Risk Assessment for Treated Soils

Wel – RA V2

Welbeck Waste Management Ltd

**Risk Assessment for Treated Soils**
**Welbeck Landfill**

**13 July 2022**



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Project Quality Assurance
Information Sheet

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| Prepared for | : | Welbeck Waste Management Ltd |
| Prepared by | : | Provectus Soils Management Limited<br>Wyvols Court<br>Swallowfield<br>Reading<br>Berkshire<br>RG7 1WY |

Compiled by        :

Projects Director

Reviewed by        :

Regional Manager

Authorised by      :

Managing Director

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# 1    INTRODUCTION

## 1.1    Background

Welbeck Waste Management have opened a soil treatment facility on a landfill on Boundary Lane, Normanton.  The treatment facility is operated by Provectus Soils Management under permit number EPR/WP3330BZ/V012.  The site has a significant need for soil for restoration use to enable the landfill to meet their obligations prior to the site closure.  The soil treatment facility was established to provide a source of suitable soils for use in the restoration areas at the site.  These restoration areas are highlighted on a drawing in Appendix A.

The Environment Agency has a historical permit request relating to undertaking a risk assessment to generate site specific targets for the restoration area and to meet their new restoration guidance document 'restore your landfill' Jan 2020.

This document provides a site specific risk assessment for the restoration soils above the upper landfill liner.  This risk assessment provides soil treatment targets for the treatment facility to ensure the long term protection of receptors at the site.

Section 2 provides a human health risk assessment for the restoration area.  Section 3 includes a controlled waters risk assessment.  The report is concluded in Section 4 with a summary of the proposed criteria for the restoration area at Welbeck landfill.

## 1.2    Site Specific Risk Assessments

The review of the information provided by FCC Environment/Welbeck Waste Management established that the following main receptors were present at the site:

- Future site users
- Site workers involved in the restoration of the landfill
- Grazing animals
- Vegetation (grassland, hedgerows, trees)
- Controlled waters receptors with the primary receptor being surface water at the periphery of the landfill

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## 2    HUMAN HEALTH RISK ASSESSMENT

### 2.1    Introduction

A human health risk assessment has been produced to enable a set of chemical criteria to be established for the restoration area.

### 2.2    Conceptual Site Model

The first step in undertaking a human health risk assessment is to produce a conceptual site model (CSM).   The CSM is a series of plausible source-pathway-receptor contaminant linkages determined in line with industry good practice.  This CSM is used, in this case, to determine a suitable set of quantitative acceptance criteria for the landfill restoration soils.  The focus of the CSM is the predominantly the operational capping area.  However, the previous areas of landfilling may also require additional restoration due to settlement of the restoration area being in excess of the expected amount at the pre-settlement filling stage of the landfill.  In addition, there are localised areas of the landfill where no waste will be deposited and so to meet the final contours, a more significant amount of filling with soil will be required.

#### 2.2.1    Potential sources of contamination

The assessment is focused on the criteria for treated soils from the soil treatment facility.   Therefore, the key potential source of contamination is the treated soils proposed for restoration use.

It is unlikely that treated soils will be used for the upper 300mm of the restoration profile as a growth medium.  It is anticipated that the topsoil will be sourced from a third party. The source of this topsoil may contain contaminants that require assessment.

#### 2.2.2    Potential Receptors

Based on the proposed final use of the landfill cap, the potential receptors of any contaminants that may be present in the soils are:

- Future site users
- Workers during the placing of the restoration cover and the planting of trees and hedgerows
- Surrounding residents
- Grazing animals
- Trees, hedgerows and grasses planted within the restored cap

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Controlled waters receptors (the aquifers and peripheral surface water) are assessed in Section 3.

No buildings are expected to be constructed on the site so below ground structures and utilities are discounted from this assessment.

### 2.2.3    Plausible Contaminant Linkages

Table 1 provides an evaluation of the potential contaminant linkages on the basis of the currently available restoration plan.   In general, the potential for significant exposure of the identified receptors is considered to be extremely low.

The site will be covered with grasses, some woodland and footpaths.  Disturbance of the soil is required to generate the airborne dusts or asbestos fibres with which receptors are subsequently exposed via inhalation and direct contact and these ground coverings will greatly restrict this from occurring.  Exposure to workers planting trees and hedgerows within the restoration soils would be greater because the soil will be dug through, but this would occur for a short duration only.  It is likely that the introduction of restoration soils will be carried out using machines and as such, their exposure would be greatly limited.

Inhalation of vapours generated from soils contaminated with volatile organic compounds (VOCs) is not expected as previously stated but would be restricted to outdoor exposure on the site for both human users and grazing animals because no buildings will be constructed.  Dilution in the atmosphere would reduce any such exposure to a minimum and this is not considered to be a plausible exposure pathway. Due to the distance of the nearest off-site residential properties, exposure through inhalation of vapours within buildings is not considered to be plausible.  In addition, the presence of a low permeability cap would minimise the migration of any vapours that were generated by any volatile contaminants within it.

The trees and hedgerows, along with the grasses planted on the restored cap have the potential to take up contaminants via their roots.  This could both affect the plants themselves as well as any grazing animals/livestock.

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**Table 1**: Assessment of Potential Contaminant Linkages

| Potential Contaminants in Soil | Potential Pathways | Potential Receptors | Discussion | Plausible Contaminant Linkage? |
|---|---|---|---|---|
| Free asbestos fibres | Inhalation of asbestos fibres | Future site users<br>Grazing animals | Very low frequency and duration of exposure expected. Exposure will be reduced by the presence of grass which will prevent the disturbance of the fibres and would be limited to near-surface soils.<br>Below the 300mm of topsoil, no exposure pathway. | ✓<br><br>✗ |
| | | Workers when placing restoration soils and planting trees and hedges | Placing of restoration soils will be a largely mechanical operation.<br>Exposure to workers when planting hedges would be more significant and to deeper depths, but for a short duration. | ✗<br><br>✓ |
| | | Off-site residents | Limited opportunity for soil to be disturbed. Distance to residential properties not expected to transport windblown fibres. | ✗ |
| All other contaminants | Dermal contact, ingestion and inhalation of soil particles.<br>Ingestion of contaminated vegetation. | Future site users<br>Grazing animals | Very low frequency and duration of exposure expected. Exposure will be reduced by the presence of grass which will prevent the disturbance of the soil particles and would be limited to near-surface soils.<br>Below the 300mm of topsoil, no exposure pathway. | ✓<br><br>✗ |
| | | Workers when placing restoration soils and planting trees and hedges | Placing of restoration soils will be a largely mechanical operation. | ✗<br><br>✓ |

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| Potential Contaminants in Soil | Potential Pathways | Potential Receptors | Discussion | Plausible Contaminant Linkage? |
|---|---|---|---|---|
|  |  |  | Exposure to workers when planting hedges would be more significant and to deeper depths, but for a short duration. |  |
|  | Inhalation of soil particles | Off-site residents | Limited opportunity for soil to be disturbed. Distance to residential properties not expected to transport windblown fibres. | ✖ |
|  | Uptake of contaminants | Vegetation | There is potential for plants to draw up contaminants through their roots. | ✓ |
| Volatile organic compounds | Outdoor inhalation of vapours | Future site users Workers when placing restoration soils and planting trees and hedges Grazing animals | Vapours emitted outdoors will be diluted in the atmosphere. | ✖ |
|  | Indoor and outdoor inhalation of vapours | Off-site residents | Vapours emitted outdoors will be diluted in the atmosphere. Migration of vapours through the cap will be limited by the presence of low permeability clays. | ✖  ✖ |

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## 2.3    Generation of Acceptance Criteria

### 2.3.1    Introduction

This Section provides justification for the selection of suitable soil acceptance criteria for each of the identified plausible contaminant linkages.

The following provides a discussion on relevant and available quantitative criteria, an evaluation of the exposure scenarios and assumptions for each of the sensitive receptors that have been identified, and a discussion on any differences between the top 300 mm of topsoil and the 700 mm of subsoil.

### 2.3.2    Guidance Documents

A number of guidance documents were used in the generation of criteria for the protection of the identified receptors.  These reference documents were as follows:

- Environment Agency Guidance: Sewage sludge in agriculture: code of practice for England, Wales and Northern Ireland. Published 23 May 2018.
- British Standards Institution (BSI) *Specification for topsoil* BS3883:2015.
- Contaminated Land: Applications in Real Environments (CL:AIRE) *'SP1010 - Development of Category 4 Screening Levels for Assessment of Land Affected by Contamination'* Final Project Report (Revision 2), 24 September 2014.
- The LQM/CIEH S4ULs for Human Health Risk Assessment, Nathaniel P et al, 2015. Copyright Land Quality Management Ltd, reproduced with permission: Publication Number S4UL3509
- HPA, Contaminated Land Information Sheet. Risk Assessment Approaches for Polycyclic Aromatic Hydrocarbons (PAHs). Public Health England, 2017.

### 2.3.3    Soil Contaminant Suite

In order to determine whether the treated soils achieve the non-hazardous waste threshold, Provectus analyses for the following suite:

- Metals (As, Cd, Cr, Cr[VI], Cu, Pb, Hg, Ni, Se, Zn)
- Speciated USEPA 16 polyaromatic hydrocarbons (PAH)
- Speciated petroleum hydrocarbons (TPH CWG method)
- Phenol
- Sulphate

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- Asbestos

This suite is considered reasonable to identify contaminants of concern that are commonly present in soils.

### 2.3.4    Receptors

The sensitive receptors considered in the derivation of acceptance criteria for the restoration topsoil are:

- Future site users
- Site workers involved in the restoration of the landfill
- Grazing animals
- Vegetation (grassland, hedgerows, trees)

A number of sources of possibly appropriate topsoil acceptance criteria were reviewed for these receptors and are discussed below.  Where a range of possible values were available for a potential contaminant, the lowest value was selected and is presented in Table 2.

The Environment Agency has published guidance on the application of sewage sludge on agricultural land[1] which includes a set of reference and maximum permissible concentrations (MPC) of potentially toxic elements (PTE) for both arable farming and grassland.  The PTEs are protective of the health of plants, animals and people.  In the absence of published quantitative criteria specific to protect grazing animals from contaminants in soil, these PTEs are considered to appropriate to use.

Where available, these PTEs are considered to be protective of all the receptors that were identified in the CSM.  Given that the restored site will be used as grazing land, it is most appropriate to use the PTE limits for grassland.  Some of the PTEs are dependent on the pH of the material which is to be applied to the land.  For the purpose of deriving acceptance criteria, it has been assumed that the pH of the restoration topsoil will be 6-7. Should the topsoil applied be more acidic than this, then lower acceptance criteria would be required.

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[1] Environment Agency Guidance: Sewage sludge in agriculture: code of practice for England, Wales and Northern Ireland. Published 23 May 2018.

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BS3883:2015[2] provides maximum acceptable concentrations for three potentially phytotoxic metals (copper, nickel and zinc) in topsoil. The concentrations are those of the arable PTEs and have therefore, been rejected as acceptance criteria in this instance in favour of the PTEs for grassland.

The PTEs are only available for metals and do not include any organic substances or asbestos. The acceptance criteria for asbestos has been set as 'not present'. For practical purposes, the commonly achieved laboratory detection limit of 0.001% by weight should be applied.

For organic substances, the risk-driving receptor is considered to be a child visiting the site for recreational purposes. In the absence of PTEs, the CLEA approach was adopted. LEAP reviewed the Category Four Screening Level (C4SL) Project Report[3] and determined that the most appropriate generic land use scenario was Public Open Space Park (POSpark), the key assumptions for this scenario being:

- The critical receptor is a female child who is exposed between the ages of 0 and 6.
- Exposure frequency is 85 days per year for ages 0 to 1 and 170 days per year for ages 1 to 6.
- Visits last for an average of 2 hours with light activity for 2/3 of that time and moderate activity for 1/3.
- Exposure pathways are direct soil ingestion, skin contact and inhalation of vapours and dusts outdoors.
- The land is predominantly grassed (75%) and not in close proximity to housing so tracking back of soil to the home is not a significant pathway.
- There are no buildings.

A number of assessment criteria have been derived for a POSpark land use by LQM. These values are known as Suitable for Use Levels (S4ULs)[4] and have been endorsed by the Chartered Institute of Environmental Health (CIEH). S4ULs are available for a range

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[2] British Standards Institution (BSI) *Specification for topsoil* BS3883:2015.

[3] Contaminated Land: Applications in Real Environments (CL:AIRE) '*SP1010 - Development of Category 4 Screening Levels for Assessment of Land Affected by Contamination*' Final Project Report (Revision 2), 24 September 2014.

[4] The LQM/CIEH S4ULs for Human Health Risk Assessment, Nathaniel P et al, 2015. Copyright Land Quality Management Ltd, reproduced with permission: Publication Number S4UL3509

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of soil organic matter (SOM) contents.  It is considered that a SOM of 6% would be most appropriate for topsoil given the organic nature of this material.   Theoretical soil saturations have not been considered in the evaluation of organic compounds.

S4ULs are available for PAHs that have been calculated using two approaches; the surrogate marker approach and the Toxic Equivalent Factor (TEF) approach.   Public Health England (PHE) guidance[5] indicates that the TEF approach is likely to underpredict the true carcinogenicity of genotoxic PAHs, so the surrogate marker approach has been selected to derive the acceptance criteria for this risk assessment.  Threshold PAHs have been assessed similarly, by using naphthalene as a marker compound due to its high volatility relative to other PAHs.

A S4UL has not been produced for lead so the C4SL was used as the acceptance criteria, noting that exposure assumptions are largely equivalent between the two sets of values.  Workers involved in the restoration works including placing of cover soils and planting of vegetation have the potential to be exposed to contaminants in the topsoil.  However, exposure would be short in duration.  Most human health risk assessment criteria focus on chronic risks arising from long term exposure which usually occur at lower doses than short term acute risks.  Therefore, the acceptance criteria which are presented in Table 2 are considered likely to be protective of restoration workers.

**Table 2**: Acceptance Criteria for Restoration Topsoil (avg. pH 6-7, SOM 6%)

| Contaminant | Value | Units | Source |
|---|---|---|---|
| **INORGANICS** | | | |
| Arsenic | 50 | mgkg$^{-1}$ | Sludge on Grassland |
| Cadmium | 3 | mgkg$^{-1}$ | Sludge on Grassland |
| Chromium | 600 | mgkg$^{-1}$ | Sludge on Grassland |
| Hexavalent Chromium | 250 | mgkg$^{-1}$ | POSpark |
| Copper | 225 | mgkg$^{-1}$ | Sludge on Grassland |
| Lead | 300 | mgkg$^{-1}$ | Sludge on Grassland |
| Mercury[1] | 1.5 | mgkg$^{-1}$ | Sludge on Grassland |
| Nickel | 125 | mgkg$^{-1}$ | Sludge on Grassland |
| Selenium | 5 | mgkg$^{-1}$ | Sludge on Grassland |
| Zinc | 200 | mgkg$^{-1}$ | Sludge on Grassland |
| Asbestos | Not present (<0.001%) | % | Reasonably achievable detection limit |
| **PETROLEUM HYDROCARBONS** | | | |
| Aliphatic EC5-6 | 180,000 | mgkg$^{-1}$ | POSpark |
| Aliphatic EC6-8 | 320,000 | mgkg$^{-1}$ | POSpark |

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[5] HPA, Contaminated Land Information Sheet. Risk Assessment Approaches for Polycyclic Aromatic Hydrocarbons (PAHs). Public Health England, 2017.

