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Middlemarsh Landfill Site

Landfill Irrigation Scheme – Risk Assessment

FCC Environment (UK) Limited

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Contents

1 Introduction

1.1 Report Objectives

This report has been prepared by ByrneLooby (BLA) on behalf of FCC Environment (UK) Limited in support of a permit variation application for the Middlemarsh Landfill Environmental Permit (EPR/BV4410IC) to add a recovery activity. The site is operated by Lincwaste Limited (the Operator), a wholly owned subsidiary of FCC Environment (UK) Limited.

A permit variation application is being submitted to allow the Operator to irrigate the restored landfill surface with stabilised non-hazardous landfill leachate during soil moisture deficit periods of the year *i.e.* on a seasonal basis. The irrigation activity is being implemented to encourage and sustain vegetation cover at the site and prevent dry conditions and vegetation dieback for the protection and maintenance of the soil cover and the capping works by the presence of a healthy vegetation cover. This irrigation activity could be carried out utilising water extracted from an aquifer. However, in the context of the Waste Framework Directive[1] (and waste hierarchy) it is proposed to utilise stabilised non-hazardous leachate as a substitute.

This document has been produced in support of the Waste Recovery Plan (Report Ref. K6143-R02) and assesses the risk from the proposed use of stabilised non-hazardous landfill leachate as an irrigant. Landfilling and subsequent restoration of the site has been progressively carried out in accordance with the site's Environmental Permit. The site ceased accepting wastes in 2014 and is now closed, although works are required across some previously restored areas to maintain the final restoration profile.

1.2 Requirement for Assessment

The Environment Agency's electronic guidance on *Waste recovery plans and deposit for recovery permits* [2] notes:

> *Your waste recovery plan must confirm that a waste is suitable in principle for the proposed use. If you apply for a bespoke deposit for recovery permit, you must provide a site-specific risk assessment for the deposit of waste to support your application.*

and

> *Waste recovery activities must not cause pollution. You must prevent or minimise emissions from your recovery activity if your risk assessment suggests that your site will have an impact on:*
>
> - *local residents, properties or designated habitat sites*
> - *groundwater or surface water*

[1] Directive 2008/98/EC of the European Parliament and of the Council, 19 November 2008
[2] Environment Agency (2021) Waste recovery plans and deposit for recovery permits https://www.gov.uk/government/publications/deposit-for-recovery-operators-environmental-permits/waste-recovery-plans-and-deposit-for-recovery-permits

This report has been prepared to assess the risk to controlled waters of constituents within the Middlemarsh stabilised landfill leachate when used as a water substitute to irrigate the protective vegetation cover that supports the integrity of the above cap restoration soils.

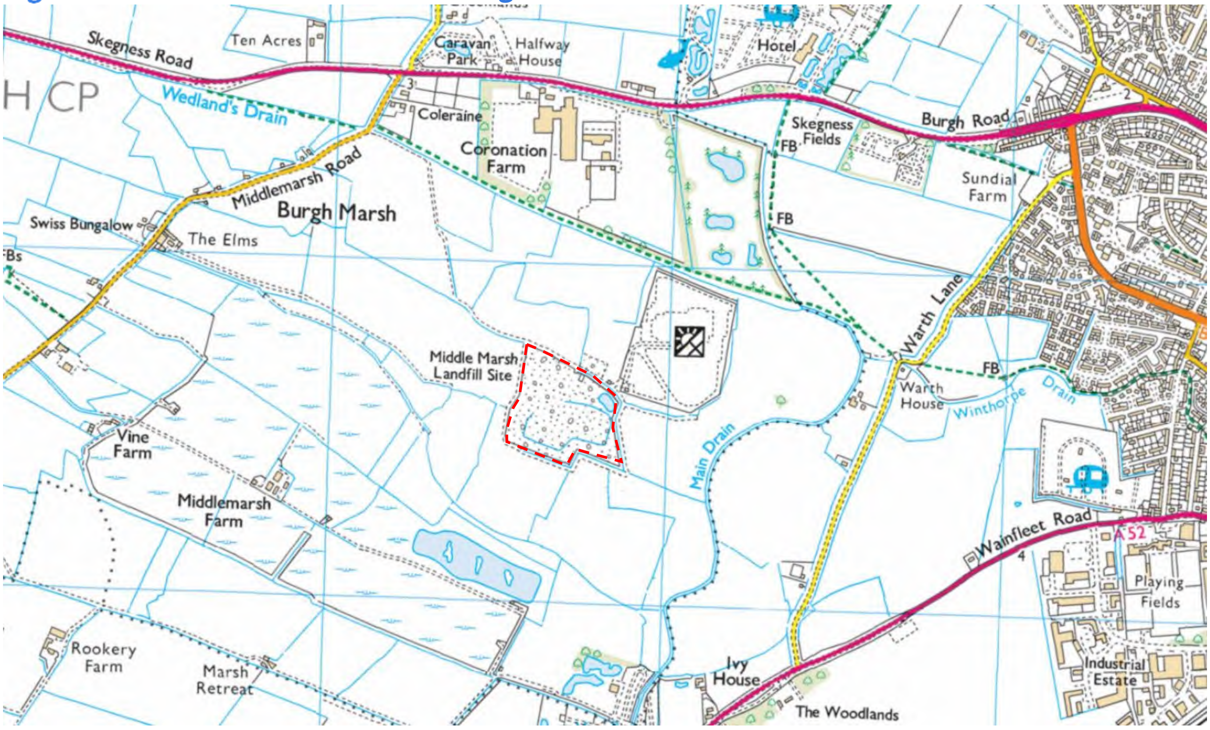
This report has been produced in accordance with the following guidance:

https://www.gov.uk/guidance/risk-assessments-for-your-environmental-permit

1.3 Site Location

Middlemarsh Landfill Site is located within the Burgh Marsh, an area of former fenland to the west of Skegness (Figure 1) at Burgh Le Marsh, Skegness, Lincolnshire, PE24 5AD.

Figure 1 Site Location and Setting



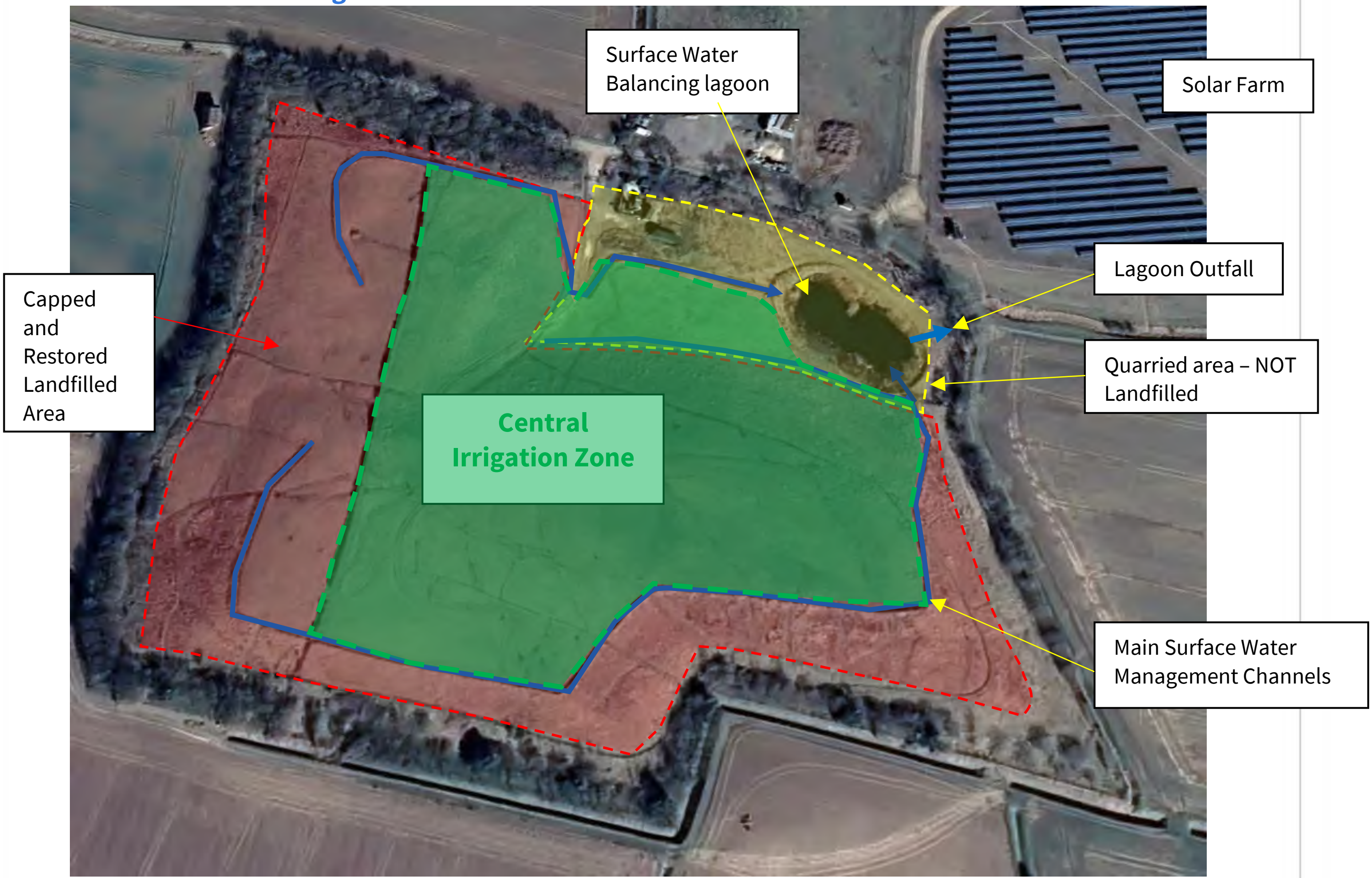
1.4 Irrigation Activity

The surrounding land is low lying fenland, in which water levels are artificially managed by the Lindsay Marsh Drainage Board, who convey the excess waters to the Wash 6km to the south of the site. Despite, this active water management, there is limited water available due to the low Effective Rainfall Rates in the East of England.

The function of the Drainage Board is therefore to prevent lands flooding in winter or after severe storms, whilst prioritising all available waters in summer for agriculture. Consequently, there is limited local water available during summer periods, when "non-agricultural" irrigation is required.

This assessment considers the environmental risk of a low-rate site derived stabilised leachate used as an alternative water supply for irrigation. Irrigation is to be undertaken at a controlled rate using porous pipe type and drip flow arrangements across a central 3.6ha zone of the landfill (Figure 2). Irrigation is intended to be restricted to the shallowest topographical slopes as captured within the main surface water run-off interception channels, and only extrapolated out to the wider steeper sloped areas following the initial operation of the system that demonstrates the infiltration characteristics of the ground surface are suitable (*i.e.* no excessive run-off due to slope gradient).

Figure 2 Irrigation Zone within Capped and Restored Area Captured by Surface Water Drainage Zone



Irrigation rates are, as established in the supporting Report K6143-R01: Middlemarsh Landfill Irrigation Scheme Overview to be between an effective rate of 1mm/day and 3mm/day, and are intended to replace summer soil moisture deficiencies in a low rainfall-high evapotranspiration area of the country.

Irrigation is a “maintenance” application to support vegetation growth and health under what are becoming increasingly drought conditions. Irrigation is not intended to support the types of optimised growth rates and crop yields as is required for productive agricultural yields and therefore smaller application rates can be considered. This also includes smaller dosages of nutrients and other leachate constituents than would normally be applied as high concentration batch loads when used as a fertiliser that is intended to optimise crop growth. Consequently, there is not an increase in the expected co-constituent contaminant content.

Irrigation during the summer season will therefore be carried out at a rate of ~1mm/day. This rate is based upon a continuous moisture need and consideration of soil infiltration characteristics.

Changes to the application rate will be based on a two-weekly review of weather conditions and will be reduced if there is a particularly wet or cool summer and increased temporarily up to 3mm per day for extended drought conditions.

