Ground Gas Information Sheets

Screening approach for landfill gas migration around landfill sites
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Screening approach for landfill gas migration around landfill sites

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Landfill gas migration risk may need to be considered when dealing with planning applications for new building development close to landfill sites, for Part IIA assessments of landfill sites or when considering the surrender of environmental permits. Installing monitoring wells outside the site in areas close to receptors or completing other monitoring (eg internal monitoring) can be difficult, costly and cause unnecessary stress to nearby residents. It may also result in blight on properties. This paper describes a risk based framework that can be used to screen the landfill gas migration risk around old landfills. It was developed for a Scottish Local Authority to help them reduce the size of planning consultation zones and has also been applied successfully on a number of sites in England to identify whether gas extraction systems in old landfills are still required. It uses basic data that is normally readily available (site history, approximate volume of waste, geology, topography etc) and allows sites to be screened to see if there is likely to be any significant risk associated with landfill gas migration. If there does appear to be a potential risk or gaps in the data the method can be used to identify the minimum amount of targeted site investigation or monitoring work required to close out the sites and/or design remediation schemes.

Introduction

Most Local Planning Authorities (LPAs) have a policy of consulting Contaminated Land Officers on applications for building development on or within 250 metres of a landfill site. This is based on advice provided in Waste Management Paper No 27, Landfill Gas (DoE, 1991). It can lead to a stretch on resources and may not be appropriate around older landfill sites that may not be generating large volumes of landfill gas and therefore cannot cause gas migration beyond a few metres. In other cases, the surrounding geology may provide a natural barrier to migration.

A risk-based framework has been developed that can be used to provide a preliminary assessment of the risk of landfill gas migration. The screening approach that is described in this paper was used to reduce the

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consultation zone around old landfill sites where possible. It is being refined as experienced is gained using it.

The approach is also valid for assessing landfill gas migration risk in relation to Part IIA sites, for Environmental Permitting and new development sites.

Conceptual site model

A robust conceptual site model (CSM) is vital for any gas risk assessment. Even a CSM derived from basic data can provide a good understanding of the likely level of risk associated with old landfill sites.

Figure 1 shows a site where there is a high risk of gas migration. A recent domestic landfill is capped, has perched water tables with dry waste below, an ineffective gas extraction system and no basal lining system. The complex geology outside the site provides pathways for gas migration, for example in fractured basalt. Nearby houses are only 2m from the landfill boundary in some cases.

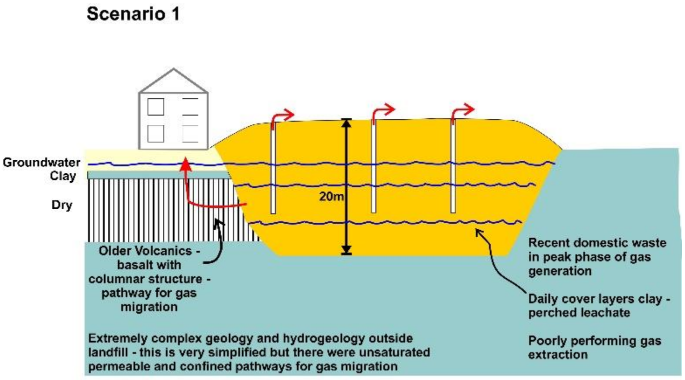

Figure 1 High risk of lateral gas migration

Figure 2 also shows a recent domestic landfill site, this time with just a few passive vent wells. The waste is of similar depth to that in scenario 1. However, in this case there is no risk of lateral migration because the geology around the landfill comprises impermeable clay. The nearby houses are 20m from the landfill.

This basic level of information allows an initial understanding of the level of risk associated with landfill gas migration. It is readily obtained in the UK from historical maps, geological maps and other easily accessible sources.

