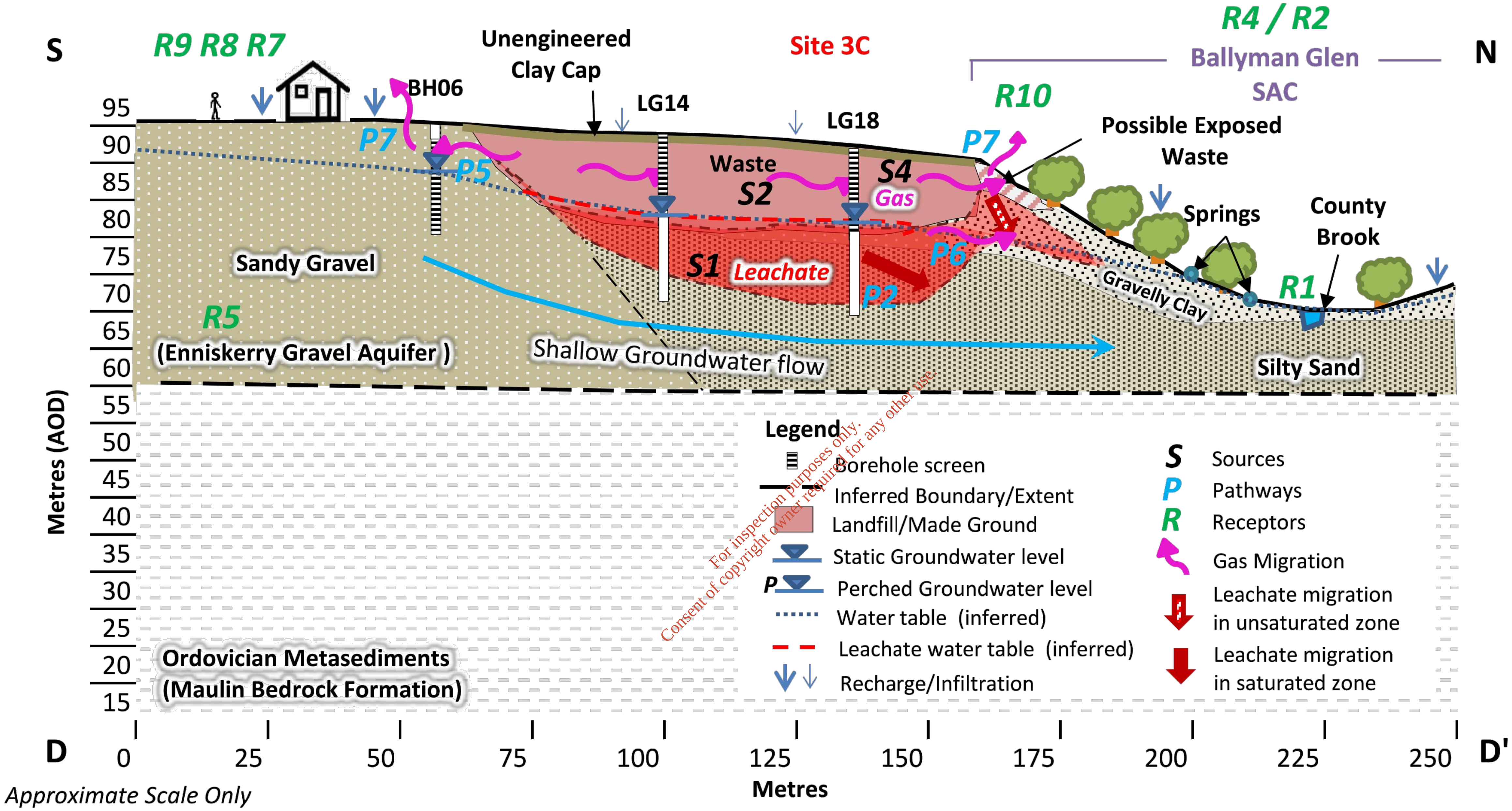
5.1.5.3 Receptors

The receptors for site 3A include: the County Brook River (Fassaroe Stream) (Receptor R1); the Ballyman Glen SAC (Receptor R4)/R2; the underlying sand and gravel aquifer (Receptor R5); current and future site users (Receptor R7): and offsite buildings and structures (Receptor R9). No private or public groundwater supply sources are present down-hydraulic gradient from Site (Receptor R3 and R6).

5.1.6 Site 3B

The conceptual site model for Site 3B is illustrated (as part of section C-C') in **Figure 22**.

5.1.6.1 Sources



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Project

FASSAROE HISTORIC LANDFILL

Title

CONCEPTUAL SITE MODEL
SITE 3C

File Ref.	Drg. No.	Rev.
MDR1206FG0022F02.dwg	Figure 22	F02

The waste mass at Site 3B (Source S2) has been well defined though a series of site investigations including the site walk-over, trial pits, boreholes and geophysical surveys. The relatively shallow waste material is dominantly comprised of municipal waste with a maximum measured depth of 4.9mbgl with an estimated area of 0.44Ha. An estimated c.8,500 tonnes of waste is present at Site 3B, based on a conversion factor for metres cubed to tonnes of 0.4 for compacted household waste[5].

WAC test analyses recorded exceedances of pH, TOC, antimony, molybdenum and TPH (see Section 4.6.1 for further detail). See Section 6.1.2 for soil exceedances from human health assessment.

Leachate is thought to be present within the base of the waste in the norther portion of Site 3B (LG16) (Source S1). Geophysical survey results suggest that the leachate plume has reached as far as 15 metres below the depth of waste at Site 3B. Leachate samples taken at LG17 highlighted the exceedances above the Groundwater Threshold Values (S.I. 9 of 2010) or the Interim Guidelines Values (EPA 2003) for several metals and major ions, as well as the detections of hydrocarbons and a small number of trace organic compounds. The list of all contaminants of potential concern for the site is summarised in Section 6.1.3.

The landfill gas monitoring dataset collected for 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 (Source S4). 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.

5.1.6.2 Pathways

The groundwater table at Site 3B is located at shallow depth, however it appears that the waste body is perched above the water table. Some deeper portions of the waste body are expected to be saturated to the north, where groundwater is intercepted. The unsaturated sand and gravel deposits can provide both lateral and vertical migration pathways for generated landfill gas at the site (Pathway P5 and P7). The saturated waste located to the north of the site could result in the migration of dissolved gas in groundwater (Pathway P6).

The vertical pathway for leachate generation is driven by direct percolation of rainfall through the waste body. Infiltrating water is considered to travel northwards, via higher permeability horizons within the waste mass. The leachate may then pool within the base of the waste in the northern portion of Site 3B (LG16) from where it can percolate into the underlying unsaturated sand and gravel deposits. Upon reaching the water table and mixing with groundwater, the sand and gravel aquifer provides both lateral and vertical migration pathways for leachate through groundwater (Pathway P2).

The general groundwater flow within the sandy gravel deposits is in a north-easterly direction towards the County Brook River (Fassaroe Stream). Multiple springs and seepages have been mapped along the river valley. The springs and seepages are often associated with tufa deposits. Spring flows are relatively small and often occur as diffuse up-wellings which coalesce downstream to form more defined channels.

[5] 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 the landfills 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 3B.

Site 3B is currently in agricultural use and utilised for grazing. The site is therefore in use by animals, farmers and walkers and is located adjacent to Enniskerry FC consequently the potential pathways for dermal contact and inhalation (Pathway P4) are considered likely.

5.1.6.3 Receptors

The receptors for both sites include: the County Brook River (Fassaroe Stream) (Receptor R1); the underlying sand and gravel aquifer (Receptor R5); existing and proposed site users (Receptor R7); adjacent site users (including adjacent football pitch) (Receptor R7); existing and any future offsite buildings and structures (Receptor R9). No private or public groundwater supply sources are present down-hydraulic gradient from Site (Receptor R3 and R6).

5.1.7 Site 3C

The section (D-D') represented in **Figure 23** traverses Site 3C from south to north. The section extends beyond the site boundary from the up-gradient boreholes BH06 to the County Brook River (Fassaroe Stream).

5.1.7.1 Source

The waste mass at Site 3C (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 13mbgl and an estimated areal extent of 0.9 Ha. An estimated c. 47,000 tonnes of waste is present at Site 3C, based on a conversion factor for metres cubed to tonnes of 0.4 for compacted household waste[6].

WAC test analyses recorded exceedances of pH, TOC, antimony, molybdenum, TDS, lead, TPH, mercury, nickel, selenium and chloride (see Section 4.6.1 for further detail). See Section 6.1.2 for soil exceedances from human health assessment.

Geophysical survey results suggest the leachate plume (Source S1) has reached as far as 20 metres below the depth of waste at Site 3C. Leachate samples taken at 2 leachate boreholes (LG14 and MW2) highlighted the exceedances above the Groundwater Threshold Values (S.I. 9 of 2010) or the Interim Guidelines Values (EPA 2003) for several metals and major ions, as well as the detections of hydrocarbons and several trace organic compounds. The list of all contaminants of potential concern for the site is summarised in Section 6.1.3.

The monitoring dataset for Landfill Gas (Source S4) 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 typically stable with a concentration between 60% v/v and 75% v/v. Similarly the carbon dioxide concentration typically exceeds 25%. Flow readings are typically low (i.e. below 2 L/hr).

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

5.1.7.2 Pathways

The base of the waste mass appears situated beneath the water table in the underlying sand and gravel aquifer. The saturated aquifer therefore provides both lateral and vertical migration pathways for leachate migration (Pathway P2) and dissolved gas through groundwater (Pathway P6). The general groundwater flow within the sandy gravel deposits is in a northeast direction towards the river. Surrounding unsaturated sands and gravel zone can provide both lateral and vertical migration pathways for generated landfill gas at the site (Pathway P5 and Pathway P7).

Multiple springs and seepages have been mapped along the river valley. The springs are often associated with tufa deposits. The spring flows are relatively small and often emerge as diffuse up-wellings which then coalesce downhill to form a more defined channel. Spring SP3 is situated down gradient of Site 3C ad is characterised by clear waters and tufa formation.

Site 3C is currently not in regular use and generally comprises scrub, therefore potential pathways for dermal contact and inhalation (Pathway P4) are considered unlikely however is should be noted that there are a number of buildings located immediately to the south of the site which are in use/occupied and the potential for gas migration to such should be considered further by the Local Authority.

There is considered to be a general absence of a formal surface water drainage system that directly connects Site 3C 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 3C.

5.1.7.3 Receptors

The receptors for Site 3C include: the County Brook River (Fassaroe Stream) (Receptor R1); the Ballyman Glen SAC (Receptor R4 / R2); the underlying sand and gravel aquifer (Receptor R5); existing and future site users and existing (including adjacent occupied properties) (Receptor R7); any future offsite buildings and structures (Receptor R9). No private or public groundwater supply sources are present down-hydraulic gradient from Site (Receptor R3 and R6).

5.2 REFINEMENT OF RISK SCREEENING & PRIORITISATION

A Tier 3 Refinement of Risk Screening exercise presented in Section 4 has been conducted for all sites to confirm the initial risk ranking assigned in the Risk Assessment Methodology Tier 1: Conceptual Site Model, Risk Screening and Prioritisation.

5.2.1 Revised Conceptual Site Model

The risk screening has been further developed based on the findings of the additional site investigation and testing and the subsequent refinement of the CSM. The revised site wide risk model (covering all 5 historic landfills) is based on the subdivisions of SPR linkages as set out in the initial CSM (Section 3.6). The CSM has been presented for the current Baseline Conditions defined on the site through Tier 2 investigation (**Table 5.1 – Revised Risk Site Wide Model (Baseline Conditions – No Development)Table 5.1**) and for baseline conditions with the Proposed Development (Table **5.2**). The site wide risk model takes account of the worst case for each SPR linkage.

Table 5.1 sets out the risk model, following detailed site investigations, for the 5 historic landfills for the existing pre-development scenario. **Table 5.2** details the risk model, following detailed site investigations, for future, post development, scenario with no mitigation measures in place.

Table 5.1 – Revised Risk Site Wide Model (Baseline Conditions – No Development)

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
S1	Leachate	P1	Vertical to groundwater then horizontally through possible surface water drainage channels into the river	R1	WFD Surface Water Body	None	Medium	No Risk	A formal Surface Water drainage system that directly connects the 5 landfill sites to the SAC and/or County Brook River has not been identified, pollutant linkage does not exist. Groundwater does emerges at the down-gradient springs which then form as riparian drains leading to the river and this is considered as part of pathway P2.
				R2	Surface Water Protected Area	None	Medium	No Risk	
		P2	Vertical & Horizontal via Groundwater	R3	Private Wells	None	Medium	No Risk	There are no known private wells along the leachate plumes (water main connection in the area)
				R4	Groundwater Dependent Terrestrial Ecosystem (GWDTE)	Highly Likely	Severe	High Risk	GWDTE present, location of alkaline fens and tufa sites identified by ecologists within the Ballyman Glen SAC. Sites are down-gradient of landfill Sites 1, 3A and 3C. Water quality at a number of the springs appears to have been affected by leachate migration from some of the landfill sites. Although not proven these effects may have had a direct effect on the tufa forming potential within these riparian streams.
				R5	Aquifer	Highly Likely	Medium	Moderate Risk	The underlying bedrock and gravel aquifers are at risk by direct connection
				R6	Public Supply Well	None	Mild	No Risk	There are no public water supply wells in the area.
				R1	Surface Water Body	Likely	Medium	Moderate Risk	The County Brook River (Fassaroe Stream) is at risk
		P3	Surface Water Drainage	R1	Surface Water Body	None	Medium	No Risk	There are no surface water drainage channels in the area, however at Site 2 there is seepage from exposed waste at collapsed river bank observed at one down-gradient location
				R2	Surface Water Protected Area	None	Medium	No Risk	

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
S2	Waste	P4	Direct dermal contact Ingestion dust and soil Inhalation of dust	R7	Current and Future Site Users	Unlikely	Mild	Very Low Risk	Sites 1, 3A and 3C are currently not in use. Currently minimal clay cap in place.
				R8	Construction Workers	Unlikely/Low Likelihood	Minor	Very Low Risk	Sites 1, 3A and 3C are currently not in use. Currently minimal clay cap in place.
S3	ACM	P4	Direct dermal contact Ingestion dust and soil Inhalation of dust	R7	Current and Future Site Users	Unlikely	Severe	Low/ Moderate Risk	Shallow soil sampling recorded a single detection of ACM in Site 1 – no detections were recorded at the remaining sites.
				R8	Construction Workers	Unlikely	Severe	Low/Moderate Risk	Shallow soil sampling recorded a single detection of ACM in Site 1 – no detections were recorded at the remaining sites.
S4	Landfill Gas	P5	Lateral Migration Subsoil	R7	Current and Future Site Users	Low Likelihood	Mild	Low Risk	Monitoring indicates that all sites are actively gassing. Offsite gas monitoring completed. The age, extent, volume and composition of waste is known. Potential for ingress to existing buildings and structures. Potentially, landfill gas migration could occur into existing adjacent buildings through cracks within the floor slab construction and/or around service/utility routes. Risks associated with gas migration into existing buildings should be considered further by the Local Authority.
				R8	Construction Workers	Likely	Severe	High Risk	
				R9	Adjacent Buildings and Structures	Low Likelihood/Likely	Severe	Moderate/ High Risk	
				R10	Non Designated Land	Low Likelihood/Likely	Minor	Very Low/Low Risk	
S4	Landfill Gas	P6	Lateral Migration Groundwater	R7	Current and Future Site Users	Unlikely	Mild	Very Low Risk	Landfill gas known to be present onsite. Offsite gas monitoring completed.
				R8	Construction	Unlikely/Low	Severe	Low/Modera	

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
					Workers	Likelihood		te Risk	Age, extent, volume and composition of waste. Groundwater and leachate levels established
				R9	Adjacent Buildings and Structures	Unlikely/Low Likelihood	Severe	Low / Moderate Risk	
S4	Landfill Gas	P7	Vertical Migration Subsoil	R7	Current and Future Site Users	Low Likelihood	Mild	Low Risk	Existing clay cap c.1-2m . The lack of an engineered cap will enable vertical migration of gas and atmospheric dispersion and dilution at surface. Landfill gas known to be present onsite however no credible dataset available. No offsite monitoring completed. Age, extent, volume and composition of waste known. Water level and effect on gassing regime known. Potential for ingress to existing buildings and structures. Vegetation die back noted.
				R8	Construction Workers	Likely	Severe	High Risk	
				R9	Adjacent Buildings and Structures	Low Likelihood/Likely	Severe	Moderate/High Risk	
				R10	Non Designated Land	Likely	Minor	Very Low /Low Risk	
S4	Landfill Gas	P8	Existing & Proposed Services Routes	R9	Adjacent Buildings and Structures	Low Likelihood/Likely	Severe	Low/Moderate Risk	Offsite gas monitoring known to have been completed.