Therefore, irrigation will be undertaken at a typical rate of up to

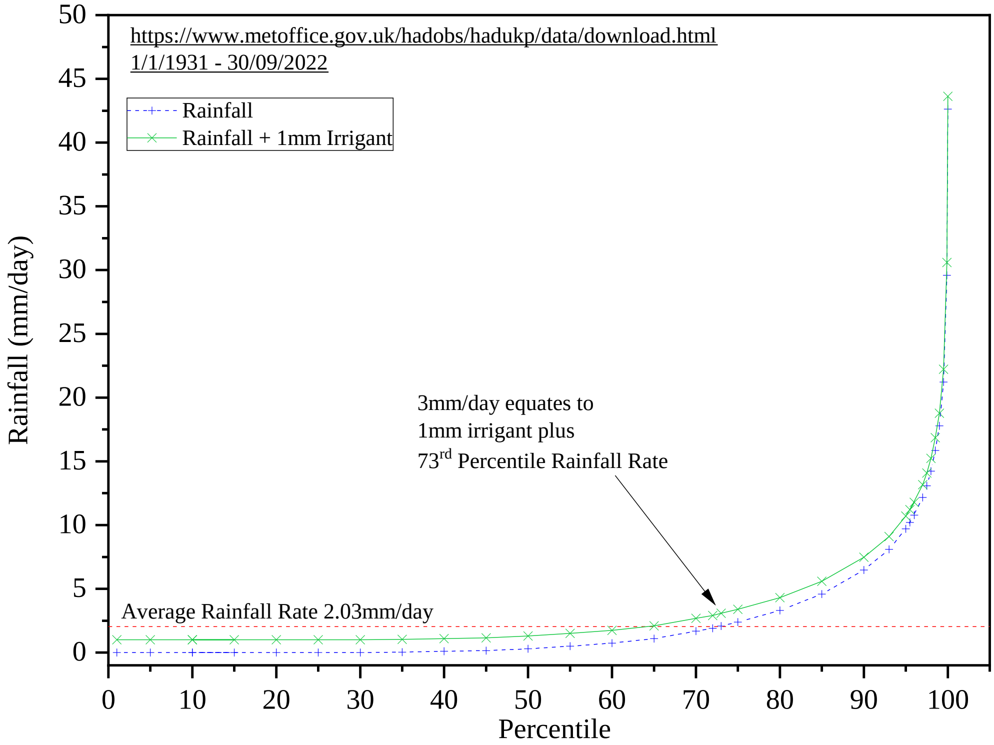
- 1mm/day, equivalent to
- 36m^3/day over a 2.3ha area; within a wider
- 3.6ha managed area; and
- up to 3,240m^3, but more typically 2,000m^3/irrigation over a 90 – 120-day period (mid-May to mid-September)

The commencement of irrigation and cessation of irrigation will be determined on a year-by-year basis.

Irrigation will be undertaken at a rate of up to 1mm/day throughout the season except for the duration of predicted storm events and weather forecasts which predict more than 5-days of continuous wet and cloudy weather whereby evapotranspiration is not expected to be of significance with respect to grassland health.

The primary objective of the scheme is to replenish soil moisture and hence there is a limitation to the quantity of irrigant that can be applied before surface run-off effects predominant over infiltration. Consequently, irrigation rates will be limited to 3mm/day, a volume equivalent to 36m^3/day over a 3.6ha area, with higher rates of up to 3mm/day only applied during extended drought periods.

Figure 3 **Rainfall Frequency from Weather Data and Comparison with Cumulative Effects of 1mm/day irrigation**

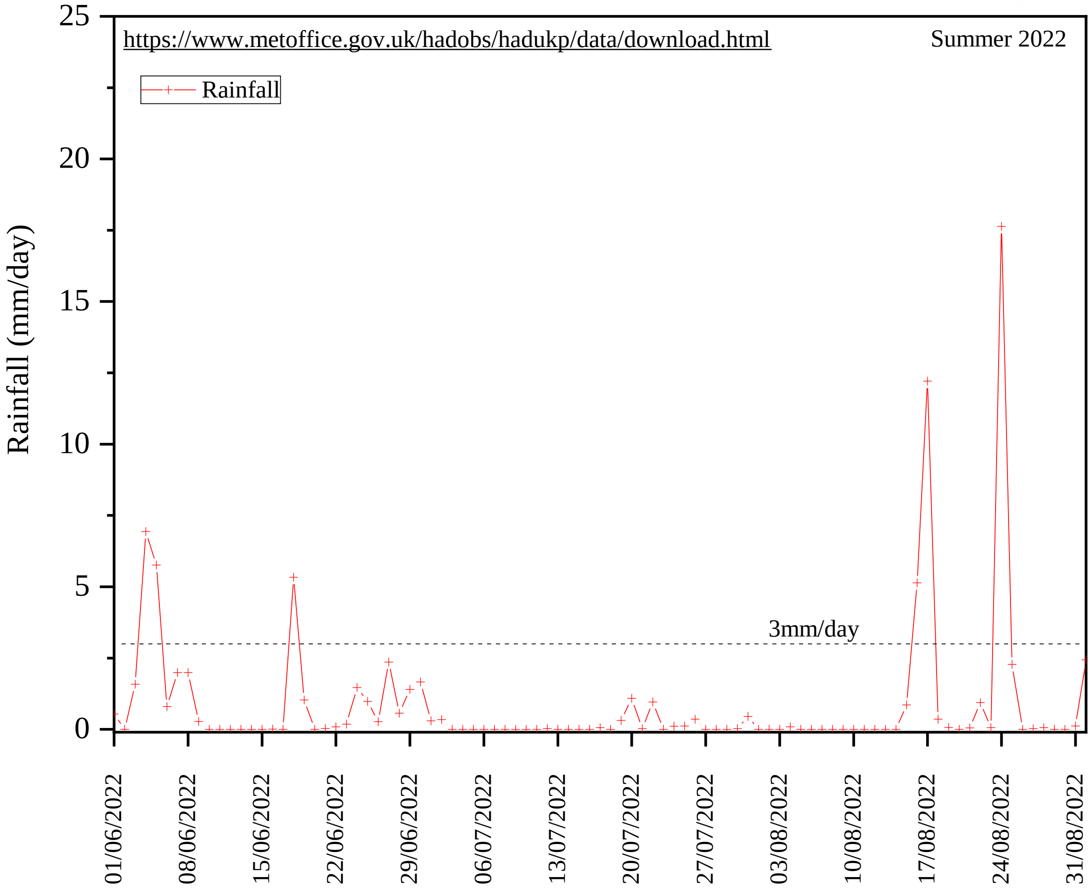


Infiltration rates of <3mm per day are guaranteed under the majority of weather conditions, as long-term rainfall records for the Wash area demonstrate that the 60th percentile rainfall rate is only 1.1mm/day and 2mm/day occurs at the 73rd percentile frequency. Consequently, even when an additional 1mm/day of irrigant is applied the potential to exceed 3mm/day is very low (Figure 3).

For example, in Summer 2022 there were only six days when rainfall exceeded 3mm/day during the 3-month June – August period when surface run-off could potentially occur (Figure 4), and each occurred as readily predicted events.

It should also be noted that on smaller rainfall events greater than 2mm, that rainfall occurs over a short period during the day, *i.e.* over several hours, and therefore as the irrigation will be over the entire day, there is an expectation that all irrigant will infiltrate into the soils during this period and not contribute to run-off.

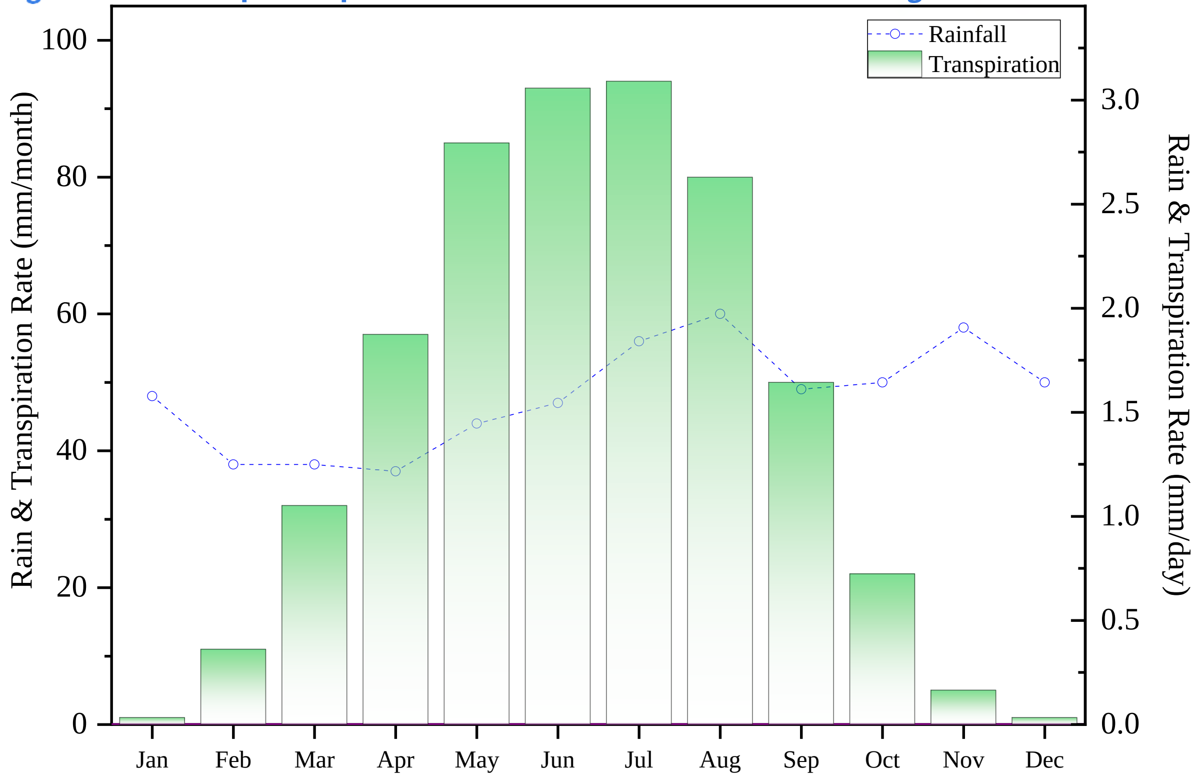
Figure 4 Summer 2022 Rainfall Patterns



With regards to water availability, the >5mm/day rainfall events will largely contribute to direct surface run-off and therefore only provide limited benefit to vegetation moisture demands. This water is "lost" with regards to replenishment, because evapotranspired water volumes are in the order of 80 - 90mm/month during May to August (2.6 – 3.1mm/day, Figure 5), and hence set an upper boundary condition of irrigation needs under the most rainfall restricted drought conditions or when the majority of rainfall is diverted to surface run-off.

Irrigation at a steady-state rate equivalent to 1mm/day is therefore an appropriate basis for ensuring proactively controlled moisture availability.