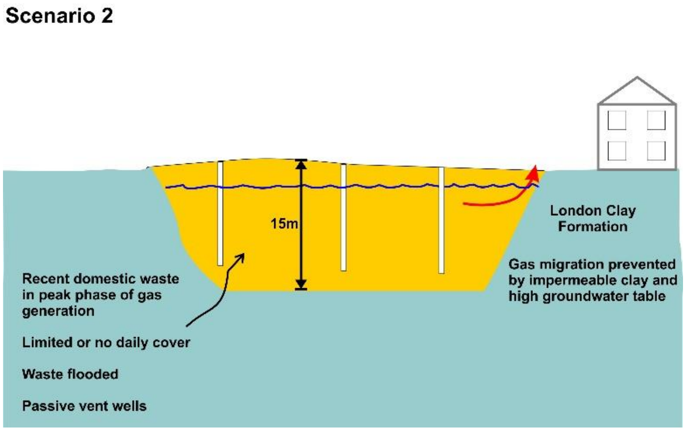

Figure 2 Negligible risk of lateral gas migration

Method overview

This method of screening landfill sites has been developed using international guidance such as that provided by New Zealand Ministry for the Environment (2004) and Environment Canada (1996) as an initial guide.

The approach requires an assessment of the level of risk associated with three components of landfill gas migration:

- Hazard component (ie the source);
- Pathway component; and
- Receptor component.

The factors that are considered for each component are discussed below.

Hazard component

The hazard component relates to the source of landfill gas (ie the landfill itself) and has four parameters to be considered:

1. The type of landfill waste accepted and its biodegradable content;
2. The age of the landfill (time since filling was completed);
3. The volume of material placed in the landfill and whether it is a wet or dry landfill; and
4. The presence of engineering measures that could reduce the risk of gas migration (liners, gas extraction) or increase the risk (engineered capping layer).

Type of landfill waste

The volume of landfill gas that can be generated from waste depends on the proportion of biodegradable material. Inert waste has a far lower biodegradable content than domestic waste. The waste composition over time has also changed and waste from before the 1960s generally had a significant ash content and lower proportion of biodegradable material than more recent waste and was not bagged like more recent waste. On this basis the risk associated with the nature of the material can be estimated as follows:

Domestic/Sanitary landfill – High – Score = 1.

Commercial/Industrial – Moderate – Score = 0.6.

Inert landfill – Low – Score = 0.1.

If the type of landfill material is unknown it should be assumed that it was domestic waste, which is a precautionary approach. It is often claimed that there may be uncontrolled fill with a high degradable content within some inert landfills. For this to cause a lateral migration of gas it would have to comprise a large proportion of the waste mass. A few small isolated areas of more degradable waste within a large mass of inert would not normally be sufficient to drive off-site migration.

If there is site investigation information available that has descriptions of the waste material it may be possible to refine the scores. For example, investigation of a landfill that was licensed to accept commercial and industrial waste was found to contain mainly colliery spoil and ash and thus the score could be lowered from 0.6 to 0.1.

Age of landfill

Gas generation occurs due to degradation of material in the landfill. The process is a complex one and is affected by many factors. It does however generally decline with age, as the degradable material is used up and is turned into landfill gas and water (Tansel and Reinhart, 2008). Gas starts to be produced when the waste is placed in the landfill and peak gas generation rates usually occur over the first few years after closure of the landfill. Gas generation then declines gradually. After 20 years the gas generation will have normally reduced significantly (although high gas concentrations may still be present in the landfill).

At a time of 40 years after closure the landfill should have reached the maturation phase and gas generation will be at residual, very low levels. In such cases the risk of gas migration is negligible unless there are open highly permeable pathways. These assumptions assumed that landfills are not capped and that the waste is at a moisture content that allows degradation to take place. In all published cases where gas migration has resulted in ingress to properties off-site the landfill has been either operational or closed for only a few years.

On the basis of a typical gas generation profile the impact of age on the level of risk can be judged as follows:

0 to 20 years – High – Score = 1.

20 to 40 years – Moderate – Score = 0.6.

>40 years – Low – Score = 0.1.

There are examples where gas migration predominantly by diffusion has occurred but not for any great distance.

Volume of material and depth of landfill

The greater the volume of waste material the greater the volume of gas that can be generated (for a given type of material). Landfills with a higher moisture content will also generate much more gas than one that is dry (biodegradation needs moisture to occur). Figure 3 (reproduced from Environment Canada, 1996) can be used to help estimate the risk associated with the volume of landfill material in a wet landfill. The numbers on the body of the graph indicate a gradation of production within each risk category (1 is lower and 3 is higher). The graph characterises a site as low medium or high gas production, which for the purpose of this assessment method is considered equivalent to low, medium and high risk. The adjusted capacity on the y-axis can be amended to take account of the proportion of inert, industrial and commercial and domestic waste. However, for the purposes of a preliminary assessment using this method the unadjusted volume of the waste is used, irrespective of type.