Table 5.2 – Revised Risk Site Wide Model (Baseline Conditions with Development)

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
S1	Leachate	P1	Vertical to groundwater then horizontally through possible surface water drainage channels into the river	R1	Surface Water Body	None	Medium	No Risk	No change to this SPR linkage as a result of the proposed development.
				R2	Surface Water Protected Area	None	Medium	No risk	
		P2	Vertical & Horizontal via Groundwater	R3	Private Wells	Unlikely	Medium	Low Risk	There are no known private wells along the leachate plumes (water main connection in the area). No change following development.
				R4	GWDTE	Highly Likely	Severe	High Risk	No change to SPR linkage with proposed development. Tufa springs still impacted by leachate.
				R5	Aquifer	Likely	Medium	Moderate Risk	The underlying bedrock and gravel aquifers are at risk by direct connection.
				R6	Public Supply Well	None	Mild	No Risk	There are no public water supply wells in the area.
				R1	Surface Water Body	Likely	Medium	Moderate Risk	The County Brook River (Fassaroe Stream) is at risk
		P3	Surface Water Drainage	R1	Surface Water Body	Unlikely	Medium	Low Risk	There are no surface water drainage channels in the area, however at Site 2 there is seepage from exposed waste at collapsed river bank observed at one down-gradient location. The proposed development will route normal rainfall events from the housing and roads areas to soakaways as such there will be no substantial change in runoff. Excess inflow from storm events greater than 1 in 5year event will be discharge directly to surface
				R2	Surface Water Protected Area	Unlikely	Medium	Low Risk	

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
									water via attenuation ponds with not potential for contamination from the waste body. As such there are no material change to these SPR linkages as a result of the proposed development.
S2	Waste	P4	Direct dermal contact Ingestion dust and soil Inhalation of dust	R7	Current and Future Site Users	Unlikely	Mild	Very Low Risk	No change to SPR linkage with proposed development Sites 1, 3A and 3C are currently not in use. Currently minimal clay cap in place.
				R8	Construction Workers	Low Likelihood	Minor	Very Low Risk	Risk to construction workers during excavations should be mitigated by the use of appropriate PPE
S3	ACM	P4	Direct dermal contact Ingestion dust and soil Inhalation of dust	R7	Current and Future Site Users	Unlikely	Severe	Low/Moderate Risk	No change to SPR linkage with proposed development. Shallow soil sampling recorded a single detection of ACM in Site 1 – no detections were recorded at the remaining sites.
				R8	Construction Workers	Unlikely	Severe	Low/Moderate Risk	No change to SPR linkage with proposed development. Shallow soil sampling recorded a single detection of ACM in Site 1 – not detections were recorded at the remaining sites. Risk to construction workers during excavations should be mitigated by the use of appropriate PPE
S4	Landfill Gas	P5	Lateral Migration Subsoil	R7	Current and Future Site Users	Likely	Mild	Moderate Risk	Monitoring indicates that all sites are actively gassing. Offsite gas monitoring completed. Age, extent, volume and composition of waste known.
				R8	Construction Workers	Likely	Severe	High Risk	
				R9	Adjacent Buildings	Likely	Severe	High Risk	

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
					and Structures				Potential for exposure to construction workers during excavations.
				R10	Non-designated Land	Low Likelihood/Likely	Minor	Very Low/Low Risk	The installation of hardstand as part of the proposed development may promote off site lateral gas migration. Potential for ingress to existing and proposed buildings and structures. Potentially, landfill gas migration could occur into existing adjacent buildings through cracks within the floor slab construction and/or around service/utility routes. If the proposed development does not proceed risks associated with gas migration into existing buildings should be considered further by the Local Authority.
S4	Landfill Gas	P6	Lateral Migration Groundwater	R7	Current and Future Site Users	Unlikely	Mild	Very Low Risk	Landfill gas known to be present onsite. Offsite gas monitoring completed. Age, extent, volume and composition of waste. Groundwater and leachate levels established
				R8	Construction Workers	Unlikely/Low Likelihood	Severe	Low/ Moderate Risk	
				R9	Adjacent Buildings and Structures	Low Likelihood	Severe	Moderate Risk	
S4	Landfill Gas	P7	Vertical Migration Subsoil	R7	Current and Future Site Users	Low Likelihood	Mild	Low Risk	Existing clay cap c.1-2m . The lack of an engineered cap will enable vertical migration of gas and atmospheric dispersion and dilution at surface. No buildings proposed to be constructed on waste bodies. Landfill gas known to be present onsite however no credible dataset available. No
				R8	Construction Workers	Likely	Severe	High Risk	

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
				R9	Adjacent Buildings and Structures	Likely	Severe	High Risk	offsite monitoring completed. Age, extent, volume and composition of waste known. Water level and effect on gassing regime known. Potential for exposure to construction workers during excavations. Potential for ingress to existing and proposed buildings and structures. Vegetation die back noted.
				R10	Vegetation Stresses/Ecology	Likely	Minor	Very Low/Low Risk	
S4	Landfill Gas	P8	Existing & Proposed Services Routes	R9	Adjacent Buildings and Structures	Likely	Severe	Moderate Risk	Offsite gas monitoring known to have been completed. No buildings proposed to be constructed on waste bodies.

5.2.2 Revised Risk Classification

In light of the results of the Tier 2 investigation and the highest risk pollutant linkages identified in the updated CSM presented in **Table 5.1** the original risk classification has not been updated. Tier 3 Quantified Risk Assessments have however been undertaken to evaluate the risk associated with key pollutant linkages identified. -

6 TIER 3 QUANTITATIVE RISK ASSESSMENT

6.1 GENERIC QUANTIFIED RISK ASSESSMENT (GQRA)

6.1.1 Landfill Gas

The Department of the Environment published a document '*Protection of New Buildings and Occupants from Landfill Gas'* in 1994. This document outlines the high level requirements for landfill gas assessment and guidelines that should be considered.

The guidelines include a recommendation that *houses with private gardens should not be erected within 50m of any landfill site where the concentration of methane exceeds one per cent (1%) by volume or where the concentrations of carbon dioxide exceeds one-half per cent (0.5%) by volume or where the landfill still has the potential to produce large quantities of gas*. This recommendation is not based on a risk assessment approach.

It is now considered that this document is out of date, although it is noted that it has not been withdrawn and is still referenced as a guidance document. It has been superseded by CIRIA Report C665 which represents the current best practice guidance in relation to ground gas assessment. It should be noted that this document does not make any reference to minimum offset distances for developments. The purpose of the risk assessment based approach is to determine the appropriate mitigation measures to appropriately deal with the risk posed by the gas.

CIRIA Report C665 proposes a holistic approach to gas risk assessment, taking account of the following factors:

- Nature of source and migration pathway;
- Borehole flow rate and surface emission rate;
- Frequency and distribution of elevated gas concentrations;
- Nature of any future development; and
- Confidence and reliability of results.

In accordance with Section 8.1.2 of CIRIA C665 for closed landfill sites and Made Ground

> *The risk assessment approach discussed in Section 8.2 can be adopted to screen potential risks or classify the ranges of measured gas concentrations and emission rates. This will determine the type of protective measures in buildings, calculate the vent trench dimensions, or determine that development is not suitable for the location.*

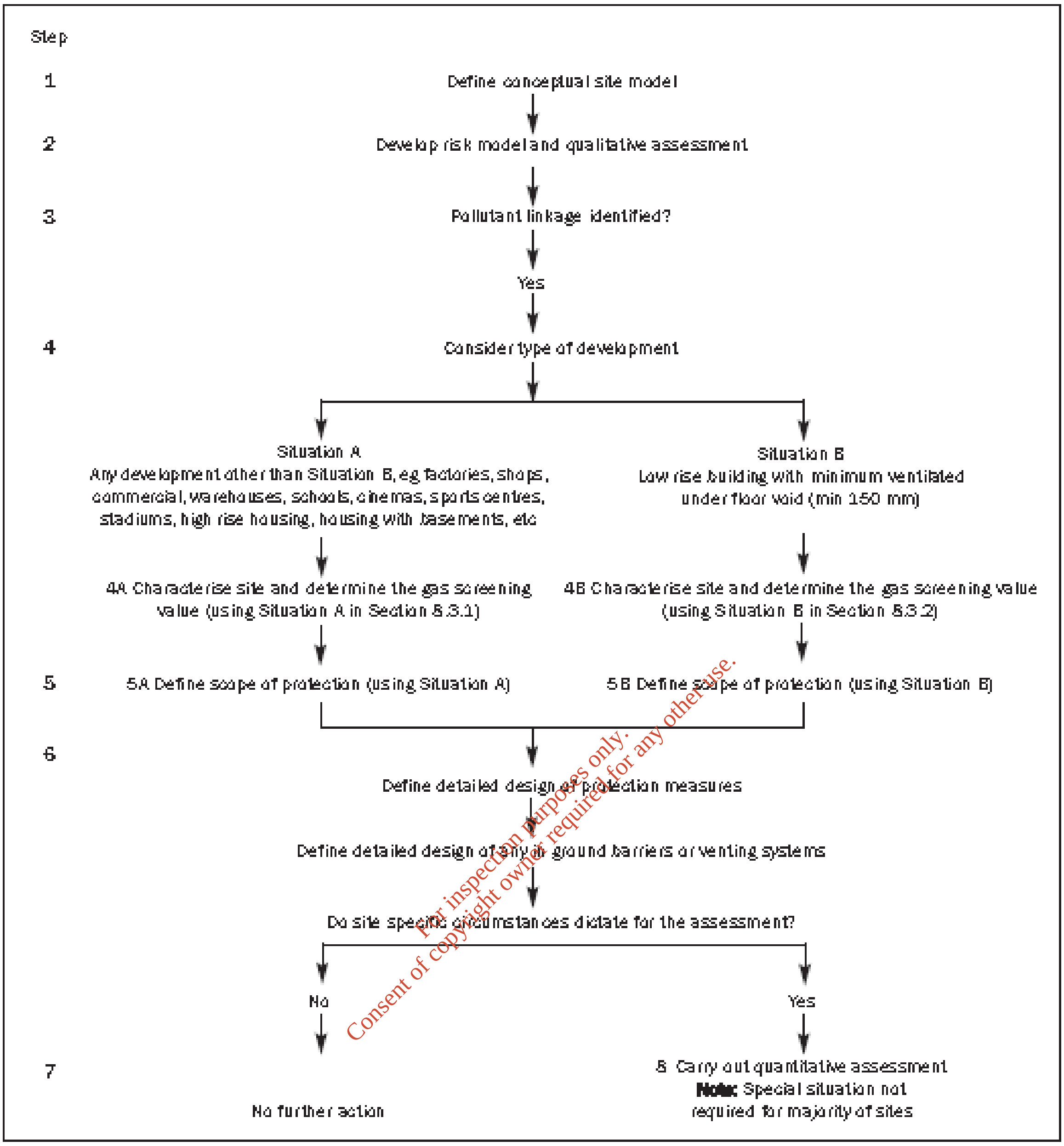

Figure 23 Risk Assessment Process for Methane and Carbon Dioxide (from CIRIA C665)

6.1.1.1 Gas Sources and Migration Pathways

The main gas source is considered to be the waste within each of the five historic landfills Site 1, 2, 3A, 3B and 3C. As detailed in **Table 5.1 and Table 5.2** there are several pathways for the gas to migrate;

- Lateral migration subsoil
- Lateral migration groundwater
- Vertical migration subsoil
- Existing and proposed services routes

Production phases of typical landfill gas is described in the 1997 EPA Report gas production and divided into 4 phases, Phase I is aerobic with phases II – IV anaerobic. Table 3.1 details the data from the EPA Section 22 Register. This dates the end date for site 2 as 1991 and sites 3B and 3C as 1995. There are no known records detailing the end dates for site 1 and site 3A. Given the waste is over 20 years old with a low to moderate flow production, this suggests the gas production is in the later stages of degradation and in line with Phase IV.

The source and pathways for each site are discussed below.

Site 1

As discussed in section 5.1.2 the waste material within site 1 is dominantly C&D waste with pockets of municipal waste with a maximum depth of waste of 14mbgl.

The waste is located above the water-table with an unsaturated zone thickness of over 5m. These unsaturated unconsolidated sands and gravel deposits are considered to represent the primary gas migration pathway, providing both lateral and vertical migration pathways for landfill gas. Gas migration may also occur at depth within the bedrock deposits, but this is considered a secondary pathway given its depth, permeability and position with respect to the groundwater table. As the waste is located above the water-table it is considered a secondary pathway as dissolved gas could travel laterally through groundwater. Migration of dissolved gases (due to the saturation limit) would be considered a secondary gas migration pathway. This will be further assessed following completion of additional rounds of gas and environmental monitoring.

Available records do not show the presence of existing services within or in close proximity to site 1, however the proposed development may include services within or near site 1 and they will need to be considered as potential pathways for gas.

Site 2

The waste material for site 2 is dominantly municipal with a maximum measured depth of 19mbgl.

Following the site investigations and as detailed in section 5.1.3 the majority of the waste body is located above the water-table within an unsaturated zone with a thickness of greater than 5m. The unsaturated sands and gravel deposits provide both a lateral and vertical migration pathway for gas via the pore spaces.

The majority of the waste is located above the water table, however, the lowest levels of the waste body are saturated and may possibly be in hydraulic connection with the underlying water-table. This could result in a potential pathway for soluble gases in the groundwater.

Site 3A

For site 3A the waste material is dominantly comprised of municipal waste with a maximum measured depth of 16mbgl.

As detailed in section 5.1.4 the waste body at site 3A appears to be mainly unsaturated with only a minor depth of leachate head to the north of the site. The groundwater elevation is considered to be located directly underneath the site but there may be a marginal unsaturated zone between the two. The unsaturated sands and gravel zone can provide both lateral and vertical migration pathways via pore spaces for generated landfill gas at the site.

Based on current records of existing services at site 3A the only known services are overhead and therefore do not create a pathway for the landfill gas to travel. This phase of the proposed development does not envisage any services to be constructed at site 3A therefore this is not considered to be a viable pathway at this time. However should future development be considered at this site a further assessment is recommended.

Site 3B

The waste material at site 3B is relatively shallow and is comprises mainly municipal waste with a maximum measured depth of 4.9mbgl.

The water-table is relatively shallow but it would appear the waste body is perched above the water-table. Some deeper portions of the waste body are saturated to the north. This would suggest dissolved landfill gas could migrate laterally through the groundwater. This will be further assessed following the completion of the additional gas and environmental monitoring.

The unsaturated sands and gravel zone can provide both lateral and vertical migration pathways for landfill gas.

Current records do not show any existing services present at site 3B.

Site 3C

The waste material in site 3C is dominantly municipal waste with a maximum depth of 13mbgl. The base of the waste would appear to be saturated and in direct connection with the watertable in the underlying sand and gravel deposits providing both lateral and vertical pathways for dissolved gas through groundwater.

Based on current records there are no known services at site 3C and there is currently no proposed development within this area but should a development be proposed the potential for migration of gas through proposed services should be assessed.

West of Site 2 and east of the existing water main, the geophysical report discussed in Section 4.3.1 shows pockets of waste along the water main line.

6.1.1.2 Production Phases of Typical Landfill Gas

Based on the 1997 EPA Report gas production is divided into 4 phases, Phase I is aerobic with phases II – IV anaerobic. **Table 3.1** details the data from the EPA Section 22 Register. This dates the end date for Site 2 as 1991 and Sites 3B and 3C as 1995. There are no known records detailing the end dates for site 1 and site 3A. Given the waste is over 20 years old with a low to moderate flow production, this suggests the gas production is in the later stages of degradation and in line with Phase IV.

6.1.1.3 Hydrogen Sulphide and Carbon Monoxide

A review of the hydrogen sulphide and carbon monoxide results were also completed for each site. A summary of the dataset is presented in Table 6.1.

Table 6.1 - Summary of Hydrogen Sulphide and Carbon Monoxide Monitoring Results

Location	Count of H2S	Max of H2S (ppm)	Count of CO	Max of CO (Ppm)
Site 1				
		Offsite		
BH05	17	0	17	0
G06	18	0	18	0
G07	18	0	18	0
G08	18	0.013	18	0
G10	18	0	18	0
G18	18	0	18	0
G19	18	0	18	0
		Onsite		
LG 11	18	0	18	10
LG 12	18	0	18	0
LG 13	18	0	18	0
Site 2				
		Offsite		
BH01	18	0	18	0
BH03	18	0	18	0
BH04	18	0	18	0
BH11	18	0	18	0
BH13	18	0	18	0
G01	18	0	18	0
G02	18	0	18	0

Location	Count of H2S	Max of H2S (ppm)	Count of CO	Max of CO (Ppm)
G03	18	0	18	0
G04	18	0	17	0
G05	17	0	17	0
G13	18	0	18	0
G20	18	0	18	0
G21	18	0	18	0
G22	18	0	18	0
G23	18	0	18	0
G24	18	0	18	0
G25	18	0	18	0
Onsite				
LG 01	17	0	17	0
LG 02	18	0	18	0
LG 03	18	0	18	0
LG 04	17	50	17	10
LG 05	18	0	18	0
LG 06	18	0	18	0
LG 07	18	0	18	10
LG 08	18	0	18	14
LG 09	18	0	18	0
LG 10	18	0	18	0
Site 3A				
Offsite				
BH07	18	0	18	0
BH09	18	0	18	0
BH10	18	0	18	0
G12	18	0	18	0
G14	18	0	18	0
Onsite				
LG 15	18	0	18	10
LG 19	18	30	18	0
LG 20	18	87	18	10
MW3 (25 dia. Pipe)	18	25	18	0
MW3 (50 dia. Pipe)	17	0	16	0
MW4	18	40	18	0
Site 3B				
Offsite				
BH08	18	0	18	0
G15	18	0	18	0
G16	18	0	18	0
G17	18	0	18	0
Onsite				
LG 16	18	0	18	32
LG 17	17	0	17	10
LG 21	17	0	17	0
Site 3C				
Offsite				
BH06	18	0	18	0
G09	18	0	18	0
G11	18	0	18	10
Onsite				
LG 14	18	50	18	0
LG 18	18	40	18	0
MW2	18	210	18	0

Full details of hydrogen sulphide and carbon monoxide monitoring are in Appendix J.

6.1.1.4 Borehole flow rate

A review of the borehole flow rates results is presented in Table 6.2.