Figure 5 Evapotranspiration Rates in the Wash Area of Eastern England



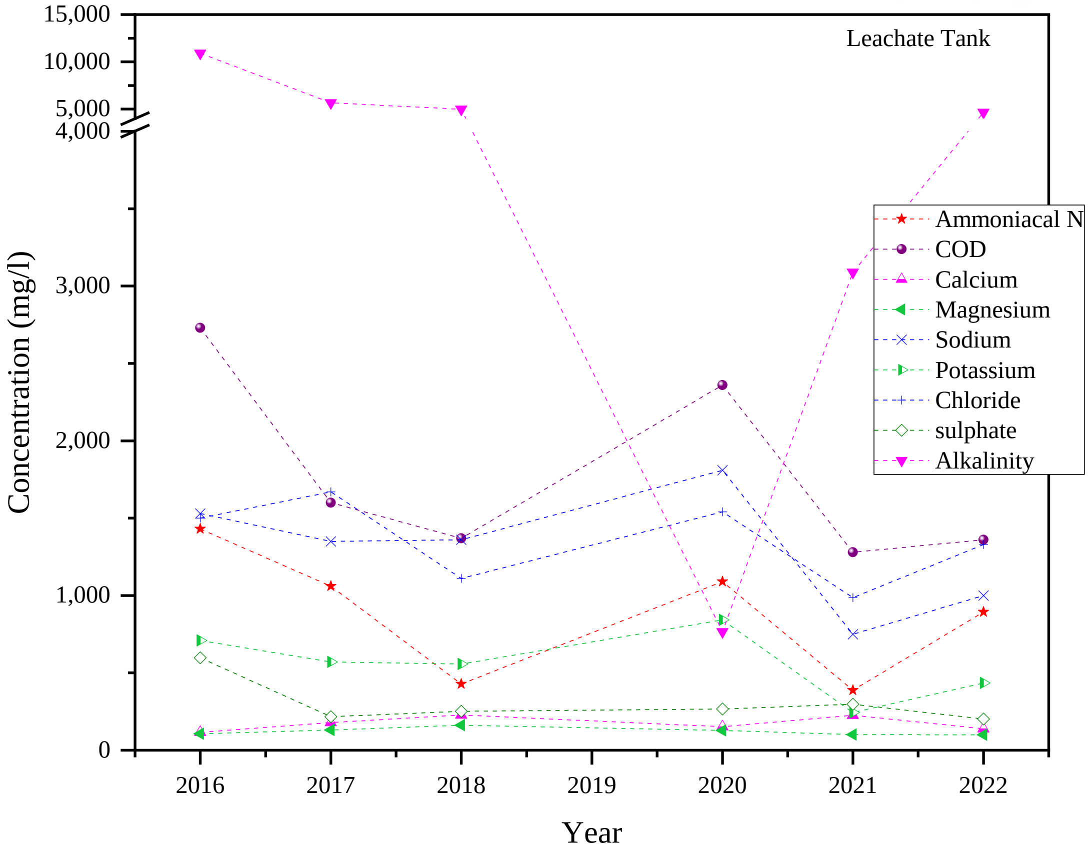
2 Source Term

2.1 Landfill Development

Middlemarsh Landfill is a closed, capped and restored non-hazardous Municipal Solid Waste landfill site which is under a "Definitive Closure" phase. The site contains a leachate which is actively manged and disposed of by off-site tankering. This leachate is well characterised by an extensive monitoring programme, and since waste deposits ceased approximately a decade ago, the leachate has stabilised into a known chemistry, which will remain at a stable concentration range during short to intermediate timescales. Consequently, there is a good knowledge basis for undertaking risk assessments as well as ensuring a known leachate application will take place.

The leachate is best described as a "brackish water" in the form of a sodium-chloride-bicarbonate water. There is a secondary component of non-hazardous substances, of which ammonium is predominant and trace levels of heavy metals and no persistent organic substances.

Figure 6 **Site "Average" Matrix Chemistry as Measured at the Tankering Point**



It is proposed that a proportion of this leachate is utilised as a seasonal irrigant during the summer period, unless weather conditions are such that irrigation is not necessary in any specific year or period within the summer.

Landfill leachates are best described as a series of substance types, namely:

1) Matrix salts
2) Primary Pollutants
3) Heavy Metals and Metalloids
4) Non-hazardous organic substances
5) Persistent Organic Pollutants

Landfill leachate, including leachate from Middlemarsh landfill, have salt ion contents ~5% of that of seawater, hence a brackish quality. Sodium and chloride are individually in the 1,000 – 2,000mg/l range, neither of which is a significant environmental hazard at 4 – 8 times Environmental Quality Standard (EQS) and Drinking Water Standard (DWS) for a terrestrial freshwater.

Of more concern and a primary focus of this assessment are the two bulk components ammoniacal-N and Biochemical Oxygen Demand (BOD). Neither, however, are persistent, and the former (*i.e.* ammonium) is in controlled amounts an essential nutrient which is applied within the immediate vicinity of the site on a routine basis to support crop growth.

The leachate is a product of the methanogenic conditions within the landfill. However, the methanogenic conditions are waning as all of the readily putrescible materials have been depleted and landfill gas generation is reducing to a rate in the order of 10 – 15m³/hr per hectare. Consequently, high BOD concentrations produced by historical landfills are not occurring in the site, and crucially cannot re-occur in future. BOD levels have reduced from the 20,000 – 90,000mg/l range that are usually found in acetogenic landfills by three orders of magnitude to the 50 – 150mg/l range for the leachates that will be prioritised for irrigation (Figure 7).

The WRAP (2011) Compost and Anaerobic Digestate Quality for Welsh Agriculture[3] review allows a context to be presented to these key leachate constituents components, as nitrogen and an organic builder are the key fertiliser-soil improver components. With respect to the degradable organic content, the WRAP review identified COD and BOD levels consistent with an acetogenic leachate and hence significantly in excess of that within the site (Table 1).

The leachate to be prioritised for irrigation is based on the ammoniacal-N content of the leachate and will be selected and blended to even out the distribution of nutrients and present a balanced load (Figure 8). This concentration range is within the lower 20% of the concentration range expected for WRP Digestate Compost type products, and therefore consistent with other nutrient applications.

The key salt ion indicators, chloride (Figure 9) and potassium (Figure 10) are also within the concentration expected for the WRAP (2011) product, consequently the grasslands will not be subject to different chemistries to that in an agricultural setting where compost , manure and digests are applied to fields. This holistic consistency between the site leachates and the various digestates is however unsurprising given that in essence a landfill functions as an anaerobic digester with respect to the matrix and primary stabilisation products produced.

Table 1 Extract from WRAP (2011)[3] Table 5 – 10-Year Average Leachable Organic Content for Digestate Compared with Abstracted Middlemarsh Site Average (2022) at the Leachate Tank

	BOD	COD	NH_4-N	TN	Cl	K	P
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Food Based Digestate#1	5,550	29,300	5,650	5,650	2,750	2,660	128
Food-Based Digestate#2	13,010	49,180	5,310	5,310	3,752	1,190	60
Manure Based Digestate	5,430	51,840	2,310	2,310	1,450	2,940	147
Green Compost #1	4,350	68,380	395	396	905	1,190	15
Green Compost #2	540	62,160	7	551	1,190	2,070	20
Green Compost #3	810	61,630	65	72	1,110	1,600	24
Green Compost #4	780	63,330	3	15	390	575	18
Green/Food Compost#1	6,370	72,050	511	516	2,250	2,660	90
Green/Food Compost#1	400	37,820	280	435	1,780	2,180	28
Green/Food Compost#1	630	77,350	7	55	457	768	24
Site Chemistry (2022)							
Middlemarsh Leachate Tank	40	1,360	894	894	1,330	435	
Proposed Application Rate	250	2,500	1,000	1,000	2,750	1,500	

Green shaded cells, application upper concentration limit
TN – Total Nitrogen.

[3] https://wrap.org.uk/sites/default/files/2020-09/WRAP-Compost_Anaerobic_Digestate_Quality_Welsh_Agriculture.pdf WRAP (2011) Report QAV032-004