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| Contaminant | Value | Units | Source |
|---|---|---|---|
| Aliphatic EC8-10 | 21,000 | mgkg$^{-1}$ | POSpark |
| Aliphatic EC10-12 | 24,000 | mgkg$^{-1}$ | POSpark |
| Aliphatic EC12-16 | 26,000 | mgkg$^{-1}$ | POSpark |
| Aliphatic EC16-35 | 490,000 | mgkg$^{-1}$ | POSpark |
| Aromatic EC5-7 | 92,000 | mgkg$^{-1}$ | POSpark |
| Aromatic EC7-8 | 100,000 | mgkg$^{-1}$ | POSpark |
| Aromatic EC8-10 | 9,300 | mgkg$^{-1}$ | POSpark |
| Aromatic EC10-12 | 10,000 | mgkg$^{-1}$ | POSpark |
| Aromatic EC12-16 | 10,000 | mgkg$^{-1}$ | POSpark |
| Aromatic EC16-21 | 7,800 | mgkg$^{-1}$ | POSpark |
| Aromatic EC21-35 | 7,900 | mgkg$^{-1}$ | POSpark |
| **OTHER ORGANICS** | | | |
| Phenol | 1,300 | mgkg$^{-1}$ | POSpark |
| Benzo(a)pyrene[2] | 21 | mgkg$^{-1}$ | POSpark |
| Naphthalene[3] | 3,000 | mgkg$^{-1}$ | POSpark |

Notes to table
- *As inorganic mercury.*
- *Surrogate marker for all genotoxic PAHs.*
- *Indicator compound for all non-genotoxic PAHs.*

It needs to be noted however, that the restoration area is on a non-hazardous landfill site and as such the soil must be classified as a non-hazardous soil under waste guidance. This means that hydrocarbons within the restoration area will be limited to 0.1% or other criteria as substantiated by EA guidance document WM3 (guidance on the classification and assessment of waste, Ver 1.2GB, October 2021).

## 2.4    Topsoil and Subsoil Criteria

### 2.4.1    Topsoil Criteria

The following table provides criteria for the upper 300mm (topsoil) layer on the restoration area to enable the protection of the identified receptors.  These criteria do not take into account the permit requirements or controlled waters assessment and are not final criteria for the upper 300mm of restoration area.

**Table 3**. Upper 300mm risk based criteria

| Contaminant | Value | Units | Source |
|---|---|---|---|
| INORGANICS | | | |
| Arsenic | 50 | mgkg$^{-1}$ | Sludge on Grassland |
| Cadmium | 3 | mgkg$^{-1}$ | Sludge on Grassland |
| Chromium | 600 | mgkg$^{-1}$ | Sludge on Grassland |
| Hexavalent Chromium | 250 | mgkg$^{-1}$ | POSpark |
| Copper | 225 | mgkg$^{-1}$ | Sludge on Grassland |
| Lead | 300 | mgkg$^{-1}$ | Sludge on Grassland |
| Mercury[1] | 1.5 | mgkg$^{-1}$ | Sludge on Grassland |
| Nickel | 125 | mgkg$^{-1}$ | Sludge on Grassland |
| Selenium | 5 | mgkg$^{-1}$ | Sludge on Grassland |
| Zinc | 200 | mgkg$^{-1}$ | Sludge on Grassland |
| Asbestos | Not present (<0.001%) | % | Reasonably achievable detection limit |
| PETROLEUM HYDROCARBONS | | | |
| Aliphatic EC5-6 | 180,000[4] | mgkg$^{-1}$ | POSpark |
| Aliphatic EC6-8 | 320,000[4] | mgkg$^{-1}$ | POSpark |
| Aliphatic EC8-10 | 21,000[4] | mgkg$^{-1}$ | POSpark |
| Aliphatic EC10-12 | 24,000[4] | mgkg$^{-1}$ | POSpark |
| Aliphatic EC12-16 | 26,000[4] | mgkg$^{-1}$ | POSpark |
| Aliphatic EC16-35 | 490,000[4] | mgkg$^{-1}$ | POSpark |
| Aromatic EC5-7 | 92,000[4] | mgkg$^{-1}$ | POSpark |
| Aromatic EC7-8 | 100,000[4] | mgkg$^{-1}$ | POSpark |
| Aromatic EC8-10 | 9,300[4] | mgkg$^{-1}$ | POSpark |
| Aromatic EC10-12 | 10,000[4] | mgkg$^{-1}$ | POSpark |
| Aromatic EC12-16 | 10,000[4] | mgkg$^{-1}$ | POSpark |
| Aromatic EC16-21 | 7,800[4] | mgkg$^{-1}$ | POSpark |
| Aromatic EC21-35 | 7,900[4] | mgkg$^{-1}$ | POSpark |
| OTHER ORGANICS | | | |
| Phenol | 1,300[4] | mgkg$^{-1}$ | POSpark |
| Benzo(a)pyrene[2] | 21 | mgkg$^{-1}$ | POSpark |
| Naphthalene[3] | 3,000[4] | mgkg$^{-1}$ | POSpark |

Notes to table

1.  As inorganic mercury.
2.  Surrogate marker for all genotoxic PAHs.
3.  Indicator compound for all non-genotoxic PAHs.
4.  Exceeds WM3 thresholds for hazardous waste – final criteria presented later in Table 3

### 2.4.2 Subsoil Criteria

The subsoil will be placed below 300 mm of topsoil and will extend to a minimum of 1m below final ground level.

All the plausible contaminant linkages that have been identified are via direct exposure with contaminants of potential concern and as such, it is considered highly unlikely that future site users or grazing animals will be exposed to contaminants within the restoration subsoil which will placed below 300 mm of topsoil.

The roots of grasses and hedgerows are unlikely to extend below the top 300 mm of

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topsoil and would therefore, also not be exposed to any contaminants present within the restoration subsoil.

It is possible that the roots of trees could extend into the subsoil and take up contaminants through their root system.  There is also potential that, during the excavation of tree pits and the planting of trees, workers could be exposed to contaminants within the subsoil at these locations.  As such, the acceptance criteria for tree pits should be the same as the topsoil criteria provided in Table 1.

Notwithstanding the acceptance criteria that have been derived, because the site is a licensed waste facility, as a minimum the topsoil and subsoil restoration cover must not contain substances that would render the material as hazardous waste.

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# 3   CONTROLLED WATERS RISK ASSESSMENT

The complete controlled waters risk assessment is included in Appendix B and was completed by Sladen Associates Ltd.  A summary of their findings is presented in this section.

This section provides a summary of the derivation of leachate targets with respect to protection of controlled waters for restoration soils to be used as part of the final cover system at Welbeck Landfill.

## 3.1   Conceptual Model and Pollutant Linkages

The capping will be covered by a minimum thickness of 0.7m of restoration soils.

The construction would be as follows:

- A basal regulating layer of suitable material of 300 mm thickness.
- The cap sealing layer, which will comprise a Geosynthetic Clay Liner.
- A Sub Soil Layer of 500 mm of Colliery Spoil.
- 700 mm thickness of restoration soils (Topsoil Layer) will be placed over the Sub Soil Layer to achieve a total minimum thickness above the sealing layer of 1.2 m.

A proportion of infiltration will pass through the landfill sealing layer will contribute to leachate within the landfill waste and will be subsequently controlled by the leachate collection system.  As such its fate does not need further detailed consideration in the present study as the impact of leachate is addressed in the various hydrogeological risk assessments.  However, the model is conservative in that it assumes that this component of the water balance is zero; such that all net infiltration to the restoration results in discharge from the restoration soils to the drainage system.

Direct discharge to groundwater from the cap would be expected to be intercepted by a surface drainage system, and it is not considered credible that any discharge to groundwater pathway would be more critical than direct discharge to surface water. Accordingly, with regard to any potential dissolved contaminants within the water emanating from the restoration soils, it is considered that, for the present site, more detailed assessment is only warranted with respect to the surface water receptor via direct discharge from the drainage system.

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### 3.2 Compliance Criteria

As the critical receptor is considered to be the surface water system, the relevant compliance criteria will be assumed to be Annual Average Environmental Quality Standards (EQS) levels where these have been published. Where no EQS is available EQS values for similar compounds have been selected.

Where new EQS values have been proposed in the document 'The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2015, these have been adopted. Otherwise, former EQS values for surface water have been adopted.

For TPH fractions, where no EQS is available, the former drinking water standard for oils and hydrocarbons (0.01 mg/l) has been adopted. There is reason to consider however, that for some THP fractions, the adopted compliance criterion is likely to be conservative with respect to protection of controlled waters, where the critical receptor is either a surface water feature or potential drinking water. The Massachusetts Department of Environmental Protection (MADEP) has published risk-based criteria that are protective of aquatic receptors (BATELLE,2007), see also SOBRA 2012. The approach involved estimating the acute and chronic toxicity of hydrocarbon fractions to aquatic organisms based on equilibrium partitioning theory.

With regard to human toxicity, the World Health Organisation (2005) has developed guidelines for drinking water standards. CL:AIRE 2017, essentially advocated use of the WHO Drinking Water Standards for controlled waters risk assessments. In the light of the above, absence of current regulatory guidance in the UK and as dilution in the receiving stream is being ignored, the former DWS (0.01 mg/l) was adopted as a relevant compliance criterion for each of the TPHCWG groupings where the expected solubility exceeds that value. Where solubility is less than 0.01 mg/l it is assumed that the fraction can pose no significant risk to controlled waters.

Details of the chemical characteristics of proposed restoration soils are not available but, based on experience from similar operations, target values will be required for a fairly wide range of potential contaminants and the following compliance criteria and solubility have been adopted (all in mg/l). The adopted organic carbon partition coefficient is also listed.

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**Table 4.** Receptor Compliance Criteria

| Substance | Compliance Criterion | Comment | Water solubility | Koc | |
|---|---|---|---|---|---|
| | mg L$^{-1}$ | | mg L$^{-1}$ | Log (cm$^3$ g$^{-1}$) | Reference |
| Benzene | 1.00E-02 | | 1.78E+03 | 1.83E+00 | SR7 |
| Toluene | 7.40E-02 | | 5.90E+02 | 2.31E+00 | SR7 |
| Ethylbenzene | 2.00E-02 | | 1.80E+02 | 2.65E+00 | SR7 |
| m-Xylene | 3.00E-02 | | 2.00E+02 | 2.69E+00 | SR7 |
| o-Xylene | 3.00E-02 | | 1.73E+02 | 2.63E+00 | SR7 |
| p-Xylene | 3.00E-02 | | 2.00E+02 | 2.65E+00 | SR7 |
| Naphthalene | 2.40E-03 | | 1.90E+01 | 2.81E+00 | SR7 |
| Benzo[a]pyrene | 1.70E-07 | | 3.80E-03 | 5.11E+00 | SR7 |
| Phenol | 7.70E-03 | | 8.41E+04 | 1.46E+00 | SR7/LQM |
| TPH Aliphatic C5-C6 | 1.00E-02 | Former DWS | 3.60E+01 | 2.90E+00 | LQM |
| TPH Aliphatic C6-C8 | 1.00E-02 | Former DWS | 5.40E+00 | 3.60E+00 | LQM |
| TPH Aliphatic C8-C10 | 1.00E-02 | Former DWS | 4.30E-01 | 4.50E+00 | LQM |
| TPH Aliphatic C10-C12 | 1.00E-02 | Former DWS | 3.40E-02 | 5.40E+00 | LQM |
| TPH Aliphatic C12-C16 | 1.00E-02 | Former DWS | 7.60E-04 | 6.70E+00 | LQM |
| TPH Aliphatic C16-C21 | 1.00E-02 | Former DWS | 2.50E-06 | 8.80E+00 | LQM |
| TPH Aliphatic C21-C34 | 1.00E-02 | Former DWS | 2.50E-06 | 8.80E+00 | LQM |
| TPH Aliphatic C35-C44 | 1.00E-02 | Former DWS | 2.50E-06 | 8.80E+00 | LQM |
| TPH Aromatic C8-C10 | 1.00E-02 | Former DWS | 6.50E+01 | 3.20E+00 | LQM |
| TPH Aromatic C10-C12 | 1.00E-02 | Former DWS | 2.50E+01 | 3.40E+00 | LQM |
| TPH Aromatic C12-C16 | 1.00E-02 | Former DWS | 5.80E+00 | 3.70E+00 | LQM |
| TPH Aromatic C16-C21 | 1.00E-02 | Former DWS | 6.50E-01 | 4.20E+00 | LQM |
| TPH Aromatic C21-C35 | 1.00E-02 | Former DWS | 6.60E-03 | 5.10E+00 | LQM |
| TPH Aromatic C35-C44 | 1.00E-02 | Former DWS | 6.60E-03 | 5.10E+00 | LQM |
| TPH Aromatic C44-C70 | 1.00E-02 | Former DWS | 1.00E-04 | 5.70E+00 | LQM |
| Arsenic | 5.00E-02 | | | | |
| Cadmium | 2.50E-04 | | | | |
| Copper | 2.80E-02 | | | | |
| Chromium | 2.00E-02 | | | | |
| Lead | 7.20E-03 | | | | |
| Mercury | 5.00E-05 | | | | |
| Nickel | 2.00E-02 | | | | |
| Zinc | 3.40E-02 | | | | |
| Water Soluble Boron | 2.00E+00 | | | | |
| Sulphate | 4.00E+02 | | | | |
| Nitrate | 11.3 | | | | |
| Ammonium as NH4 | 0.77 | | 8.99E+05 | Kd = 1 cm$^3$ g$^{-1}$ | Buss et al |

For simplicity, where the relevant current standard for some metals is expressed as bioavailable but no data are available, former EQS levels will be adopted

For the pathway associated with discharge of perimeter drain water to the surface water system, no dilution within the surface water following discharge will be considered, which is conservative. Compliance criteria will be assumed to apply to drain water prior to discharge.

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### 3.3    Contaminant Transport Modelling

Numerical modelling undertaken as part of the present study has made use of the SEEP/W program developed by Geo-Slope International Ltd.  This was chosen as it allows rapid parametric studies to be undertaken and the implications of various assumptions to be graphically displayed.  The program has been specifically formulated to allow accurate simulation of unsaturated as well as saturated flow systems.  The program is based on the well-established finite element method for continuum analysis.  Although similar analysis may be undertaken using finite difference based methods, the finite element approach offers some advantages; in particular the method is less sensitive to such factors as node spacing as conditions are not assumed to be linear within elements.  In this process the study geometry is divided into a number of elements.  Potential patterns of contaminant transport may be mapped on the results of the SEEP/W analysis with the use of a companion program CTRAN/W.

### 3.4    Derived Soil Criteria

The criteria for the protection of controlled waters are based upon soil leachate quality rather than dry weight analysis of contaminants.  The criteria derived from the modelling are values for an annual average over the restoration area rather than specific criteria for all soils.

The following suite of contaminants are generally present in soils that are treated at the Welbeck site and have had leachate criteria derived for the protection of controlled waters:

- BTEX
- Naphthalene
- Benzo[a]pyrene
- Phenol
- Speciated TPH
- Arsenic
- Cadmium
- Copper
- Chromium
- Lead
- Mercury
- Nickel
- Zinc
- Water Soluble Boron

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- Sulphate

In addition, a limited number of soil batches may contain inclusions from materials with the following waste codes:

- 19 02 05* sludges from physico/chemical treatment containing hazardous substances
- 20 03 03 street-cleaning residues

For batches of soil containing the above waste codes then we would include the assessment of leachable ammonium and nitrate.  The reason for this is that the above three waste codes may contain organic matter that could result in the generation of ammonium and nitrate in soil leachate.

The derived soil leachate criteria are included in Table 5.  These criteria are an annual average for soil leachate quality.