Table 6.2 - Summary of Flow Monitoring Results (peak and steady)

Location	Number of Flow measurement (Peak)	Max of Flow Measurement (Peak) (l/hour)	Number of Flow measurement (Steady)	Max of Flow Measurement (Steady) (l/hour)
Site 1				
		Offsite		
BH05	16	9	17	9
G06	18	6.6	18	3.5
G07	18	7.1	18	6.9
G08	17	6.5	18	6.3
G10	16	3.4	18	3.1
G18	16	0.4	18	0.3
G19	17	1.2	18	0.6
		Onsite		
LG 11	16	0.4	18	0
LG 12	16	2.8	18	0.7
LG 13	16	4	18	0
Site 2				
		Offsite		
BH01	16	3.6	18	3.4
BH03	17	10.2	18	10.2
BH04	17	11.4	18	10.8
BH11	17	7.5	18	7.2
BH13	17	5.2	18	4.7
G01	15	3.9	18	3.8
G02	18	3.9	18	5
G03	17	5.4	18	4.7
G04	18	0.4	18	0.1
G05	16	6.5	17	6.3
G13	18	6.7	18	6.4
G20	16	13.8	18	13.6
G21	16	6.5	18	5.8
G22	17	20	18	19.8
G23	17	3.5	18	3.4
G24	17	11	18	10.5
G25	17	9.3	18	9
		Onsite		
LG 01	17	3.1	17	2.5

Location	Number of Flow measurement (Peak)	Max of Flow Measurement (Peak) (l/hour)	Number of Flow measurement (Steady)	Max of Flow Measurement (Steady) (l/hour)
LG 02	17	7.4	18	7
LG 03	17	5.4	18	4.3
LG 04	16	10.8	17	7.6
LG 05	18	7.1	18	7
LG 06	17	7.3	18	3.3
LG 07	18	3.9	18	3.9
LG 08	18	4.9	18	4.6
LG 09	18	7.8	18	6
LG 10	18	5.5	18	4.8
Site 3A				
Offsite				
BH07	17	5.9	18	1.6
BH09	17	2.2	18	1.6
BH10	17	4.2	18	1.6
G12	17	1.9	18	1.4
G14	16	4	18	1.3
Onsite				
LG 15	18	6.4	18	5.8
LG 19	18	45.6	18	45
LG 20	18	26.7	18	26.5
MW3 (25 dia. Pipe)	13	1.6	10	1.5
MW3 (50 dia. Pipe)	16	5	16	4.9
MW4	18	44.8	18	43.5
Site 3B				
Offsite				
BH08	16	3.7	18	1.4
G15	16	3.1	18	1.3
G16	16	0.3	18	0.1
G17	16	2.2	18	2.2
Onsite				
LG 16	18	4.3	18	3.3
LG 17	16	6.6	16	6.2
LG 21	16	3.1	16	2.5
Site 3C				
Offsite				
BH06	16	3.4	18	0.9
G09	17	4	18	3.1
G11	16	3.4	18	1.2
Onsite				
LG 14	18	2.8	18	1.9
LG 18	18	3.7	18	1.2

Location	Number of Flow measurement (Peak)	Max of Flow Measurement (Peak) (l/hour)	Number of Flow measurement (Steady)	Max of Flow Measurement (Steady) (l/hour)
MW2	16	19.5	17	11.7

Full details of flow rates are in Appendix J.

6.1.1.5 Nature of the Proposed Development

Whilst the detailed layout has yet to be confirmed, any future development will comprise a mixed commercial and residential development. It is anticipated that no buildings would be located within the landfill areas and these would be developed instead as open space/amenity.

6.1.1.6 Confidence and Reliability of Results

It should be noted that the gas risk assessment is based upon eighteen rounds of monitoring and provides an initial indication of gas risks only. The monitoring period covers a wide range in weather conditions and atmospheric pressure. The current dataset complies with minimum monitoring requirement stated by CIRIA C665 guidance, in excess of 10 rounds although it could be extended to 24 months due to very high generation potential and high sensitivity of development.

6.1.1.7 Gas Risk Assessment

Any future development will include mixed use development including low rise housing. Given the proposed mixed use of the development the Wilson and Card has been utilised for Situation A and the NHBC traffic light classification has also been used for low rise residential development (Situation B)[7].

6.1.1.8 Wilson and Card Methodology

As detailed in CIRIA C665 the Wilson and Card method is used for all development types except those in Situation B. This method uses both gas concentrations and borehole flow rates to define a characteristic situation for a site based on the limiting borehole gas volume flow for methane and carbon dioxide. The limiting borehole gas volume flow is renamed as the gas screening value (GSV).

Gas screening value (litres/hour) = max borehole flow rate (l/hr) x max gas concentration (%) / 100.

Table 6.3 presents the Gas Screening Value calculation carried out for both methane and carbon dioxide. The maximum steady flow rate has been used and the worst case screening value between methane and carbon dioxide is adopted for the classification.

[7] Low rise residential development is considered to be a non flat/apartment development consisting of one to three stories in height.

Table 6.3 - Gas Screening Value Calculation (Wilson and Card Methodology)

Location	Max of Flow (Peak)	Max of CH4 (%)	Max of CO2 (%)	Gas Screening Value	Class
Site 1					
Onsite	0.7	13.6	18.9	0.13	CS2
Offsite	9	23.9	8.1	2.15	CS3
Site 2					
Onsite	7.6	73.7	36.6	5.60	CS4
Offsite	19.8	55.7	25.5	11.03	CS4
Site 3A					
Onsite	45	71.7	37	32.27	CS5
Offsite	1.6	0	3.2	0.05	CS1
Site 3B					
Onsite	6.2	73.1	39.4	4.53	CS4
Offsite	2.2	0	4.2	0.09	CS2
Site 3C					
Onsite	11.7	83.5	37.2	9.77	CS3
Offsite	3.1	22.2	19.6	0.69	CS2

6.1.1.9 NHBC Traffic Light System

The NHBC have developed a characterisation system that is similar to the Wilson and Card system, but is specific to low-rise housing development with a clear ventilated underfloor void. This is a risk-based approach that is designed to allow an identification of gas protection for low-rise housing developments by comparing the measured gas emission rates to generic "traffic lights" scenarios. The traffic lights include "typical maximum concentrations" and are provided for initial screening purposes and risk-based gas screening values (GSVs) for consideration in situations where the typical maximum concentrations are exceeded.

This method is carried out for both methane and carbon dioxide.

It should be noted that the method used to develop the GSV thresholds in Table 8.7 of CIRIA C665 is based on a number of assumptions regarding the proposed structures. For the purpose of this assessment it is assumed the low rise development for the site is as per CIRIA guidance

Following the completion of the Wilson and Card screening it was decided to complete NHBC traffic light system for all sites due to the potential of low rise housing in the proposed development.

Using table 8.7 from *CIRIA C665 Assessing risks posed by hazardous ground gases to buildings* along with peak methane, carbon dioxide and GSV (calculated using Modified Wilson and Card), the following tables detail the Traffic Light Classification for all sites.

Table 6.4 – Traffic Light Classification - Methane

Site Number	Position	Peak methane	GSV (l/hr)	Traffic Light

		(% v/v)		Classification
1	Onsite	13.60	0.10	Green
	Offsite	23.90	2.15	Red
2	Onsite	73.70	5.60	Red
	Offsite	55.70	11.03	Red
3A	Onsite	71.70	32.27	Red
	Offsite	0.00	0.00	Green
3B	Onsite	73.10	4.53	Red
	Offsite	0.00	0.00	Green
3C	Onsite	83.50	9.77	Red
	Offsite	22.20	0.69	Amber2

Table 6.5 – Traffic Light Classification – Carbon Dioxide

Site Number		Peak carbon dioxide (% v/v)	GSV (l/hr)	Traffic Light Classification
1	Onsite	18.90	0.13	Green
	Offsite	8.10	0.73	Green
2	Onsite	36.60	2.78	Amber2
	Offsite	25.50	5.05	Amber2
3A	Onsite	37.00	16.65	Red
	Offsite	3.20	0.05	Green
3B	Onsite	39.40	2.44	Amber2
	Offsite	4.20	0.09	Green
3C	Onsite	37.20	4.35	Red
	Offsite	19.60	0.61	Green

6.1.1.10 Proposed Protection Measures

Wilson and Card

In accordance with Table 8.6 of CIRIA C665 the typical scope of gas protection measures proposed are presented for each site area in **Table 6.6** for the characteristic situation for each site using the Wilson and Card method.

Table 6.6 – Proposed Protection Measures – Wilson and Card

Characteristic Situation	Site Area	No. of levels of protection	Gas Protection Measures (Situation B)
CS1	Site 3A - offsite	None	No special precautions
CS2	Site 1 onsite Site 3B offsite Site 3C offsite	2	a. Reinforced concrete cast in situ floor slab (suspended, non-suspended or raft) with at least 1200g DPM[2] and underfloor venting b. Beam and block or pre-cast concrete and 2000g DPM/ reinforced gas membrane and underfloor venting. All joints and penetrations sealed.
CS3	Site 1 offsite	2	All types of floor slabs as above. All joints and penetrations sealed. Proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor sub-space.
CS4	Site 2 onsite & offsite Site 3B onsite Site 3C onsite	3	All types of floor slabs as above. All joints and penetrations sealed. Proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor sub-space
CS5	Site 3A onsite	4	Reinforced concrete cast in situ floor slab (suspended, non-suspended or raft). All joints and penetrations sealed. Proprietary gas resistant membrane and ventilated or positively pressured underfloor sub-space, oversite capping and in-ground ventilating layer and in-ground venting wells or barriers
CS6		5	Not suitable unless gas regime is reduced first and quantitative risk assessment carried out to assess design of protection measures in conjunction with foundation design

Whilst CIRIA C665 sets out typical gas protection measures this guidance has been superseded with respects to the detailed design of gas protection measures. The detailed gas protection system shall be designed in accordance with relevant guidance, including but not limited to:

- BS 8485:2015 – Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings (BSI, 2015);
- Protecting development from methane (CIRIA, 1995); and
- Assessing risks posed by hazardous ground gases to buildings (CIRIA. 2007).

Where these standards conflict, the most up to date relevant guidance will be applied.

Traffic Light System

Based on the traffic light classification for each site for low rise housing development only, the scope of protections measures as defined in Box 8.4 of CIRIA C665 are presented in **Table 6.7**.

Table 6.7 – Proposed Protection Measures – Traffic Light System

Traffic light classification	Site Number	Protection measures required
Green	Site 3A offsite Site 3B offsite	Negligible gas regime identified and gas protection measures are not considered necessary
Amber 1		Low to intermediate gas regime identified, which requires low-level gas protection measures, comprising a membrane and ventilated sub-floor void to create a permeability contrast to limit the ingress of gas into buildings. Gas protection measures should be as prescribed in BRE Report 414 (Johnson, 2001). Ventilation of the sub-floor void should facilitate a minimum of one complete volume change per 24 hours.
Amber 2	Site 1 onsite	Intermediate to high gas regime identified, which requires high-level gas protection measures, comprising a membrane and ventilated sub-floor void to create a permeability contrast to prevent the ingress of gas into buildings. Gas protection measures should be as prescribed in BRE Report 414 (Johnson, 2001). Membranes should always be fitted by a specialist contractor. As with amber 1, ventilation of the sub-floor void should facilitate a minimum of one complete volume change per 24 hours. Certification that these passive protection measures have been installed correctly should be provided.
Red	Site 1 Offsite Site 2 onsite & offsite Site 3A onsite Site 3B onsite Site 3C onsite & offsite	High gas regime identified. It is considered that standard residential housing would not normally be acceptable without a further gas risk assessment and/ or possible remedial migration measures to reduce and/or remove the source of gas.

As set out above, detailed gas protection system shall be designed in accordance with relevant guidance, including but not limited to:

- BS 8485:2015 – Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings (BSI, 2015);
- Protecting development from methane (CIRIA, 1995); and
- Assessing risks posed by hazardous ground gases to buildings (CIRIA. 2007).

Where these standards conflict, the most up to date relevant guidance will be applied.

6.1.1.11 Summary of Gas Risk Assessment

The Fassaroe Historic Landfill sites lie 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).

A review of the gas regime at the site (based on the currently available information) suggests that the main gas generation at the site is the waste within the landfills. The main pathway for gas migration from the waste materials is considered to be through the permeable superficial deposits, with limited contributions through groundwater and the deeper bedrock deposits which are considered to be of a lower permeability.

Following the completion of the Wilson & Card and the Traffic Light assessments the proposed protection measured for each site are detailed in **Table 6.6**and **Table 6.7**. Protection measures will need to include gas barriers to prevent migration of gases from the landfills where further monitoring cannot dismiss the risk from gas within the proposed development areas.

We would recommend that a gas management strategy is developed for the site, taking account of the available data and any future development layout. This strategy should identify the gas protection measures that can be installed to limit gas migration from the landfills and the protection measures that will be required to properties, supported by relevant appraisal / assessment. This strategy will need review and update once the further information is available.

6.1.2 Human Health Risk Assessment

6.1.2.1 Introduction

This section assesses the risk to human health as a result of soil contamination identified at the site. Data confirming the contamination status of soils at the site has been derived from multiple stages of investigation, the most recent and comprehensive data being provided by the ground investigation undertaken by RPS in 2015. The assessment is constrained to the extents of the known landfills (5 no.) and considers the available data and compares it against relevant screening criteria. A tabulated summary of the results is provided within *Appendix K.*

6.1.2.2 Risk Assessment Methodology

The assessment of risks posed to human health by the presence of soil contaminants is based upon the guidelines outlined in CLR11 (*DEFRA & EA, 2004*), which provides a framework for risk assessment and follows the tiered process, with each subsequent tier involving a higher degree of input into the assessment should risks above tolerable levels be identified within the previous tier. This approach is outlined below.

6.1.2.3 Tier 1 – Qualitative Risk Assessment

This stage qualitatively identifies each of the Source-Pathway-Receptor components that are present on site, which forms the basis of the risk assessment approach. The Tier 1 assessment is presented within the Preliminary Risk Assessment in Section 3.5.

6.1.2.4 Tier 2 – Generic Quantitative Risk Assessment (GQRA)

The Tier 2 risk assessment aims to identify contaminants of concern and their spatial distribution and requires benchmarks against which to compare the concentrations of soil contaminants. This requires the comparison of contaminant concentrations with a relevant standard.

There are a number of standards available that may be adopted, although none provide a complete up to date list of screening criteria. Consideration has been given to the following standards when selecting a set of screening criteria:

Soil Guideline Values (SGV 2009) published by the UK Environment Agency

- Category 4 Screening Levels (C4SLs), published by CL:AIRE 2014, CL:AIRE SP1010 Development of Category 4 Screening Levels for Assessment of Land Affected by Contamination, September 2014 (DEFRA in 2014); and
- Suitable 4 Use Levels (S4ULs), Published by LQM, 2015. Land Quality Management Ltd, the LQM/CIEH S4ULs for Human Health Risk Assessment (LQM in 2015) ;

The standard selected should take consideration of the purpose of the assessment. This assessment is being undertaken in support of a planning application and on this basis the following standards shall be applied for the stated contaminants:

- Suitable 4 Use Levels (S4ULs), for all contaminants for which there are published values;
- Category 4 Screening Levels (C4SLs), for lead; and
- Generic Assessment Criteria (GAC) developed by Contaminated Land: Application in Real Environments (CL:AIRE), 2010. Soil Generic Assessment Criteria for Human Health Risk Assessment (CL:AIRE) for where there are no S4ULs or C4SLs available.

Where asbestos has been identified as a Contaminant of Concern (CoC) this has also been considered. In the absence of a screening criteria the Laboratory Limit of Detection (LLoD) has been used as a screening criteria.

6.1.2.5 Application of Screening Criteria

A comparison with the selected criteria provides the risk assessor with an indication as to whether a particular contaminant may pose a risk to human health and whether additional assessment is required. A site specific appraisal is required to establish the statistical basis on which the contaminant concentrations should be assessed and compared against the standards. This appraisal should consider the following:

- The nature and cause each contaminant at the site;
- If the contamination is likely to be present in ‘hotspots’ or is likely to be distributed horizontally and / or vertically within the site;
- The suitability of the data set for statistical treatment; and
- The site use and layout (existing or proposed depending on the purpose of the assessment).

A consideration of the above allows the assessor to consider the most appropriate statistical treatment of the data to allow comparison with the selected standard, including the use of:

- Maximum values;
- Segregation of data by lithology;
- Ninety-fifth percentile Upper Confidence Levels (95% UCL) and outliers; and

- Averaging areas.

Table 6.8 presents the selected approach for the site together with a justification for the selected approach.

Table 6.8 – Summary of Selected Statistical Approach

Contaminant	Data Treatment Option			
	Maximum Value or 95% UCL and outliers	Segregation of Data by Lithology	Averaging Areas	Justification
Inorganic Contaminants	Maximum Value and 95% UCL and outliers if required	Yes	Yes	Data derived from 5 different landfills which are geographically distinctive. Capping and landfilled materials are considered to represent different contamination 'sources' and therefore the results have been separated as such for the assessments. For these reasons, for the most part, the datasets are too small for the calculation of the 95% UCL value and maximum values have been compared against screening criteria. If an exceedance of screening criteria is observed, where datasets are large enough, 95% UCL statistical analysis has been undertaken.
PAH and TPH	Maximum Value and 95% UCL and outliers if required	Yes	Yes	Data derived from 5 different landfills which are geographically distinctive. Capping and landfilled materials are considered to represent different contamination 'sources' and therefore the results have been separated as such for the assessments. For these reasons, for the most part, the datasets are too small for the calculation of the 95% UCL value and maximum values have been compared against screening criteria. If an exceedance of screening criteria is observed, where datasets are large enough, 95% UCL statistical analysis has been undertaken.
VOCs	Maximum Value	Yes	N/A	Significant majority of laboratory analysis results below the laboratory detection limit, so statistical analysis is not required.

6.1.2.6 Tier 2 – Generic Quantitative Risk Assessment

The following sections provide a summary of the findings of the risk assessment for the capping and landfilled materials within each of the five landfills.