Figure 7 **Leachate Degradable Organic Content**

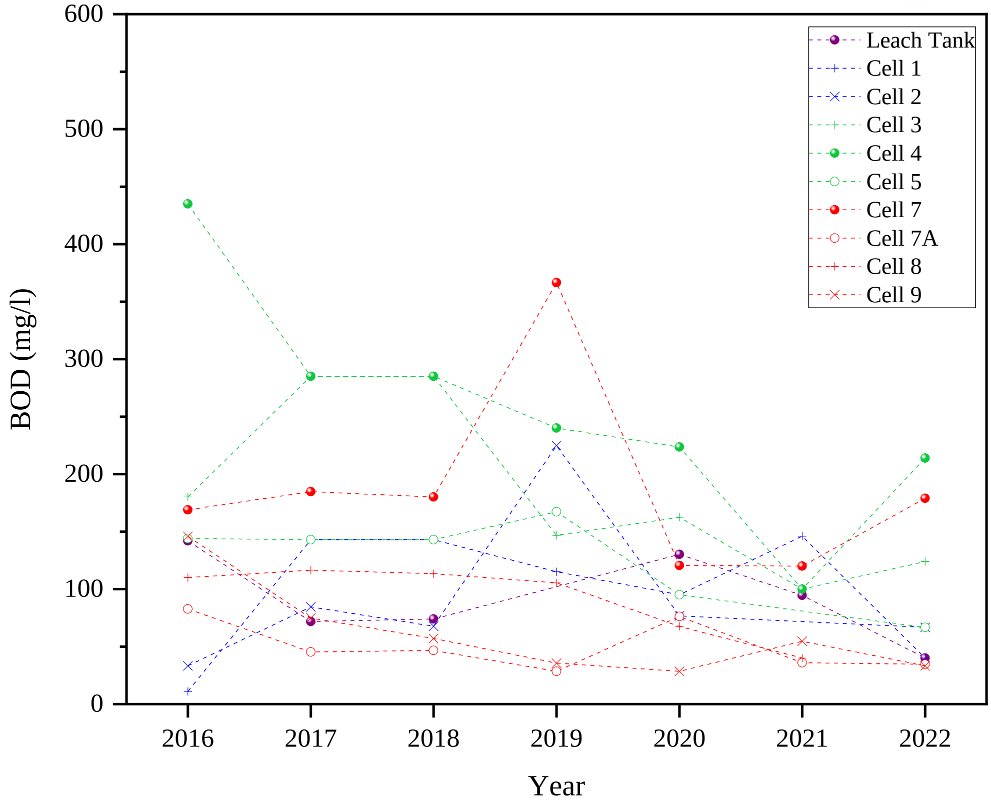


Figure 8 **Leachate Nitrogen Content (Ammoniacal-N)**

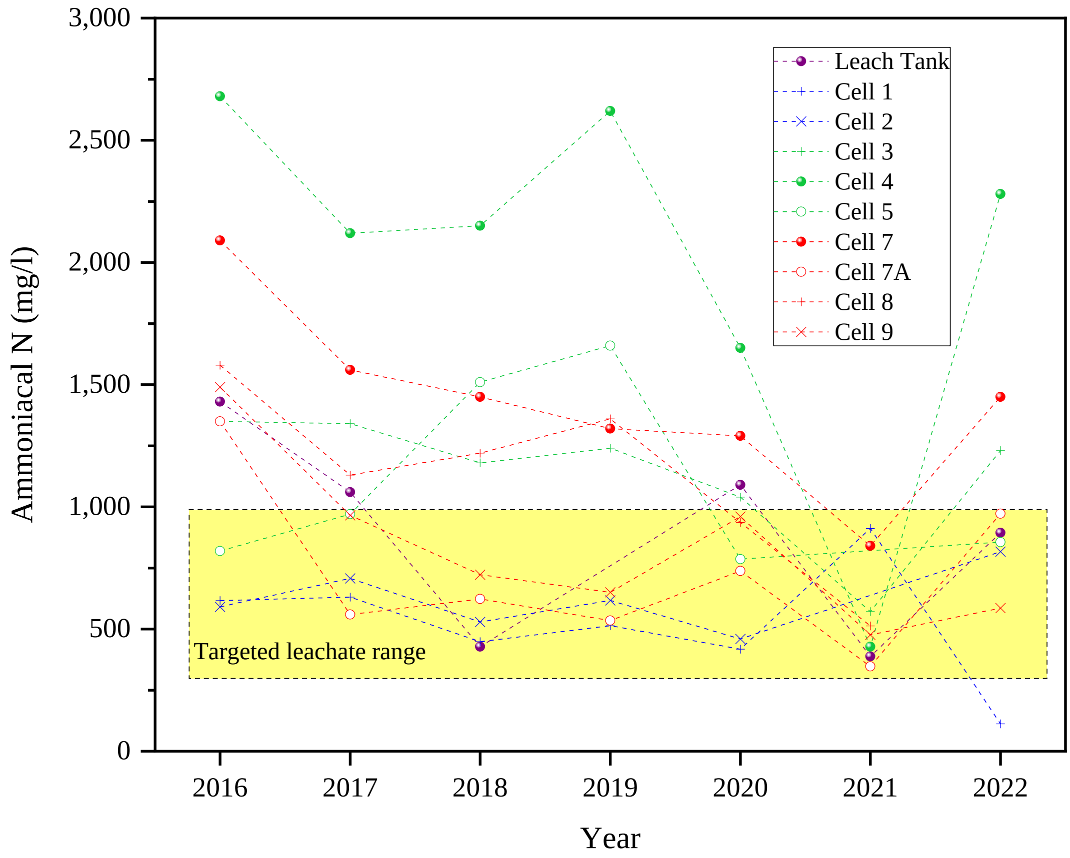


Figure 9 **Leachate Chloride**

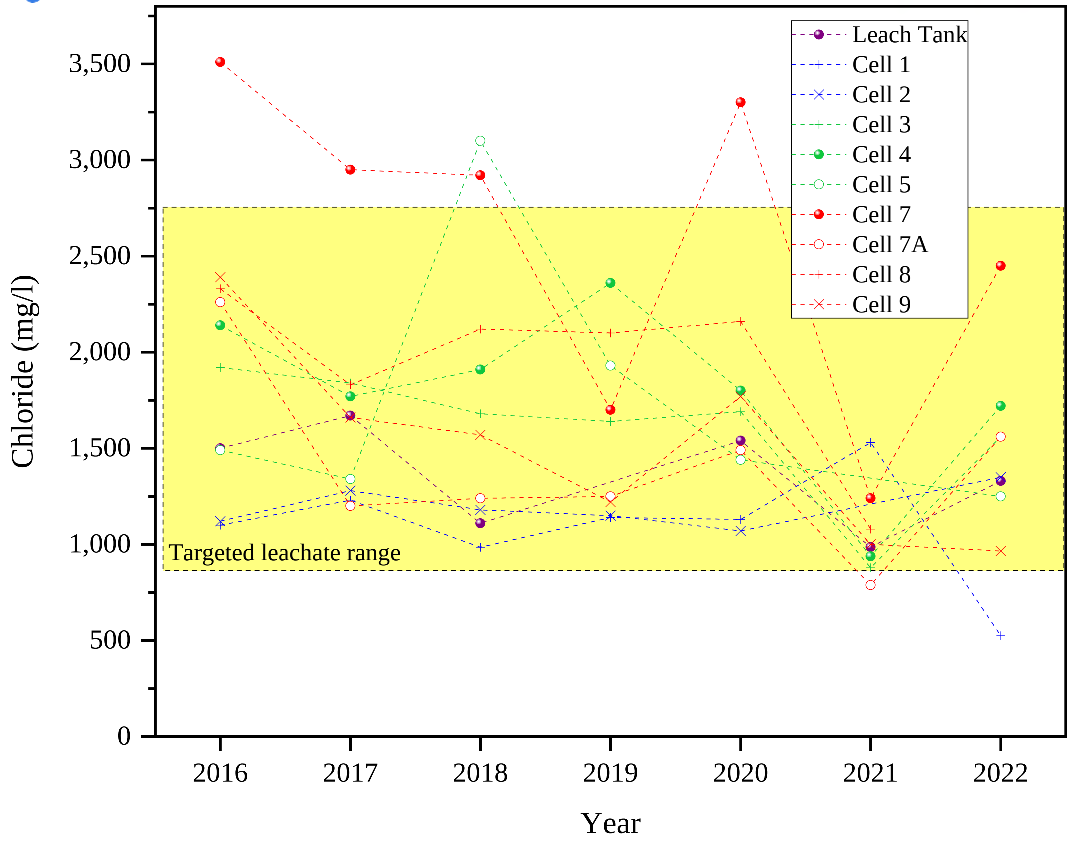
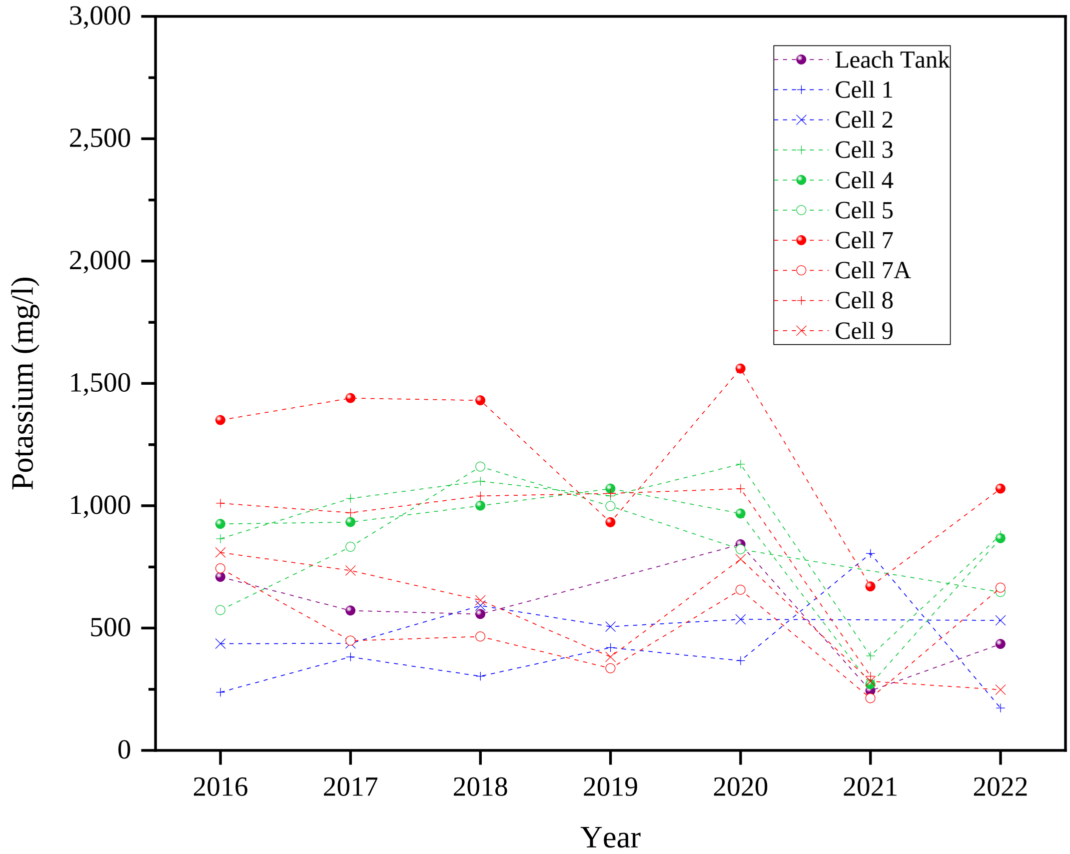


Figure 10 **Leachate Potassium**



2.2 Priority Substances

The heavy metal and metalloid content of the leachate is generally consistent with EQS levels with the arsenic, lead, cadmium, copper and zinc straddling the EQS limits for surface water (Table 2). The leachate therefore has little if any potential to pollute Controlled Waters with respect to irrigation for moisture purposes. Chromium and nickel do however consistently exceed their respective EQS. As the leachate is produced under methanogenic conditions, then the chromium content must be in the Cr(III) as hexavalent Cr(VI) cannot exist under methanogenic landfill conditions, and would be immediate reduced to Cr(III).

Table 2 Heavy Metals and Metalloids

		Chromium	Nickel	Copper	Zinc	Arsenic	Lead	Cadmium
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
EQS (MAC)		**0.032**	**0.034**	**0.03***	**0.03***	**0.05**	**0.014**	**0.0009**
Leachate Tank	2021	0.11	0.12	<0.01	0.02	0.07	<0.01	0.0003
	2022	0.15	0.12	<0.01	0.05	0.05	<0.01	0.0005
Cell 1	2021	0.22	0.15	0.03	0.05	0.05	<0.01	0.0008
	2022	<0.01	0.07	0.04	0.14	<0.01	<0.01	<0.0002
Cell 2	2022	0.11	0.12	0.12	0.29	0.02	<0.01	0.0006
Cell 3	2021	0.05	0.08	0.02	0.03	0.02	<0.01	<0.0002
	2022	0.19	0.18	<0.01	0.04	0.02	<0.01	0.0008
Cell 4	2021	0.12	0.12	0.04	0.10	0.05	<0.01	<0.0002
	2022	0.35	0.16	<0.01	0.02	0.17	<0.01	0.0011
Cell 5	2022	0.11	0.15	0.07	0.44	0.03	<0.01	0.0007
Cell 7	2021	0.24	0.17	0.01	0.10	0.05	<0.01	0.0003
	2022	0.43	0.34	0.48	0.65	0.03	0.02	0.0018
Cell 8	2021	0.16	0.12	0.01	0.13	0.05	<0.01	0.0005
Cell 7A	2021	0.09	0.11	0.53	0.29	0.03	<0.01	<0.0002
	2022	0.41	0.27	<0.01	0.13	0.02	<0.01	0.0013
Cell 9	2021	0.13	0.13	0.48	0.23	0.06	<0.01	0.0003
	2022	0.16	0.12	0.10	0.26	0.05	<0.01	0.0003

* m-BAT based EQS ~0.03mg/l for copper and zinc (as PNEC – Point of No Effect Concentration)
EQS (MAC) Environmental Quality Standard (Maximum Allowable Concentration)

The second key priority substance type are the identifiable organic substances. Organic screens are carried out on the leachate as per the Permit Schedule on a 4-yearly schedule; the most recent of which was undertaken in June 2022.

Organic substances in leachates are breakdown products from the solid organic materials within the waste mass, the majority of which are the large fulvic and humic type substances. However, there is a component of specifically identifiable substances, which comprise a combination of the BTEX and substituted BTEX as well as mecoprop above leachate screening levels (Figure 11).

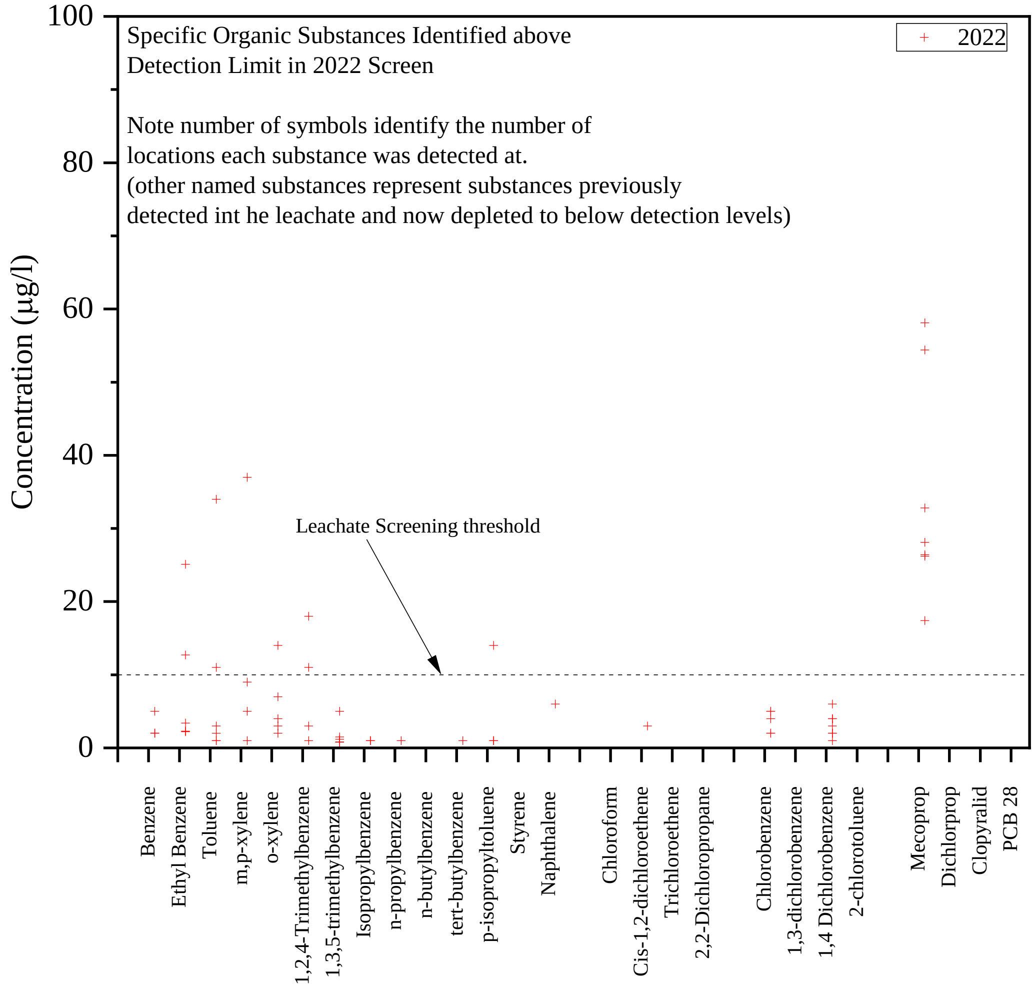
EQS levels are available for the principle organic substances present (Table 3). The substance concentrations within the leachate are generally within their Annual Average EQS level, except for xylene, which only exceeds the 30µg/l EQS at one location (Cell 4), and the mecoprop which is between its 18µg/l Annual Average and 187µg/l Maximum Allowable Concentration (MAC) for freshwaters.