**Table 5.** Derived Soil Leachate Criteria

| Substance | Compliance Criterion (mg/l) | Derived Leachate Targets (mg/l) | | | |
|---|---|---|---|---|---|
| | | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
| Benzene | 0.01 | 0.018 | 0.046 | 0.31 | 4.4 |
| Toluene | 0.074 | 0.62 | 22 | No Restriction | No Restriction |
| Ethylbenzene | 0.02 | 0.98 | No Restriction | No Restriction | No Restriction |
| m-Xylene | 0.03 | 1.9 | No Restriction | No Restriction | No Restriction |
| o-Xylene | 0.03 | 1.3 | No Restriction | No Restriction | No Restriction |
| p-Xylene | 0.03 | 1.5 | No Restriction | No Restriction | No Restriction |
| Naphthalene | 0.0024 | 0.1 | No Restriction | No Restriction | No Restriction |
| Benzo[a]pyrene | 0.00000017 | No Restriction | No Restriction | No Restriction | No Restriction |
| Phenol | 0.0077 | 0.021 | 0.11 | 2.2 | 150 |
| TPH Aliphatic C5-C6 | 0.01 | 0.49 | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C6-C8 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C8-C10 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C10-C12 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C12-C16 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C16-C21 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C21-C34 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C35-C44 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C8-C10 | 0.01 | 0.46 | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C10-C12 | 0.01 | 0.14 | 12 | No Restriction | No Restriction |
| TPH Aromatic C12-C16 | 0.01 | 0.34 | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C16-C21 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C21-C35 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C35-C44 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C44-C70 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| Arsenic | 0.05 | 0.068 | 0.079 | 0.11 | 0.17 |
| Cadmium | 0.00025 | 0.00027 | 0.00031 | 0.00043 | 0.00067 |
| Copper | 0.028 | 0.038 | 0.044 | 0.06 | 0.094 |
| Chromium | 0.02 | 0.027 | 0.031 | 0.043 | 0.067 |
| Lead | 0.0072 | 0.0098 | 0.011 | 0.015 | 0.024 |
| Mercury | 0.00005 | 0.000054 | 0.000063 | 0.000085 | 0.00013 |
| Nickel | 0.02 | 0.027 | 0.031 | 0.043 | 0.067 |
| Zinc | 0.13 | 0.17 | 0.2 | 0.27 | 0.42 |
| Water Soluble Boron | 2 | 2.7 | 3.1 | 4.3 | 6.7 |
| Sulphate | 400 | 540 | 630 | 850 | 1,300 |
| Nitrate** | 11 | 15 | 18 | 24 | 38 |
| Ammonium** | 0.77 | 2.3 | 4.8 | 17 | 86 |

* Note: Zone 1 Target set at Compliance Criterion (EQS)

** for batches with 19 02 05, 19 02 06 and 20 03 03 waste inclusions

Although there are a number of assumptions inherent in the present analysis, in so far as possible these have been chosen to be consistent with design assumptions for the overall site.

The sensitivity analysis of the parameters used in the modelling has been focused on incorporating a significant number of conservative assumptions into the analysis to

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provide reassurance to the site owner and local regulators, in particular:

- Apart from for ammonium, the source of potential leachate within the restoration soils has been assumed to be constant with time. This is considered to be particularly conservative for potentially more soluble mobile contaminants.
- Evaporation to the atmosphere has been ignored due to the effect of the soil treatment and residual volatiles being below detect levels, however, this is likely be significant for volatile, relatively mobile, organic compounds.
- The potential leakage to the waste mass has been assumed to be zero.
- Degradation half-lives have been assumed to much higher than would likely be observed in aerobic near surface soil conditions.
- The hydraulic conductivity of the restoration soils has been assumed to be significantly higher than would be anticipated.
- The organic matter content of the restoration soils has been assumed to be relatively low.
- A proposed minimum thickness of restoration soils has been adopted as the base case.

Analysis has been undertaken to illustrate the sensitivity of the analysis to seasonal variance in infiltration, variation in cover thickness and variation in restoration soil saturated hydraulic conductivity.  In view of the significantly conservative assumptions outlined above, more detailed analysis of sensitivity it is not considered warranted.

### 3.5   Summary

The restoration system will comprise a cap sealing layer which will in turn be overlain by the restoration soils. The restoration soils will have a minimum overall 0.7m thickness above the barrier layer. However, depending on such factors as the magnitude of post construction settlements, the overall thickness of the restoration soils is likely to be significantly greater in some areas.

Levels of top-up will depend on settlement experienced over the coming years.  This will need to be addressed separately as necessary; the intention will be to place the required soil depth initially.

The restoration system will be entirely above the site groundwater level and analysis suggests that it will remain unsaturated during average conditions if the saturated

conductivity of the restoration soils is relatively high. For lower conductivities saturated conditions may develop, particularly in winter months, which would tend to increase run-off and reduce infiltration and hence reduce potential leaching. Any infiltration into the restoration soils that permeates through the barrier will contribute to leachate within the waste mass and be treated accordingly. It is expected, however, that this will be a small component of the overall water balance and that most of the infiltration will travel laterally within the restoration system and discharge to a surface water drain.

Analysis has been undertaken to derive defensible leachate targets for the treated soils that will be protective to surface water. For some potential contaminants there is the potential for significant attenuation within the restoration system prior to discharge.

Numerical modelling of the flow system in the restoration soils has been undertaken to quantify potential levels of attenuation. Based on the site conceptual model, for the present site, the discharge to groundwater pathway is considered to be less critical than the discharge to perimeter drain and thence to surface water pathway.

For site management, the cover area has been divided into five zones representing different distances from the surface water drainage system.

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# 4    PROPOSED SOIL TREATMENT TARGETS

## 4.1    Introduction

The completion of the risk assessment for the restoration area has led to a number of criteria to be proposed.  Some of these criteria are contaminant limits based upon dry weight analysis, some are soil leachate targets.

The final criteria will also need to be limited to the landfill requirements and its status as a permitted non-hazardous waste disposal site.

This section provides the following for the restoration area:

- types of waste
- waste acceptance criteria and procedures

## 4.2    Types of Waste

The treated materials from the soil treatment facility will be treated to meet the risk based targets for the restoration area.  The waste code for the treated materials will be as follows:

- 19 13 02 - Solid wastes from soil remediation other than those mentioned in 19 13 01

Apart from meeting the risk based contaminant targets, the output from the soil treatment facility will be non-hazardous waste, with no odours, nor visual impact from contamination.

## 4.3    Proposed Criteria for Restoration Area

The proposed chemical criteria for the landfill restoration area in Table 6 will ensure the following:

- Prevent harm caused by direct contact or inhalation of contaminants in treated soil
- Prevent detrimental impact to controlled waters receptors
- Ensure all soils are suitable for use on a permitted non-hazardous landfill

In addition to the chemical criteria, the following aesthetic criteria are also proposed:

- No soils with residual odours or visual impact from hydrocarbons to be used in the restoration area

The validation procedures that have been utilised to date, with separate reports for each batch of treated soils sent to the FCC compliance team will continue unchanged.  The leachate quality results will be compiled as an average over an annual basis to ensure compliance with the requirements of the controlled waters assessment.

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**Table 6.** Restoration Soil Criteria

| Substance | Soil Contaminants (mg/kg) | | Derived Leachate Targets (mg/l)[3] | | | |
|---|---|---|---|---|---|---|
| | Upper 300mm | Below 300mm | Zone 2[2] | Zone 3[2] | Zone 4[2] | Zone 5[2] |
| Benzene | NH | NH | 0.018 | 0.046 | 0.31 | 4.4 |
| Toluene | NH | NH | 0.62 | 22 | - | - |
| Ethylbenzene | NH | NH | 0.98 | - | - | - |
| m-Xylene | NH | NH | 1.9 | - | - | - |
| o-Xylene | NH | NH | 1.3 | - | - | - |
| p-Xylene | NH | NH | 1.5 | - | - | - |
| Naphthalene | NH | NH | 0.1 | - | - | - |
| Benzo[a]pyrene | 21 | NH | - | - | - | - |
| Phenol | NH | NH | 0.021 | 0.11 | 2.2 | 150 |
| TPH Aliphatic C5-C6 | NH | NH | 0.49 | - | - | - |
| TPH Aliphatic C6-C8 | NH | NH | - | - | - | - |
| TPH Aliphatic C8-C10 | NH | NH | - | - | - | - |
| TPH Aliphatic C10-C12 | NH | NH | - | - | - | - |
| TPH Aliphatic C12-C16 | NH | NH | - | - | - | - |
| TPH Aliphatic C16-C21 | NH | NH | - | - | - | - |
| TPH Aliphatic C21-C34 | NH | NH | - | - | - | - |
| TPH Aliphatic C35-C44 | NH | NH | - | - | - | - |
| TPH Aromatic C8-C10 | NH | NH | 0.46 | - | - | - |
| TPH Aromatic C10-C12 | NH | NH | 0.14 | 12 | - | - |
| TPH Aromatic C12-C16 | NH | NH | 0.34 | - | - | - |
| TPH Aromatic C16-C21 | NH | NH | - | - | - | - |
| TPH Aromatic C21-C35 | NH | NH | - | - | - | - |
| TPH Aromatic C35-C44 | NH | NH | - | - | - | - |
| TPH Aromatic C44-C70 | NH | NH | - | - | - | - |
| Arsenic | 50 | NH | 0.068 | 0.079 | 0.11 | 0.17 |
| Cadmium | 3 | NH | 0.00027 | 0.00031 | 0.00043 | 0.00067 |
| Copper | 225 | NH | 0.038 | 0.044 | 0.06 | 0.094 |
| Chromium | 600 | NH | 0.027 | 0.031 | 0.043 | 0.067 |
| Hexavalent Chromium | 250 | NH | - | - | - | - |
| Lead | 300 | NH | 0.0098 | 0.011 | 0.015 | 0.024 |
| Mercury | 1.5 | NH | 0.000054 | 0.000063 | 0.000085 | 0.00013 |
| Nickel | 125 | NH | 0.027 | 0.031 | 0.043 | 0.067 |
| Selenium | 5 | NH | - | - | - | - |
| Zinc | 200 | NH | 0.17 | 0.2 | 0.27 | 0.42 |
| Water Soluble Boron | NH | NH | 2.7 | 3.1 | 4.3 | 6.7 |
| Asbestos Fibres | <0.001% | <0.1% | - | - | - | - |
| Sulphate | NH | NH | 540 | 630 | 850 | 1,300 |
| Nitrate[1] | NH | NH | 15 | 18 | 24 | 38 |
| Ammonium[1] | NH | NH | 2.3 | 4.8 | 17 | 86 |

Notes

-: No criteria
NH: Non Hazardous
[1] for batches with 19 02 05 and 20 03 03 wastes only
[2] where the soil leachate target is below the laboratory detection limit, the detection limit will be deemed the target for restoration
[3] Zone 1 will be as per EQS levels to as per Table 5

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APPENDIX A. RESTORATION AREAS

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**NOTES**

1. ALL DIMENSIONS IN MILLIMETRES AND ALL LEVELS IN METRES ABOVE ORDNANCE DATUM.

2. DO NOT SCALE FROM THIS DRAWING.

3. ANY ANOMALIES IDENTIFIED WITH THE DETAILS SHOWN ON THIS DRAWING ARE TO BE BROUGHT TO THE ATTENTION OF SIRIUS ENVIRONMENTAL PRIOR TO CONSTRUCTION WORKS COMMENCING.

**KEY**

- LATEST AVAILABLE GROUND CONTOURS
- PROPOSED POST SETTLEMENT CONTOURS
- SITE BOUNDARY
- EXISTING SURFACE WATER DITCH
- PROPOSED SURFACE WATER DITCH
- PROPOSED SURFACE WATER DISCHARGE LOCATION
- EXISTING SURFACE WATER DISCHARGE LOCATION
- EXISTING SURFACE WATER MONITORING LOCATION
- EXISTING SURFACE WATER BODY OR SURFACE WATER COLLECTION AREA
- CATCHMENT A
- CATCHMENT B
- CATCHMENT C
- CATCHMENT D
- EXISTING SITE ACCESS TRACKS
- BIO-RETENTION AREA
- EXISTING/PROPOSED PIPE CROSSING

WEST POND EXISTING LAGOON

NORTH POND EXISTING LAGOON

RIVER CALDER

CATCHMENT A: 5.56 Ha
CATCHMENT B: 13.02Ha
CATCHMENT C: 3.61 Ha
CATCHMENT D: 13.18 Ha
CATCHMENT E: 5.8 Ha
CATCHMENT F: 1.6 Ha
CATCHMENT G: 4.6 H
CATCHMENT H: 2.9 Ha
CATCHMENT I: 15.9 Ha
CATCHMENT J: 7.5 Ha

DITCH PIPED UNDER ACCESS TRACK
DITCH AT TOE OF CAPPED AREA
DITCH RUNNING ALONG THE NORTHERN SIDE OF THE EXISTING ACCESS TRACK
LAGOON/SWALE FEATURE IN NATURAL LOW POINT FOR CATCHMENT C
HEADWALL AND PIPE CROSSING TO REPLACE THE EXISTING
BUND CONSTRUCTED WITH A CREST LEVEL OF 24.2mAOD TO ENABLE ENCLOSURE OF SMALL LAGOON/SWALE FEATURE FOR CATCHMENT C
NEW OUTLET
DITCH CONSTRUCTED INCORPORATING EROSION MATTING
DITCH PIPED UNDER ACCESS TRACK.
BRICK DECANTING TOWER DISCHARGING TO THE RIVER CALDER.
DISCHARGE POINT FOR CATCHMENT B. WORKS REQUIRED TO DECANT TOWER. DETAILED DESIGN WORKS CAN ONLY BE UNDERTAKEN AFTER AN OPERATION TO CLEAN OUT AND INVESTIGATE THE EXISTING STRUCTURE
EXISTING OUTFALL TO RIVER CALDER TO BE USED AND RE-NAMED AS AN ADDITIONAL OFFICIAL OUTFALL POINT FOR THE SITE AND CATCHMENT B
BUND CONSTRUCTED WITH A CREST LEVEL OF 20.3mAOD TO ENABLE ENCLOSURE OF THE DECANTING TOWER AREA AND CREATION OF THE REQUIRED ATTENUATION CAPACITY FOR CATCHMENT B
CLEANING REQUIRED ALONG WITH SURVEY OF THE CONDITION OF THE EXISTING TWIN 160mm DIAMETER PIPEWORK.
CLEANING REQUIRED ALONG WITH SURVEY OF THE CONDITION OF THE EXISTING 300mm PIPEWORK.
PIPE CROSSING
BIO RETENTION AREA RETAINED
IMPROVEMENT OF THIS EXISTING DITCH INCLUDING THE ADDITION OF EROSION MATTING
LAGOON/SWALE FEATURE IN NATURAL LOW POINT FOR CATCHMENT A
BUND CONSTRUCTED WITH A CREST LEVEL OF 27mAOD TO ENABLE ENCLOSURE OF SMALL LAGOON/SWALE FEATURE FOR CATCHMENT A
HEADWALL AND PIPE CROSSING
DITCH FITTED IN TO THE EAST OF THE SCREENING BUND. EDGE OF BUND MAY HAVE TO BE EXCAVATED IN SOME LOCATIONS AND EXISTING GAS PIPEWORK MAY REQUIRE SOME ADJUSTMENT
UNDERLINER DRAINAGE MANHOLE TO BE SEALED AND DEPRESSION FILLED IN
DITCH FALLS TO EXISTING DRAIN OUTLET
ACCESS BRIDGE
SITE COMPOUND AREA

OUTLET 1
OUTLET 2

SW1, SW2, SW3, SW7, SW8, SW14

CROSSING

| | | | | |
|---|---|---|---|---|
| 1 | MINOR AMENDMENTS | | 11.03.22 | MCC |
| REV | DESCRIPTION | | DATE | BY |

**CLIENT**

FCC Environment
FCC Environment (UK) Limited
Ground Floor West, 900 Pavilion Drive, Northampton Business Park, Northampton, NN4 7RG