6.1.2.7 Inorganic Contaminants

Capping Materials

Tables 1 and 3 of *Appendix K* summarise the results of the laboratory analysis for inorganic contaminants encountered within soils within the capping layer within Sites 1, 2, 3A, 3B and 3C, and compares them with the relevant screening values for a public open space (parks) end use.

Comparison with the screening criteria identifies that concentrations of inorganic contaminants within the capping materials are low and that the identified concentrations lie below the relevant screening criteria. On this basis it is considered that the identified concentrations of inorganic contaminants within the capping layer within each of the 5 landfills are unlikely to pose an unacceptable risk to human health for a future public open space (parks) end use.

Landfill Materials

Tables 2, 4, 5, 6 and 7 of *Appendix K* summarise the results of the laboratory analysis for inorganic contaminants encountered within the landfill materials within Sites 1, 2, 3A, 3B and 3C and compares them with the relevant screening values for a public open space (parks) end use.

Comparison with the screening criteria identifies that the concentrations of inorganic contaminants within the landfill materials are generally low and in the majority of cases lie below the relevant screening criteria. The exception to this is lead within Site 2, where a concentration of 4,955 mg/kg was recorded within the landfill materials within trial pit TP6 (excavated during a previous ground investigation) lying above the screening value of 1,300 mg/kg. Statistical analysis of the dataset has derived a 95% UCL of 1,903.07 mg/kg for lead, again lying above the screening criteria. The statistical analysis indicates 5 statistical lead outliers to be present, however due to the likely heterogeneous nature of landfilled materials, it is considered that these outliers cannot be excluded from the statistical dataset.

On this basis therefore, it is considered that identified concentrations of lead within the landfill materials in Site 2 may present an unacceptable risk to human health for a future public open space (parks) end use.

6.1.2.8 Total Petroleum Hydrocarbons (TPH) and BTEX Compounds

Capping Materials

Tables 1 and 3 of *Appendix K* summarise the results of the laboratory analysis for TPH / BTEX soil analysis contaminants encountered within soils in the capping materials in Sites 1, 2, 3A, 3B and 3C and compares them with the relevant screening values for a public open space (parks) end use.

Comparison with the screening criteria identifies that the concentrations of TPH / BTEX within the capping materials are low and that all determinants lie below the relevant screening criteria. On this basis therefore it is considered that the identified concentrations of TPH / BTEX contaminants within the capping layer within each of the 5 landfills are unlikely to pose an unacceptable risk to human health for a future public open space (parks) end use.

Landfill Materials

Tables 2, 4, 5, 6 and 7 of *Appendix K* summarise the results of the laboratory analysis for TPH / BTEX soil analysis contaminants encountered within soils in the landfill materials in Sites 1, 2, 3A, 3B and 3C and compares them with the relevant screening values for a public open space (parks) end use.

Comparison with the screening criteria identifies that the concentrations of TPH / BTEX within the landfill materials are low and that all determinants lie below the relevant screening criteria. On this basis therefore it is considered that identified concentrations of TPH / BTEX contaminants within the landfill materials within each of the 5 landfills are unlikely to pose an unacceptable risk to human health for a future public open space (parks) end use.

6.1.2.9 Polycyclic Aromatic Hydrocarbons (PAH)

Capping Materials

Tables 1 and 3 of *Appendix K* summarise the results of the laboratory analysis for PAH contaminants encountered within soils in the capping materials in Sites 1, 2, 3A, 3B and 3C and compares them with the relevant screening values for a public open space (parks) end use.

Comparison with the screening criteria identifies that concentrations of PAH within the capping materials are low and generally lie below the relevant screening criteria. The exception to this is dibenzo(ah)anthracene within Site 2, where a concentration of 1.2 mg/kg was encountered within borehole LG10, marginally exceeding the screening criteria of 1.1 mg/kg. Only 1 sample from this material was analysed for the presence of PAHs and therefore no statistical analysis of the dataset can be undertaken.

On this basis it is considered that dibenzo(ah)anthracene within the capping material within Site 2 may pose an unacceptable risk to human health for a future public open space (parks) end use.

Landfill Materials

Tables 2, 4, 5, 6 and 7 of *Appendix K* summarise the results of the laboratory analysis for PAH contaminants encountered within soils in the landfill materials in Sites 1, 2, 3A, 3B and 3C and compares them with the relevant screening values for a public open space (parks) end use.

Comparison with the screening criteria identifies that the concentrations of PAH within the landfill materials are low with a small number of exceedances of the relevant screening criteria:

- Benzo(b)fluoranthene within Site 1, within borehole LG13, with a concentration of 19 mg/kg exceeding the screening criteria of 13 mg/kg;
- Benzo(a)pyrene within Site 1, within borehole LG13, with a concentration of 15 mg/kg exceeding the screening criteria of 11 mg/kg;
- Dibenzo(ah)anthracene within Site 1, within borehole LG11, with a concentration of 1.9 mg/kg exceeding the screening criteria of 1.1 mg/kg; and
- Dibenzo(ah)anthracene within Site 2, within borehole LG04, with a concentration of 2.9 mg/kg exceeding the screening criteria of 1.1 mg/kg.

Statistical analysis of the dataset has shown that the 95% UCL for the majority of these contaminants lie marginally above the respective screening criteria, the exception being benzo(a)pyrene within Site 1. The statistical analysis indicates a number of statistical outliers to be present for each of the PAH contaminants, however due to the likely heterogeneous nature of landfilled materials, it is considered that these outliers cannot be excluded from the statistical dataset.

On this basis therefore it is considered that identified concentrations of PAH within the landfill materials in Sites 1 and 2 may potentially pose an unacceptable risk to human health for a future public open space (parks) end use.

6.1.2.10 Other organic compounds [Volatile Organic Compounds (VOCs), Semi-Volatile Organic Compounds (SVOCs), and Phenols]

Tables 1 to 7 within *Appendix* K summarise the results of the laboratory results for VOC, SVOC and phenol analysis, where encountered above the laboratory detection limit and compares them with CL:AIRE GACs for a residential without plant uptake end use scenario.

VOCs, SVOCs and Phenols were encountered at generally low concentrations, predominantly lying below the laboratory detection limit, with no concentrations exceeding the appropriate screening values, where such values exist. On this basis therefore it is considered that identified concentrations of VOCs, SVOCs and Phenols are unlikely to pose a risk to human health.

6.1.2.11 Asbestos

A total of 53 soil samples obtained from the capping and landfill materials were analysed for the presence of asbestos during the recent ground investigation undertaken by RPS.

Asbestos was identified above the laboratory limit of detection within 1 of the 53 samples, where asbestos cement containing amosite and chrysotile was encountered within the landfill materials in Site 1 (TP13 at 2.5 mbgl). The presence of asbestos within the landfill materials is, in general, unlikely to pose a risk to future site users given that an informal capping layer is present over these materials. Where this capping layer is compromised a risk may be present.

In Sites 2 and 3B, where asbestos might be expected to be present, if the exposed landfill faces are not suitably capped, there is a risk that future site users may be exposed to the asbestos contamination.

6.1.2.12 Summary of Risks to Human Health

Future Site Users

The Tier 2 human health risk assessment has identified that contaminant concentrations are generally below the selected screening criteria for a public open space (parks) use.

The risk assessment has identified elevated concentrations of PAHs within the landfill materials in Site 1, elevated concentrations of lead and PAHs within the landfill materials in Site 2 and elevated concentrations of PAH within the capping materials in Site 2. In addition, asbestos containing materials have been encountered at 1 location within the landfill materials in Site 1.

Despite the presence of elevated concentrations of contaminants and the presence of asbestos within the landfilled materials, it is not considered that future site users are likely to be exposed to the contamination due to the depth at which the contamination is present (>1.0 m). With regard to the PAH contamination within the capping materials within Site 2, additional sampling may be considered to further determine levels of contamination within these materials. Should a clean cap be placed at this location however, this would likely mitigate risks to future site users by preventing exposure to the contamination.

A suitable capping layer should also be constructed in any faces where landfill materials in Sites 2 and 3B are exposed as a result of any future development, to mitigate potential risks to site end users in these areas.

Where site levels are altered, the findings of this risk assessment will require review.

Construction Workers

The human health risk assessment outlined within this section is designed to assess potential long term contamination risks to future site users and as such is not suitable to assess potential, short term, risks to construction workers future development may be proposed in Sites 2 and 3B.

It is considered however that the concentrations of contaminants identified during the ground investigation are unlikely to constitute a risk to construction workers during the development on Sites 2 and 3B where appropriate measures are adopted. Due to the heterogeneous nature of landfilled materials however, there is a possibility that asbestos and areas of gross contamination may be present and a suitable watching brief should be employed during construction for any such contamination. In addition, suitable hygiene and welfare facilities and PPE should be provided in accordance with the requirements of the Safety, Health and Welfare at Work (General Application) Regulations 2007, Safety Health and Welfare at Work (Exposure to Asbestos) Regulations 2006 and 2010 amendments and the Safety Health and Welfare at Work (Construction) Regulations 2013 to manage potential risks to construction workers. Appropriate procedures should also be in place to remediate any such contamination encountered during construction in line with the Safety Health and Welfare at Work (Exposure to Asbestos) Regulations 2006 and 2010 amendments and the Safety Health and Welfare at Work (Construction) Regulations 2013.

6.1.3 Water Environment Generic Quantified Risk Assessment

The EPA provide guidance on the management of contaminated land sites (EPA 2013) which outlines the requirement for a GQRA, that utilise Generic Assessment Criteria (GAC) to identify pollutant (SPR) linkages for which a Detailed Quantified Risk Assessment (DQRA) should be undertaken.

The GACs adopted for this assessment are those recommended by the EPA. The EPA recommend that values for screening of the impact on groundwater may come from several sources, including the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. no. 9 of 2010), the EPA's Groundwater Threshold Values (GTVs), the EPA's Interim Guideline Values (IGVs) or relevant Environmental Quality Standards (EQSs), when considering a surface water receptor. For the purpose of the DQRA presented herein the groundwater quality dataset has been compared with the Schedule 5 GTVs presented in the Environmental Objectives (Groundwater) (Amendment) Regulations 2016 (Statutory Instruments No. 366 of 2016) which update / supersede the Schedule 5 GTV's presented in Environmental Objectives (Groundwater) Regulations 2010 (SI No. 9, 2010). The groundwater quality results are compared to all three sets of GACs, and the surface water is only compared to the surface water annual average EQS.

The results of the GQRA provides a list of contaminants/chemicals of potential concern (COPC), in soil, groundwater or surface water, that will be required to be taken forward for DQRA.

6.1.3.1 Aquifer Receptor - *Gravel Aquifer (Receptor R5)*

Analytical results and the results of the screening exercise are presented in Appendix G & H.

The main contaminants of concern (which exceed statutory and guideline threshold values) in the leachate generated from the waste body within the sand and gravel aquifer at each Site are summarised in Section 4.6.2 Leachate Assessment. A summary of that assessment showing the parameters where the leachate concentration exceeded the GAC is presented in **Table 5.26** below.

Table 6.9 – Summary of Leachate Concentrations above GACs

Parameter	Site 1	Site 2	3A	3B	3C
**Denotes a leachate sample from the site exceeded the relevant GAC for this parameter*					
Aluminium	*	*	*	*	*
Ammoniacal Nitrogen	*	*	*	*	*
Arsenic	*	*	*	*	*
Barium	*	*	*	*	*
Boron		*	*	*	*
Cadmium	*		*		*
Calcium	*		*	*	*
Chloride	*	*	*	*	*
Chromium		*	*	*	*
Copper	*	*	*	*	*
Cyanide	*				
Electrical Conductivity		*	*	*	*
Iron	*	*	*	*	*
Lead	*	*	*	*	*
Manganese	*	*	*	*	*
Mercury		*			
Nickel	*	*	*	*	*
Ortho-phosphate	*	*	*	*	*
Potassium	*	*	*	*	*
Sulphate	*				
Sodium		*	*	*	*
Total Dissolved Solids	*	*	*	*	*
Zinc	*	*	*	*	*
TPH	*	*	*	*	*
Benzene			*	*	*
Benzo (a) pyrene	*				

Parameter	Site 1	Site 2	3A	3B	3C
**Denotes a leachate sample from the site exceeded the relevant GAC for this parameter*					
Benzo (b) fluoranthene	*				
Ethyl Benzene			*		
Fluoranthene	*				
m&p-Xylene			*		
MTBE			*		
Naphthalene	*	*	*		*
Phenol			*	*	*
Total PAHs	*	*	*	*	*
Toluene			*	*	
Trans-1,2-dichloroethene			*		
Vinyl Chloride			*	*	

A number of other organic compounds (including 2,4-diethyphenol, 3&4-methylphenol, 3,5-diemthyphenol and various PAHS) have also been identified in leachate although no appropriate water assessment criteria are available.

A number of the contaminants of concern as listed in **Table 6.9** are considered to be leachate marker parameters considering their particularly high concentration within the leachate body in each landfill, the common absence or low background concentrations in groundwater / surface water, particularly where the parameters are characterised by conservative / recalcitrant behaviour during transport in the subsurface. For the purpose of this assessment leachate marker parameters include ammoniacal nitrogen, chloride, the heavy metal arsenic and petroleum hydrocarbons.

The results of geophysical surveys confirm the presence of a leachate plume beneath the landfill sites.

Groundwater samples taken down-gradient of the waste bodies confirm: elevated levels of ammoniacal nitrogen (e.g. at Site 2); a number of heavy metals down-gradient of Sites 2, 3A and 3B, although trace organics remain below LoD. There are no down-gradient groundwater boreholes at Site 1 or 3C however based on observations of leachate quality and the similarly of the hydrogeological environment to the other sites and the evidence from the geophysical surveys it is reasonable to assume the presence of a contamination plume moving down-gradient.

Up-gradient groundwater samples have also shown elevated levels of ammonia (at Site 1) and heavy metals at all sites. This may indicate there is significant infiltration through the leachate and that that a perched leachate head at the up-gradient perimeter of the waste-body is affecting the groundwater quality up-gradient of the site possibly causing localised mounding of the water-table leading to the plume dispersing out from the site. There are no direct up-gradient boreholes at Site 3B. Elevated levels of ammonia and heavy metals, in up-gradient and down-gradient boreholes, indicate groundwater quality beneath all sites has been impacted by the historic landfilling of waste at Fassaroe.

Table 6.10 – Summary of Leachate Markers Parameters for Site 2

Parameter (units)	Leachate Dataset		Groundwater Dataset		Spring Dataset	
	Location	Concentration*	Location~	Concentration*	Location ~	Concentration*
Ammoniacal Nitrogen (mg/l)	LG01 LG03 LG07 LG09 LG10	14.7 – x – x 286 – 270 – x 475 – 310 – 335 439 – 280 – 374 496 – 330 – 67	G20 (u/g) BH1 (d/g)	0.07 – 0.93 - < 0.94 – 2 - x	SP1	25.7 – 18 - <
Chloride (mg/l)	LG01 LG03 LG07 LG09 LG10	25 – x – x 483 – 780 – x 968 – 1100 – 592 866 – 1000 – 705 1190 – 1300 – 115	G20 (u/g) BH1 (d/g)	20.6 – 46 – 6.6 23.3 – 21 - x	SP1	109 – 120 – <
Arsenic (ug/l)	LG01 LG03 LG07 LG09 LG10	77 – x – x 18 – 8.9 – x 205 – 10 – 92 390 – 9.7 – 45 47 – 14 - 17	G20 (u/g) BH1 (d/g)	16 – < - < 29 - < - x	SP1	709 - < - <
TPH (C6-C40) (mg/l)	LG01 LG03 LG07 LG09 LG10	0.143 – x –x 0.286 – 0.310 – x 1.38 - < - x 0.258 - < - x 0.256 – 0.390 - x	G20 (u/g) BH1 (d/g)	< - < < - < - x	SP1	0.047 - < - x

** Data is presented for Round 1 – Round 2 – Round 3; x denotes no sample taken; < denotes below Limit of Detection*
~ u/g denotes up-gradient; d/g denotes down-gradient of landfill site.

The concentration of key leachate marker parameters is summarised in Table 6.10 and Table 6.11 for Site 2 and Site 3A respectively. Data for those sites is presented as they include groundwater monitoring locations that are situated down-gradient or lateral to the landfill site and down-gradient springs. It is evident from the dataset presented that off-site groundwater quality does not demonstrate a large impact from leachate. This may relate to dilution with groundwater or the limitations of the monitoring network considering: the highly elevated concentrations; the evidence of plume development identified from the site geophysics; the absence of down-gradient monitoring locations (due to stability / access constraints); and potential for a greater impact observed on certain (but not all) springs, most notably spring SP1 situated down gradient from landfill Site 2.

Table 6.11 – Summary of Leachate Markers Parameters for Site 3A

Parameter (unit)	Leachate Dataset		Groundwater Dataset		Spring Dataset	
	Location	Concentration*	Location~	Concentration*	Location~	Concentration*
Ammoniacal Nitrogen (mg/l)	LG15 LG19 MW4	81.7 – 100 -157 620 – 540 – 33.8 454 – 590 - 337	BH7 (u/g) BH9 (u/g) BH10 (lat)	< - 0.86 - < < - 3.5 - < < - 14 - <	SP4 SP5	5.8 – 4.1 - < < - 0.075 - <
Chloride (mg/l)	LG15 LG19 MW4	76.9 – 190 – 1070 1400 – 1700 – 47.8 631 – 1100 - 549	BH7 (u/g) BH9 (u/g) BH10 (lat	nm - 28 – 20.5 16.2 – 23 – 12.9 26.1 – 31 – 24.3	SP4 SP5	37.8 – 63 – 70.5 34 – 49 - x
Arsenic (ug/l)	LG15 LG19 MW4	202 – 11 – 187 56 – 73 – 30 64 – 19 - 64	BH7 (u/g) BH9 (u/g) BH10 (lat	18 - < - 49 24 - < - 32 33 – 1.5 - 24	SP4 SP5	127 - < - 15 < - < - x
TPH (C6-C40) (mg/l)	LG15 LG19 MW4	0.783 – 0.64 – x 3.15 – 0.75 – x 0.796 – 1.6 - x	BH7 (u/g) BH9 (u/g) BH10 (lat	< - < - x < - < - x < - < - x	SP4 SP5	< - < - x < - < - x

** Data is presented for Round 1 – Round 2 – Round 3; x denotes no sample taken; < denotes below Limit of Detection*
~ u/g denotes up-gradient; d/g denotes down-gradient of landfill site; nm denotes not measured.