For other organic substances reported as present, concentrations are within that of the EQS for a similar substance (*e.g*. trimethylbenzene, is consistent with xylene, *i.e*. dimethylbenzene).

Table 3 Priority Hazardous Substances, Priority Substances, Specific and Other Pollutants Environmental Quality Standards

	AA	MAC	
	µg/l	µg/l	
Toluene	74	380	as 95th%ile
Xylene	30		
Benzene	10	50	
Naphthalene	2	130	
Trichloroethene	10		
Dichlorobenzene	20	200	
Mecoprop	18	187	as 95th%ile

Figure 11 Specific Organic Substances Identified in the Leachate

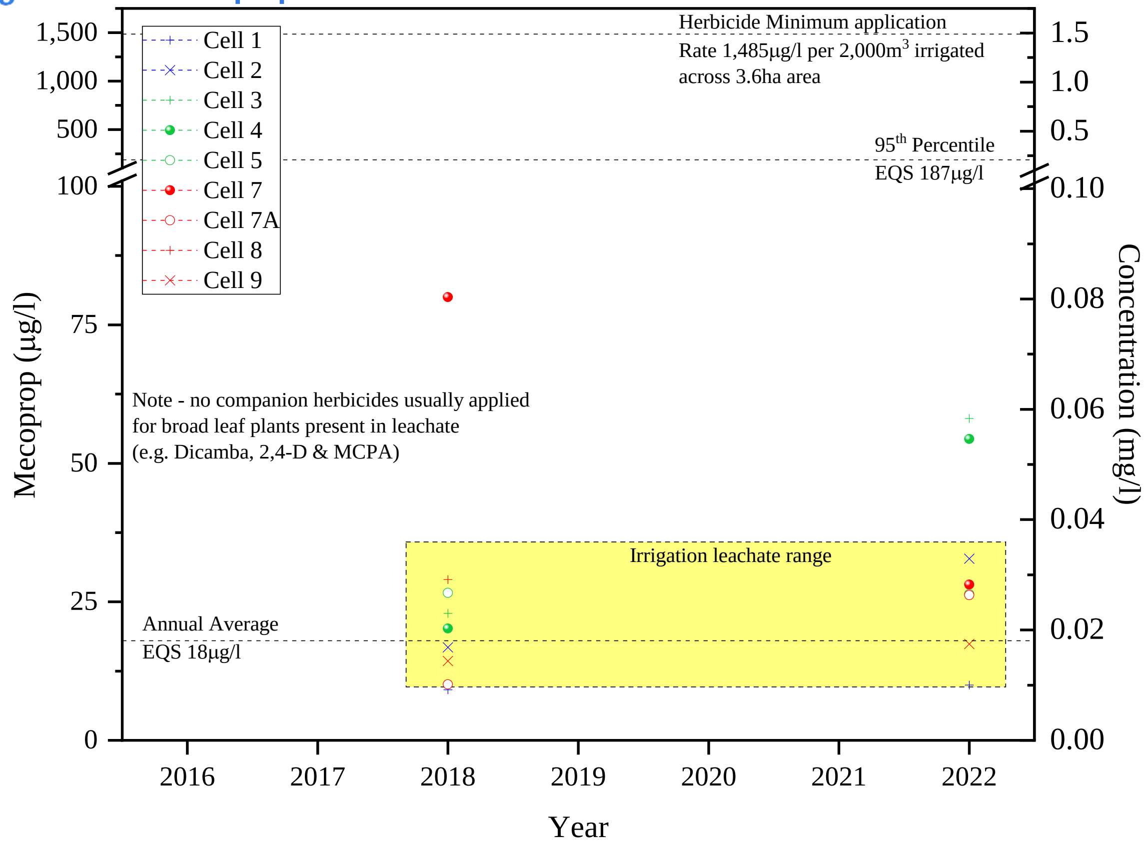


No other specific pollutants, priority hazardous substances, priority substances or other pollutants have been detected as present within the leachate. Given that the leachate is in a stabilised form with no additional wastes deposited in the site, this chemistry and the organic substances is a good representation of the state of the leachate available for irrigation.

The specific substances identified within the leachate are therefore of no particular concern for a leachate irrigant. These substances are also degradable and would not accumulate within the restoration soils being irrigated. The BTEX and similar BTEX substances, such as trimethylbenzene and propylbenzene are in addition volatile and will most likely be lost to atmosphere during the actual irrigation stage, consequently it is unlikely that these substances could actually remain in the water phase.

Mecoprop is the only non-volatile organic substance which could be considered as consistently exceeding Annual Average EQS levels, although this is a localised exceedance, restricted to Cell 3 and Cell 4. At 10 – 30µg/l, the remainder of the locations approximate to the EQS (Figure 12).

Figure 12 Mecoprop Distribution



Mecoprop is not present at a concentration that could cause harm, as at source, peak concentrations are <40% of the 187µg/l Maximum Allowable Concentration. Consequently, there is no potential for a toxic shock load to be applied.

At this concentration range, mecoprop is significantly below minimum herbicidal use concentrations, which would equate to a loading rate equivalent to ~1,500µg/l if diluted down to a 2,000m^3 volume, *i.e.* quantities consistent with the entirety of the irrigation volume if applied on a single occasion.

Mecoprop is a herbicide specially intended for use on grassland crops. The herbicidal properties of mecoprop are also usually combined with dicamba, 2,4-D and MCPA for its full effectiveness. However, as none of these substances are present, and as mecoprop is significantly below effective use concentrations, then there is no expectations of harm from the mecoprop (or herbicidal) properties of the leachate in general affecting the grassland ecology that the irrigation is intended to support. Of greater risk to the surrounding water system would therefore be from herbicidal applications in the surrounding fields when cereal crops are being grown.

3 Comparison with Other Recovered Products Applied to Land

3.1 Introduction

In this case leachate is to be applied as a surrogate for water. A more analogous descriptor for the leachate is a water product derived from a digester and therefore analogies can for risk assessment purposes be made to other recovery process materials which are commonly applied to land.

In this form, the leachate irrigant can be described as a "*water-based product, which contains nutrient levels of nitrogen (as ammonium) and a trace component of other substances"*. In this case the other substances present are secondary to the process and although may in part be beneficial nutrients, concentrations may have a bearing that limits the quantity of the base product (*i.e*. the water content of the leachate) that can be applied.

Precedents have been set for setting suitable product standards and limitations to the ancillary components within a product, which may cause harm. This includes the EU Fertilising Product Regulations[4], which although partially transcribed into UK law[5], has been used as a precedent for setting End of Waste status for Single Nutrient and Compound Nutrient Fertilisers from waste materials[6]. These regulations were specifically designed to reintroduce wastes to the market as a Recovery Product partially in order to meet recycling and circular economy objectives, but also to relieve pressure on a strained primary product market which is causing environmental harm.

Other earlier precedents include the WRAP protocols for compost and digestates[3] and the Code of Practice for the use of Sewage Sludge in Agriculture[7]

These various laws and Codes of Practice set out principles for the addition of Primary and Secondary Macronutrients and Micronutrients as well as a Contaminant Content of Potentially Toxic Elements which may also be present in the product being applied to land.

In the majority of cases, the principal component being applied is one or a combination of:

1) Primary Macronutrients: N, K, P and Organic Matter
2) Secondary Macronutrients: Ca, Mg, Na, S,
3) Micronutrient: *e.g*. Cu, Zn

[4] Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003
[5] *e.g*. The Fertilising Products Regulations 2020 SI 2020 No.887
[6] *e.g*. DOW190905/01A, dated 25 March 2022 for the use of a fly ash sourced from the combustion of meat and bone meal (MBM) as a fertiliser
[7] https://www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice/sewage-sludge-in-agriculture-code-of-practice-for-england-wales-and-northern-ireland

4) Contaminants: *e.g.* Cd, Ni, Pb, inorganic As

As macronutrients are required to be present above at least 5% for a single nutrient fertiliser, or as 1.5% for a combined nutrient fertiliser, *i.e.* 50,000mg/l or 15,000mg/l. in this context the ammonium and potassium content of the leachate would only be considered as a 10 – 15-fold dilution of a fertiliser product, and therefore be considered as a low level “post mixing” dosage of a liquid fertiliser.

3.2 Application Rates

The Sewage Sludge Guidelines[7] present a series of Maximum Permissible annual rate of Potentially Toxic Element (PTE) application to lands over a 10-year period. Application rates are set as kg/ha, and therefore can be directly compared to a leachate irrigation application rate to define a framework for the irrigation scheme

Table 4 Irrigation PTE Application Rate Compared to Sewage Sludge Code of Practice Annual Average Limits as set out in Guidance Section 6.3 PTE Limits in soil used for arable farming[7]

Irrigation Rate 3,240m³ per 3.6ha area
900m³ per hectare

	Sewage Sludge	Irrigation Application Rate at 900m³/ha		Irrigant Concentration	
	SS CoP Limit	Maximum Load	Typical Load	Maximum (2021-2022)	Typical (2021-2022)
	kg/ha/yr	kg/ha/yr	kg/ha/yr	g/m³ (mg/l)	g/m³ (mg/l)
Chromium	15	0.43	0.18	0.48	0.2
Nickel	3	0.31	0.14	0.34	0.15
Arsenic	0.7	0.15	0.06	0.17	0.07
Copper	7.5	0.48	0.01	0.53	0.01
Zinc	15	0.59	0.05	0.65	0.05
Lead	15	0.02	0.01	0.02	0.01
Cadmium	0.15	0.002	0.0003	0.0018	0.0003

Maximum potential Application rates for chromium are ~35 times lower than the Code of Practice annual limits, whist nickel is 10% of that of the code of practice application rates, if applied at maximum leachate concentrations. However, as the leachate will continue to deplete over time, then progressively the loading rates will be reduced.

These factors are themselves conservative as the above factors assume the outlier peak concentrations are continually applied when typical loading rates are approximately 50% of that of the outlier-based concentration predictions.

These application rates can be converted to a soil concentration increase in the upper 0.2m rooting zone of the restoration soils, which assuming a 1.5T/m³ restoration soil density, equates to a quantity of 300kg soil per m², or 3,000,000kg of soil per hectare. Estimated soil concentration increases are <1mg/kg after 10 years for all metals and metalloids at “expected” loading rates, with an upper boundary rate of 2mg/kg (Table 5). Cadmium is two orders of magnitude lower at up to 0.005mg/kg and an expected increase of <0.0009mg/kg.