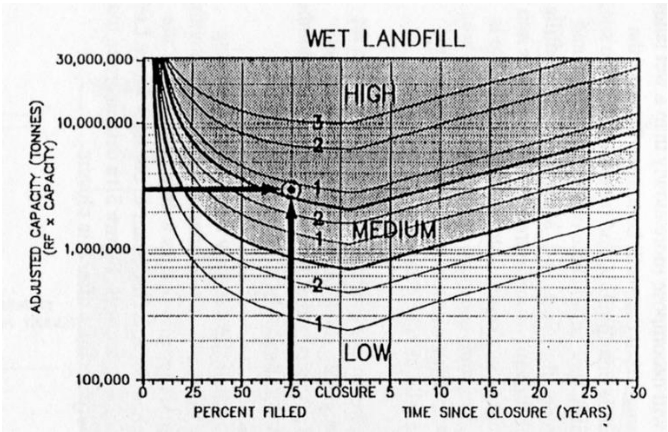

Figure 3 Risk associated with volume of landfill (Environment Canada, 1996)

Only a worst case approximation of the volume is required, based on estimates of the plan area of the landfill and the likely maximum depth. The plan area can be estimated from old OS maps and the likely depth is based on side slopes marked on maps and any other available information (eg geological maps and strata that are known to have been quarried). The risk score can be assessed as follows using Figure 3:

High risk – Score = 1.

Medium risk – Score = 0.6.

Low risk – Score = 0.1.

The depth of the landfill will have an influence on the risk of landfill gas migration. There is a much lower risk associated with shallow landfills that are less than 5m deep compared to deeper landfill sites, especially those over 10m depth. Gas will always take the easiest route to the surface and often this occurs at the boundary of the site (at the interface between waste and natural ground). With a shallower landfill the pressure or diffusion gradient to the surface may be greater than that for lateral migration at depth and so the gas migrates to the surface in preference to moving off-site.

Gas monitoring in wells and surface emissions monitoring during earthworks has been completed at a number of sites where surcharging or embankments have been constructed. This has shown that surcharging shallow Made Ground containing gas only increased surface emissions within 5m to 10m from the edge of the surcharged area (Figure 4).

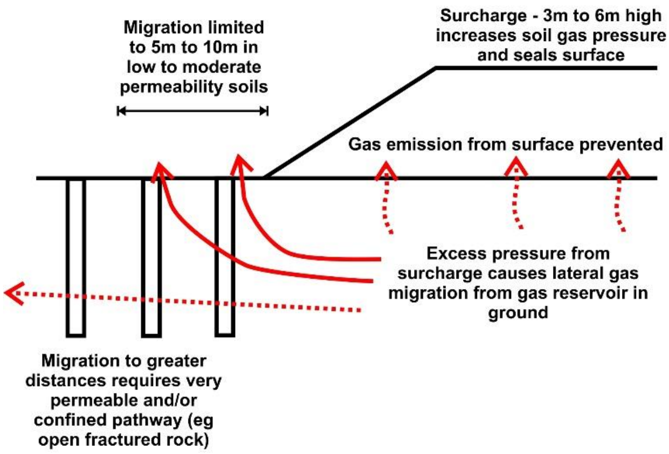

Figure 4 Lateral gas migration from below surcharge

Engineering measures

The potential for significant landfill gas migration will be substantially reduced if the site has a landfill liner and/or a gas extraction system. Conversely if the site is unlined and has no internal management system then the risk of gas migration will increase. The presence of gas vent trenches and wells around the perimeter of a landfill site will also reduce the risk of landfill gas migration.

The presence of an engineered impermeable cap will increase the risk of gas migration as will impermeable layers of soil within the waste (for example daily cover layers), if there is no effective gas extraction system. The level of risk can be assessed as follows:

High risk – No liner or gas management system and an impermeable capping layer – Score = 1.

Moderate risk – Unlined and uncapped - Score = 0.6.

Low risk – Fully engineered landfill – Score = 0.1.