6.1.3.2 Surface Water Receptor

<u>*County Brook River (Fassaroe Stream) (Receptor R1)*</u>

Surface water concentrations were compared to Environmental Quality Standards (EQS) protective of Freshwater bodies from the Environmental Objectives (Surface Waters) (Amendment) Regulations 2015 (S.I. No. 386 of 2015). These standards are considered to be the most appropriate generic assessment criteria for assessing the risk to surface water courses.

The main contaminants of concern (exceeding EQS) in the County Brook River (Fassaroe Stream) are summarised in Section 4.6.5 Surface Water and include BOD, chromium, copper, lead, nickel and some trace organics. Ammoniacal nitrogen was not identified in surface water at concentrations above the EQS in Round 1. In subsequent rounds ammoniacal nitrogen has been identified at concentrations above the LoD although observed concentrations do not routinely exceed the EQS at any location, with concentrations typically approaching the EQS where present.

Surface water quality exceedances correspond primarily to sampling location SW3 (upstream of Site 1), SW4 (close to Site 3A) and SW5 (up-gradient of all sites). Similarly, detection of hydrocarbons is observed at SW3, SW4 and SW5 and were restricted to Round 1. Surface water quality exceedances above EQS's at SW5 are indicative of contributions from other up-gradient contaminant sources.

There are no exceedances observed at SW1 and SW2, suggesting that Sites 2 has less of an impact on the County Brook River (Fassaroe Stream) than the other sites.

The surface water quality results demonstrate that the landfill sites are likely have the potential of affecting water quality within the County Brook River (Fassaroe Stream), although a measurable and reproducible effect is not evident and any small effects are mitigated by the dilution capacity within the drainage system and main river itself.

Springs (Receptor R4)

Small spring flows were encountered along the river valley, emerging as diffuse up-wellings which coalesce downstream to form a more defined channel that ultimately discharge into the County Brook River (Fassaroe Stream). The spring water is derived from groundwater within the up-gradient sand and gravel aquifer and supports the designated features of the Ballyman Glen SAC. For the purpose of the GQRA the water quality dataset for the five spring samples analysed, identified as being down-gradient of Site 1, 2, 3A and 3B, were compared to Environmental Quality Standards (EQS) protective of Freshwater bodies from the Environmental Objectives (Surface Waters) (Amendment) Regulations 2015 (S.I. No. 386 of 2015), reflecting the fact that spring discharges travel a short distance before discharging to the river. These standards are considered to be the most appropriate generic assessment criteria for assessing the risk to surface water courses.

The main contaminants of concern (which exceed EQS) at all five springs are summarised in Section 4.6.5 Surface Water include BOD, ammoniacal nitrogen and a number of heavy metals including arsenic, chromium and lead.

A summary of the water quality observed at springs considered to be located down-gradient of specific landfill site is presented in **Table 6.10** and **Table 6.11**. These tables present data for the key leachate marker parameters. An impact on water quality was observed in SP1, down-gradient of Site 2, with most EQS exceedances and the highest concentrations of heavy metals and ammonia. Furthermore, SP1 is the only spring sampling location where hydrocarbons and di-n-Butylphthalate where detected, albeit the latter is only marginally above the detection limit. SP4, down-gradient of Site 3A shows exceedances above EQS for arsenic, BOD and ammonia and SP2, down-gradient of Site 1 shows exceedances above EQS for lead, zinc and BOD.

It should be noted that a potential impact on water quality was also observed in SP3, down-gradient of Site 3C where exceedance above the EQS for cadmium, chromium, copper, lead, zinc and BOD are observed, although ammoniacal nitrogen and chloride remain low.

There is no detection of any other trace organic contaminants or hydrocarbons contaminants in the spring water samples with the exception of SP1 (Site 2).

It is therefore possible that concentration of trace organics and hydrocarbons in the River at SW3, SW4 and SW5 are derived from up-gradient contaminant sources such as runoff from the Ballyman Road. Elevated concentrations of BOD and heavy metals are likely to originate from the waste bodies assessed in this report.

Analysis of down-gradient spring water quality confirms that the County Brook River (Fassaroe Stream) has been impacted by the landfilling of waste at Fassaroe, although systematic effects are not clear in all monitoring rounds. It is notable that potential effects at the springs are typically greater than seen in the groundwater samples obtained from the monitoring network.

Tufa Springs & Alkaline Fen (GWDTE within the SAC) (Receptor R2)

Two out of five down-gradient springs (SP1 and SP4) show visual evidence of ochre staining, while the remainder of springs show the presence of tufa (calcite) deposits. The results of environmental monitoring completed to date do not provide a clear or reproducible relationship between the contamination status of the springs, the measured field parameters and the visual observations for individual springs sampled. The monitoring dataset does identify a measurable effect on spring water quality that can be attributed to the leachate migration from the landfill sites although any associated effect on the surface watercourse is less clear and mitigated by attenuation within the drainage system and surface water course associated with the SAC. Although direct effects have been observed it is not known whether these effects have peaked or are stable, or declining. However, the age of the landfill (typically filling in the early 1990s or earlier), the rapid transport expected along the short pathway in the sand and gravel (between the landfill sites and springs within the SAC), and gas dataset showing highly methanogenic albeit generally stable conditions would suggest that effects on the SAC should have established themselves.

The evidence collected to date demonstrates that the five landfill sites have the potential to affect conditions with the Alkaline Fen of the Ballyman Glen SAC and associated watercourse. It is possible that this affect could have a localised impact on tufa forming potential within a small number of the streams situated downstream of affected springs and the quality within therein. The ecological appraisal of the SAC will determine the extent and significance of any measurable and visual effects on the designated features of the Ballyman Glen SAC (i.e. tufa forming potential and alkaline fens).

6.2 DETAILED QUANTIFIED WATER ENVIRONMENT RISK ASSESSMENT

A Detailed Quantitative Risk Assessment (DQRA) has been undertaken to quantify the potential significance of the soil and groundwater contamination upon the quality of the water environment and to allow the likely effect any proposed remediation options to be evaluated.

The UK Environment Agency has developed a methodology for deriving site-specific remedial objectives for contaminated soils and/or groundwater to protect the aquatic environment (EA Remedial Targets Methodology (RTM): Hydrogeological Risk Assessment for Contaminated Land, 2006). The RTM approach consists of up to four levels of assessment which progressively follow the pathway from the contaminant source to the receptor. A Remedial Target Criteria (or RTC) that defines the maximum source concentration required to meet a specified water quality criterion (or “target concentration”) is derived at each level. The RTCs become less stringent at the progressive levels of assessment as additional processes of attenuation are considered (e.g. physical dispersion, retardation and biodegradation) which affect contaminant concentrations along the pollutant linkage from the source to the receptor.

A DQRA has been carried out individually for each of the landfill sites using the RTM and Worksheet (Release 3.2, issued January 2013). The assessment has been completed for the principal leachate marker parameter of ammoniacal nitrogen. Ammoniacal nitrogen has been selected as it is a contaminant of concern that occurs at high concentrations in leachate with a site-wide average concentration of c. 300 mg/l. Ammoniacal Nitrogen therefore has the greatest magnitude of exceedance with the target concentration used for the down gradient water environment receptor (e.g. 0.065 mg/l surface water annual average EQS). The highest concentrations of ammonaical nitrogen were typically measured in Round 1 (c. 370 mg/l) with a decreasing site-wide average concentration measured with each subsequent round. Ammoniacal nitrogen has been identified in groundwater and spring water samples.

The models have been developed based on site-specific data collated during the Tier 2 site investigation to reflect the updated Tier 3 CSM developed for each of the five landfill sites. Where site-specific data is unavailable suitably conservative generic data has been adopted.

The Tier 2 intrusive investigation works and associated environmental monitoring have demonstrated that two possible models for the setting individual landfill may apply:

- A perched landfill system, characterised by a perched leachate body that migrates from the waste mass to the underlying sand and gravel aquifer, although the depth of unsaturated zone is often small or absent; or

- Sub water-table landfill where leachate levels and groundwater levels are similar, suggesting leachate quality reflects that of shallow groundwater quality at the water-table.

Landfill Site 1 and Site 3B seem to be representative of a perched system, whereas Site 3C and the north area of Site 2 seem more consistent with the sub water table system. The conditions at Site 3A are more uncertain.

To reflect the potential difference in conceptual settings a number of different RTM assessment levels have been used for the DQRA presented herein. A Soil Level 3 Assessment has been undertaken to represent perched landfill system (Model 1). This assessment considers the effect of dilution at the water table through mixing with laterally flowing groundwater in the saturated aquifer and subsequent attenuation (by physical dispersion) during lateral transport in the saturated aquifer.

A Groundwater Level 3 Assessment has been used to consider possible sub-water table landfill scenarios (Model 2). This model does not include the effect of dilution with groundwater at the water table and therefore represents a very conservative approach for assessing risk to environmental receptors, as it assumes leachate concentrations are indicative of groundwater contaminations. Clearly any RTCs derived from Model 2 are considerably lower than derived through Model 1.

For the purpose of deriving RTCs, appropriate water quality criteria (target concentrations) are required for the receptors affected. The receptors considered as part of the DQRA and a discussion of relevant standards is given below in the order of increasing distance from the identified source:

Receptor R5: Groundwater in the sand and gravel aquifer – Plume development and observed effects principally on lateral and up-gradient monitoring locations confirm the impact of leachate on groundwater. Furthermore the presence of at least partially saturated waste at a number of the landfill sites, confirms direct effects on the shallow groundwater in localised areas. As this groundwater body constitutes a locally important aquifer unit Schedule 5 Groundwater Threshold Values (GTV) (as presented in the Environmental Objectives (Groundwater) (Amendment) Regulations 2016) have been used as target concentrations for the derivation of RTCs and for comparison of predicted concentrations beneath the landfill sites.

However, as the groundwater body affected by leachate is of limited aerial extent and occurs in an area unlikely to be exploited for water supply, it is risk to the Ballyman Glen SAC and County Brook River (Fassaroe Stream) that is the principal focus of the DQRA presented herein.

Receptor R4: Ballyman Glen SAC GWDTE – The designated features of the SAC include tufa forming streams situated downstream from springs and / or groundwater seepages and the alkaline fen communities within the SAC. The process of tufa formation is strongly dependent on the pH and carbonate inventory of the stream water, which is in turn dependent on the carbonate chemistry of groundwater from limestone gravel aquifer. Tufa formation is also dependent on the quantitative flow in those streams hence the groundwater discharge thereto. Other characteristics of water quality - such as the total chemical load (i.e. TSS) or effect of specific contaminants - may have an effect on the tufa forming potential although the nature of these effects and sensitivity of tufa formation to them is not known. The ecological communities that form the Alkaline Fen of the SAC may have quality requirements for the groundwater discharging in those areas. Water quality standards are not available for determination of risk and/or effect on the designated features of the SAC, however, predicted concentrations at the springs / seepages do provide an indication of likely level of impact that could be encountered at this receptor (R4).

Receptor R1: County Brook River (Fassaroe Stream) – The County Brook River is a WFD surface water body. Environmental Quality Standards (EQS) protective of Freshwater bodies as presented in Environmental Objectives (Surface Waters) (Amendment) Regulations 2015 (S.I. No. 386 of 2015) are therefore used for determining risk to the water course. The evaluation is risk for the County Brook River is determined after the effect of dilution within the river channel and assuming a baseline quality characterised by the non-detection of the modelled contaminant of concern, i.e. ammoniacal nitrogen.

The Groundwater Level 3 Assessment also allows the concentration of the modelled contaminant to be calculated at the down gradient receptor. By using the groundwater dilution factor at the water table calculated in the Soil Assessment (Level 2) and the calculated dilution factor associated with Q95 flow in the County Brook River (Receptor 1) it is possible to calculate predicted concentration at three key points within the system for Model 1 and Model 2: 1) Diluted concentrations in groundwater beneath the landfill; 2) Concentration at the point of groundwater emergence (i.e. springs in the SAC); and 3) Diluted concentration in the surface water receptor, at the Q95 (low) flow. These predicted concentrations allow the CSM and field observation to be evaluated with respect to the models of landfill setting.

The Remedial Targets Worksheets for each site are included as Appendix L.

6.2.1 Input Parameters

6.2.1.1 Site Characteristics

The main inputs for each site are summarised in **Table 6.12** .

Table 6.12 – Input Parameters for the Remedial Targets Worksheet Model

Site Name	Site 1	Site 2	Site 3a	Site 3b	Site 3c	Source
Landfill surface area (ha)	0.72	4.21	2.65	0.66	0.87	Site Mapping / Geophysics
Thickness of saturated gravel aquifer (m)	22	30	30	35	25	Conceptual Site Model
Hydraulic conductivity of gravel aquifer, K (m/d)	10	10	10	10	10	Literature / Local Experience
Hydraulic gradient across landfill site, i (-)	0.10	0.15	0.05	0.02	0.12	Water-table Map
Groundwater flow through gravel aquifer under the site (m^3/d)	744	5916	1267	126	893	Calculated using Darcy's Law (W, K and i)
Maximum depth of waste (mbgl)	14	19	16	5	13	Drilling / Geophysics
Width of waste body along groundwater flow path, W (m)	60	135	106	65	60	Site Mapping / Geophysics
Length of waste body along groundwater flow path, L (m)	115	340	219	85	113	Site Mapping / Geophysics
Distance to river along flow path (m)	107	160	96	400	90	Site Mapping / Geophysics
Q95 River Flow (L/s)	27	30	23	23	23	EPA Hydronet Data Extrapolation

6.2.1.2 Contaminants of Concern

The contaminant of concern that has been modelled for each site is ammoniacal nitrogen. Ammoniacal nitrogen is selected as the leachate concentrations were many orders of magnitude higher than the regulatory thresholds for the receptors and ammonia was at elevated concentrations at both groundwater and surface water receptors.

6.2.1.3 Target Concentrations

The target concentrations for groundwater (R5) and surface water (R1) receptors are based on current statutory threshold values. The GTV for ammonia is 0.175mg/l (Groundwater Regulations S.I. No. 366 of 2016) and the surface water annual average EQS for ammonia is 0.065mg/l (Surface Water Regulation S.I. No 386 of 2015).

6.2.1.4 Infiltration

The current infiltration at each of the sites is taken as the GSI recharge rate for the area of 575mm/yr. The actual infiltration rate may be lower due to the presence of the landfill capping on site. However the caps are not considered to be impervious as there appears to be landfill gas venting diffusely through the cap and the drainage and vegetative indicators are not typical of an impervious layer. This recharge rate is therefore considered to be conservative.

6.2.1.5 Biodegradation

The attenuation of ammoniacal nitrogen in soils and groundwater has received considerable attention in scientific literature, most notably Report NC/02/49 (NGWCLC, 2003) and Buss et al., 2004. The attenuation and biodegradation of reduced nitrogen are expected to occur in the subsurface. Biodegradation typically occurs by nitrification (biological oxidation) and is not therefore expected in anaerobic conditions. In oxidising conditions the half-life for ammonium in groundwater within a sand-gravel is expected to be 1 to 6 years.

Although variable the oxidation-reduction potential measured in groundwater (in Rounds 1, 2 and 3) and at springs (Round 3) is only occasionally negative, implying oxidising hydrochemical conditions prevail. However, as the dataset set is limited for down gradient monitoring locations the DQRA has not allowed for degradation of ammonia in the unsaturated or saturated zones, assuming reducing conditions predominate. Significant degradation of ammonia can occur but this will be site specific and no such data is available to date for each site. As such ammoniacal nitrogen concentrations are attenuated in the DQRA by dilution at the water table and / or physical dispersion during flow through the saturated aquifer.

6.2.1.6 Time Since Contamination Entered Groundwater

The time when contamination entered the groundwater is estimated at 20 years, approximately the same time when waste landfilling at Site 2 ceased. However the model has been run for steady state conditions and is therefore independent of the age / maturity of the waste mass.

6.2.2 Modelling Results and Discussion

The RTM Worksheet is used to calculate RTCs for Groundwater (Level 3) (i.e. Receptor 4) and for Surface Water (Level 4 that includes dilution within the watercourse) (Receptor 1). The RTCs generated for both receptors are then compared to average source concentration for each site (Round 1 to round 3) to determine whether the contaminant source (of ammonia) would result in the target concentration being exceeded at the receptor (gravel aquifer and County Brook River (Fassaroe Stream)).

Ammonia source concentrations are taken from leachate quality results. Where more than one leachate results for the same waste body an average ammonia concentration value is used. Other quality parameters (e.g. heavy metals) have not been included in the Remedial Targets Worksheet Model, however with considerably higher concentrations in waste leachate and the water environment, ammonia is considered as the worst case scenario for the DQRA.

The results for the DQRA based on current site conditions are summarised in **Table 6.13**. Red text denotes where the average ammonia leachate concentration is in excess of the RTC calculated for groundwater or surface water.