Increases in soil concentration of this magnitude will not be discernible in the restored soils.

Table 5 Predicted Soil Concentration Increase in the Upper 0.2m of the Soil Profile Assuming Soil Density of 1.5T/m³ (Quantity of 300kg/m² of Surface Area)

	Application Rate per year*		Concentration Increase per Year		Concentration Increase per 10yrs		Permissible Conc in Soil
	Max	**Ave**	**Max**	**Ave**	**Max**	**Ave**	**Max as per SS-COP**
	kg/ha	**kg/ha**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
Chromium	0.43	0.18	0.14	0.06	1.4	0.6	600
Nickel	0.31	0.14	0.10	0.05	1.0	0.5	100 – 180**
Copper	0.48	0.01	0.16	0.003	1.6	0.03	170 – 330**
Zinc	0.59	0.05	0.20	0.02	2.0	0.2	200 – 300**
Arsenic	0.15	0.06	0.05	0.02	0.5	0.2	50
Lead	0.02	0.01	0.006	0.003	0.06	0.03	300
Cadmium	0.0016	0.0003	0.00054	0.00009	0.0054	0.0009	3

*as per Table 4 SS-COP – Sewage Sludge Code of Practice *Soil pH Dependent

4 Potential Hazard Pathways

4.1 Conceptualised Irrigation

Irrigation is intended to be undertaken at a low level rate. Daily application rates of up to 36m³/day (3,240m³ per 90 day summer period) equates to typical irrigation rates of 1.5m³/hr over the 3.6ha area, which will be distributed at 0.417m³/ha/hr or 0.116L/s per hectare.

This low irrigation rate is intentional as the purpose is to infiltrate into the soil restoration surface and be available for vegetation without inducing surface run-off. Higher irrigation rates (than 36m³/day) would only be implemented under severe extended dry conditions.

There are four pathway routes for this irrigant towards Environmental Receptors, namely:

- Direct volatilisation under summer weather conditions;
- Evapotranspiration induced by the grassland vegetation;
- Infiltration into the soil, followed by lateral migration through the restoration surface; and
- Direct surface run-off.

Volatilisation and evapotranspiration are direct releases to atmosphere, whilst infiltration into the soil will be through a mitigation medium, whereby attenuation processes such as mineral surface adsorption, *in-situ* biodegradation and vegetative uptake will immobilise, destroy or otherwise retard the leachate constituents as the moisture being applied is evaporated

The infiltration pathway is a sub-surface pathway whereby irrigant not evapotranspirated will migrate vertically to the capped surface through the 1m thick restoration soils and then be diverted laterally under the slope gradient to the edge of the site and then through the host-sediments surrounding the landfill to enter the groundwater and interconnected surface water system.

Surface run-off will be via a more direct route, of mixing with waters from a rainfall event, capture by the surface water drainage system to be conveyed to the on-site flow balancing lagoon in the northeast corner of the site before release to the surface water system managed by the local drainage board.

4.2 Geology and Hydrogeology

The site is located within an area of fenland which is in a sequence of

- Terrington Beds (Salt Marsh and Tidal Creek Deposits, mainly clay and silt)
- Glacial Till (Boulder Clay)
- Ferriby Chalk Formation / Red Chalk Formation
- Carstone Formation (Greenish brown sandstone)

Figure 13 Extract from BGS Sheet 116: Skegness

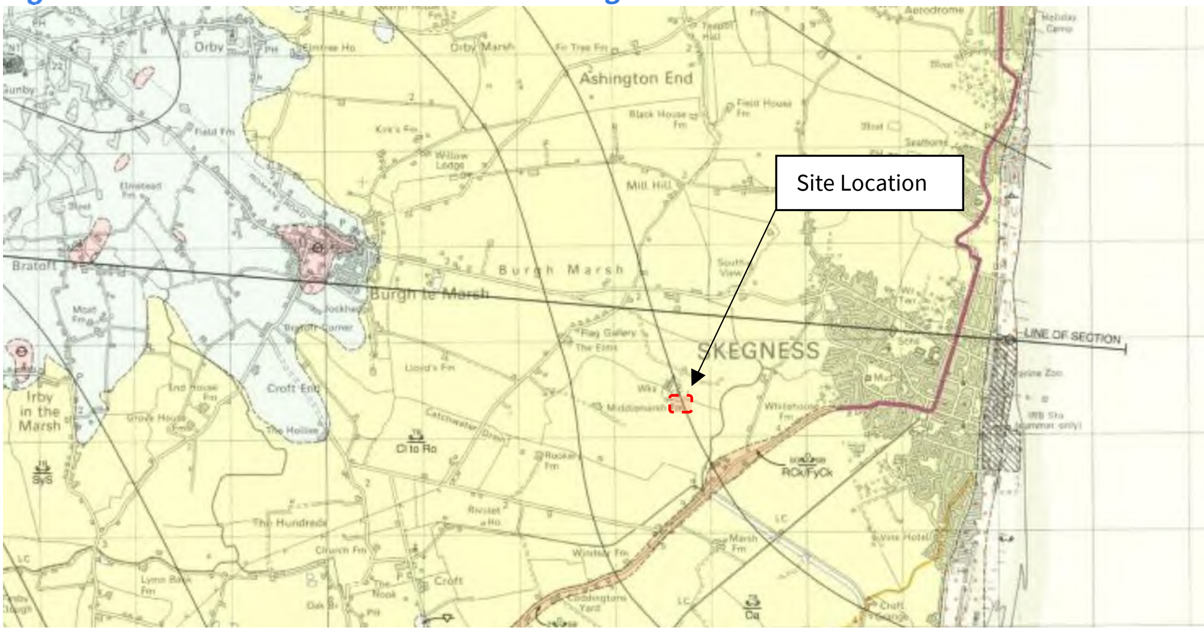
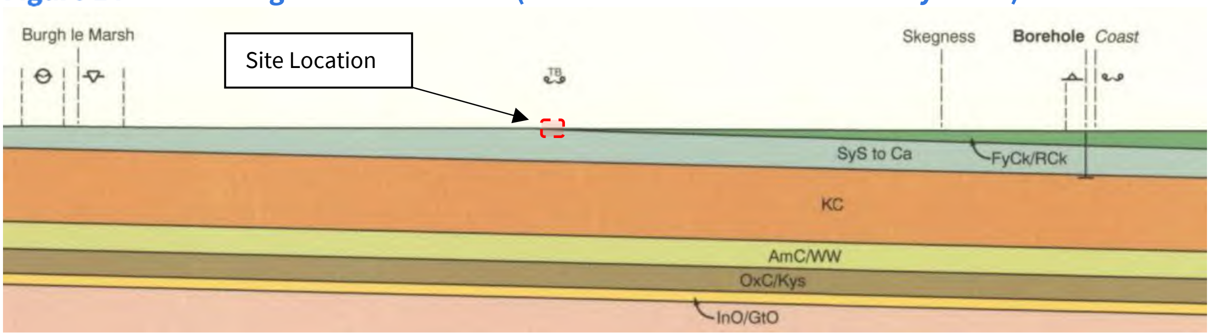


Figure 14 Geological Cross-Section (Site Off-set from Section Line by 550m)



The site is located above the boundary between the Carstone Formation and the base of the Lower Chalk, as illustrated on Figure 13 and Figure 14. These formations are however physically separated from the landfill by the intervening Glacial Clay which forms the basal natural geological barrier of the landfill.

The landfill is hosted by the Terrington Beds, a silt to fine grained sand deposit formed within salt marshes which includes interlaminated clays and peat horizons. These sediments were deposited within marine and brackish water transgression environment along low lying inland major water courses.

The Terrington Beds are 3 – 4m in thickness and are present between -1mAOD and 4mAOD, depending on location. The Terrington Beds are characterised by the Environment Agency as a low Permeability superficial deposits and been classified as Unproductive Strata. The Terrington Beds are therefore a pathway and not a potential receptor.

The Glacial Clay is similarly classified as unproductive Strata which overlies Chalk in the centre and east of the site, a Principal Aquifer and the Carstone Formation a Secondary A Aquifer in the west and southwest of the site.

The landfill is an engineered containment landfill, which benefits from 1m of restoration soils, above a Polyethylene cap, and is lined by a combination of:

- GCL and HDPE for the base and sides of Cell 1;
- GCL on the base and sides of Cells 1 – 6; and
- 600mm Compacted Clay on the base and sides of Cells 7 – 9.

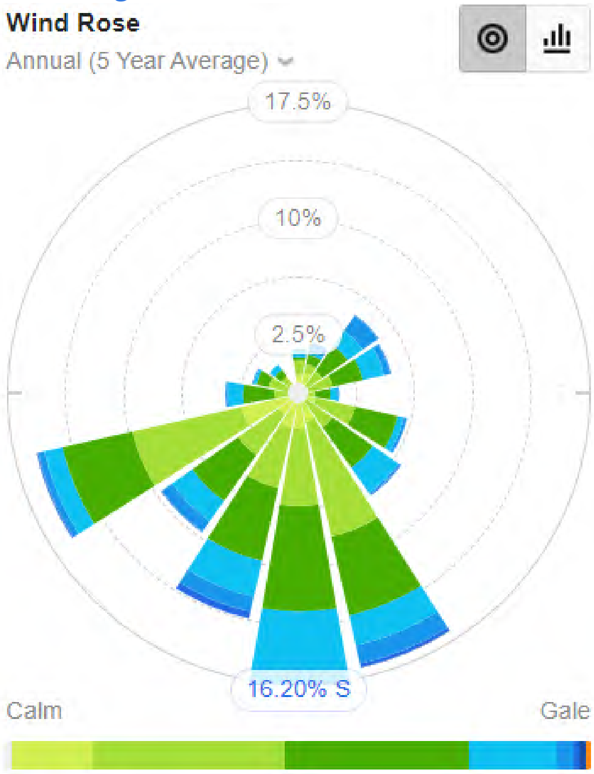
The landfill therefore does not form a pathway. However, even in the event that the irrigated leachate were to penetrate into the site, the irrigant would percolate through the waste mass to be collected by the basal drainage system to be either re-used for irrigation or disposed of off-site.

4.3 Meteorological Conditions

Wind directional data has been obtained by the Skegness weather station[8], the nearest identified Meteorological Office Station to the Middlemarsh Landfill Site. The data is presented in Figure 15. The prevailing wind direction is from the South.

[8] Skegness Wind Forecast, Lincolnshire - WillyWeather

Figure 15 Wind Rose for Skegness weather station



5 Hazard Receptors

5.1 Potentially Sensitive Receptors

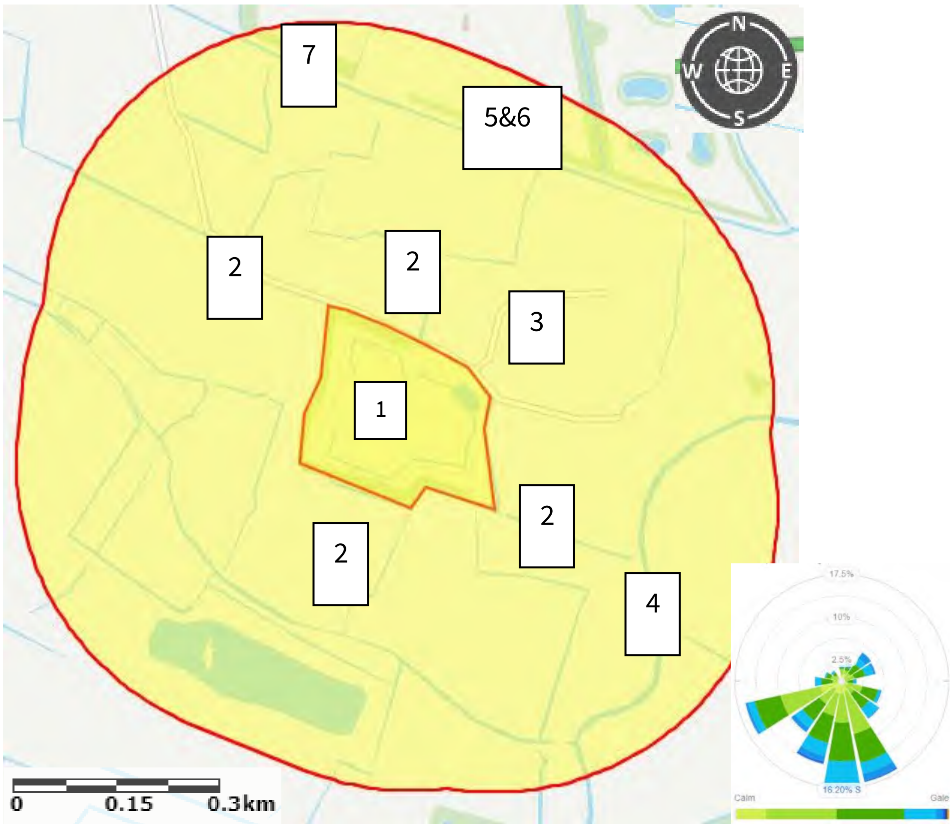
A review of sensitive receptors within 500m is listed in Table 6. The location of these potentially sensitive receptors is indicated in Figure 16.

