TIER 3 RISK ASSESSMENT

PREPARED FOR

LIMERICK CITY COUNCIL

AT

ILLEGAL LANDFILL SITE,
ST MARYS PARK,
LIMERICK

TIER 3 RISK ASSESSMENT (DETAILED QUANTITATIVE RISK ASSESSMENT) FOR THE WATER ENVIRONMENT, ECOLOGY & HUMAN HEALTH RECEPTORS

for

ILLEGAL LANDFILL SITE, ST. MARY'S PARK, LIMERICK

TABLE OF CONTENTS

TABLES

APPENDICES

APPENDIX A DRAWINGS

Drawing No.	Title	Scale
C4559/01	Site Location Plan	NTS
C4559/02	Teagasc (GSI) Soils and Subsoils Data Plan	NTS
C4559/03	Hydrogeology Vulnerability Plan	NTS
C4559/04	Exploratory Hole Location Plan	NTS
C4559/05	Schematic Cross Section Location Plan	NTS
C4559/06	Schematic Cross Section A-A'	NTS
C4559/07	Schematic Cross Section B-B'	NTS
C4559/08	Waste Mass Zonation Plan	NTS
C4559/09	Groundwater Hazard Plan	NTS
C4559/10	Soil Hazard Plan	NTS
C4559/11	Revised Conceptual Site Model	NTS
C4559/12	Groundwater DQRA Compliance Points	NTS

NTS: Not to Scale

APPENDIX B GROUND INVESTIGATION LOGS

APPENDIX C LABORATORY CHEMICAL TEST RESULTS

APPENDIX D CONTAMINATION SUMMARY TABLES - SOIL AND GROUNDWATER

APPENDIX E RTM WORKSHEETS FOR COMPLIANCE POINTS 'A', 'B' AND 'C'

APPENDIX F SITE-SPECIFIC CALCULATION FOR EXPOSURE FREQUENCY

APPENDIX G CLEA V1.06 RESULTS

APPENDIX H SITE-SPECIFIC CALCULATIONS FOR LEAD IN SOIL

APPENDIX I REFERENCES FOR HUMAN HEALTH RISK ASSESSMENT

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EXECUTIVE SUMMARY

Introduction	An area of land within St. Mary's Park, Limerick City, to the rear of properties on St. Munchin's Street has been subjected to illegal landfilling. In 2010, Limerick City Council ("LCC") undertook a Tier 1 Environmental Risk Assessment in accordance with the "Code Of Practice for Environmental Risk Assessment of Unregulated Waste Disposal Sites", 2007. The assessment concluded that the site should be categorised as "Class B" (i.e. moderate risk) site, given the postulated source-pathway-receptor linkages for surface water drainage, leachate migration and landfill gas. Further assessment was subsequently undertaken by Verde Environmental Consultants Ltd on behalf of LCC that encompassed Tiers 1, 2 and part of Tier 3 of the requirements of the Code of Practice. With respect to completing the requirements of the Tier 3 assessment, Detailed Quantitative Risk Assessment (DQRA) was required to quantify the potential risk posed by the landfilled waste to the water environment, human health and the adjacent Lower River Shannon Special Area of Conservation (SAC). This present report presents the findings of these DQRAs.
Site Details	The site occupies approximately 3.5ha of the overall area of St Mary's Park. The landfill forms a linear feature which is approximately 600m in length, extending, in places, to within *circa* 5m of the residential properties located on the eastern side of St. Munchin's Street. Available information suggests that the total area of the landfill is 17,000m^2. Materials within the landfill have been found to include mixed municipal wastes, animal bedding, manure, construction and demolition wastes totalling an estimated 30,600 tonnes to an average depth of 1.1m below ground level (bgl). Approximately 16,700 tonnes appears to be on the surface, while approximately 13,900 tonnes is buried. Asbestos, paint and other potentially hazardous materials may be present within the waste mass. An extensive clean-up by LCC took place in 2001 where wastes were excavated to a depth of up to 3.0m bgl, it is understood that in the intervening time period, inert fill was used to backfill and raise site levels in areas closest to the rear of the houses. Areas of deeper, older waste may, however, be present. The site borders the boundary of the Lower River Shannon SAC. The River Shannon is present to the north and far west, and the Abbey River is located to the east and south. The topography of the SAC (wet grassland) to the east is generally flat and level. A series of drainage ditches run across the wet grassland area, which is subject to regular flood events.
Ground Conditions	Ground conditions within the northern part of the landfilled area comprise waste materials to a maximum recorded depth of 1.0m. These comprise mixed wastes of variable composition and include horse manure, plastic, wood, demolition wastes and asbestos-containing materials. Waste materials within the southern part of the landfill were proven to a greater thickness (between 1.2 and approximately 2.0m bgl). In this area, reworked natural soils were found to overlie the wastes over part of the area. Shallow underlying soils comprised brown sandy silt with some clay, aggregate fill and occasional cobbles and municipal wastes. These are underlain in turn by natural silt/clay alluvium. Shallow groundwater is present within the natural soils and waste mass.
Potential Pollutant	Potential pollutant linkages were identified through an updated conceptual site model. Residual linkages to surface water (specific the Abbey River), the Lower River Shannon SAC