Table 6.13 – DQRA Model Results for Baseline Conditions

Model Parameter / Output	Unit	Site 1		Site 2		Site 3A		Site 3B		Site 3C		Comment
		Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	
Ammoniacal Nitrogen Concentration in Leachate	mg/l	20.5		306		366		567		203		Average concentration over three monitoring rounds
Infiltration Rate	mm/yr	575	575	575	575	575	575	575	575	575	575	GSI Recharge Rate
Thickness of Mixing Zone	m	12.4	12.4	29.8*	29.8*	23.9	23.9	9.66	9.66	12.11	12.11	Calculated in RTM
Groundwater flow under site	m3/d	744	744	5916	5916	1267	1267	126	126	893	893	Darcy's Law, using width and mixing zone thickness.
Seepage Rate to Groundwater	m3/d	11.3	11.3	66.3	66.3	41.7	41.7	10.4	10.4	13.7	13.7	Calculated
Calculated Factors												
Dilution Factor (in groundwater)[1]	-	69.4	NA	85.3	NA	35.7	NA	15.5	NA	82.9	NA	RTM Soil Level 2
Attenuation Factor (In saturated aquifer)[2]	-	1.06 - 1.3		1.003		1.000 - 1.006		5.61 - 10.82		1.021 - 1.175		RTM Soil Level 3 - RTM Groundwater Level 3
Dilution Factor for mixing in Watercourse	-	206	206	39	39	48	48	191	191	145	145	Based on Q95 flow and seepage rate to groundwater calculated above
Predicted Concentrations (For Source Concentrations CL)												
(R5) Groundwater beneath landfill site[3]	mg/l	0.30	20.5	3.59	306	10.25	366	36.6	567	2.4	203	Based on Leachate Concentration and dilution factor for Model 1 or Leachate Concentration (Model 2)
(R4) Groundwater at point of Spring / SAC emergence[4]	mg/l	0.23	15.72	3.58	305	10.20	364	3.4	52.4	2.08	173.7	RTM Groundwater Level 3 using calculated concentration in groundwater following mixing for model 1 or leachate concentration for Model 2
(R1) River (County Brook River)	mg/l	0.0011	0.076	0.092	7.81	0.21	7.65	0.018	0.27	0.014	1.20	Based on modelled concentration at R4 and dilution factor for watercourse / river (County Brook River).
Remediation Target Criteria (Red denotes where average leachate concentration exceeds RTC)												
RTC for Groundwater[5]	mg/l	12.1	NA	14.9	NA	2.3	NA	2.7	NA	14.5	NA	RTM Soil Level 2 RTC. Based on GTV of 0.175 mg/l
RTC for EQS at Spring / SAC[6]	*mg/l*	*4.783*	*0.085*	*5.561*	*0.065*	*2.320*	*0.065*	*5.638*	*0.703*	*5.503*	*0.076*	*RTM Soil Level 2 RTC (Model 1) / RTM Groundwater level 3 (Model 2)*

RTC for Surface Watercourse with dilution EQS (County Brook River) 7	mg/l	983.7	17.4	217.3	2.5	110.4	3.1	1077.5	134.4	797.9	11.1	Based on surface water EQS of 0.065mg/l.

1 Dilution factor, Df, as calculated in RTM for mixing at water table beneath landfill sites. RTM Level 2 Soils. NA denotes Not Applicable for Model 2

2 Attenuation factor, Af, as calculated in RTM for saturated groundwater pathway (Range represents the AF calculated for the Level 3 Soil and Level 3 Groundwater models)

3 Predicted concentration in groundwater based on the Df and leachate source concentration (C_L / Df); NA denotes Not Applicable as not calculated for Model 2 which assumes leachate / groundwater are the same.

4 Calculated concentration in groundwater at spring / SAC. Result calculated in RTM for Level 3 Groundwater. Model 1 uses a groundwater concentration calculated using the Df presented in the table. Model 2 uses the leachate concentration CL directly

5 RTC for groundwater calculated on the basis of the target concentration set at the groundwater GTV of 0.175mg/l

6 NA denotes Not Applicable - In the absence of water quality criteria applicable to SAC. no RTC has been calculated for the SAC / Spring (See Text)

7 RTC for surface water calculated on the basis of the EQS for surface waters of 0.065 mg/l. Includes dilution within the River.

* Saturated thickness reduced as plume to deep

Table 6.13 demonstrates that ammoniacal nitrogen concentrations identified in leachate at all five sites at Fassaroe exceed the groundwater RTC under current conditions, therefore impacting the underlying gravel aquifer. The predicted concentration of ammoniacal nitrogen at the spring exceeds the EQS for surface water for both models. Dilution within the down-gradient surface watercourse river (County Brook River) provides a significant capacity to reduce concentrations. Despite the dilution capacity of the surface water, ammoniacal nitrogen concentrations exceed the RTC for all sites for Model 2 and for Site 2 and Site 3A for Model 1.

The low attenuation factor in groundwater calculated for all sites clearly demonstrate the limited capacity that mechanical dispersion in the saturated aquifer has for attenuating the concentration of ammoniacal nitrogen over the short pathway to the Ballyman Glen SAC applicable to each site. In the absence of any biodegradation with the aquifer, the principal mechanism for the attenuation of ammoniacal nitrogen in leachate is through mixing with groundwater at the water table. It is therefore notable that the predicted concentrations at the springs / SAC that result from Model 2 (based on leachate concentrations applied to groundwater) appear to be significantly greater than the actual concentration measured at the 5 springs monitored. The results suggest that for most sites that mixing at the water table (Model 1) is occurring and is crucial for limiting water quality effects observed at the SAC.

Field measurements of oxidation-reduction potentially suggest that biodegradation by nitrification may occur in the saturated aquifer down-gradient of the landfill sites. However this process has not been included in the model for conservatism and in light of the short residence time in the aquifer implied by the RTM model. As such the effects on water quality predicted by either model in **Table 6.13** represent worst-case outcomes.

In summary the results seem to support the following:

- The potential for a significant impact on groundwater beneath the historical landfills (Receptor R5);
- Measurable effects on water quality at springs / SAC (Receptor 4), the magnitude of which is dependent on the degree of mixing at the water table and is likely to be variable depending on the nature of pollutant linkage connecting the leachate source to the springs; and
- Significant dilution capacity within the watercourse (Receptor R1) that can attenuate water quality effects if there is significant dilution through mixing at the water table.

7 REMEDIATION OPTIONS APPRAISAL

7.1 INTRODUCTION

This section presents a Remedial Options Appraisal (ROA) undertaken in accordance with CLR 11, in light of the findings of the Tier 2 and Tier 3 assessment previously described. The ROA, in the first instance, identifies the feasible remedial options. Following identification of the feasible options a detailed evaluation is undertaken to identify the most appropriate option. The ROA includes the following:

- Summary of effects associated the 5 landfill sites with respect to water environment receptors, human health and associated with landfill gas generation;
- Identification of remedial options; and
- High level appraisal of each option identified.

7.2 SUMMARY OF EFFECTS

7.2.1 Water Environment

Geophysical surveys have identified leachate plume development at all sites. Elevated concentrations of ammonia and heavy metals have been identified in up-gradient and down-gradient boreholes and are consistent with a direct effect of leachate on groundwater quality beneath all sites. This confirms the impact on groundwater by the historic landfilling of waste at Fassaroe. The magnitude of the observed impact on groundwater quality is typically small considering the hydrogeological setting and leachate quality identified on the sites, which may reflect dilution at the water table and/or limitations in the monitoring network that result from constraints on the installation of down-gradient monitoring boreholes.

The water quality dataset for springs within Ballyman Glen SAC that are situated down-gradient of the landfill sites highlights water quality impacts associated with leachate at a number of monitoring points. These effects are not observed at all springs with only two out of the five springs monitored showing visual evidence of ochre staining and/or possible sheening (i.e. SP1 and SP4). The remaining springs are typically characterised by clear waters and the build-up of tufa deposits, consistent with the discharge of calcareous, mildly alkaline waters from the sand and gravel aquifer. These observations are consistent with the outcome of the DQRA which demonstrates that the detailed setting of each landfill site will control the magnitude of effects on groundwater dependent receptors (i.e. springs).

The water quality dataset confirms the impact of leachate on the springs, with elevated concentration of ammoniacal nitrogen, chloride, some heavy metals and occasional organic compounds (most notably at Spring SP1 and Spring SP4). In Round 1 the springs characterised by the absence of tufa formation were associated with spring water of low pH and elevated concentrations of contaminants associated with leachate. However this relationship was not reproduced in subsequent monitoring rounds, with no systematic variability observed with pH, contamination status and tufa formation.

The groundwater and spring water quality dataset suggests that the landfill sites do have the potential to affect water quality within the County Brook River (Fassaroe Stream), although the magnitude of the effect is strongly mitigated by the dilution capacity within the river. This outcome is supported by the DQRA.

The results of the first monitoring round did identify exceedances principally at sample locations SW3, SW4 and SW5. Similarly, hydrocarbons were also detected in SW3, SW4 and SW5 in Round 1. Surface water quality exceedances above EQSs at SW5 is indicative of contributions from other up-gradient contaminant sources. In Round 1 there are no exceedances observed at SW1 and SW2, suggesting that Sites 2 does not have a measurable effect on water quality in County Brook River (Fassaroe Stream) despite the leachate quality observed on the site and water quality observed at Spring 1. Despite the observations in Round 1, the water quality dataset did not generally exceed relevant EQSs at any location in the two subsequent monitoring rounds.

In summary, the landfill sites do have the potential to affect surface water quality within the County Brook river (Fassaroe Stream) although water quality effects are not routinely observed, are largely restricted to upstream sections when they occur and are observed at locations situated at positions situated upstream of the landfill sites. These observations are consistent with the continued WFD Status of the County Brook Stream, which is classified as 'good'.

A DQRA was undertaken for each landfill site for ammoniacal nitrogen, one of the principal contaminants of concern associated with leachate on the sites. The DQRA confirms that that all five sites have the potential to impact the underlying sand and gravel aquifer and potentially the County Brook River (Fassaroe Stream) although dilution in that water course is likely to be unaffected if dilution through mixing at the water table is a significant process. The monitoring works undertaken on the site demonstrate that the actual impact on down-gradient groundwater quality reduces significantly over relatively short distances of 20 to 50m, as indicated by down-gradient borehole and spring water quality. This reduction in concentrations highlights the dilution and natural attenuation capacity along the groundwater pathway. The significant flow in the County Brook River (Fassaroe Stream) also provides dilution to the potential impact on surface water quality, and for the case of ammonia concentrations, reduces the concentrations in the river below laboratory detection limit.

The evidence collected to date demonstrates that the five landfill sites have the potential to affect conditions with the alkaline fen of the Ballyman Glen SAC and its associated watercourse. It is possible that this affect could have a localised impact on tufa forming potential and water quality within a small number of the streams situated downstream of affected springs. The ecological appraisal of the SAC will determine the extent and significance of any measurable effects on the designated features of the Ballyman Glen SAC (i.e. tufa forming potential and alkaline fens).

7.2.2 Landfill Gas

A review of the gas regime at the site (based on the currently available information) suggests that the main source of gas generation at the site is the waste within the landfills. The main pathway for gas migration from the waste materials is considered to be through the permeable superficial deposits, with limited contributions through dissolved gas in groundwater. The deeper bedrock is not considered to be a significant gas migration pathway owing to its depth and low permeability.

An initial review of methane and carbon dioxide concentrations within and outside the waste mass typically identifies lower concentrations outside the waste mass than within. The decrease in gas concentrations is more pronounced for methane than for carbon dioxide indicating that methane may be venting vertically through the landfill cap and natural deposits. There are a small number of occasions where higher concentrations of recorded gases are present outside the recorded areas of the waste mass. It is considered that these may be related to preferential pathways. These locations require further consideration. The current data does not suggest a link between groundwater levels and gas flow rates.

Following the completion of the Wilson & Card and the NHBC Traffic Light assessments the proposed protection measures for each site are detailed in **Table 6.6** and **Table 6.7**. Protection measures will need to include gas barriers to prevent migration of gases from the landfills where further monitoring cannot dismiss the risk from gas within the proposed development areas.

7.2.3 Human Health

The Tier 2 human health risk assessment has identified that contaminant concentrations are generally below the selected screening criteria for a public open space (parks) use.

The risk assessment has identified elevated concentrations of PAHs within the landfill materials in Site 1, elevated concentrations of lead and PAHs within the landfill materials in Site 2 and elevated concentrations of PAH within the capping materials in Site 2. In addition, asbestos containing materials have been encountered at 1 location within the landfill materials in Site 1.

Despite the presence of elevated concentrations of contaminants and the presence of asbestos within the landfilled materials, it is not considered that future site users are likely to be exposed to the contamination due to the depth at which the contamination is present (>1.0 m). With regard to the PAH contamination within the capping materials within Site 2, additional sampling may be considered to further determine levels of contamination within these materials. Should a clean cap be placed to mitigate potential ground gas risks and / or risks to the water environment at this location, this would likely mitigate risks to future site users by preventing exposure to the contamination.

7.3 IDENTIFICATION OF FEASIBLE REMEDIAL OPTIONS

Remediation is required at the site to mitigate potential risks to the water environment (where an unacceptable level of impact is demonstrated through the ecological appraisal) and human health in relation to the waste mass at each of the landfill sites and associated leachate / landfill gas generation. The proposed remedial options shall conform to the requirements of Chapter 7 (remediation Techniques) of the EPA Code of Practice. The remediation options proposed shall enable the known or predicted effects to be eliminated or reduced relative to baseline conditions.

The pollutant linkages potentially requiring remediation are summarised in the revised CSM presented in **Table 5.1** and **Table 5.2** and include:

- Leachate Source – Groundwater Receptor (Moderate Risk);
- Leachate Source – Groundwater Pathway – GWTDE Receptor (High Risk);
- Leachate Source – Groundwater Pathway – Surface Water Body Receptor (Moderate Risk);
- Landfill Gas Source – Lateral / vertical migration Pathway – Existing and Future Site User Receptor (Moderate Risk) and

- Landfill Gas Source – Lateral / vertical migration – Future Construction Workers Receptor (High Risk).
- Waste (PAHs and certain metals) – Existing and Future Site Users (Low / Moderate Risk)
- Waste (Asbestos) - Existing and Future Site User Receptor (Low / Moderate Risk)

The proposed ROA shall consider approaches to mitigate the magnitude of effects associated with these pollutant linkages. In addition at specific sites there remains a moderate risk in association with landfill gas migration along existing subsurface infrastructure and the potential for Asbestos Containing Material (ACM).

The factors and associated criteria that will be used to evaluate the remedial options to achieve the remedial objectives with respect to the site specific conditions and constraints are summarised in **Table 7.1**.

Table 7.1 - Remedial Option Selection Criteria

Factor	Criteria
Effectiveness	Performance with respect to reducing the respective pollutants to levels that are acceptable or breaking pathways. Therefore options that are not suitable for the particular physical and chemical characteristics of the site are not considered any further.
Timescale	Remediation techniques that require a significant period of time to successfully meet the remedial objectives are not considered suitable for this site given the proposed development timetable.
Cost	Only remedial options that fulfil the remedial objectives within an acceptable cost bracket have been considered any further. The appraisal of cost is based on small treatment volumes that are anticipated to be presented, and therefore remedial approaches with significant set up/mobilisation cost are not considered suitable for the site.
Durability	All remedial options must be long lasting and minimise the potential for residual impacts to become apparent as the requirement for further remedial works post development of the site is unacceptable.
Commercial Availability	There are many remediation technologies that have been used within the UK, however only a limited number of these are commercially available in the UK.
Track Record	Only remedial options with a proven track record in the UK have been selected. Options with no or poor UK track records may impact on other factors in this table such as effectiveness, timescale and cost.
Environmental Impact	Some remedial options have not been selected because of the likely environmental impacts. Examples include energy and material requirements.
Compatibility	The risk assessment has identified a number of pollutant linkages that may require different remediation techniques to successfully meet the remedial objectives. Therefore all remedial options must be compatible with each other as well as the proposed development scheme.
Permissions	Some remedial options will require forms of waste management licences and potentially other forms of licensing such as discharge consents etc. The form of licence may influence the selection of the remediation technique because of the likely timescales required for applications and the cost of application.
Site Constraints	The site conditions may limit the likely effectiveness of a given remedial technique due to issues such as access, available space and ground conditions.

7.4 OPTIONS APPRAISAL

In considering potential remedial options, account must be taken of the contamination related objectives and constraints. Monitored Natural Attenuation (MNA) has not been considered as part of the ROA in light of the observed impacts on groundwater and groundwater dependent receptors identified during the Tier 2 investigations however monitoring is likely to form part of any remediation programme ultimately delivered on the site.