The probability of exposure to fugitive emissions including odour and dust is determined by distance of the receptor to the site and the likelihood of the hazard reaching the receptor *i.e.* frequency of prevailing wind in that direction. The probability of exposure is irrespective of the type of hazard presented.

Table 6 Potentially Sensitive Receptors within 500m of Middlemarsh Landfill Site

Receptor No.	Receptor	Category	Direction from Site	Approximate distance from the site boundary (m)	Location Relative to Prevailing Wind Direction	Frequency Downwind (%)
1	Hedgerow	Watershed	Within Site	0	Downwind	Up to 16.2
2	Arable Agricultural Fields and Drains	Commercial/Water courses	Surrounding Site	<10	Upwind/downwind/ crosswind	Up to 16.2
3	Skegness Solar Park	Commercial	NE	30	Downwind	9.2
4	Main Drain	Watercourse	NE/E/SE	240	Upwind and crosswind	9.2
5	Footpath	Public Right of Way	N	390	Downwind	16.2
6	Unnamed Drain	Watercourse	N	390	Downwind	16.2
7	Coronation Farm industrial estate	Commercial	NW	423	Downwind	6.8

Figure 16 Location of Potentially Sensitive Receptors within 500m of the Middlemarsh Landfill Site[9]



The closest receptor is the hedgerow located at the centre of the site, which acts as a watershed dividing the drains to the north and south of the site.

[9] MAGIC (defra.gov.uk)

The surrounding area is predominantly agricultural. The closest downwind off-site receptor is the solar farm at the northeast edge of the site. There is a commercial industrial estate at Coronation Farm 500m to the north.

Beyond the 500m search area, there are properties along Warth Lane, 730m to the east of the site, and then the outskirts of Skegness, 1km to the northeast. Ivy House, a hotel and caravan park are 700 – 800m to the south of the site. Middlemarsh Farm is similarly 700m to the southeast of the site, in a generally upwind direction, whilst the other properties to the southeast and east along Middlemarch Road are at least 1km from the site.

5.2 Emission Pathway

The leachate is to be irrigated by a “slow weep” through permeable pipework to diffuse across the soil surface beneath the vegetation cover. The irrigant waters are intended to be bioavailable to the near surface soil rooting zone at a rate consistent with normal plant uptake rates. The irrigant will therefore not be spray irrigated as an above ground mist, where dissolved components may be prone to volatilisation as downwind airborne emissions.

Evapotranspiration is an indirect emission route whereby the irrigant infiltrates into the soil and is then volatilised through the grassland vegetation. This will be the dominant, if not the entirety of the water pathway route to atmosphere, and there will be a low to negligible risk to off-site receptors as leachate constituents will be retained by the soil and vegetation.

5.3 Potentially Sensitive Habitats

The site is remote from any specific habitat sites. There is an area of deciduous woodland located 660m to the south-east of the site. The closest habitats site is Gibraltar Point which is designated as a Site of Special Scientific Interest (SSSI) and a Special Area of Conservation (SAC) some 3.2km to the south-east of the site (Figure 17).

5.4 Hydrogeological and Hydrological Receptors

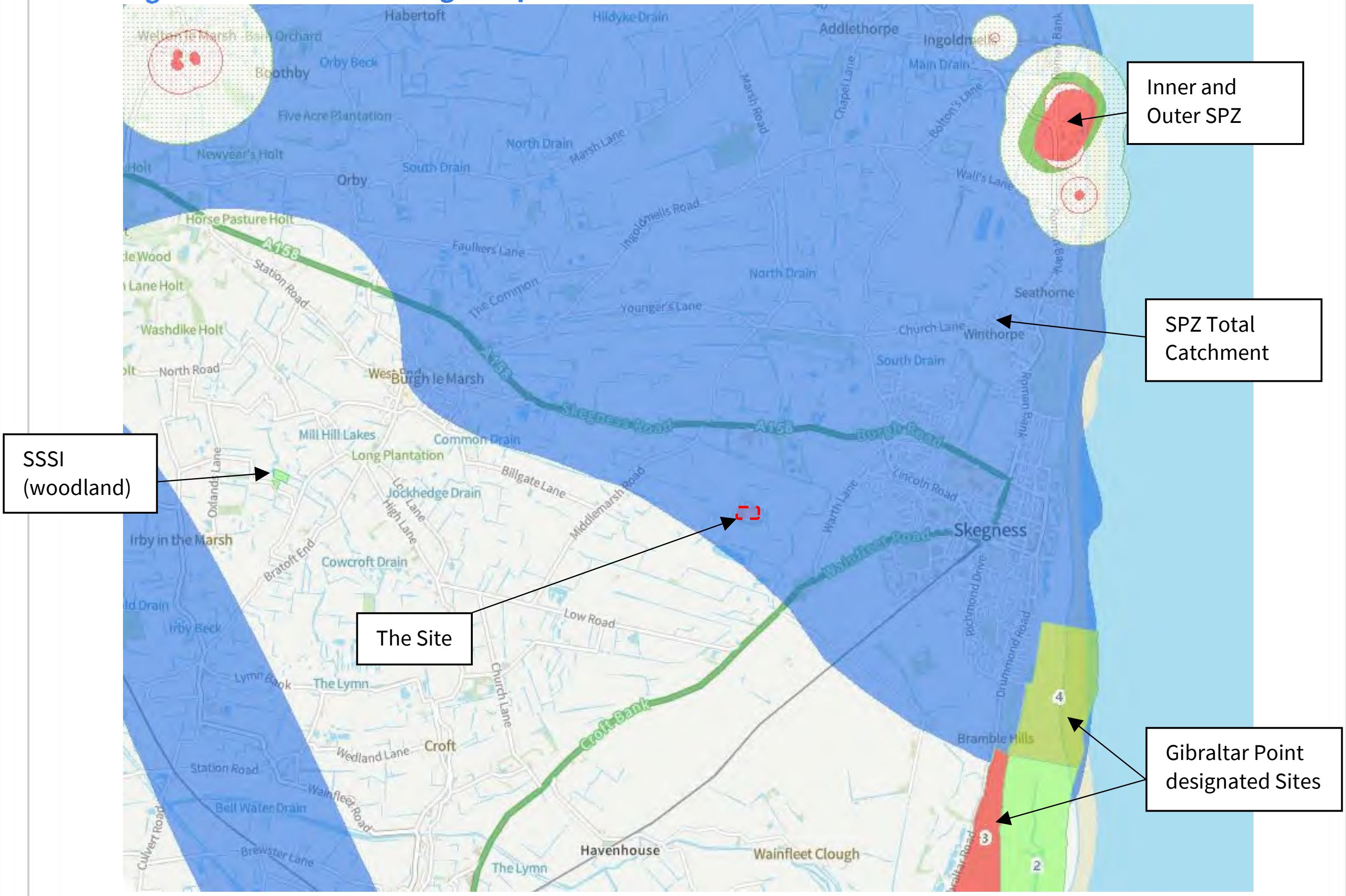
The site is also located at the edge of the catchment for the combined Skegness and Welton le Marsh Source Protection Zones (SPZ). This total catchment is based on the geological boundary at the edge of the Carstone Formation and is primarily from the thickening Chalk formation to the east of the site at Skegness (Figure 14) and the mixed Formations of Chalk, Roach Formation and Spillsby Sandstone Formation at depth beneath Welton le Marsh.

These strata being abstracted from are hydraulically independent from the superficial sediments at Middlemarsh landfill Site.

As almost the entirety of Central and Eastern England is classified as a Nitrate Vulnerability Zone (NVZ), it is unsurprising that the site is in a designated zone. In this case, the designation[10] is for surface water for almost the entirety of the fenland area.

[10] https://mapapps2.bgs.ac.uk/ukso/home.html?layers=NVZEng

Figure 17 Surrounding Receptors and Source Protection Zones



5.5 Odour Sensitive / Volatilisation Receptors

Irrigation will be undertaken using near surface slow rate release systems whereby airborne emissions will be minimised by the grass sward itself and infiltration into the soil rooting zone. At low irrigation rates odorous emissions will also be minimised, however, precedents have been set for significantly higher irrigation rates used to irrigate short rotation (willow) coppice systems by the applicant, and for example into woodlands and open fields by, for example, Cornwall Council, that demonstrate no off-site loss of amenity during leachate irrigation.

Given the significant atmospheric pathway distance to the receptors (see Section 5.1), irrigation is not expected to cause a risk, or discernible amenity impact to these surrounding receptors.

No residential receptors are located within 500m of the Site with the closest businesses comprising of storage units located more than 420m to the north. Offices within the Coronation Farm industrial estate is located beyond 500m of the Site. The closet downwind receptor is the unmanned solar farm at the northeast edge of the site, with the closest residential properties located 730m to the east of the site along Warth Lane and then the outskirts of Skegness, 1km to the northeast.

Ivy House, a hotel and caravan park are 700 – 800m to the south of the site. Middlemarsh Farm is similarly 700m to the southeast of the site, in a generally upwind direction, whilst the other properties to the southeast and east along Middlemarch Road are at least 1km from the site.

Consequently, the distance of receptors to the irrigation area and given the passive design of the process in combination with the management procedures employed at the site, these receptors are considered unlikely to be affected and the residual/mitigated risks are considered low. Therefore, odour has not been considered further in this report. Similarly, it has not been deemed necessary to produce an Odour Management Plan (OMP) for the Irrigation Scheme.

Evapotranspiration is an indirect route whereby the irrigant infiltrates into the soil and is then volatilised by the grassland plants. This will be the dominant, if not the entirety of the water pathway route to atmosphere. Consequently, there will be no risk to off-site receptors as leachate constituents will be retained by the soil and vegetation. Moreover, the risk of run-off contaminated by leachate from the irrigation scheme reaching groundwater and surface water is considered to be low to negligible.

5.6 Irrigated Zone

The two principal "reservoirs" for leachate constituents are the vegetation (grasses, other plants etc) and the host soil. As noted above and illustrated in Table 5, there is no potential for the soils to become contaminated by the irrigant as application rates and loads applied are so low that there is little if any potential for there to be a discernible change in soil metal or metalloid composition.

A similar exercise was undertaken in combination with the Environment Agency by the applicant for willow-based short rotation coppice (SRC) evapotranspiration systems. Those systems are designed to maximise evapotranspiration and therefore significantly higher leachate loads are applied, which even under those high intensity irrigation programmes there was no expectation that the soils could become contaminated. In fact, monitoring of the soil composition prior to irrigation demonstrated that there was far more variability in the soil content than could ever be applied during irrigation.