Linkages	and human health were assessed by DQRA.
Risk Evaluation - Controlled Water Receptors	DQRA has identified a potential risk to the Abbey River under both normal and flood conditions, with the potential impact being greater under the latter conditions where flood water may be very close to, or even make contact with, the waste mass. Given the limitations inherent in any risk assessment model, the small total mass flux of contamination, the relatively low risk identified and the potential for dilution within the receiving water, we conclude that the overall risk posed by site-measured leachable concentrations of chromium, manganese, sulphate and phosphorus is negligible to low and that posed by ammoniacal nitrogen is low to moderate. However, any elevated contaminant concentrations realised at the receptor will be minor and highly localised. The risk to the River Shannon itself and the underlying Dinantian Pure Unbedded Limestone aquifer are both considered negligible.
Risk Evaluation - Ecological Receptors	We have considered whether the measured concentrations of contaminants in near-surface soils immediately adjacent to the SAC could have a direct impact on the ecosystem. Considering the relatively low concentrations recorded and the insignificant exposure intensity, we conclude that this risk is negligible. Using the data from the water environments risk assessment, we have also assessed whether the risk posed by the contaminants of concern entering flood water, drainage water and the Abbey River itself could detrimentally impact individual species or ecosystem functionality within the SAC. Given the low concentrations and mass flux, we consider that the risk is negligible to low for all contaminants except ammonia, for which the potential risk is considered to be moderate, although any impact would be confined to a very small area.
Risk Evaluation - Human Health Receptors	The human health DQRA has demonstrated that the potential risks to human health associated with inorganic and organic contaminants present in near-surface soils is insignificant. Asbestos-containing materials have been recorded within near-surface soils in some parts of the landfilled area. Since there is limited information regarding the forms of asbestos present and, considering the proximity and sensitivity of receptors, we consider that near-surface asbestos within the landfill should currently be considered to present a potentially unacceptable risk to human health. It is recommended that further assessment of the risk from asbestos and appropriate remedial measures be undertaken to address the potential risk to residents and persons working on the site.
Risk Evaluation - Ground Gas	Vapour exposure risk, assessed within the human health DQRA, is negligible. The risk posed by landfill-derived bulk ground gases (methane and carbon dioxide) has not been separately assessed in this present report but current concentrations of these within the landfilled area are very low and that there may not be a viable ground gas transport pathway towards adjacent properties (see Verde "Tier 2/3 Environmental Risk Assessment" report, ref. 20476, July 2011). Current risk is therefore assessed as negligible but may change if there are future alterations to ground cover in the landfilled area or if further putrescible waste is illegally deposited.
Recommendations	Although the modelled impacts are low to moderate, according to the EPA COP risk matrix, the site should be categorised a Class A – Highest Risk site due to the direct linkages between the waste body with surface water and the SAC. Therefore, in accordance with the EPA Cop the site will need to be remediated. Remediation of the site will first require the segregation and removal of all mixed waste items such as plastic, wood, metal, electronic items etc. Once these are removed, it is considered that much of the remaining soils may be suitably categorised as inert fill if a

	diligent segregation process is undertaken. This however will require further verification during the remediation process including consultation with the EPA. Before undertaking any remediation programme a full ecological assessment will also need to be undertaken at the site according to requirements in relation to protection of the SAC. This ecological assessment will need to be undertaken in conjunction with the design of the remediation plan.