Table 7.2 – Remediation Options Appraisal

Remediation Options		
Source	Treatment Options	Suitability
Waste & Leachate (Associated with former landfill sites)	Civil Engineering (Excavate and Disposal at Landfill)	Effectiveness: High. Removes all contamination. Unclear if sufficient landfill space to receive waste generated.Disposal options are limited (may have to be exported) as 625,500 tonnes which would not have been accounted for in Regional Waste Management Plans Timescales: Quick assuming sufficient landfill space to receive waste requiring disposal. Cost: Extremely high cost considering total volume of waste to be removed from landfill sites and leachate management / disposal that would be required. Durability: Permanent. Commercial Availability: Widely availed. Track record: Proven track record. Environmental Impact: Short term impacts could be large considering the depth of the waste mass to be removed, the proximity to the Ballyman Glen SAC and stability issues identified during site works; Temporary exposure of waste mass by removal of existing landfill cap could mobilise leachate to groundwater and associated receptors in short term; Leachate management and extraction required during excavation which is likely to complex and difficult; Requires haulage and will lead to loss of landfill void as well as requirement to import fill materials to backfill voids created; Release of noxious odours and gases, potential to attract pests (birds, flies, rodents), and the generation of dust and other nuisances including wind-blown litter. Compatibility: Will address all contamination pollutant linkages including human health. Permissions: Planning and waste authorisations Site Constraints: Access to areas may be difficult with large plant. Practicalities of excavating 625,500 tonnes of waste, to significant depths (up to 20m), lying directly adjacent to a steep densely-wooded river valley and Special Area of Conservation (SAC), would be extremely difficult with significant environmental impact; Deep excavations required that would require backfilling. Given the large volumes of waste involved (625,500 tonnes), this increases the handling and transport requirements thereby increasing the short term potential for pollution.
	Engineered Low Permeability Landfill Cap. (Likely to be integrated with other gas management measures for human health	Effectiveness: Moderate. Will reduce leachate generation on each landfill site, whilst minimising disruption to quantitative groundwater flow within the aquifer, thereby reducing impacts on receptors situated down-hydraulic gradient from landfill sites. Complies with waste minimisation and sustainability principles. Timescales: Very quick. Cost: Low (construction cost and any upgrade). Durability: Long-term. May potentially require upgrade / replacement

Remediation Options		
	associated with future development – see below)	Commercial Availability: Widely availed. Track record: Proven track record. Environmental Impact: Minimises disturbance of contaminated material and associated risks. Small reduction in water balance for local sand and gravel aquifer system, hence reduction of groundwater through flow to the SAC and County Brook River. Minimises risk to site workers and the public. Compatibility: Would address all gas issues if integrated with comprehensive gas management measures for any future development. Will reduce impacts on groundwater dependent receptors, but may not eliminate effects thereon. Would reduce impacts on groundwater. Would mitigate risk to human health associated with waste mass and/or cap materials. Permissions: Planning and waste authorisations Site Constraints: Few Constraints.
	Impermeable Barriers / Cut off walls (full isolation of landfill sites likely to be required)	Effectiveness: Low. Extensive barrier system would be required (possibly full isolation) considering proximity to SAC, This would require deep barriers possibly keyed into bedrock and leachate management to prevent breakout of landfill site would be required to eliminate risk on water quality at SAC and County Brook River. Timescales: Quick. Cost: Moderate. Durability: Long-term / permanent. Commercial Availability: Widely availed. Track record: Proven track record, but not necessarily in this setting. Environmental Impact: Significant effect on groundwater through flow in aquifer hence discharge to the SAC and water levels therein. Leachate breakout could affect groundwater water quality in the SAC and associated watercourses. Compatibility: Not designed to manage gas risk. Does not mitigate human health risks associated with waste mass and/or cap materials. Permissions: Planning and waste authorisations Site Constraints: Stability issues may prevent practical installation of deep barriers.
	Permeable Reactive Barriers	Effectiveness: Moderate if can be constructed to appropriate depth. Could require replacement. Should be feasible to manage key contaminants of concern. Timescales: Quick subject to access. Cost: Moderate. Could require replacement Durability: Long-term. Commercial Availability: Widely availed. Track record: Proven track record, but not necessarily in this setting. Environmental Impact: Minimal effect on groundwater through flow to the SAC and associated groundwater receptors. .

Remediation Options		
		Compatibility: Not designed to manage gas risk. Does not mitigate human health risks associated with waste mass and/or cap materials. Permissions: None required. Site Constraints: Stability issues may prevent useful installation of deep barriers.
Leachate (Associated with former landfill sites)	Pump and Dispose	Effectiveness: Will significantly reduce leachate generation and loss to groundwater. May help to reduce landfill gas generation; Timescales: Open-ended, long-term until waste mass no longer produces significant leachate; Cost: High construction and operation costs; Durability: Should reduce effects on groundwater and associated groundwater dependent receptors, but requires operational system at all times. Commercial Availability: Widely availed. Track record: Proven track record. Environmental Impact: Significant quantity of leachate disposal required either off-site or using onsite treatment plant. Compatibility: Unclear if it will address gas risk. Will reduce but not eliminate impacts on groundwater; will reduce but may not eliminate effects on groundwater dependant receptors. Does not mitigate human health risks associated with waste mass and/or cap materials. Permissions: Planning and waste authorisations. Site Constraints: Access to areas may be difficult with large plant.
	Pump and Treat	Effectiveness: Will significantly reduce leachate generation and loss to groundwater. Should reduce landfill gas generation; Timescales: Open-ended, long-term until waste mass no longer produces significant leachate; Cost: High construction and operation costs; Durability: Should reduce effects on groundwater and associated groundwater dependent receptors, but requires operational system at all times. Commercial Availability: Widely availed. Track record: Proven track record. Environmental Impact: Significant quantity of leachate disposal required either off-site or using onsite treatment plant. Compatibility: Unclear if it will address gas risk. Will reduce but not eliminate impacts on groundwater; will reduce but may not eliminate effects on groundwater dependant receptors. Does not mitigate human health risks associated with waste mass and/or cap materials. Permissions: Planning and waste authorisations. Construction of permanent treatment-plant would be required. Site Constraints: Access to areas may be difficult with large plant.

Remediation Options		
Contaminated Groundwater (Leachate contaminants of concern most notably ammoniacal nitrogen, heavy metals and some organic compounds)	Pump and Dispose	Effectiveness: Would reduce potential for contaminated groundwater to affect SAC. Does not change leachate generation and impacts on groundwater around the landfill sites. Timescales: Long-term open-ended pump and dispose system would be required. Cost: High construction and operational costs expected as significant groundwater removal would be required. Durability: Should reduce effects on groundwater receptors but would require operational system in the long term which would require renewal / upgrade. Commercial Availability: Widely availed. Track record: Proven track record. Environmental Impact: Large volume of water will require disposal; Pumping induced drawdowns would significantly alter groundwater flow system, significantly reduce groundwater through flow to the SAC / Country Brook River and could result in drying of the fen at the margins. Compatibility: Only addresses water quality impact observed on the SAC and Country Brook River. Does not address landfill gas issues; Does not address impacts on groundwater beneath / around the landfill sites. Does not mitigate human health risks associated with waste mass and/or cap materials. Permissions: None required. Site Constraints: requires down-gradient borehole network to be installed at all site. Access to required areas will be extremely problematic for heavy plant required..
	Pump and Treat	Timescales: Long-term open-ended pumping and treatment would be required. Cost: High construction and operational costs expected as significant groundwater removal would be required. On-site treatment for ammoniacal nitrogen, heavy metals and organics may be costly. Pipeline to treatment plant would be required. Durability: Should reduce effects on groundwater receptors but would require operational system in the long term which would require renewal / upgrade. Commercial Availability: Widely availed. Track record: Proven track record. Environmental Impact: Large volume of water will require disposal; Pumping induced drawdowns would significantly alter groundwater flow system, significantly reduce groundwater through flow to the SAC / Country Brook River and could result in drying of the fen at the margins. Compatibility: Only addresses water quality impact observed on the SAC and Country Brook River. Does not address landfill gas issues; Does not address impacts on groundwater beneath / around the landfill sites. Does not mitigate human health risks associated with waste mass and/or cap materials. Permissions: Planning and waste authorisations. Construction of permanent treatment-plant would be required. Site Constraints: requires down-gradient borehole network to be installed at all site. Access to required areas will be extremely problematic for heavy plant required.

Remediation Options		
Landfill Gas	Engineered Low Permeability Landfill Cap and / or Gas Protection Measures for Land-use (As designed by Gas Risk assessment)	Effectiveness: High. Will manage gas risk on site Timescales: Quick. Cost: Moderate. Gas protection measures dependent on complexity but gas risk is significant on the site Durability: Long-term. May potentially require upgrade / replacement Commercial Availability: Widely availed. Track record: Proven track record. Environmental Impact: Risk to current and future users should be managed, Reduced leachate generation hence impact on groundwater and groundwater dependent receptors shall also be reduced (see above). Small reduction of quantitative groundwater through flow to the SAC and County Brook River expected. Compatibility: Will reduce magnitude of effects associated with groundwater and groundwater dependent receptors. Will manage human health risks associated with waste mass and/or cap materials. Permissions: Planning and waste authorisations. Site Constraints: Few Constraints.
Asbestos	Civil Engineering (Excavate and Disposal at landfill)	Effectiveness: Removes contamination. Timescales: Relatively quick where asbestos has been waste has been located and quantified Cost: Cost effective for small volumes anticipated at the site. However, extremely expensive relative to other treatment options Durability: Permanent. Commercial Availability: Widely availed. Track record: Proven track record. Environmental Impact: Extensive mitigation measures required to prevent exposure to site workers and the public. Release of noxious odours and gases, potential to attract pests (birds, flies, rodents), and the generation of dust and other nuisances including wind-blown litter. Required haulage and will lead to loss of landfill void as well as requirement to import fill materials to backfill voids created. Short term dust and odour nuisance may be created during works. Compatibility: Addresses all contaminant sources at site (accepting that impacted perched groundwater is removed as part of the process) so no compatibility issues. Permissions: Planning and waste authorisations. Site Constraints: Access to areas may be difficult with large plant.

7.5 SELECTED REMEDIAL OPTION

On the basis of the remedial options appraisal outlined in **Table 7.2** the following options appear to be most suited to addressing the pollutant linkages identified on the Fassaroe site:

- Waste Removal;
- Engineered Low Permeability Landfill Cap and Gas Protection Measures for Land-use;
- Permeable Reactive Barriers; and
- Gas Protection Measures.

7.5.1 Waste Removal

Complete removal of the waste mass would remove the contamination source hence severe all pollutant linkages identified in the **Table 5.1**. However there would be significant issues associated with this approach;

- **Excavation:** Based on the site investigations undertaken as part of the ERA, the volume of waste present across the five sites is estimated to be 625,500 tonnes. The below ground depths to which waste has been landfilled were found approximately to range from 13 to 19mbgl for four of the sites with Site 3B having a depth of approximately 5mbgl. Excavation and replacement of the waste would lead to the removal of the source of environmental pollution and thereby eliminate the potential for future environmental liabilities. However, the practicalities of excavating this volume of waste, to the depths outlined above, lying directly adjacent to a steep densely-wooded river valley and SAC, would be extremely difficult and could result in significant impacts on the SAC considering the short pathway to the environmental receptors. Excavating aged waste can cause the release of noxious odours and gases, the potential to attract pests (birds, flies, rodents), and the generation of dust and other nuisances including wind-blown litter. In addition, any excavated waste would need to be replaced with clean soil material in order to reinstate the areas. Significant traffic movements would be required in order to excavate/ replace the required volume of material from/ to the site with the potential to significantly impact on local communities over several years.
- **Disposal:** The disposal of approximately 625,500 tonnes of waste would present major difficulties particularly given the current waste management challenges in Ireland with regard to suitably licensed facilities and their remaining landfill capacity. It is likely that the excavated waste would have to be hauled considerable distances for landfill, pre-treatment or to be exported. The EPA reported residual waste capacity in Irish landfills to be “critically low” in ‘Ireland’s Environment 2016 - An Assessment’ (EPA, November 2016). Furthermore, emergency measures were exercised by the EPA in 2016 with the re-opening of Knockharley and Ballynagran Landfills due to the serious risk of environmental pollution occurring as a result of disposal options not being available to manage residual waste nationally. The requirement to dispose of a further 625,500 tonnes of waste material, which has not been accounted for any of the Regional Waste Management Plans, would constitute a major issue in this regard. The environmental impacts associated with the loading and haulage of this volume of waste to licenced facilities capable of accepting this volume of material would be considerable, as would the length of time required to do so given the piecemeal controlled management that would be required. To put this into context, the licensed capacity of Ballynagran landfill, Co. Wicklow in recent years was 175,000 tonnes per year, versus potentially 625,500 tonnes of waste in Sites 1, 2, 3A, 3B and 3C at Fassaroe.

- **Cost:** The cost of excavating approximately 625,500 tonnes of waste and disposing elsewhere is a consideration also. Assuming a gate fee of €120 per tonne (exluding landfill levy), the costs alone of disposal would be in excess of €28 million. On top of this the costs of excavation, haulage and environmental management of the sites during the excavation and replacement with clean material would run into further multi-millions. The Eastern - Midlands Region Waste Management Plan 2015 – 2021 states that local authorities are “committed to targeting and addressing the highest risk sites as soon as possible and subject to funding being made available”. However, obtaining funding at the scale required for the excavation and disposal of the entirety of the waste bodies at the Fassaroe sites when more feasible, environmentally sustainable and cost effective remedial measures can be implemented would be difficult to justify.

7.5.2 Engineered Low Permeability Landfill Cap

The capping of a landfill with a low permeability barrier is an accepted method for reducing leachate generation on landfill sites. A capping option is considered viable on the historical landfill sites, would be cost effective and would be a low impact approach that will mitigate human health risks associated with asbestos and PAHs in soils and will result in a net betterment to the water environment by improving water quality without significant reducing groundwater flow to the Ballyman Glen SAC. Furthermore an engineered low permeability cap would also enable landfill gas management measures for any future development of the site.

To evaluate the potential betterment that the capping of the each landfill site may have the water environment, the DQRA for baseline conditions presented in **Table 6.13** was updated for all sites assuming they are capped in accordance with EPA Landfill Guidelines.

For the post-development scenario a reduced infiltration rate of 67mm/yr for all sites has been used. This is based on the assumption that a remediation strategy will be put in place capping the landfills, using the EPA landfill design for non-hazardous landfill (EPA Landfill Manuals Landfill Design, 2000; Page 96). This designs uses a compacted mineral cap layer of a minimum 0.6m thickness having a hydraulic conductivity of less than or equal to $1x10^{-9}$m/s. The estimated infiltration rate is equal to the average effective rainfall through this compacted mineral layer. Thus the RTM model was modified to reflect the reduced infiltration rate that would result.

The results for the updated DQRA based on a capped scenario are summarised in **Table 7.3**.

Table 7.3 – DQRA Model Results for Engineered Low Permeability Cap

Model Parameter / Output	Unit	Site 1		Site 2		Site 3A		Site 3B		Site 3C		Comment
		Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	
Ammoniacal Nitrogen Concentration in Leachate	mg/l	20.5		306		366		567		203		Average concentration over three monitoring rounds
Infiltration Rate	mm/yr	67	67	67	67	67	67	67	67	67	67	See text
Thickness of Mixing Zone	m	12.4	12.4	29.8*	29.8*	23.9	23.9	9.66	9.66	12.11	12.11	Calculated in RTM
Groundwater flow under site	m3/d	744	744	5916	5916	1267	1267	126	126	893	893	Darcy's Law, using width and mixing zone thickness.
Seepage Rate to Groundwater	m3/d	1.3	1.3	7.7	7.7	4.9	4.9	1.2	1.2	1.6	1.6	Calculated
Calculated Factors												
Dilution Factor (in groundwater)[1]	-	578.5	NA	722.0	NA	290.3	NA	117.3	NA	693.8	NA	RTM Soil Level 2
Attenuation Factor (In saturated aquifer)[2]	-	1.06 - 1.3		1.003		1.000 - 1.006		5.61 - 10.82		1.021 - 1.175		RTM Soil Level 3 - RTM Groundwater Level 3
Dilution Factor for mixing in Watercourse	-	1765	1765	335	335	409	409	1640	1640	1244	1244	Based on Q95 flow and seepage rate to groundwater calculated above
Predicted Concentrations (For Source Concentrations CL)												
(R5) Groundwater beneath landfill site[3]	mg/l	0.035	20.5	0.42	306	1.26	366	4.83	567	0.293	203	Based on Leachate Concentration and dilution factor for Model 1 or Leachate Concentration (Model 2)
(R4) Groundwater at point of Spring / SAC emergence[4]	mg/l	0.027	15.72	0.423	305	1.254	364	0.45	52.4	0.25	173.7	RTM Groundwater Level 3 using calculated concentration in groundwater following mixing for model 1 or leachate concentration for Model 2
(R1) River (County Brook River)	mg/l	0.00002	0.0089	0.0013	0.91	0.0031	0.891	0.0003	0.032	0.0002	0.139	Based on modelled concentration at R4 and dilution factor for watercourse / river (County Brook River).
Remediation Target Criteria (Red denotes where average leachate concentration exceeds RTC)												
RTC for Groundwater[5]	mg/l	101.2	NA	126.7	NA	50.8	NA	20.5	NA	121.4	NA	RTM Soil Level 2 RTC. Based on GTV of 0.175 mg/l
RTC for EQS at Spring / SAC[6]	*mg/l*	*107*	*0.085*	*47.1*	*0.065*	*18.9*	*0.065*	*45.2*	*0.703*	*46.1*	*0.076*	*RTM Soil Level 2 RTC (Model 1) / RTM Groundwater level 3 (Model 2)*

RTC for Surface Watercourse with dilution EQS (County Brook River) 7	mg/l	189655	149.6	15787	21.9	7708	26.7	74206	1153.6	57341	95.0	Based on surface water EQS of 0.065mg/l.

Table 7.3 also highlights the exceedance in average ammonia leachate concentration above the Groundwater or Surface Water RTC in red. The results confirm that a substantial improvement in water quality can be expected as the result of capping, particularly for Model 1 where dilution at the water table is the principal mechanism of attenuation as expected at the majority of landfill sites.

The new capping system will reduce the infiltration of rainwater through the waste and therefore reduce the volume of leachate entering the underlying aquifer and ultimately the stream. The reduced recharge to the aquifer as a result of the capping layers has the potential to impact on the hydrology of the down-gradient tufa springs. It is estimated the recharge within the spring groundwater catchment could reduce by up to 7% as a result of the capping. This could lead to a drop in groundwater levels and/or a drop in groundwater flow to the springs. The impact is mitigated by the expected improvement in groundwater quality which will lead to the potential for improved tufa depositions rates or new tufa deposits.

Where the runoff from the capping layer can be reintroduced to groundwater, such that it does not re-saturate the waste and is sufficiently far enough up gradient from the springs to allow the hydrochemistry to equilibrate with the in-situ groundwater, this will mitigate the potential reduction in groundwater recharge the impact on the spring hydrology.