Sirius Planning
4245 Park Approach, Thorpe Park, Leeds. LS15 8GB. 0113 264 9960

**JOB TITLE**

WELBECK LFS

**DRAWING TITLE**

Proposed Scheme of Surface Water Drainage

| DRAWN | DATE | APPROVED | DATE |
|---|---|---|---|
| M.C | 19/03/2018 | J.C | 19/03/2018 |

| SCALE | SHEET | DRAWING NUMBER | REVISION |
|---|---|---|---|
| 1:2500 | A1L | WR7346/21/11 | 1 |

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**KEY**

— 100 — LATEST AVAILABLE GROUND CONTOURS

—— ENVIRONMENT PERMIT BOUNDARY

— 105 — PROPOSED RESTORATION CONTOURS

- - - - RESTORATION PHASE BOUNDARIES

—— LIMIT OF NON HAZARDOUS WASTE

FUTURE RESTORATION AREAS BY WASTE RECOVERY

PHASE 1
PHASE 2
PHASE 3
PHASE 4
PHASE 5

RIVER CALDER

| REV | DESCRIPTION | DATE | BY |
|-----|-------------|------|-----|
| | | | |

**CLIENT**

FCC Environment

FCC Environment (UK) Limited
Ground Floor West, 900 Pavilion Drive, Northampton Business Park, Northampton, NN4 7RG

Sirius Environmental

4245 Park Approach, Thorpe Park, Leeds. LS15 8GB. 0113 264 9960

**JOB TITLE**

WELBECK LANDFILL
Waste Recovery Plan

**DRAWING TITLE**

Waste Recovery Operations Plan

| DRAWN | DATE | APPROVED | DATE |
|-------|------|----------|------|
| M.C | 10/05/2018 | D.T | 10/05/2018 |

| SCALE | SHEET | DRAWING NUMBER | REVISION |
|-------|-------|----------------|----------|
| 1:3500 | A1L | WR7358/10/WRP1 | 0 |

**APPENDIX B. SLADEN ASSOCIATES REPORT**

# CONTROLLED WATERS RISK ASSESSMENT
# WELBECK LANDFILL
# RESTORATION SOILS

Prepared for

**Provectus Soils Management Ltd**

Date : June 2022                    Report No :  22 2447

# CONTROLLED WATERS RISK ASSESSMENT
# WELBECK LANDFILL
# RESTORATION SOILS

**Prepared for:**      **Provectus Soils Management Ltd**

Sladen Associates
Unit 5, Netherton Workshops
New Road, Highley
Bridgnorth, Shropshire
WV16 6NN

Tel     : 01746 860222
Fax    : 01746 862330

REPORT No 22 2447

# CONTROLLED WATERS RISK ASSESSMENT
# WELBECK LANDFILL
# RESTORATION SOILS

**CONTENTS**

**LIST OF FIGURES**

# CONTROLLED WATERS RISK ASSESSMENT
# WELBECK LANDFILL
# RESTORATION SOILS

## 1   INTRODUCTION

The present report documents derivation of leachate targets with respect to protection of controlled waters for restoration soils to be used as part of the final cover system at Welbeck Landfill.

This report describes modelling of flow patterns and potential contaminant migration within the restoration system.  This modelling was undertaken to assist in development of the conceptual model and in order to allow predictions to be made as to the likely degree of dilution and attenuation of potential contaminants and their likely fate in the cover and drainage systems.  As such it assists in the quantification of the risks to controlled waters that may be associated with migration of any potential contaminants remaining within the restoration soils used.

The present report does not consider potential risks to human health, suitability of restoration soils to support vegetation or geotechnical stability.  Final selection of acceptance criteria should also address those issues as well as pragmatic considerations.

## 2   THE SITE

### 2.1   SITE LOCATION

Welbeck Landfill is located in a low lying area, within the valley of the River Calder, some 3 km north east of Wakefield Town Centre, on the fringe of the urban area at National Grid Reference 4361 , 4219, see Figure 1. The operational part of the site consists of a number of engineered cells.  The landfill is being reclaimed progressively and it is proposed to use treated soils as part of the cover system for some areas.

Details of the landfill construction and site geology and hydrogeology are included in the following reports:

Welbeck Landfill, nr Wakefield, West Yorkshire, PPC Permit WP3330BZ:
   Hydrogeological Risk Assessment Review, prepared for Waste Recycling Group by SLR Consulting Ltd.  Report No:403-0197-00763, November 2009.  ('2009 HRA Report')

Welbeck Landfill, Yorkshire - Hydrogeological Risk Assessment Review, prepared for FCC Environment by SLR Consulting Ltd.  March 2015. ('2015 HRA Review')

and

Welbeck Landfill, 2021 Hydrogeological Risk Assessment Review.  Prepared for FCC
    Environmental by SLR Consulting Ltd.  Report No: 416-0197-00991, June 2021.
    ('2021 HRA Review')

Details of the proposed capping system in the proposed restoration soils deposition area
    are given in:

Specification for Construction of 2020 Capping, Welbeck Landfill Site.  Prepared for FCC
    Environment by SLR Consulting Ltd.  Report No: WR7746_1 Rev 2, Sept 2020.
    ('Capping Specification')

Assumptions adopted in the present study are generally consistent with those made in
the HRA Reports.

## 2.2   PROPOSED LANDFILL RESTORATION SYSTEM

The capping will be covered by a minimum thickness of 0.7 m of restoration soils.

The construction would be as follows:

- A basal regulating layer of suitable material of 300 mm thickness.
- The cap sealing layer, which will comprise a Geosynthetic Clay Liner.
- A Sub Soil Layer of 500 mm of Colliery Spoil.
- 700 mm thickness of restoration soils (Top Soil Layer) will be placed over the Sub
  Soil Layer to achieve a total minimum thickness above the sealing layer of 1.2 m.

It is expected that the general restoration soils will comprise soil forming materials and
soil conditioners, including compost, in order to achieve the standard required for
restoration to agriculture. Depending on such factors as post construction settlement the
thickness of restoration soils could be significantly thicker than 0.7 m in some areas.

Ditches may be provided within the restoration soils to reduce the risk of soil erosion due
to surface run-off.  It is anticipated that any such ditches would be lined to prevent
erosion or water loss and would be designed to take only surface run-off, rather than
discharge of pore water from within the restoration soils.  As the cover system is
expected to be generally in an unsaturated condition, discharge of pore water to the
drains would, in any case, not be anticipated.

The area where placement of restoration soils is proposed is shown edged in orange in
Figure 2.

## 3   INITIAL CONCEPTUAL MODEL OF POTENTIAL POLLUTION LINKAGES

### 3.1   ANTICIPATED PATTERN OF FLOW WITHIN THE RESTORATION SYSTEM

A proportion of the long term average precipitation falling on the restoration system will
result in run-off.  This would likely be greatest during significant storm events and would
typically be expected to represent less than about 5 to 10 % of total precipitation unless
the cover system became saturated.  The completed restoration will be vegetated and
evapotranspiration will represent a significant part of the water balance.

The climate data for this area indicates that the long term annual rainfall is about
1070 mm/yr and the average effective rainfall for grassland is expected to be less than
204 mm (2009 HRA Report).

The restoration system will be entirely above the groundwater level and therefore would
be expected to be operating normally in an unsaturated condition.  It would be

anticipated therefore that the net infiltration within the restored landfill areas will enter the restoration soils and result in a profile of unsaturated moisture content within the restoration soils that would comply with the moisture retention characteristics of the soils present.

A small proportion of the overall net infiltration would be expected to permeate through the sealing system into the landfilled wastes. However, the primary flow direction in the restoration/protection soils would be expected to be in a generally sub-horizontal downslope direction.

The proportion of flow through the seal into the wastes would be dominated by any imperfections or damage that may be present. The restoration soils could potentially become saturated during periods of relatively high infiltration, i.e. particularly in winter months, which could potentially increase surface run-off and reduce infiltration. Apart from periods when the restoration soils become saturated, and assuming the leakage through the sealing layer is small, flow volume within the restoration soils will be controlled primarily by the net infiltration and would not be influenced greatly by the absolute value of saturated hydraulic conductivity of the restoration soils. All else being equal, the degree of saturation of the restoration soils would be expected generally to increase in the downslope direction as the volume of water flow would increase with increasing upstream 'catchment' although local changes in gradient of the cover system could complicate this picture. In particular, relatively flatter areas would be expected to show a relatively higher degree of saturation.

For the present assessment, increased run-off due to saturation is a less critical condition than the unsaturated condition as it would result in less infiltration to the restoration soils and hence reduced average flow volumes and potential leachate generation in the restoration soils.

It is expected that both run-off from the restoration system and discharge of water from the restoration soils would be directed to a surface drainage system, which would itself discharge to surface water, in the case most likely the River Calder.

## 3.2 POTENTIAL CONTROLLED WATERS RECEPTORS AND CREDIBLE POLLUTION LINKAGES

The proportion of infiltration that passes through the sealing layer will contribute to leachate within the wastes and will be controlled by the leachate collection system. As such its fate does not need further detailed consideration in the present study as the impact of leachate is addressed in the various hydrogeological risk assessments. Indeed for the present study it is conservative to assume that this component of the water balance is zero such that all net infiltration to the restoration results in discharge from the restoration soils to the drainage system.

Direct discharge to groundwater from the cap would be expected to be intercepted by a surface drainage system, and it is not considered credible that any discharge to groundwater pathway would be more critical than direct discharge to surface water. Accordingly, with regard to any potential dissolved contaminants within the water emanating from the restoration soils, it is considered that, for the present site, more detailed assessment is only warranted with respect to the surface water receptor via direct discharge from the drainage system.

# 4 METHODOLOGY

## 4.1 ASSUMPTIONS

The present work is based on the following assumptions:

- Infiltration to the cap will equal the effective precipitation less run-off.
- Effective precipitation is 204 mm per year, it is anticipated that the restoration soils would be vegetated shortly after placement.
- Loss through the sealing system to the wastes will be ignored, which is conservative.
- Direct surface flow run-off to surface drainage will be considered for completeness although a relatively low value will be assumed.
- There would potentially be some attenuation during flow through the restoration system, which would be expected to be greatest for areas of the restoration situated farthest from the surface drainage system.
- Degradation would be considered where appropriate but there would be no assumed loss of mass of contaminant due to volatilisation etc, within the surface drainage system.
- For the drain to surface water pathway, dilution within the final receiving stream will be ignored.  This is also conservative.

Generically, the leachate target has therefore been calculated as follows:

SLT = EQS x AFC x DFD
Where:
SLT = Soil Leachate Target (mg/l)
EQS = The relevant Compliance Criterion (Environmental Quality Standard) for the substance (mg/l)
AFC = Attenuation Factor during transport in the Restoration Flow System
DFD = Dilution Factor in Surface Drain System

DFD would be taken as unity for List 1 Substances.

## 4.2   POTENTIAL CONTAMINANTS OF CONCERN AND COMPLIANCE CRITERIA

As the critical receptor is considered to be the surface water system, the relevant compliance criteria will be assumed to be Annual Average Environmental Quality Standards (EQS) levels where these have been published.  Where no EQS is available EQS values for similar compounds have been selected.

Where new EQS values have been proposed in the document 'The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2015, these have been adopted.  Otherwise former EQS values for surface water have been adopted.

For TPH fractions, where no EQS is available, the former drinking water standard for oils and hydrocarbons (0.01 mg/l) has been adopted.  There is reason to consider however, that for some THP fractions, the adopted compliance criterion is likely to be conservative with respect to protection of controlled waters, where the critical receptor is either a surface water feature or potential drinking water.  The Massachusetts Department of Environmental Protection (MADEP) has published risk-based criteria that are protective of aquatic receptors (BATELLE,2007), see also SOBRA 2012.  The approach involved estimating the acute and chronic toxicity of hydrocarbon fractions to aquatic organisms based on equilibrium partitioning theory.  Criteria in pore water and sediment were derived for eight groupings (fractions) of petroleum hydrocarbons based on similar toxicological and chemical properties, are set out in the following table:

| Hydrocarbon Fraction | Toxicity-based Water Criterion (mg/l) |
|---|---|
| Aliphatics C5-C8 | 0.22 |
| Aliphatics C9-C12 | 0.0063 |
| Aliphatics C13-C18 | * |
| Aliphatics C19-C36 | * |
| Aromatics C6-C8 | 1.2 |
| Aromatics C9-C12 | 0.046 |
| Aromatics C13-C15 | 0.0052 |
| Aromatics C16-C24 | * |

*Note: These fractions are not likely to be toxic, toxicology-based pore water concentration exceeds mean aqueous solubility.

With regard to human toxicity, the World Health Organisation (2005) has developed the following guidelines for drinking water standards:

| Hydrocarbon Fraction | Toxicity-based Drinking Water Criterion (mg/l) |
|---|---|
| Aliphatics C5-C8 | 15 |
| Aliphatics C9-C16 | 0.3 |
| Aliphatics C17-C36 | * |
| Aromatics C6-C8 | 0.01 (benzene) 0.7 (toluene) |
| Aromatics C9 - C16 | 0.1 |
| Aromatics C16-C35 | 0.09 |

CL:AIRE 2017, essentially advocated use of the WHO Drinking Water Standards for controlled waters risk assessments.

In the light of the above, absence of current regulatory guidance in the UK and as dilution in the receiving stream is being ignored, the former DWS (0.01 mg/l) was adopted as a relevant compliance criterion for each of the TPHCWG groupings where the expected solubility exceeds that value. Where solubility is less than 0.01 mg/l it is assumed that the fraction can pose no significant risk to controlled waters.

Details of the chemical characteristics of proposed restoration soils are not available but, based on experience from similar operations, target values will be required for a fairly wide range of potential contaminants and the following compliance criteria and solubility have been adopted (all in mg/l). The adopted organic carbon partition coefficient is also listed.

| Substance | Compliance Criterion | Comment | Water solubility | Koc | |
|---|---|---|---|---|---|
| | mg L$^{-1}$ | | mg L$^{-1}$ | Log (cm$^3$ g$^{-1}$) | Reference |
| Benzene | 1.00E-02 | | 1.78E+03 | 1.83E+00 | SR7 |
| Toluene | 7.40E-02 | | 5.90E+02 | 2.31E+00 | SR7 |
| Ethylbenzene | 2.00E-02 | | 1.80E+02 | 2.65E+00 | SR7 |
| m-Xylene | 3.00E-02 | | 2.00E+02 | 2.69E+00 | SR7 |
| o-Xylene | 3.00E-02 | | 1.73E+02 | 2.63E+00 | SR7 |
| p-Xylene | 3.00E-02 | | 2.00E+02 | 2.65E+00 | SR7 |
| Naphthalene | 2.40E-03 | | 1.90E+01 | 2.81E+00 | SR7 |
| Benzo[a]pyrene | 1.70E-07 | | 3.80E-03 | 5.11E+00 | SR7 |
| Phenol | 7.70E-03 | | 8.41E+04 | 1.46E+00 | SR7/LQM |
| TPH Aliphatic C5-C6 | 1.00E-02 | Former DWS | 3.60E+01 | 2.90E+00 | LQM |
| TPH Aliphatic C6-C8 | 1.00E-02 | Former DWS | 5.40E+00 | 3.60E+00 | LQM |
| TPH Aliphatic C8-C10 | 1.00E-02 | Former DWS | 4.30E-01 | 4.50E+00 | LQM |
| TPH Aliphatic C10-C12 | 1.00E-02 | Former DWS | 3.40E-02 | 5.40E+00 | LQM |
| TPH Aliphatic C12-C16 | 1.00E-02 | Former DWS | 7.60E-04 | 6.70E+00 | LQM |
| TPH Aliphatic C16-C21 | 1.00E-02 | Former DWS | 2.50E-06 | 8.80E+00 | LQM |
| TPH Aliphatic C21-C34 | 1.00E-02 | Former DWS | 2.50E-06 | 8.80E+00 | LQM |
| TPH Aliphatic C35-C44 | 1.00E-02 | Former DWS | 2.50E-06 | 8.80E+00 | LQM |
| TPH Aromatic C8-C10 | 1.00E-02 | Former DWS | 6.50E+01 | 3.20E+00 | LQM |
| TPH Aromatic C10-C12 | 1.00E-02 | Former DWS | 2.50E+01 | 3.40E+00 | LQM |
| TPH Aromatic C12-C16 | 1.00E-02 | Former DWS | 5.80E+00 | 3.70E+00 | LQM |
| TPH Aromatic C16-C21 | 1.00E-02 | Former DWS | 6.50E-01 | 4.20E+00 | LQM |
| TPH Aromatic C21-C35 | 1.00E-02 | Former DWS | 6.60E-03 | 5.10E+00 | LQM |
| TPH Aromatic C35-C44 | 1.00E-02 | Former DWS | 6.60E-03 | 5.10E+00 | LQM |
| TPH Aromatic C44-C70 | 1.00E-02 | Former DWS | 1.00E-04 | 5.70E+00 | LQM |
| Arsenic | 5.00E-02 | | | | |
| Cadmium | 2.50E-04 | | | | |
| Copper | 2.80E-02 | | | | |
| Chromium | 2.00E-02 | | | | |
| Lead | 7.20E-03 | | | | |
| Mercury | 5.00E-05 | | | | |
| Nickel | 2.00E-02 | | | | |
| Zinc | 3.40E-02 | | | | |
| Water Soluble Boron | 2.00E+00 | | | | |
| Sulphate | 4.00E+02 | | | | |
| Nitrate | 11.3 | | | | |
| Ammonium as NH4 | 0.77 | | 8.99E+05 | Kd = 1 cm$^3$ g$^{-1}$ | Buss et al |

For simplicity, where the relevant current standard for some metals is expressed as bioavailable but no data are available, former EQS levels will be adopted

For the pathway associated with discharge of perimeter drain water to the surface water system, no dilution within the surface water following discharge will be considered, which is conservative. Compliance criteria will be assumed to apply to drain water prior to discharge.