The Environment Agency therefore concluded that there was no purpose to setting soil concentration limits for the irrigation programme. Consequently, as these irrigation proposals are solely intended as a maintenance dose application to support the grassland, *i.e.* a low volumetric irrigation rate, there is similarly no potential of harm occurring when all applied persistent substances are adsorbed by the soil mineral surfaces.

Infiltration into the soil, is as discussed above of no direct environmental harm. Consequently, the restoration soils themselves are not considered to be a receptor at risk from the proposed irrigation schedule. Similarly, as metal concentrations in the soils will not cause a discernible change in topsoil composition, the potential for harmful bioaccumulation within the vegetation is low to negligible.

5.7 Run-off Routes

The superficial sediments are classified as unproductive strata, and the bedrock groundwaters are protected by *in-situ* Glacial Clay. Consequently, there are no hydrogeological receptors at risk from irrigation. Therefore, there is a single receptor which can be considered, namely surface water.

The pathway to surface water is either indirect where percolating through the restoration soils, or direct if there is an irrigant bearing run-off entering the surface water management drains adjacent to the edge of the site which then feed into the Drainage Board channels which bisect the fens. These channels are actively pumped into the “Main Drain”, which although 283m to the east of the site is likely only to enter the Main Drain at the Gotts Pumping Station some 775m to the south of the site near Ivy House and before the drain crosses the A52.

6 Risk Assessment

6.1 Introduction

Water based risk assessments follow a Source – Pathway – Receptor relationship.

In this case the Source is the irrigation waters, and the receptor is off-site surface water quality. This surface water is expected to be used as an agricultural irrigant abstracted from the drainage network surrounding the site, with water levels in the drains controlled by the Drainage Board and will be at a balanced level based on general stormwater run-off recharge, controlled recharge inputs from the Main Drain and pumping out of excess waters following rainfall events.

The drainage system is managed solely for the benefit of agriculture, hence there is a need to prevent land flooding during autumn, winter and spring and hence there are preferential considerations for the use of any available water.

The irrigation with leachate is not intended to mix with this drainage channel water, as the sole purpose of irrigation is to provide a continuous maintenance of water to support the health of the grassland sward. There will under the majority of conditions be no contact between the irrigated waters.

6.2 Mixing Effects

Rainfall durations and intensities are usually classified[11] as

- Slight Rain <0.5mm/hr
- Moderate Rain 0.5 – 4mm/hr
- Heavy Rain 4 – 8mm/hr
- Very Heavy Rain >8mm/hr
- Slight Shower <2mm/hr
- Moderate Shower 2 – 10mm/hr
- Heavy Shower 10 – 50mm/hr
- Violent Shower >50mm/hr

These rates and descriptions, in combination with the regional rainfall patterns (Figure 3 and Figure 4) demonstrate that when irrigating at a site rate of up to 1mm/day, that the potential for there to be significant mixing of irrigation waters which are applied at a lower level rate to that of incidental rainfall is low.

[11] https://water.usgs.gov/edu/activity-howmuchrain-metric.html

For example, under slight rain events or slight showers, the potential to overcome direct infiltration effects is low to negligible. Similarly moderate rainfall or showers at the lower end of the range will not cause run-off effects under summer conditions, whilst higher intensity events will immediately induce significant dilution given that 10mm/hr applied for 2 – 3hrs would immediately introduce a combined 32-fold dilution factor, as the rainfall would take place over a shortened duration *i.e.* eight times faster than irrigation rates and be up to 4 times greater volume than the irrigation rate.

At these rates any leachate applied by constant rate irrigation would be reduced significantly to below a level of concern. Under heavy intensity rainfall events, dilution would be even more significant and therefore reduce the potential for harm to negligible.

Under standard weather conditions, all leachate irrigated will percolate into the topsoil layer of the restored surface. Consequently, there is no potential for harm.

Surface water run-off is a consequence of high intensity rainfall events that rapidly saturate the upper surface of the soil and prevent infiltration. Consequently, rainfall rates of 3 – 4mm in an hour has the potential to saturate the surface layer, for short periods (*i.e.* several hours) during the summer period, after which direct percolation will continue.

Taking the scenario as outlined above for the volume of leachate irrigated will result in

- an irrigation volume of 1mm x 3.6ha = 4.5m^3 in a 3hour period
- a rainfall volume of 4mm x 3.6ha = 144m^3 in a rainfall event
- resulting in a dilution factor of 32

At this dilution rate, leachate concentrations will be reduced to below levels of concern for the primary leachate constituents, even when considering conservative concentrations (Table 7), except for ammoniacal-N, which if applied at the upper concentration level could result in the on-site surface water balancing lagoon continuing in the order of 16mg/l ammoniacal-N. This, however, would not directly enter the surrounding surface water system, as the off-site flow is attenuated by the surface water management on-site lagoon, and only intended to be released slowly.

Table 7 Direct Mixing Effect assuming Conservative Leachate Composition

Substance	Irrigant	Preliminary Mixing (3.6ha)	Secondary Mixing (Whole Site Area)
Chromium	0.7mg/l	0.022mg/l	0.011mg/l
Nickel	0.5mg/l	0.016mg/l	0.008mg/l
Arsenic	0.17mg/l	0.005mg/l	0.003mg/l
Mecoprop	0.1mg/l	0.003mg/l	0.002mg/l
BOD	250mg/l	8mg/l	4mg/l
Ammoniacal-N	1,000mg/l	31mg/l	16mg/l
	750mg/l	23mg/l	12mg/l
	500mg/l	16mg/l	8mg/l
Chloride	2,800mg/l	88mg/l	45mg/l

The scenario outlined in Table 7, represents the worst-case scenario for the proposed irrigation, which is to induce a low salinity metal, metalloid and mecoprop solution into the on-site lagoon. Under heavy rainfall events, then dilution factors will only increase and therefore concentrations decrease further. Under lower intensity rainfall events, no surface run-off will occur. Even so, this "worst case scenario" is considered as highly conservative, as a proportion of the mixture would percolate into the soils and not be available for off-site transfer.

As noted above, there is only a single substance exceeding EQS levels, namely ammoniacal-N. This concentration for a single short-term event is however not of environmental significance in this situation, even though the site is within a NVZ. It is accepted that the ammonium concentration is in excess of the agricultural background[12] induced concentration in the groundwater (9.5mg/l in the Terrington Beds due to the over-application of fertiliser for the majority of a century) and is above EQS levels (*i.e*. 0.6mg/l as an Annual Average). However, the surrounding channels are effectively closed systems which are periodically dry due to management and therefore do not support an ecology of water dependent aquatic species, whilst under weather events, such as that which can induce a summer surface water run-off from the site, there are additional flow contributions from the surrounding field system and road connections which flow into the same drainage channels.

These contributions will dilute the applied ammonium further and will be derived from an area several times larger than the landfills, and given a slow release to the surface water system, there will be significant dilution by which time the ammoniacal-N contributions from the run-off will not be discernible within the wider off-site drainage channel network prior to mixing within the Main Drain, the only permanent water course, and therefore Controlled Water in the downstream vicinity of the site.

In all likelihood, however, the drainage water will be retained locally and used as an irrigant on surrounding fields. As noted previously, there is no potential for adverse effects from the metal, metalloids and organic content of the leachate and therefore the resultant solution can only act as an additional nutrient supply when applied to fields. All other substances will be below EQS levels.

Ammonium however is not persistent substance, and the potential introduction off-site is only a periodic and finite quantity; therefore in this location, ammoniacal-N concentrations will reduce by the following mechanisms:

1) immediate dilution within the receiving waters
2) the loss of ammonium bearing waters to the main drain
3) ammonium bearing waters being used for crop irrigation
4) ammonium being diluted by replenishment irrigation waters introduced from the Main Drain, upstream of the site
5) ammonium volatilisation from open channel waters

The latter mechanism will rapidly reduce dissolved ammonium concentrations, particularly when direct evaporation is occurring. However, it is also expected that water levels within the drains will

[12] Caulmert (2016) Middlemarsh Landfill Site. Hydrogeological Risk Assessment Review. Rep 2184.1.FCC.DRBS.SV.A3

be replenished for agricultural purposes and therefore ammonium will within a short distance from the site always be diluted.

This scenario must however by definition by a short-term individual event as rainfall events which are as high as 4mm, the threshold level for a surface release of irrigant occur on very few days per month and equates to the 83rd rainfall intensity frequency. Consequently, the duration of a slightly elevated ammonium concentration in the drainage channel immediately adjacent to the site is minimal and of an insufficient duration to cause harm.

It should also be noted that in periods where high duration and intensity rainfall was prolonged during summer, irrigation would not be required as a soil moisture deficit would not develop. Such weather events are readily predicted by weather forecasting and therefore for the days or week that such weather fronts are approaching irrigation can cease. Consequently, it is considered that although, such an occurrence could occur, the likelihood of such an occurrence is very low.

7 Summary and Conclusion

There is an increasing need to irrigate the surface of landfill sites, particularly in the drought affected zones in the East of England, such as at Middlemarsh landfill. As potable water is becoming an ever increasingly scarce resource, the site's landfill leachate is proposed to be used as an irrigant. This site is not grazed and has been restored to grassland.

The leachate is a stabilised leachate from an engineered containment landfill site, which has known chemical composition.

Under the majority of weather conditions, leachate can be applied at a steady rate, equivalent to up to 1mm/day application rates. This would equate to a seasonal maximum volume of 3,240m^3 over the 3.6ha infiltration and downslope area, or 900m^3 per hectare.

Under the majority of weather conditions, it is reasonable to expect that all irrigant will percolate into the soil, where the irrigation water component will be utilised by the surface vegetation to support growth, without inducing surface run-off. Irrigation rates of this magnitude are below that required to support optimal growth rates and are therefore a maintenance dosage to off-set the effects of evapotranspiration and loss of the vegetation cover.

There are threshold weather conditions whereby surface run-off could occur following high intensity or duration rainfall events. However, these events are specifically the conditions where irrigation is not required. Significantly, such weather events are always predictable, and irrigation can be temporarily stopped.

No surface run-off of a leachate bearing solution is therefore expected to occur.

Ammoniacal-N is the only potential substance of concern within the irrigant that could potentially be present under an extreme condition, and an outline scenario has been presented, whereby a small volume (~345m^3) of an effluent containing 8 – 16mg/l ammoniacal-N could be produced. However, it is expected that at least half of this volume and load would actually percolate into the restoration soil surface, whilst the remainder would be released at a slow rate into the surrounding surface water drainage system.

This drainage system is artificially managed and used for summer irrigation. However, the leachate contributions would only contribute a beneficial nutrient load to these waters when irrigated. There is therefore no potential for harm to controlled waters, or other water users from these proposals.

Notwithstanding the above, the scenario leading to a release of up to 200m^3 of an 8 – 16mg/l ammoniacal-N solution can be prevented from occurring using a proactive management system which prevents irrigation under such weather conditions.

Where surface run-off waters are retained for an extended time period within the site's surface water management lagoon before release, then this water can be used to supplement irrigation if available.

Given soil moisture deficit rates during summer periods, even under all weather conditions, there is not expected to be a summer release of any leachate constituents from the host soils. Metal and metalloid accumulation rates within even the topsoil layer are in the long term expected to be below discernible concentrations. Consequently, there can be no harm occurring to the restoration soils.

As a primary retention mechanism for conservative low attenuation substances is by evaporation of the holding waters, some chloride accumulation is expected to occur during summer periods. However, comparisons with Willow Based "forced evapotranspiration rates" at significantly higher loading rates have shown no indication of harm, and significantly no increase in chloride concentrations in winter run-off waters, the period when it is assumed that high solubility salts accumulated during warmer periods are released from the soils.

Low level constant irrigation of the site's leachate solution to overcome at least a part of the summer soil moisture deficit is therefore a low-risk activity, which has limited, if any, potential to cause harm. The irrigation will therefore be of benefit to the health of the vegetation surface by ensuring that minimum soil moisture contents are available to support growth.

The fact that the irrigant will also contain a nitrogen nutrient source is, however, an additional benefit to supporting growth.

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