Landfill Gas Management

A gas management strategy should for any future development be developed for the site having regard to its proposed mixed residential and commercial zoning. This strategy should identify the gas protection measures that can be installed to limit gas migration from the landfills and the protection measures that will be required to properties, supported by relevant appraisal / assessment. This strategy will need review and update once the further information is available, but shall be based on gas protection measures outlined in Section 4.6.6 in order to protect human health in relation to ground gases associated with the landfill site.

Human Health

A clean cap should be placed to mitigate potential ground gas risks and / or risks to the water environment at this location however this would likely mitigate risks to future site users by preventing exposure to the contamination.

It is considered however that the concentrations of contaminants identified during the ground investigation are unlikely to constitute a risk to construction workers during any future development where appropriate measures are adopted. Due to the heterogeneous nature of landfilled materials however, there is a possibility that asbestos and areas of gross contamination may be present and a suitable watching brief should be employed during construction for any such contamination. In addition, suitable hygiene and welfare facilities and PPE should be provided in accordance with the requirements of the Safety, Health and Welfare at Work (General Application) Regulations 2007, Safety Health and Welfare at Work (Exposure to Asbestos) Regulations 2006 and 2010 amendments and the Safety Health and Welfare at Work (Construction) Regulations 2013 to manage potential risks to construction workers. Appropriate procedures should also be in place to remediate any such contamination encountered during construction in line with the Safety Health and Welfare at Work (Exposure to Asbestos) Regulations 2006 and 2010 amendments and the Safety Health and Welfare at Work (Construction) Regulations 2013.

The capping system will comprise engineering and restoration layers. The details of the restoration layers must be consistent with the proposed after use of the facility. The main objectives of the capping system are to:

- Minimise infiltration of water and maximise run off;
- Promote surface drainage and maximise run off;
- Control gas migration; and
- Provide a physical separation between waste and plant and animal life

The proposed capping system is in accordance with the EPA Landfills Manuals – Landfill Site Design. The capping system should consist of at a minimum the following:

- Top soil (150 – 300mm) and subsoil of at least 1m total thickness;
- Drainage layer of 0.5m thickness having a minimum hydraulic conductivity of 1x10-4m/s
- Compacted mineral layer of a minimum 0.6m thickness having a hydraulic conductivity of less than or equal to 1x10-9m/s or a geosynthetic material (e.g. GCL) or similar that provides equivalent protection; and
- A gas collection layer of natural material (minimum 0.3m) or a geosynthetic layer.

Consideration should be given to the inclusion of a flexible membrane liner in the capping system.

7.5.3 Permeable Reactive Barriers

The high level ROA suggests that permeable reactive barriers may potentially address the water quality risk to the Ballyman Glen SAC and associated watercourse, without reducing the quantitative groundwater flow within the aquifer to the SAC. However, site constraints suggest that the feasibility of construction of such a barrier may be questionable considering the stability issues identified along the northern boundary of the majority of landfill sites and the proximity to the river valley and boundary of the Ballyman Glen SAC. The feasibility of such a system needs further consideration and design.

7.5.4 Final Conceptual Site Model

A final CSM has been produced for the Fassaroe site a based on the implementation of engineered capping and gas management system, with associated gas protection measures for the potential future development of the site. The final post-development CSM is provided in *Table 7.4*.

Table 7.4 – Revised Risk Site Wide Model with Engineered Cap and Gas Mitigation Measures

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
S1	Leachate	P1	Vertical to groundwater then horizontally through possible surface water drainage channels into the river	R1	WFD Surface Water Body	None	Medium	No Risk	The mitigation measures include capping of landfill Sites and will significantly reduce the vertical movement of rainwater through the waste and therefore significantly reduce leachate generation.
				R2	Surface Water Protected Area	None	Medium	No Risk	
		P2	Vertical & Horizontal via Groundwater	R3	Private Wells	None	Medium	No Risk	There are no known private wells along the leachate plumes (water main connection in the area)
				R4	Groundwater Dependent Terrestrial Ecosystem (GWDTE)	Likely	Medium	Moderate Risk	Landfill capping will reduce the risk from High to Moderate as a result of reduced leachate generation. Some leachate discharge will still occur as some of the waste is located beneath the water-table elevation and there will be a limited amount of seepage through the capping. Impacts on springs / SAC will be greatest where conditions most closely reflect model 2 (leachate concentrations reflecting groundwater concentrations at water table)
				R5	Aquifer	Likely	Medium	Moderate Risk	The reduced leachate generation will significantly reduce the risk to the underlying aquifer.
				R6	Public Supply Well	None	Mild	No Risk	There are no public water supply wells in the area.
				R1	Surface Water Body	Unlikely	Mild	Very Low Risk	The capping of the landfill sites will reduce the leachate generation and the risk to the County Brook River (Fassaroe Stream) from moderate to low risk
		P3	SW Drainage	R1	Surface Water Body	None	Medium	No Risk	The drainage from the landfills will be directed

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
				R2	Surface Water Protected Area	None	Medium	No Risk	to a dedicated surface water drainage and attenuation system. As such the runoff will not come in contact with the waste the SPR link age is broken.
S2	Waste	P4	Direct dermal contact Ingestion dust and soil Inhalation of dust	R7	Future Site Users	None	Mild	No Risk	Sites 1, 3A and 3C are currently not in use. Currently minimal clay cap in place. The provision of an engineered cap would address human health direct contact pathways
				R8	Construction Workers	Unlikely/Low Likelihood	Minor	Very Low Risk	Risk to construction workers during excavations should be mitigated by the use of appropriate PPE
S3	ACM	P4	Direct dermal contact Ingestion dust and soil Inhalation of dust	R7	Future Site Users	None	Severe	No Risk	Shallow soil sampling recorded a single detection of ACM in Site 1 – not detections were recorded at the remaining sites. The provision of an engineered cap would severe link for human health direct contact pathways
				R8	Construction Workers	Unlikely	Severe	Low/Moderate Risk	Shallow soil sampling recorded a single detection of ACM in Site 1 – not detections were recorded at the remaining sites. Risk to construction workers during excavations should be mitigated by the use of appropriate PPE
S4	Landfill Gas	P5	Lateral Migration Subsoil	R7	Future Site Users	Unlikely	Mild	Very Low Risk	Monitoring indicates that all sites are actively gassing. Offsite gas monitoring completed. Age, extent, volume and composition of waste known. Potential for exposure to construction workers during excavations.
				R8	Construction Workers	Likely	Severe	High Risk	
				R9	Adjacent Buildings and Structures	Unlikely	Severe	Moderate	
				R10	Non Designated	Low Likelihood	Minor	Very Low Risk	

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
					Land				The installation of an engineered cap and hardstand as part of the proposed development may promote off site lateral gas migration. Potential for ingress to existing and proposed buildings and structures. As part of any future development, any new buildings adjacent to site to be constructed with full gas protection measures. Potentially, landfill gas migration could occur into existing adjacent buildings through cracks within the floor slab construction and/or around service/utility routes. If future development does not proceed risks associated with gas migration into existing buildings should be considered further by the Local Authority.
S4	Landfill Gas	P6	Lateral Migration Groundwater	R7	Future Site Users	Unlikely	Mild	Very Low Risk	Landfill gas known to be present onsite. Offsite gas monitoring completed. Age, extent, volume and composition of waste. Groundwater and leachate levels established
				R8	Construction Workers	Unlikely/Low Likelihood	Severe	Low/Moderate Risk	
				R9	Adjacent Buildings and Structures	Unlikely	Severe	Low Risk	
S4	Landfill Gas	P7	Vertical Migration Subsoil	R7	Future Site Users	Unlikely	Mild	Very Low Risk	Existing clay cap c.1-2m . Engineered cap will eliminate vertical migration of gas and atmospheric dispersion and dilution at surface. New buildings adjacent to site to be constructed with full gas protection measures. No buildings proposed to be constructed on waste bodies.
				R8	Construction Workers	Likely	Severe	High Risk	

Source		Pathway		Receptor		Likelihood of Occurrence	Severity of Consequence	Risk Classification	Comments
				R9	Adjacent Buildings and Structures	Low Likelihood	Severe	Moderate Risk	Landfill gas known to be present onsite however no credible dataset available. No offsite monitoring completed. Age, extent, volume and composition of waste known. Water level and effect on gassing regime known. Potential for exposure to construction workers during excavations. Potential for ingress to existing and proposed buildings and structures. Vegetation die back noted.
				R10	Non Designated Land	Likely	Minor	Very Low/Low Risk	
S4	Landfill Gas	P8	Existing & Proposed Services Routes	R9	Adjacent Buildings and Structures	Low Likelihood	Severe	Low / Moderate Risk	Offsite gas monitoring known to have been completed. No buildings proposed to be constructed on waste bodies. New buildings adjacent to site to be constructed with full gas protection measures.

8 SUMMARY AND CONCLUSIONS

Five unregulated historical landfill sites are situated immediately south of the County Brook River (Fassaroe Stream) in Fassaroe, Co. Wicklow (Site 1, 2, 3A, 3B ad 3C). The five former landfill sites are the responsibility Wicklow County Council (WCC), with four (Site 2, 3A, 3B and 3C) having been designated Historic Unregulated Local Authority Landfills in accordance with Section 22 of the Waste Management Act 1996 as amended (the Act) and presented in the Eastern Midlands Region Waste Management Plan 2015 – 2021. All landfill sites are associated with the historical deposition of municipal waste with the exception of Site 1 that contains predominantly C&D waste. The historical landfill sites all operated between the early 1970's and mid-1990s.

Current land-use on the Fassaroe site is characterised by one-off housing developments in a predominantly agricultural setting. The Fassaroe site and associated landfills are located on land in the ownership of Cosgrave Developments is zoned for major new development under the Draft Bray Municipal District Local Area Plan 2018, including residential high density open space and a neighbourhood centre. Before any redevelopment of the Fassaroe Site can be undertaken, an Environmental Risk Assessment is required that evaluates the risk that historical waste deposition poses to environmental receptors and human health. The ERA must be undertaken in accordance with the Waste Management (Certification of Historic Unlicensed Waste Disposal and Recovery Activity) Regulations 2008 (S.I. No. 524 of 2008) and adopt the approach of the EPA Code of Practice for Unregulated Waste Disposal Sites (EPA, 2007).

The ERA outlined herein delivers a Tier 1 desk based risk assessment, followed by a Tier 2 intrusive investigation and associated programme of environmental monitoring. The Tier 1 and Tier 2 works then inform a Tier 3 Quantified Risk Assessment that defines the risk to environmental receptors and human health and underpins the Remediation Options Appraisal. The ROA therefore conforms to the EPA Code of Practice and identifies feasible mitigation measures that would protect the environmental and human health receptors from the predicted and/or observed impacts associated with historical waste disposal at the five former landfill sites. The ERA therefore forms the key element of supporting information required for the application for a Certificate of Authorisation from the Environment Protection Agency (EPA) in relation to the historic landfill sites, as descried in the Waste Management Regulations 2008 (S.I. No. 524 of 2008).

Following the completion of the Tier 1 desk based risk assessment an initial Conceptual Site Model for baseline conditions on the Fassaroe site was developed; the highest risk active Source-Pathway-Receptor (Pollutant) Linkages identified; and a Tier 1 Risk Prioritisation & Classification exercise completed. These works identified the need for a Tier 2 intrusive investigation and associated programme of environmental investigation undertaken between December 2015 and March 2018. Tier 2 works undertaken on the Fassaroe Site included:

- Geophysical Investigation;
- Trial Pits: Excavation of twenty eight (28) trial pits and the collection of soil samples using 50m (Sites 1, 3b and 3C) and 75m (Sites 2 and 3A) sampling grids;
- Monitoring Boreholes: Completion of intrusive targeted investigation involved the installation of twenty one (21) combined gas/leachate monitoring boreholes, twenty five (25) gas monitoring boreholes and eleven (11) groundwater monitoring boreholes by cable and rotary percussive drilling

- Landfill gas monitoring programme comprising eighteen (18) monitoring rounds that included 8 No. weekly rounds between 7th March and 27th April 2016 and 10 No. monthly gas monitoring round between May 2016 to February 2017.
- Environmental monitoring programme that involved sampling leachate, groundwater, spring water and surface water monitoring network over three rounds at contrasting times within the hydrogeological system [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 water samples (leachate, groundwater, spring and surface water) were subject to an extensive suite of analysis that included contaminants of concern typically associated with methanongenic historic landfill sites.

The key characteristics of each landfill site is summarized below:

- **Site 1:** Surface area of 0.53 Ha with maximum proven depth of waste of 14m. Predominantly C&D waste with pockets of municipal waste. Evidence of filling since 1970's. Active gassing of methane and carbon dioxide, although less than seen for other sites infilled with municipal waste. Appears to be a perched landfill system, with unsaturated zone beneath waste mass hence mixing of groundwater and leachate at the water table. Spring SP2 situated c. 85m down gradient of the site and characterised by clear flow, tufa formation and elevated (mildly alkaline) pH.
- **Site 2:** Surface area of 4.5 Ha with maximum proven depth of waste of 19m. Municipal waste deposited between 1979and 1991. Discrete leachate body although there may be direct continuity between leachate and groundwater in the north. Notable vegetation die back on / around landfill in 2015. Visible erosion and waste exposure in north of site. Active gassing of carbon dioxide and methane. Spring SP1 situated c. 60m down gradient from site and is characterised by ochre, sheening and absence of tufa in most rounds.
- **Site 3A:** Surface area of 4.5 Ha with maximum proven depth of waste of 16m. Municipal waste although age of deposition uncertain. Active gassing of carbon dioxide and methane. Unsaturated waste mass, with leachate only in north. Presumed to be a largely perched landfill system with mixing of leachate and groundwater at the water table. Spring SP4 situated c. 25m down gradient of the landfill site and Spring SP5 situated c. 60m down gradient. SP4 characterised by ochre staining whereas SP5 characterised by clear water and tufa formation.
- **Site 3B:** Surface area of 0.44 Ha with maximum proven depth of waste of 4.9m. Municipal waste deposited between 1994 and 1995. Active gassing of carbon dioxide and methane. Notable vegetation die-back in 2015. Presumed to be a perched landfill system with mixing at the water table.
- **Site 3C:** Surface area of 0.9 Ha with maximum proven depth of waste of 13m. Municipal waste deposited between 1992 and 1995. Active gassing of carbon dioxide and methane. Notable vegetation die-back in 2015. Appears to be a subwater table waste with groundwater and leachate in continuity. Several springs situated down gradient of the site although none sampled.

The five landfill sites are located in particularly sensitive environmental setting, with the following principal environmental receptors identified:

- **Ballyman Glen SAC**: The five landfill sites are situated immediately south of the SAC which is located in the river valley and designated on the basis of petrifying springs with tufa formation and alkaline fens. The SAC is dependant of groundwater discharge and therefore constitutes a Groundwater Dependent Terrestrial Ecosystem;

- **County Brook River (Fassaroe Stream)**: WFD surface waterbody of good status; and
- **Enniskerry Groundwater Body** (IE_EA_G_038): Designated a locally important gravel aquifer (Lg) although there is no down-gradient use of groundwater. This waterbody is considered to have a WFD quality status of good.

A detailed summary of the effects of the five landfill sites has been provided in Section 7.2 in terms of the observed impact or potential risk to the environmental receptors, human health or associated with landfill gas.

Landfill gas has been demonstrated to represent a significant risk to current and future site users that requires mitigation particularly if the Fassaroe site is to be redeveloped. The concentration of PAHs and limited presence asbestos containing materials in the waste mass and current capping materials has been shown to potentially represent a risk to human health and does require mitigation.

Groundwater has been shown to have been impacted by leachate generated on the landfill sites. Similarly a water quality impact observed at a number of the springs situated down-gradient of the landfill sites has been demonstrated, although many springs do not show any impact being characterised by clear flow and tufa formation.

The landfill sites do have the potential to affect surface water quality within the County Brook river (Fassaroe Stream) although water quality effects are not routinely observed, are largely restricted to upstream sections when they occur and are observed at locations situated upstream of the landfill sites. It seems that the very high dilution capacity within the County Brook River does afford protection to that watercourse. These observations are consistent with the continued WFD Status of the County Brook Stream, which is classified as 'good'.

The evidence collected to date demonstrates that the five landfill sites have the potential to affect conditions within the alkaline fen of the Ballyman Glen SAC and its associated drainage system. It is possible that this affect could have a localised impact on tufa forming potential and water quality within a small number of the streams situated downstream of affected springs, as evidenced at two springs. The ecological appraisal of the SAC will determine the extent and significance of any measurable effects on the designated features of the Ballyman Glen SAC (i.e. tufa forming potential and alkaline fens).

The results of the Detailed Quantified Risk Assessment (DQRA) suggest that the mixing of leachate with laterally flowing groundwater in the saturated gravel aquifer affords significant protection to the SAC, its drainage system and watercourses situated down gradient of the landfill sites. The most significant effects of the landfills would appear to be restricted to those areas where leachate and groundwater are found to be in direct continuity (i.e. submerged landfill waste mass) although this only occurs locally at some of the landfill sites. The results of the DQRA demonstrate that a significant net betterment, in terms of water quality, can be achieved by controlling infiltration using an engineered low permeability cap. Furthermore the construction of such cap is unlikely to significantly reduce the quantitative net groundwater flow to the SAC, would address risks to human health and would allow greater control of risks associated with landfill gases generated on the landfill sites.

Although waste removal would remove the contamination source, thus severing the pollutant (SPR) linkage entirely, short term impacts at the SAC and watercourse could be exacerbated and stability issues may affect its delivery. Notwithstanding the high cost of full waste removal it is uncertain whether there are appropriate sites for the disposal of the volume excavated materials that would be required. It is for this reason an engineered low permeability capping solution allied with controlled water and ecological monitoring would represent the preferred strategy for managing the risks associated with the historical landfill sites, assuming a net betterment approach be acceptable to the regulator.