# 5 DEVELOPMENT OF EXTENDED CONCEPTUAL MODEL

## 5.1 GENERAL

The patterns of water flow within the restoration system are important to the assessment of risks to controlled waters. The flow system in the, generally unsaturated, cover system can be relatively complex and in order further to develop the conceptual model of water flow conditions, a numerical model was developed to simulate flow and contaminant transport in the restoration system. The model simulates 2 dimensional flow and contaminant transport in a vertical section through the restoration system.

## 5.2 MODELLING SOFTWARE

Numerical modelling undertaken as part of the present study has made use of the SEEP/W program developed by Geo-Slope International Ltd. This was chosen as it allows rapid parametric studies to be undertaken and the implications of various assumptions to be graphically displayed. The program has been specifically formulated to allow accurate simulation of unsaturated as well as saturated flow systems. The program is based on the well-established finite element method for continuum analysis. Although similar analysis may be undertaken using finite difference based methods, the finite element approach offers some advantages; in particular the method is less sensitive to such factors as node spacing as conditions are not assumed to be linear within elements. In this process the study geometry is divided into a number of elements. Potential patterns of contaminant transport may be mapped on the results of the SEEP/W analysis with the use of a companion program CTRAN/W.

## 5.3 VERTICAL SECTION MODEL

### 5.3.1 GEOMETRY ANALYSED

The presently proposed restoration area, Figure 2, is of a somewhat complex shape and with varying surface gradients. For the presently considered site areas, a typical section has been adopted for analysis as indicated on Figure 2. The geometry modelled is shown in Figures 3 at five times vertical scale exaggeration. In some areas the treated soils would be placed 'upstream' of other landfill areas. This has been ignored in the analysis, which is conservative as attenuation would occur within the downstream areas.

The upper surface was modelled as an infiltration boundary with a review such that if water pressure at the surface exceeds atmospheric, infiltration does not occur, i.e. run-off would be expected. The right hand boundary, which represents the topographic high point and which was assumed to be a water divide, was modelled as a no flow boundary. The lower boundary, representing the cap sealing layer, was modelled as a no-flow boundary. The left hand basal boundary was modelled as a zero (atmospheric) water pressure boundary/potential seepage face, as conditions at the downstream surface drain are assumed to be atmospheric.

The cover was modelled as a single layer system, representing the sub soil and restoration soil (base case assumed 1200 mm thick).

With this system, the overall volume of groundwater flow is controlled by the infiltration rather than hydraulic properties of the soil layer, unless the system becomes saturated and then the saturated hydraulic properties would control the degree of run-off and the volume of flow within the cover soils.

In the normal, unsaturated, condition, effective conductivity of the unsaturated soils will depend on moisture content, which will depend upon the degree of negative pore pressure in the pore fluid. This will be constrained to come into equilibrium with the rate

of infiltration.  It follows that the solution to the flow problem must be iterative and this is accommodated by the software.

It is necessary to assume a relationship between negative water pressure and both volumetric water content and hydraulic conductivity.  However, as the flow volumes are controlled by infiltration, unless the system becomes saturated in which case there would not be negative pore pressures, selection of these relationships is less critical than would otherwise be the case.  Accordingly literature relationships were selected, for the shapes of the water content and conductivity relationships with negative pore pressure, from the software library functions of soils expected to be generally similar to the restoration system:

| Unit | Saturated Hydraulic Conductivity (m/s) | Saturated Volumetric Water Content (Porosity) |
|---|---|---|
| Restoration Soils | Base Case 1.0e-4 <br> Low Value 1.0e-5 | 0.3 |

It is anticipated that the above base case saturated conductivity is likely to be greater than the field conditions, as previous experience has shown that the restoration soils include significant proportions of silts and clays.  However, adoption of lower saturated conductivities results in increased run-off and less flow in the cover and would therefore not be conservative.  Once the assumed conductivity is high enough to prevent saturated conditions under average infiltration conditions, the absolute value of assumed saturated hydraulic conductivity does not greatly influence predicted rates of attenuation as flow volumes is controlled by volume of infiltration.

Similarly the proposed Sub Soil Layer of colliery spoil may have relatively high saturated hydraulic conductivity but, if coarser, when unsaturated would have relatively lower effective hydraulic conductivity and the majority of the flow would be through the restoration soils.

Analysis was therefore run for both the base case and lower saturated conductivity case and the condition showing the lower rate of attenuation, the higher saturated conductivity condition, was adopted for evaluation of leachate targets.

Figure 4 shows the soil moisture retention and conductivity curves adopted.

### 5.3.2   PREDICTED FLOW CONDITIONS FOR STEADY STATE INFILTRATION

Figure 5 shows the predicted base case flow conditions within the restoration soils as contours of total head.

### 5.3.3   IMPLICATIONS FOR CONTAMINANT TRANSPORT

During transport through the system, the effective velocity of dissolved phase potential contaminants will be retarded by adsorption and the processes of dispersion, downstream dilution and, for organic compounds, bio-degradation will lead to potential attenuation through dilution and loss of mass of contaminant.  Although mechanical dispersion and dilution would be expected to be independent of the nature of the dissolved substance, both adsorption and potential bio-degradation would be strongly dependent on the contaminant present.  As such the analysis requires additional compound specific parameters.  However, if bio-degradation is ignored, as would be appropriate for example for potential metal contaminants, although retardation will affect the rate of transport, and will delay attainment of 'steady state' conditions, it will not affect the predicted long term 'steady state' distribution of potential conservative contaminants in which the source concentration is not reducing with time as eventually desorption will

come into equilibrium with adsorption. For the present purposes, therefore, considering long term conditions and no source reduction, discussion of adsorption and bio-degradation parameters is only warranted for organic compounds. The assumption that the source concentration remains constant implies that there is no depletion of the source, which is very conservative.

For organics, partitioning is assumed to be proportional to the organic matter content of the soil. The relevant material parameters for this analysis are the Organic Carbon Partition Coefficient (Koc) and the half life of biodegradation. The assumed values of Koc are based on the Environment Agency Report SR7 (2008) and have been tabulated in Section 4.2, above. For compounds not included in that document, data are based on LQM (2009) or Buss et al (2004). The values of fraction of organic carbon was assumed to be 0.01 (1%) for the restoration soils, which is likely very conservative, particularly where compost materials are introduced.

For the present study, adopted degradation rates are based primarily on EA P2 228 (2002). The data presented in EA P2 228 for shallow sand and gravel aquifers under aerobic conditions have been adopted. These are considered very conservative for the present case as the flow system within the restoration soils is expected to be mainly unsaturated and will always be at very shallow depth and therefore with ready availability or air. In fact, data for near surface soil are potentially more relevant. Biodegradation rates in soil are generally much more rapid than in groundwater. For example Howard et al 1991 suggest half lives for benzene may be 2 to 45 times shorter in soil than in groundwater.

It is generally found that for TPH compounds, rates of degradation in the field reduce with increasing molecule size. For TPH fractions where no guidance is given in EA P2 228, approximate half lives have been estimated based on the guidance given in EA P2 228 for BTEX and scaling half lives based on the general relationship between half life and molecule size proposed in New Zealand Guidance. With the exception of naphthalene, EA P2 228 (2002) does not report degradation rates for PAH compounds. Other PAH compounds are not generally critical with respect to the water environment. This is because of low solubility and generally high partition coefficients. Data presented by Surampalli et al (2004), based on field studies, suggest typical half lives in unconfined shallow aquifers for PAH compounds of less than 2 years. For the present study arbitrary but relatively high half-life of 10 years has been adopted for PAH compounds other than naphthalene. More detailed assessment is not considered warranted as these compounds are not highly mobile in the groundwater environment and rarely are critical.

The adopted values are summarised in the table below:

| Substance | Half Life (days) | Source |
|---|---|---|
| Benzene | 350 | Upper Limit EA Report P2-228/TR |
| Toluene | 200 | Upper Limit EA Report P2-228/TR |
| Ethylbenzene | 200 | Upper Limit EA Report P2-228/TR |
| m-Xylene | 200 | Upper Limit EA Report P2-228/TR |
| o-Xylene | 200 | Upper Limit EA Report P2-228/TR |
| p-Xylene | 200 | Upper Limit EA Report P2-228/TR |
| Benzo[a]pyrene | 3650 | High value based on literature, e.g. Surampalli et al 2004 |
| Naphthalene | 300 | Upper Limit EA Report P2-228/TR |
| Phenol | 100 | Upper Limit EA Report P2-228/TR |
| TPH Aliphatic C8-C10 | 700 | Upper Limit for BTEX EA Report P2-228/TR scaled according to NZ Practice |
| TPH Aromatic C8-C10 | 700 | As TPH C8-C10 scaled according to NZ Practice |
| TPH Aromatic C10-C12 | 1750 | As TPH C8-C10 scaled according to NZ Practice |
| TPH Aromatic C12-C16 | 2450 | As TPH C8-C10 scaled according to NZ Practice |
| TPH Aromatic C16-C21 | 3500 | As TPH C8-C10 scaled according to NZ Practice |
| TPH Aromatic C21-C35 | 3500 | As TPH C8-C10 scaled according to NZ Practice |
| Ammonia | 730 | Buss et al 2004 |

As noted above, some PAH compounds and higher level TPH fractions have very low aqueous solubility.  Where the aqueous solubility is less than the adopted compliance criterion, more detailed analysis of potential fate and transport is not warranted.  Where the EQS depends on the carbonate content of the receptor, the highest reported value has been adopted.  This is considered justified as no dilution within the receptor has been assumed.

The restoration soils will be placed at varying distances from the surface water drains.  Infiltration water with dissolved phase contaminants leached from the restoration soils placed further from the surface drainage will take considerably longer to reach the discharge than from areas closer to the drain, with consequent varying attenuation potential.  In order to accommodate this aspect, the restoration soils were divided into five zones, Zone 1 corresponding to: 0 to 20 m from the discharge drainage, Zone 2: 20 to 50 m,  Zone 3: 50 to 100 m, Zone 4: 100 to 150 and Zone 5: greater than 150 m.  Analysis was undertaken for each of the five zones for a range of partition coefficients and half-lives, to reflect the range of organic compounds potentially present in the restoration soils.  Figure 6 shows an example of the Zone 3 area as source for benzene.  This analysis assumes unit concentration within the source zone.  Based on this and similar analyses for other potential contaminants and source zones, the potential attenuation associated with each zone can be estimated.  Figure 7 shows the predicted discharge concentration vs time for benzene and for conservative compounds, with sources assumed in Zone 2 and Zone 3, for the condition of constant infiltration and base case conductivity.  Note that for this analysis potential retardation of conservative substances has been ignored.  Although retardation due to adsorption is likely to occur and would affect breakthrough times, as discussed above, for a constant source, the final steady state concentration distribution downstream would be the same.

The modelled overall distance from crest to discharge (240 m) is essentially the maximum present.  Lesser distances would be less critical as flow volumes and velocities would be less and hence rates of attenuation greater.

The restoration system attenuation factor is defined as the ratio of the source concentration to concentration at discharge.  The following table gives examples of the derived restoration system attenuation factors:

| Compound | Attenuation Factor for Restoration Zone | | | | |
|---|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
| Conservative Compound (No Degradation) | 1 | 1.09 | 1.26 | 1.71 | 2.67 |
| Benzene | 1 | 1.76 | 4.59 | 30.7 | 436 |
| Toluene | 1 | 8.33 | 291.5 | >10,000 | VH |
| Naphthalene | 1 | 42.0 | >10,000 | VH | VH |
| Benzo(a)pyrene | 1 | VH | VH | VH | VH |

VH = Very High

### 5.3.4  EFFECT OF TRANSIENT INFILTRATION CONDITIONS

In reality infiltration to the cover system will be variable with time.  In addition to daily variations reflecting varying short term weather conditions, there would be expected to be a seasonal effect where a relatively high proportion of total infiltration occurs during winter months, primarily due to lower potential evapotranspiration during the winter.  Under steady state conditions, assuming average infiltration, predicted horizontal 'Darcy' groundwater velocities are of the order of 7e-7 m/s near the centre of the cover.  This suggests that in a single year, the advective transport distance within the cover system would be in the order of about 65 m.  Seasonal fluctuations in infiltration would not therefore be expected to significantly affect the impact of sources remote from the perimeter but may lead to variations in discharge rates of leachate originating as infiltration nearer the perimeter of the cover.

To study the effect of seasonal variations on flow conditions within the cover, a transient model was developed.  A simplified seasonal infiltration function was adopted in which the entire year's infiltration was assumed to occur in six months with no infiltration for the remaining six months.  The model simulated a period of 10 years.  This simulation showed some seasonal variation in the degree of saturation of the cover system such that during winter months, at times of highest potential infiltration, the cover materials would be expected to be in a more saturated condition, which implies a higher proportion of run-off and consequently a somewhat lower proportion of total flow through the cover soils.  Following the winter period, flows may increase somewhat as water comes out of storage when degrees of saturation reduce.

Figure 8 shows the potential effect of seasonally varying infiltration on predicted contaminant concentration at discharge.  Sources of benzene of assumed concentration unity, within each zone are illustrated.  As discussed above, one effect of seasonal variation in potential infiltration is that during periods of highest potential infiltration the restoration soils are more likely to reach saturation, possibly leading to increased run-off and reduced actual total annual infiltration even though the rate of infiltration in winter is higher than in summer.  For the simplified model adopted, which includes yearly variations but does not include shorter term infiltration variations, the model suggests that average concentration at discharge to the drain will not be higher than predicted assuming uniform infiltration throughout the year.  As annual average EQS values have been adopted, it is therefore considered reasonable to adopt the uniform infiltration condition for assessment purposes.

### 5.3.5   EFFECT OF DEPLETING SOURCE CONCENTRATION

As noted above, for most substances a constant source zone concentration was assumed, which is conservative.  It follows that the predicted maximum concentrations will correspond to long term 'steady state' conditions.  For ammonium however, this assumption is considered unduly conservative as the source is considered to be decay of organic matter.  Accordingly it was assumed that the source concentration of ammonium would reduce with time.  The rate of decomposition would depend upon the nature of the organic material present and generally occurs exponentially.  For the present model it is assumed that the source would decay to negligible within a period ten years, which is consistent with the source concentration reducing to half of its original level each year. For this assumption the peak concentration does not correspond to the long term 'steady state' condition.  The further the source from the discharge, the longer will be the time to peak concentration but the lower the peak value.  Figure 9 shows the predicted discharge concentration with time for each of the assumed 'source' zones for ammonium. As may be seen, the further the source from the discharge, the longer to peak concentration but the lower the peak value.  The peak values were used for derivation of attenuation factors.