1. INTRODUCTION

1.1 Preamble

In 2010, Limerick City Council ("LCC") undertook a Tier 1 Environmental Risk Assessment, in accordance with guidelines presented in the EPA *"Code Of Practice for Environmental Risk Assessment of Unregulated Waste Disposal Sites"* (2007), of land within St Mary's Park, Limerick that has been subject to illegal waste tipping (the "site"). The findings of the investigation concluded that the "illegal landfill" was categorised as "Class B" (i.e. moderate risk), given the postulated source-pathway-receptor linkages for surface water drainage, leachate migration and landfill gas.

Verde Environmental Consultants Ltd ("Verde") was subsequently commissioned by LCC to undertake supplementary risk assessment of the site, so that further site-specific information could be obtained. In consultation with LCC, site works comprising a geophysical survey, intrusive ground investigation (with the collection of soil and groundwater samples for laboratory analysis) and landfill gas monitoring were undertaken. The findings of that assessment are presented in Verde's "Tier 2/3 Environmental Risk Assessment" report (ref. 20476, July 2011).

That assessment encompassed Tiers 1, 2 and part of Tier 3 of the requirements of the EPA Code of Practice (2007). To complete the scope of a Tier 3 assessment, Detailed Quantitative Risk Assessment (DQRA) has been undertaken to allow an assessment of the potential risk posed by the landfilled waste to the water environment, human health and the designated Lower River Shannon Special Area of Conservation (SAC).

This report presents and interprets the DQRA, which has been based upon the salient aspects of the previous investigation and assessment works undertaken at the site.

1.2 Scope of Report

The report, which was designed to meet the requirements of all relevant guidance current at the time of preparation, provides factual and interpretative information relating to the potential risk posed by contamination in, on or under the ground at the illegally landfilled area at the site. The assessment gas addressed the risk posed to human health (site users and occupants of adjacent properties), the water environment (*via* migration through shallow groundwater during normal and flood events) and the receiving ecosystem.

1.3 Data Sources and Conditions

The findings and opinions provided in this document are given in good faith and are subject to the limitations and constraints imposed by the methods and information sources described in this report. The comments and opinions presented in this report are based on the previous findings of desk study and ground investigation work carried out at the site. Verde can accept no liability for the accuracy or reliability of other information relied upon.

There may be other conditions prevailing on the site which have not been revealed by the previous investigations and which have not been taken into account by this report. Responsibility cannot be accepted for any conditions not revealed by previously completed investigations. Any figure or opinion on the possible configuration of strata, contamination or other spatially variable features between or beyond investigation positions is conjectural and given for guidance only.

Confirmation of ground conditions between exploratory holes should be undertaken if deemed necessary. Evaluation of groundwater is based on observations made at the time of the investigation, or subsequently. It should be noted that groundwater levels and quality may however vary because of seasonal and other effects.

This report has been prepared for the sole use of Limerick City Council.

No other third party may rely upon or reproduce the contents of this report without the written approval of Verde. If any unauthorised third party comes into possession of this report, they rely on it entirely at their own risk and the authors do not owe them any Duty of Care or Skill.

2. SITE DETAILS AND DESCRIPTION

2.1 Site Location

The site on which the illegal landfill is located lies within the northern half of Kings Island at St Mary's Park, Limerick. The National Grid Reference for the approximate centre of the site is 557700m E, 658550m N. The location of the site is shown on Drawing No. C4559/01, which is included within Appendix A.

2.2 Site Description

The area under investigation occupies approximately 3.5ha of the overall park area, being situated to the rear of residential properties located on St. Munchin's Street.

The site is immediately adjacent to the boundary of the Lower River Shannon Special Area of Conservation (SAC). The River Shannon itself is present to the north and far west and the Abbey River is located to the east and further to the south. The topography of the SAC (wet grassland) to the east is generally flat and level, lying at approximately 2.0m above Ordnance Datum (aOD). St. Mary's Estate, to the west, lies at an elevation of between approximately 3.0m aOD on the boundary with the landfill, rising to between 4.0m and 5.0m aOD across the estate.

Available information indicates that the wet grassland is moderately species rich and is dominated by iris (*Iris pseudacorus*), reed canary grass (*Phalaris arundinacea*), creeping bent (*Agrostis stolonifera*) and creeping buttercup (*Ranunculus repens*). In addition there are other typical wet grassland species such as spearwort (*Ranunculus flammula*) and marsh bedstraw (*Galium palustre*).