In the UK many landfill gas extraction systems that were installed in the early 1990s (25+ years ago) are coming to (or are well past) the end of their operational lives. The gas monitoring data collected during operation can be very useful in assessing current risk and whether the system needs replacing. In most cases the system was installed 15 years or more after landfilling and it is unlikely to need replacing after 40 years of gas production. This is because gas generation will now be at very low levels, such that at most passive venting measures will be adequate.

Pathway component

There are two parts to the pathway component. The first is the nature of the soils/rock surrounding the landfill and the likely permeability. This is determined from geological maps (solid and drift geology). Soils with lower permeability (eg clayey soils) will limit the risk of gas migration and soils/rocks with a higher permeability (eg highly fractured rock or sand and gravel deposits) will increase the risk.

Groundwater conditions will also influence the risk of gas migration (lateral gas migration through saturated soils is limited).

The other consideration is the likely presence of preferential pathways such as faults or large services. The level of risk can be assessed as follows:

High risk – Open or high permeability pathway – Score = 1.

Moderate risk – Permeable soils such as sand and gravel - Score = 0.6.

Low risk – Low permeability soils or rock – Score = 0.1.

An additional consideration is whether preferential pathways may be present. For the preferential pathway to be significant gas must first reach it and then must be able to migrate along it. Often generic statements are made that services form preferential pathways. This is not necessarily true. If a service crosses a landfill it might easily collect gas and if it has permeable backfill or gas can enter a pipe it can migrate along it. For services that do not cross a landfill the gas first has to reach the service and the risk of this will depend on the geology, etc and should be assessed in the same way as gas ingress to a building.

The score for preferential pathways should also be ranked from 0 to 1.0 depending on how likely it is to provide a short circuit for gas migration to a building, compared to diffuse migration through the ground.

Receptor component

It is difficult to apply generic scores to the receptor component. At one end of the scale housing with stone floors on earth would incur a score of 1 and the other extreme an industrial building with a thick suspended reinforced concrete floor slab and high ventilation rates would have the lowest score of 0.1.

The score is highly dependent on the floor slab and foundation construction and also whether basements or cellars are present. Every effort should be made to determine the likely type of construction (even the age of housing and an external inspection can give strong clues as to the likely floor and foundation construction).

A further consideration which is included in the receptor component, but probably spans the whole assessment is whether there is any evidence of gas migration either at present or in the past. Again a score between 0 to 1 is assigned based on whether there has been previous evidence (eg dying vegetation, gas recorded inside properties, reports of odours in buildings, etc).

Overall risk score

The overall risk of gas migration from a site is determined by multiplying the individual scores together. The overall level of risk is based on the following assumptions:

- Low risk – Individual scores comprise 4 low, 2 moderate and 2 high ($0.1^4 \times 0.6^2 \times 1^2 = <3.6 \times 10^{-5}$)

- Low/moderate risk - Individual scores comprise 3 low, 4 moderate and 1 high ($0.1^3 \times 0.6^4 \times 1 = <1.3 \times 10^{-4}$)

- Moderate risk - Individual scores comprise 8 moderate ($0.6^8 = <0.017$)

- High risk - > 0.017.

It is important to note that these values are a guide to help judgement and make assessments of different sites consistent. They should not be seen as absolute boundaries.

Landfill gas migration modelling

To complement the qualitative assessment of risk and help define the boundary for consultation, gas migration modelling may be carried out. The gas migration modelling uses a one dimensional convective – dispersive solute transport equation that is used in the GASSIM programme.

The general form of the equation is:

$$R\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - V\frac{\partial C}{\partial x}$$

Where C is the gas concentration, x is the distance along the migration pathway, t is time, D is the diffusion coefficient, V is the flow velocity and R is a retardation factor.

The precise analysis will depend on the results of the qualitative assessment.

The model is generally only run up to a time period of 20 years. Experience has shown that the model gives a good fit to gas monitoring data outside landfill sites up to about 15 to 20 years in most cases.

An example is shown in Figure 5, which compares measured concentrations at 12 years after migration starts to predicted total landfill gas concentrations (methane + carbon dioxide) at 15 and 20 years. The measured total landfill gas concentrations that extend beyond 100m comprise a mix of methane, oxidised methane (carbon dioxide) and natural carbon dioxide that is present across the surrounding area. Beyond 20 years the model can overestimate the distance over which elevated concentrations occur for most sites. One reason for this is because the model assumes that the gas in the soil pore spaces at the limit of the plume is not diluted, for example by atmospheric air ingress to the ground.