### 5.3.6   EFFECT OF INCREASING THICKNESS OF RESTORATION SOILS

The base case modelling assumes a minimum thickness of soils above the barrier layer of 1.2 m.  In practice the thickness is likely to be significantly greater.  The effect of increasing thickness is to reduce average flow velocities and increase rates of contaminant attenuation.  This is illustrated in Figure 10 for assumed benzene sources in Zone 2 and in Zone 3, where predicted discharge concentrations for 1.2 m and 2.4 m soil thicknesses above the barrier layer are compared.

### 5.3.7   EFFECT OF REDUCING RESTORATION SOIL SATURATED HYDRAULIC CONDUCTIVITY

As discussed above, provided the saturated hydraulic conductivity is sufficient to maintain unsaturated conditions within the restoration soils, flow velocities and volumes and hence potential rates of attenuation will be governed by the infiltration.  Should the saturated hydraulic conductivity be such that saturated conditions develop, flow volumes would reduce below infiltration due to run-off and rates of attenuation would be expected to increase.  This is illustrated in Figure 11 for an assumed benzene source in Zone 3, where the saturated hydraulic conductivity of the restoration soils is reduced by one order of magnitude compared to the base case.  As may be seen, predicted attenuation increases.  In addition to the increased attenuation, dilution within the perimeter drain would also be increased as a result of increased run-off.

## 6   DEVELOPMENT OF LEACHATE TARGETS FOR POTENTIAL CONTAMINANTS IN RESTORATION SOILS

### 6.1   GENERAL

Leachate Targets are required to ensure protection of controlled waters through the restoration to perimeter drain to surface water pathway.

As discussed above, the restoration to groundwater pathway was judged, for the present site, to be non-critical at the conceptual model stage.  It is conservative to assume that all flow may be to the surface drainage system.  Any intermediate condition, which would see some fraction of discharge to surface water and the remaining fraction to the groundwater, would lead to lower potential impact on the receptor being considered as some attenuation  would occur within the groundwater system.

As Annual Average EQS values are being adopted as compliance criteria, the analysis will consider average conditions. It should be noted therefore that derived leachate targets relate to annual average concentrations leaching from the placed soils rather than maxima.

## 6.2 RESTORATION TO PERIMETER DRAIN TO SURFACE WATER PATHWAY

As noted in Section 4.1 above, in general the Soil Leachate Target is given by:

SLT = EQS x AFC x DFD or,
SLT/AFC = EQS x DFD

The factor DFD will be controlled by the ratio of direct surface run-off to water discharge through the restoration soils. Average surface run-off is expected to be less than about 5 to 10 % of total precipitation, estimated to be on average 1070 mm/year. The average effective rainfall has been estimated at about 204 mm/year, i.e. about 20% of total precipitation. If run-off is assumed to be a nominal 5 % of total precipitation, a first order estimate of DFD would therefore be (0.05 + 0.20)/0.20 = 1.25. Note that DFD is assumed unity for List 1 substances.

The factor AFC is not constant but depends upon distance of the source soils from the perimeter drain and average values have been determined for five zones as follows:

AFC1: Zone 1, 0 to 20 m from downstream drain
AFC2: Zone 2, 20 to 50 m from downstream drain
AFC3: Zone 3, 50 to 100 m from downstream drain
AFC4: Zone 4, 100 to 150 m from downstream drain
AFC5: Zone 5 More than 150 to 240 m from downstream drain

If we consider separate leachate targets for each area (SLT1, SLT2 etc), compliance will be achieved provided that:

SLT1.Q1/AFC1 + SLT2.Q2/AFC2 + SLT3.Q3/AFC3 + SLT4.Q4/AFC4 + SLT5.Q5/AFC5 <= EQS.DFD.QT

As the zones are of different lengths this leads to the following for 240 m case from crest to drain:

Q1 = 0.083.QT
Q2 = 0.125.QT
Q3 = 0.201.QT
Q4 = 0.201.QT
Q5 = 0.375.QT

There is no unique solution to the above expression. It would, for example, be acceptable to specify a high SLT for any one zone and relatively low values for each of the others. However, one acceptable solution would be to set SLT1 = AFC1.EQS.DFD, SLT2 = AFC2.EQS.DFD etc. This has the intuitive advantage of resulting in higher leachate targets with increasing distance from the perimeter drain, as well as simplicity and is therefore the recommended approach.

## 6.3 DERIVED LEACHATE TARGETS

Leachate targets are therefore derived as follows:

SLT = EQS x AFC x DFD

Derived leachate targets for pore water (leachate) are summarised in the following table.

| Substance | Compliance Criterion (mg/l) | Derived Leachate Targets (mg/l) | | | |
|---|---|---|---|---|---|
| | | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
| Benzene | 0.01 | 0.018 | 0.046 | 0.31 | 4.4 |
| Toluene | 0.074 | 0.62 | 22 | No Restriction | No Restriction |
| Ethylbenzene | 0.02 | 0.98 | No Restriction | No Restriction | No Restriction |
| m-Xylene | 0.03 | 1.9 | No Restriction | No Restriction | No Restriction |
| o-Xylene | 0.03 | 1.3 | No Restriction | No Restriction | No Restriction |
| p-Xylene | 0.03 | 1.5 | No Restriction | No Restriction | No Restriction |
| Naphthalene | 0.0024 | 0.1 | No Restriction | No Restriction | No Restriction |
| Benzo[a]pyrene | 0.00000017 | No Restriction | No Restriction | No Restriction | No Restriction |
| Phenol | 0.0077 | 0.021 | 0.11 | 2.2 | 150 |
| TPH Aliphatic C5-C6 | 0.01 | 0.49 | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C6-C8 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C8-C10 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C10-C12 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C12-C16 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C16-C21 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C21-C34 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aliphatic C35-C44 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C8-C10 | 0.01 | 0.46 | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C10-C12 | 0.01 | 0.14 | 12 | No Restriction | No Restriction |
| TPH Aromatic C12-C16 | 0.01 | 0.34 | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C16-C21 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C21-C35 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C35-C44 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| TPH Aromatic C44-C70 | 0.01 | No Restriction | No Restriction | No Restriction | No Restriction |
| Arsenic | 0.05 | 0.068 | 0.079 | 0.11 | 0.17 |
| Cadmium | 0.00025 | 0.00027 | 0.00031 | 0.00043 | 0.00067 |
| Copper | 0.028 | 0.038 | 0.044 | 0.06 | 0.094 |
| Chromium | 0.02 | 0.027 | 0.031 | 0.043 | 0.067 |
| Lead | 0.0072 | 0.0098 | 0.011 | 0.015 | 0.024 |
| Mercury | 0.00005 | 0.000054 | 0.000063 | 0.000085 | 0.00013 |
| Nickel | 0.02 | 0.027 | 0.031 | 0.043 | 0.067 |
| Zinc | 0.13 | 0.17 | 0.2 | 0.27 | 0.42 |
| Water Soluble Boron | 2 | 2.7 | 3.1 | 4.3 | 6.7 |
| Sulphate | 400 | 540 | 630 | 850 | 1,300 |
| Nitrate | 11 | 15 | 18 | 24 | 38 |
| Ammonium | 0.77 | 2.3 | 4.8 | 17 | 86 |

\* Note: Zone 1 Target set at Compliance Criterion (EQS)

# 7  PARAMETER UNCERTAINTY AND SENSITIVITY

Although there are a number of assumptions inherent in the present analysis, in so far as possible these have been chosen to be consistent with design assumptions for the overall facility.  The approach to management of parameter uncertainty has been to incorporate a significant number of conservative assumptions into the analysis, in particular:

- Apart from for ammonium, the source of potential leachate within the restoration soils has been assumed to be constant with time.  This is considered to be particularly conservative for potentially more soluble mobile contaminants.
- Evaporation to the atmosphere has been ignored but would likely be significant for volatile, relatively mobile, organic compounds.
- The potential leakage to the waste mass has been assumed to be zero.
- Degradation half lives for organic compounds have been assumed to be much higher than would likely be observed in aerobic near surface soil conditions.
- The saturated hydraulic conductivity of the restoration soils has been assumed to be significantly higher than would be anticipated.

- The organic matter content of the restoration soils has been assumed to be relatively low.
- A proposed minimum thickness of restoration soils has been adopted as the base case.

Analysis has been undertaken to illustrate the sensitivity of the analysis to seasonal variance in infiltration, variation in cover thickness and variation in restoration soil saturated hydraulic conductivity. In view of the significantly conservative assumptions outlined above, more detailed analysis of sensitivity it is not considered warranted.

# 8   SUMMARY CONCLUSIONS

The restoration system will comprise a cap sealing layer overlain by a sub soil layer of 500 mm of colliery spoil, which will in turn be overlain by the restoration soils. The restoration soils will have a minimum overall 0.7 m, i.e. an overall thickness above the barrier layer of at least 1.2 m. However, depending on such factors as the magnitude of post construction settlements, the overall thickness of the restoration soils is likely to be significantly greater in some areas.

The restoration system will be entirely above the site groundwater level and analysis suggests that it will remain unsaturated during average conditions if the saturated conductivity of the restoration soils is relatively high. For lower conductivities saturated conditions may develop, particularly in winter months, which would tend to increase run-off and reduce infiltration and hence reduce potential leaching. Any infiltration into the restoration soils that permeates through the barrier will contribute to leachate within the waste mass and be treated accordingly. It is expected, however, that this will be a small component of the overall water balance and that most of the infiltration will travel laterally within the restoration system and discharge to a surface water drain, which would discharge eventually to the River Calder.

Analysis has been undertaken to derive defensible leachate targets for the treated soils that will be protective to surface water. For some potential contaminants there is the potential for significant attenuation within the restoration system prior to discharge. Numerical modelling of the flow system in the restoration soils has been undertaken to quantify potential levels of attenuation. Based on the site conceptual model, for the present site, the discharge to groundwater pathway is considered to be less critical than the discharge to perimeter drain and thence to surface water pathway.

For site management, the cover area has been divided into five zones representing different distances from the surface water drainage system.

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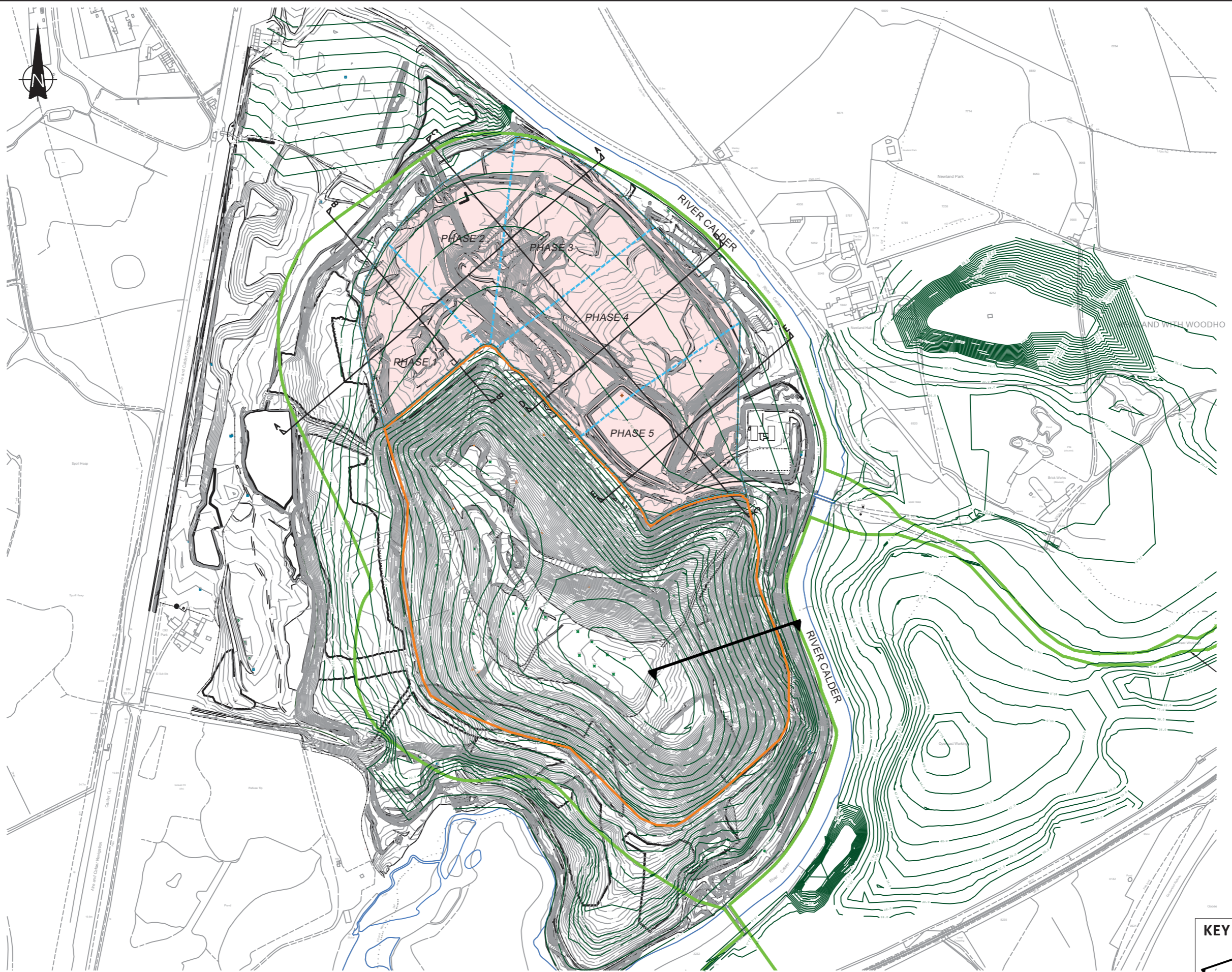
**FIGURES**
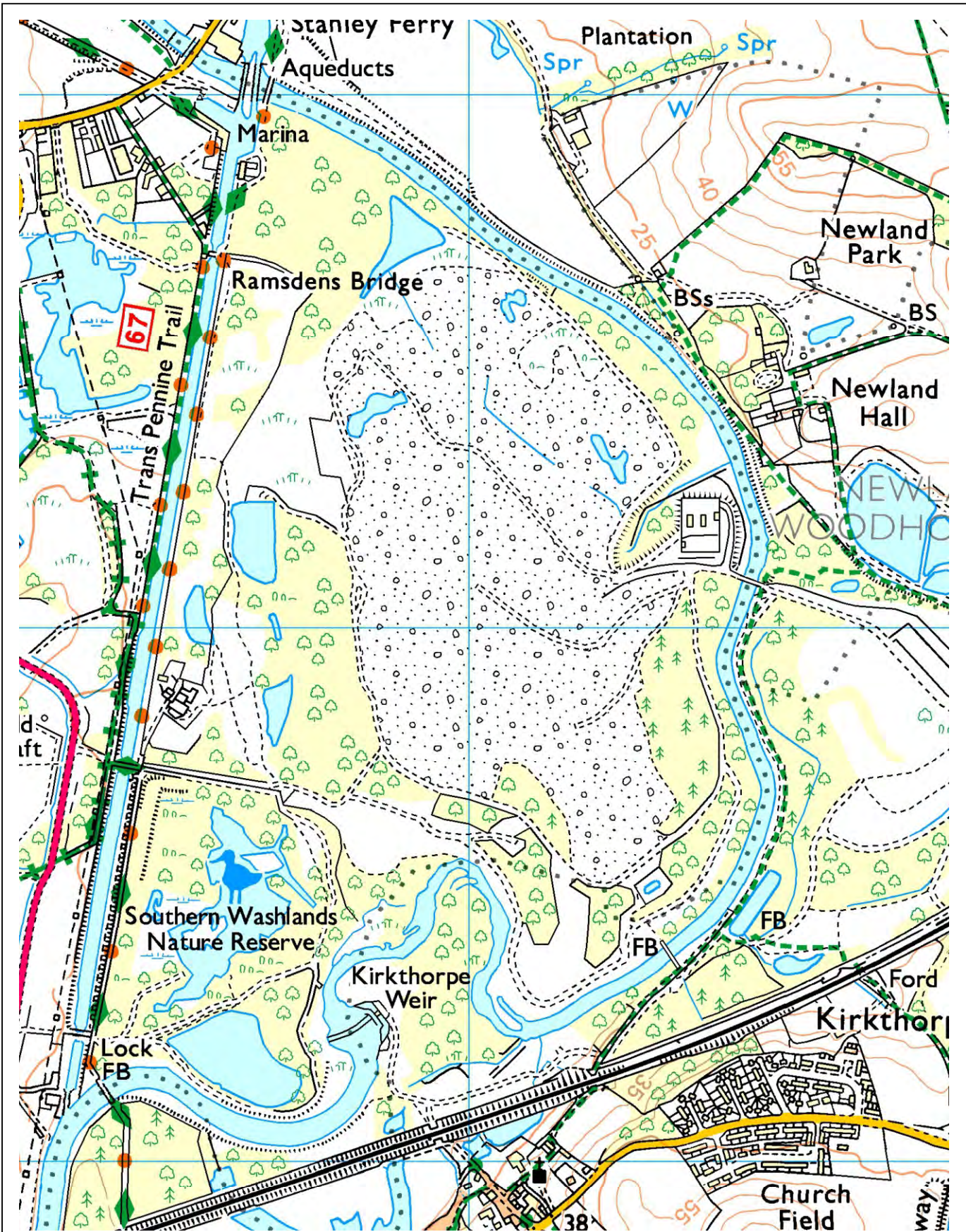
SITE LOCATION PLAN

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|---|---|---|---|

Not to scale

PROPOSED TREATED SOIL RESTORATION AREA

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|---|---|---|
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**KEY**

Cross Section used for Analysis

**Zone 1**  **Zone 2**  **Zone 3**  **Zone 4**  **Zone 5**

Sub Soil and Restoration Soil

Barrier

(Note 5 times Vertical Exaggeration)

Elevation (mAOD)

Distance from Perimeter Drain (m)
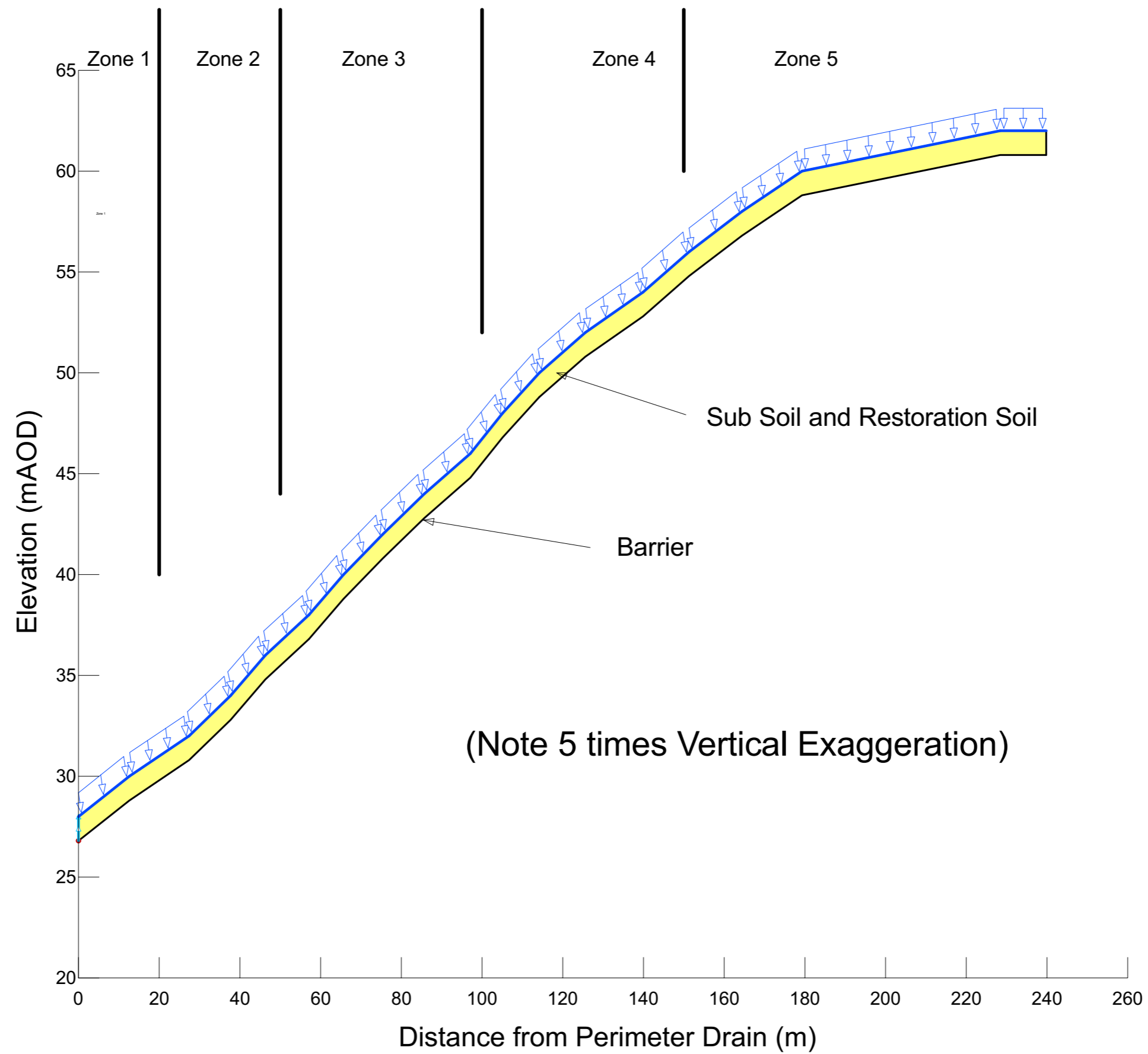
GEOMETRY MODELLED - VERTICAL SECTION MODEL

## Volumetric Water Content

**Matric Suction (kPa)** — x-axis (0 to 200)
**Volumetric Water Content** — y-axis (0 to 0.35)

Legend: Restoration Soils

## Hydraulic Conduc?vity

**Matric suc?on (kPa)** — x-axis (0.01 to 1000)
**Hydraulic Conduc?vity (m/s)** — y-axis (1.00E-12 to 1.00E-03)

Legend: Lower Conduc?vity Case, Base Case
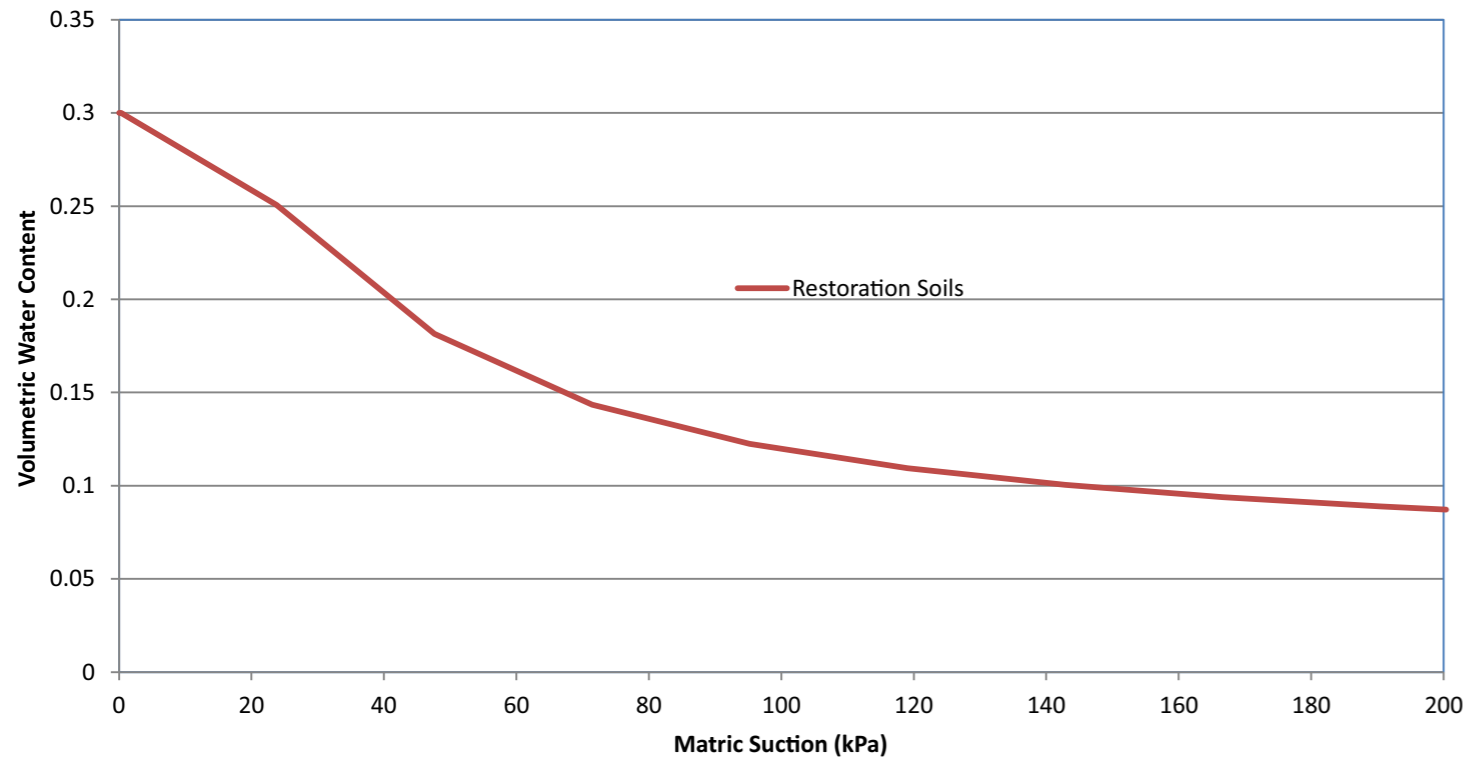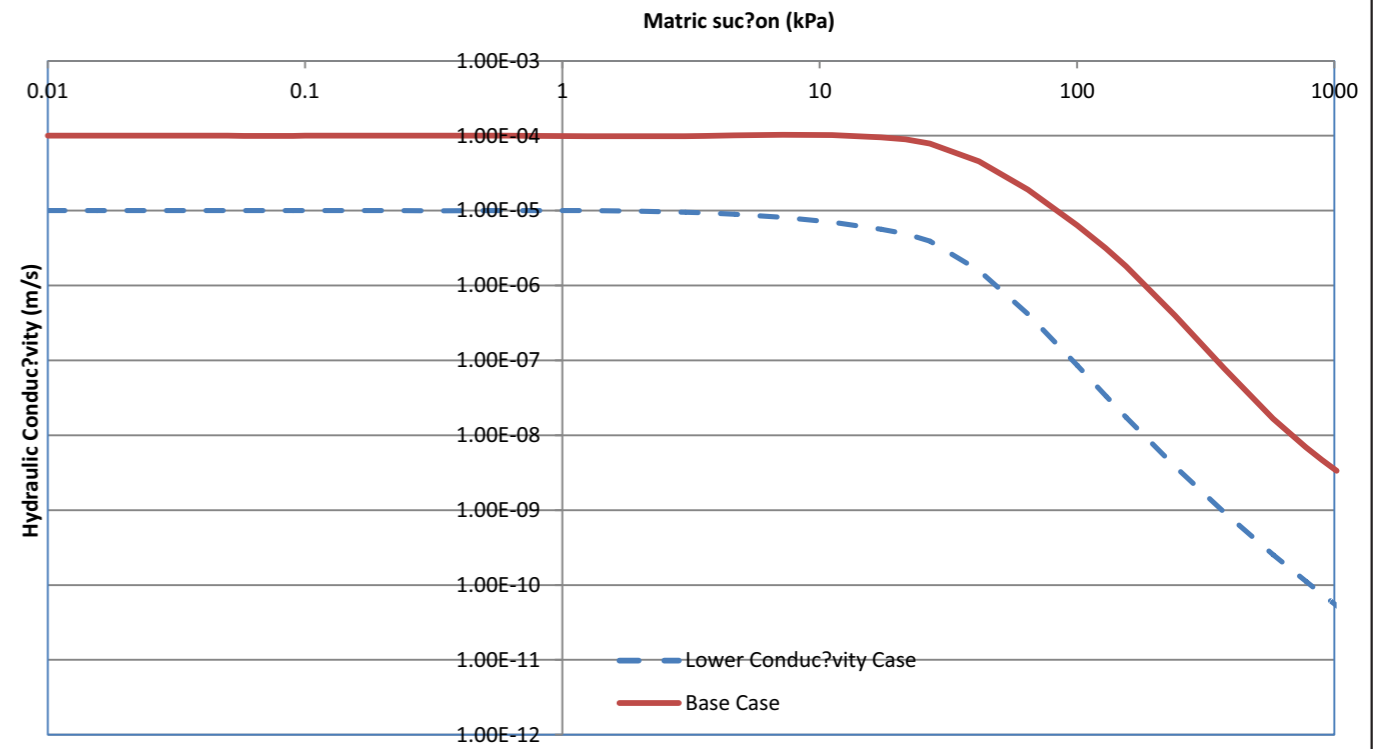
SOIL WATER RETENTION/CONDUCTIVITY CURVES

Zone 1     Zone 2     Zone 3     Zone 4     Zone 5

Elevation (mAOD)

(Note 5 times Vertical Exaggeration)

Distance from Perimeter Drain (m)
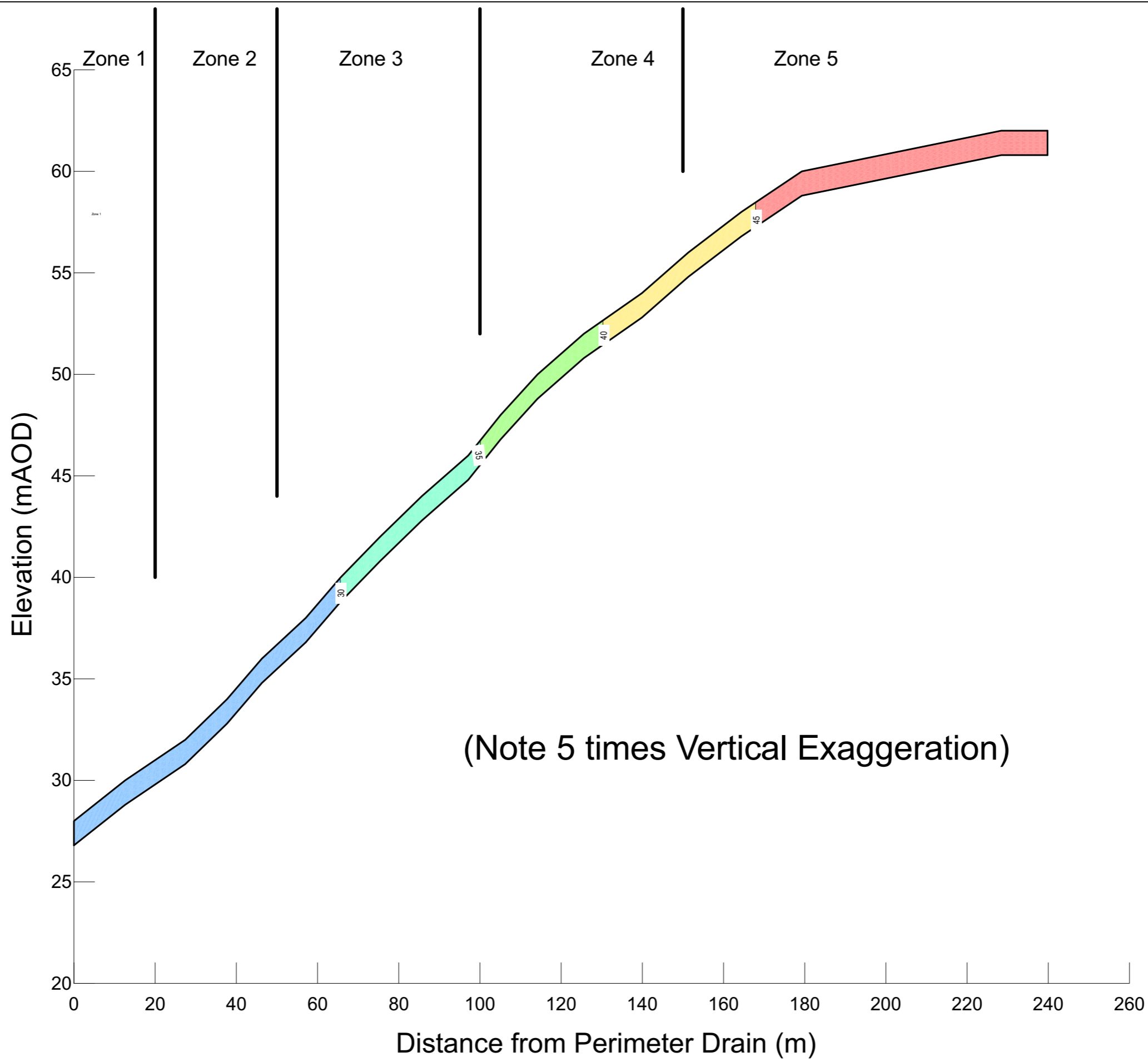
PREDICTED TOTAL HEAD CONDITIONS IN COVER SYSTEM