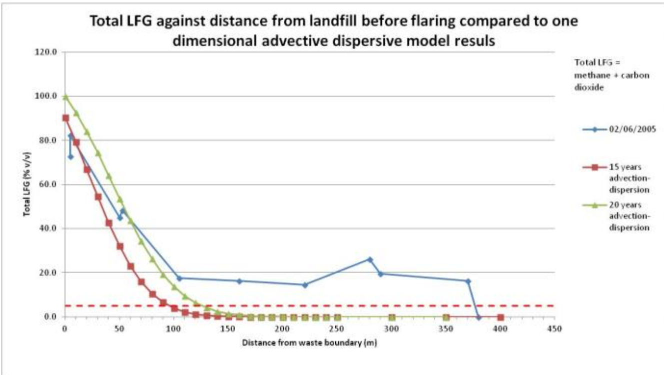

Figure 5 Comparison of model results with monitoring data

The migration distance estimated by the model is sensitive to the value assigned to the porosity of the soil or rock in the migration pathway. Careful choice is required. In the example in Figure 5 migration is via open fractured rock in a fault zone.

Guidance on suitable values for porosity of soils (if data on measured values is not available) is provided by the English Environment Agency Publication SR3 (Environment Agency, 2009), as presented in Table 1. Soil types can be assessed using guidance from the USEPA (2001).

Figure 6 can be used to define whether a soil is a sand, loam or clay.

Table 1 Soil porosity

Soil type	Total porosity	Air filled porosity	Water filled porosity
Clay	0.59	0.12	0.47
Silty clay	0.63	0.12	0.51
Silty clay loam	0.58	0.12	0.46
Clay loam	0.56	0.14	0.42
Sandy clay loam	0.53	0.16	0.37
Silt loam	0.58	0.14	0.44
Sandy silt loam	0.52	0.14	0.38
Sandy loam	0.53	0.2	0.33
Sand	0.54	0.3	0.24

From Environment Agency (2009)

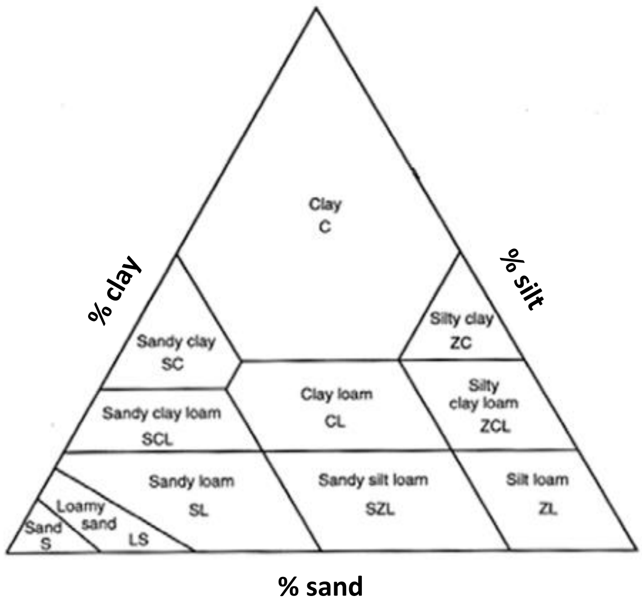

Figure 6 Soil classification (Hodgson, 1997)

Geological materials that do not behave like porous media (ie like soils) include fractured bedrock where the primary porosity occurs in the fractures. Karts formations do not behave like soils and the primary porosity is in fractures and solution features.

There is guidance on the range of porosity values that may be assumed for different types of rock taking fracturing into account (Table 2 and Table 3). However, the values can vary widely and careful choice is required. If rock exposures are present and can be accessed during a walkover study of a site then this is a good opportunity to assess the fracturing of the rock.