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|---|---|---|---|
| | 22-2447 | Welbeck Landfill, Wakefield | 5 |

(Note 5 times Vertical Exaggeration)

**Elevation (mAOD)** (y-axis)

**Distance from Perimeter Drain (m)** (x-axis)
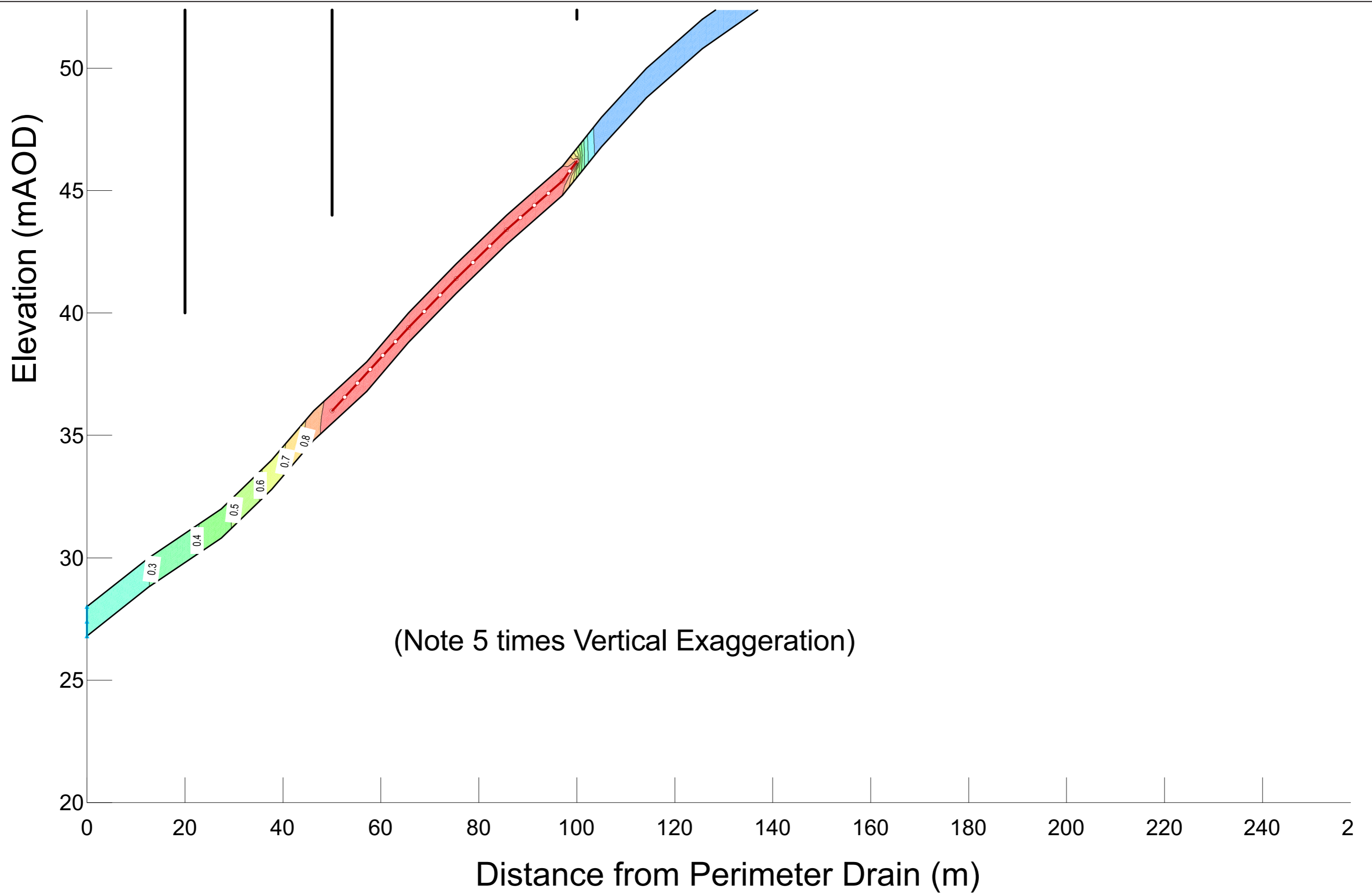
PREDICTED LONG TERM CONCENTRATION CONTOURS FOR BENZENE, SOURCE IN ZONE 3
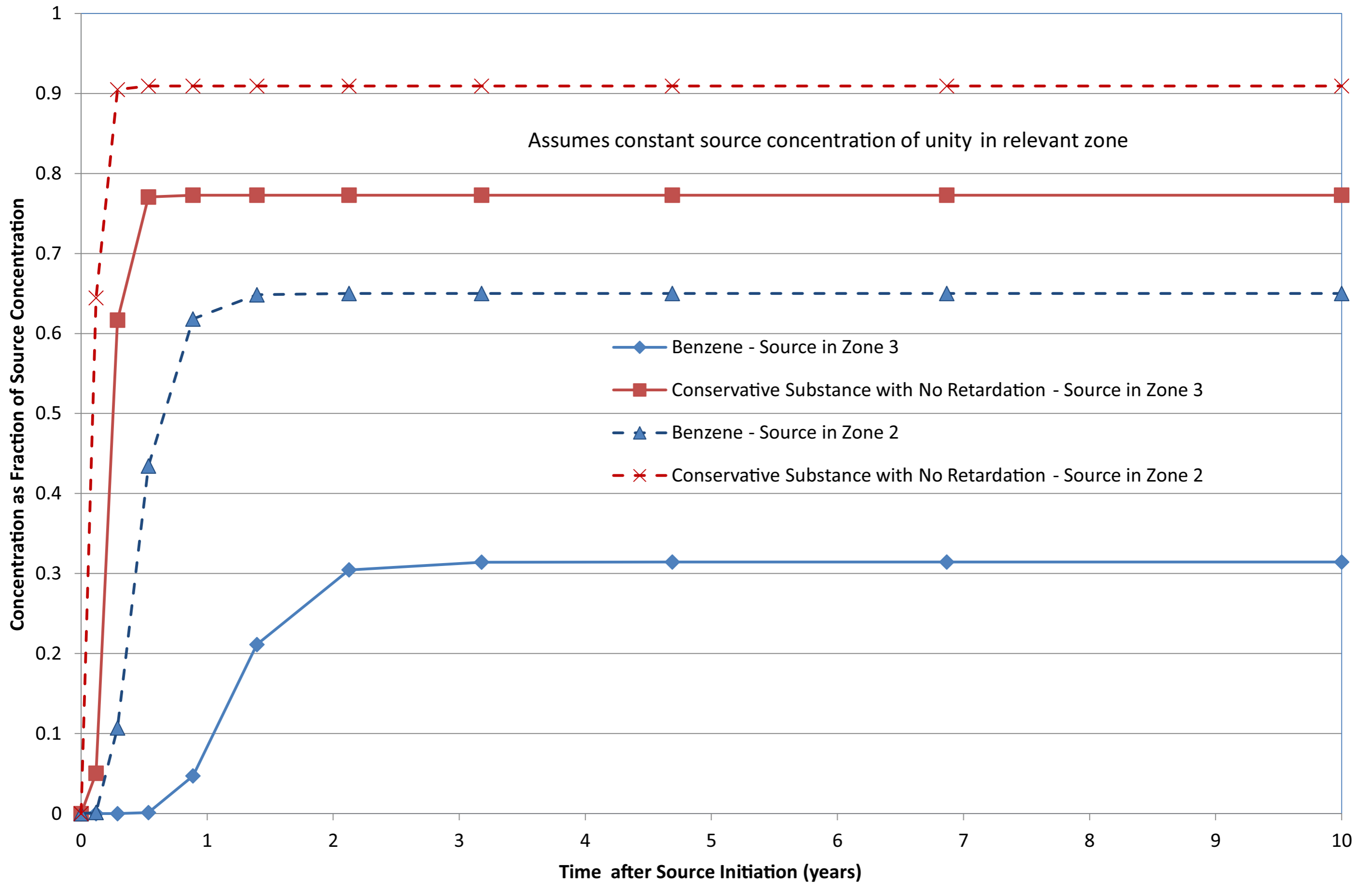
| SLADEN ASSOCIATES | Report No 22-2447 | Project Welbeck Landfill, Wakefield | Figure 6 |

Assumes constant source concentration of unity in relevant zone

Legend:
- Benzene - Source in Zone 3
- Conservative Substance with No Retardation - Source in Zone 3
- Benzene - Source in Zone 2
- Conservative Substance with No Retardation - Source in Zone 2

Y-axis: Concentration as Fraction of Source Concentration

X-axis: Time after Source Initiation (years)

VARIATION IN PREDICTED DISCHARGE CONTAMINANT CONCENTRATION VERSUS TIME FOR BENZENE AND CONSERVATIVE COMPOUND - ASSUMED STEADY INFILTRATION

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|---|---|---|---|
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Assumes constant source concentration of unity in relevant zone

**Legend:**
- Assumed Constant Infiltration - Source in Zone 2
- Assumed Infiltration in Winter Only - Source in Zone 2
- Assumed Constant Infiltration - Source in Zone 3
- Assumed Infiltration in Winter Only - Source in Zone 3
- Assumed Constant Infiltration - Source in Zone 4
- Assumed Infiltration in Winter Only - Source in Zone 4
- Assumed Constant Infiltration - Source in Zone 5
- Assumed Infiltration in Winter Only - Source in Zone 5

X-axis: Time (years)
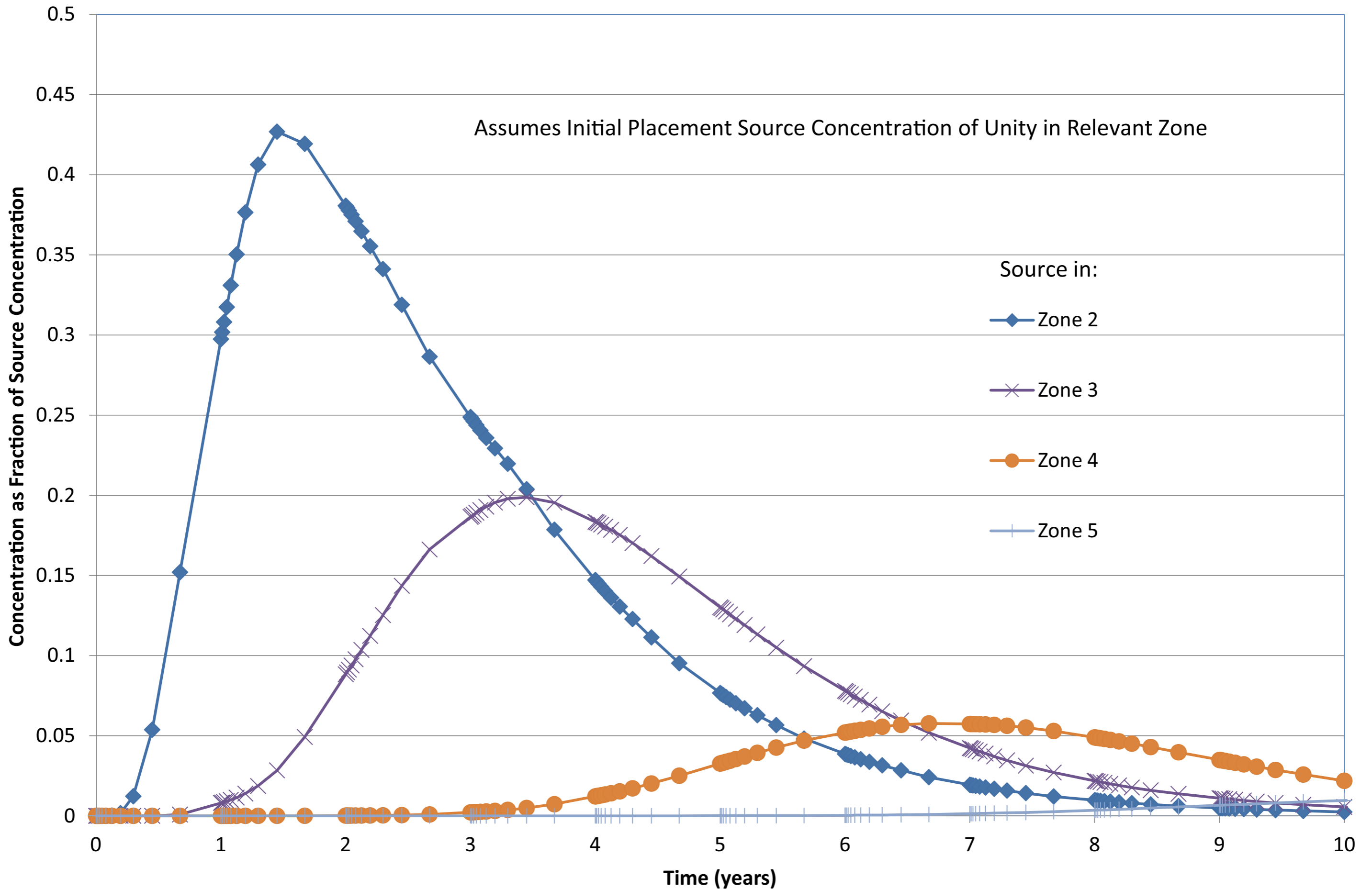Y-axis: Concentration as Fraction of Source Concentration

VARIATION IN PREDICTED DISCHARGE CONTAMINANT CONCENTRATION VERSUS TIME FOR BENZENE - ASSUMED SEASONALLY VARYING INFILTRATION

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| Report No | Project | Figure |
|---|---|---|
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PREDICTED DISCHARGE CONCENTRATION OF AMMONIUM VS TIME FROM SOURCE PLACEMENT

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EFFECT OF INCREASING THICKNESS OF RESTORATION SOILS ON PREDICTED DISCHARGE CONCENTRATION

Assumes constant source of benzene concentration of unity in relevant zone

Legend:
- Base Case - Source in Zone 2
- Restoration Soils Thickness Increased by 1.2m - Source in Zone 2
- Base Case - Source in Zone 3
- Restoration Soils Thickness Increased by 1.2m - Source in Zone 3

X-axis: Time after Source Initiation (years)
Y-axis: Concentration as Fraction of Source Concentration

**SLADEN ASSOCIATES**

| Report No | Project | Figure |
|---|---|---|
| 22-2447 | Welbeck Landfill, Wakefield | **10** |

EFFECT OF REDUCING SATURATED CONDUCTIVITY OF RESTORATION SOILS ON PREDICTED DISCHARGE CONCENTRATION

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