Table 2 Range of porosity values for rock (Freeze and Cherry, 1979)

Rock type	Total porosity
Fractured basalt	0.05 - 0.5
Karst Limestone	0.05 - 0.5
Sandstone	0.05 - 0.3
Limestone, dolomite	0 - 0.2
Shale	0 - 0.1
Fractured crystalline rock	0 - 0.1
Dense crystalline rock	0 - 0.05

Table 3 Representative porosity values for rock (McWorter and Sunada, 1977)

Rock type	Total porosity	Effective porosity
Sandstone	0.14 – 0.49	0.12 – 0.41
Siltstone	0.21 – 0.41	0.01 – 0.33
Limestone	0.07 – 0.56	0 – 0.36
Weathered granite	0.34 – 0.57	--
Weathered gabbro	0.42 – 0.45	--
Basalt	0.03 – 0.35	--
Schist	0.24 – 0.49	0.22 – 0.33

Example

The conceptual site model for an old landfill site is shown in Figure 7. The site had a gas extraction system installed in the early 1990s and an assessment was required to see if it could be converted to a passive venting well system.

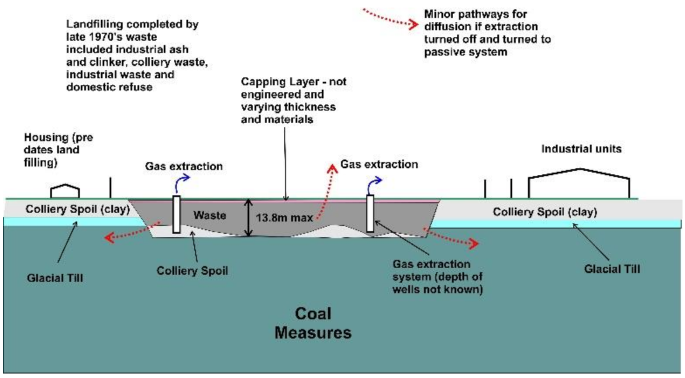

Figure 7 Conceptual site model

The risk screening system as applied to this site is summarised in Table 4. For this site historical gas monitoring data was available that showed there was no evidence of significant gas migration outside the site (only diffusive transport for a short distance). The houses had been present for 15 years prior to the flare system being installed with no known issues of gas migration.

Monitoring records from recent operation of the gas extraction system confirmed this assessment. It was concluded that active system could be decommissioned with conversion of wells to passive vents. Utility records were to be obtained to confirm the absence of preferential pathways across the site. A short period of continuous gas monitoring was proposed after the extraction system was turned off to demonstrate that the gas regime was not dependent on the extraction system and that gas pressure in the landfill would not increase. Once this was demonstrated the system could be converted to passive wells.

Conclusions

A risk screening approach to assess the risk of landfill gas migration is described. The approach can be used for initial screening using readily available information such as historical and geological maps and other published sources. It will allow effective planning of any site investigation to target the highest risk areas around a landfill.

The screening approach can be combined with landfill gas migration modelling. Use of the model has shown that it provides useful results, but can overestimate the gas migration distance when time periods greater than 20 years are used.

The method has been used successfully on numerous sites in the UK. It is being continually refined as experience is gained in its use.

Table 4 Summary of risk screening

Factor	Details	Risk factor	Risk Score
Hazard component			
Type of landfill	waste materials including industrial ash and clinker, colliery waste, industrial waste and domestic refuse. Limited evidence of domestic waste	Moderate	0.6
Age of landfill	40 years. Exact date not known. From historical reports was infilled after 1974. Maps and descriptions of waste indicate likely to be late 1970s	Moderate	0.6
Volume of landfill	The landfill is capped with a 1m thick clay cap and there is no evidence of groundwater table in the waste material Volume is 163m x 135m x 14m. At 1.2 tonnes /m^3 mass = 369,684t	Low	0.1
Engineering measures	1m non engineered clay cap, landfill is not lined and there is no evidence of daily cover layers that are engineered	High	1
Pathway component			
Geology	Geology outside the site comprises Colliery Spoil (clay) over a thin layer of Glacial Till over Weathered Coal Measures. Predominantly cohesive soils. There are no faults.	Low	0.1
Preferential pathways?	Services likely to enter houses from street. Houses pre date landfill so not likely that buried services cross the landfill. Assume moderate but check service records and amend if necessary	Moderate	0.6
Receptor component			
Receptor	Housing	High	1
Evidence of gas migration?	Houses have surrounded site since it was filled with no recorded incidents prior to installation of flare system in late 1980s or early 1990s. Some evidence of diffusive flow of gas out landfill for short distances. Consider as moderate until utility records confirm absence of preferential pathways and continuous flow monitoring confirms absence of gas pressure in landfill	Moderate	0.6
OVERALL RISK			
		Moderate	**1.30E-03**

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