The landfill forms a linear feature which is approximately 600m in length, extending, in places, to within *circa* 5m of the residential properties that are located on the eastern side of St. Munchin's Street. Available information suggests that the total area of the landfill is 17,000m^2. Materials within the landfill have been found to include mixed municipal wastes, animal bedding, manure, construction and demolition wastes totalling an estimated 30,600 tonnes to an average depth of 1.1m bgl. Of this, approximately 16,700 tonnes appears to be on the surface, while approximately 13,900 tonnes is buried. Asbestos, paint and other potentially hazardous materials may be present within the waste mass.

An access track runs from the northern entrance towards the southern end of the waste mass where it is present as a bulbous raised area. These soils are considered to be more recently deposited material and are in direct contact with the SAC's western reaches. This part of the site has been partially vegetated by the invasive species butterfly bush (*Buddleia davidii*) and Japanese knotweed (*Fallopia japonica*).

3. ENVIRONMENTAL SETTING

3.1 Site History

The site is currently owned by Limerick City Council.

Historical Ordnance Survey of Ireland (OSI) information dating back to the 1830s, indicates that a fort was located where the St. Mary's Park housing development currently lies, whilst military exercise grounds were present locally.

Available information provided by Limerick City Council indicates that St. Mary's Park itself was constructed in the 1930s. It was anticipated that intermittent waste disposal occurred in an area referred to as the "Back Field" (i.e. the area to the rear of the houses situated on St. Munchin's Street). An extensive local authority clean-up took place in 2001 where wastes were excavated to a depth of up to 3.0m bgl, it is understood that in the intervening time period, inert fill was used to backfill and raise site levels in areas closest to the rear of the houses. Areas of deeper, older waste may, however, be present.

3.2 Site Geology

The geological data for the site indicates that shallow undisturbed natural strata (overburden) comprise marine/estuarine alluvial soils which consist of silt and clay. These soils are attributable to the Abbey River and are present across the site and to the north and east of the river within the SAC. These soils are anticipated to have a relatively low permeability. Information with respect to the Teagasc soils and sub-soils, obtained from the Geological Survey of Ireland (GSI), is presented as Drawing No. C4559/02 included within Appendix A.

The underlying solid geology comprises limestone, which consists of undifferentiated limestone (Dinantian Pure Unbedded Limestone) and calcareous shale of the Carboniferous period. Previous geophysical investigation of the site indicates that bedrock is present at an approximate depth of 6m below ground level (bgl).

Further information on ground conditions encountered at the site during invasive investigation works is presented within subsequent sections of this report.

3.3 Hydrology and Hydrogeology

Surface Water

The River Shannon is located to the north of the site, flowing in a westerly direction, whilst the Abbey River branches off from the River Shannon approximately 100m to the north of the northern tip of the landfilled area. The Abbey River subsequently flows in a south-easterly and southerly direction, parallel to the landfill, at a distance of approximately 200m, before rejoining the River Shannon towards the south-western point of the island.

The SAC boundary closest to the illegally landfilled area runs along the eastern portion of the island. The SAC area immediately to the east of the landfilled material is a floodplain that normally floods in the winter, slowly draining during spring and summer months through a network of linear land drains which run across the SAC in a grid pattern, trending roughly west-east and perpendicular to Abbey River. The land drains are not maintained and enter a single drain that subsequently runs parallel to the river bank. Drainage from the wet grassland is through a tidal flap into the Abbey River at the northern end of Kings Island.

Information obtained from the OSI indicates that the middle and southern parts of the site are the most susceptible to flooding. These parts of the site are adjacent to a protrusion of the landfilled area towards the SAC boundary and anecdotal information suggests that the waste mass may be partly covered during flood events. It is also indicated that the wetland area may be subject to tidal inundation given its low level.

Previous ecological assessments undertaken at the site, as reported by Limerick City Council in 2001, indicated that there were no particularly rare species within this part of the SAC but that the species recorded became richer further towards the east of the SAC, adjacent to the Abbey River.

Groundwater

The principal legislation governing water quality in Ireland is the European Communities (Water Policy) Regulations 2003 (SI 722, 2003), which transposed the requirements of Directive 2000/60/EC, establishing a framework for Community action in the field of water policy (the Water Framework Directive, WFD) into Irish law.

Information presented on the National Draft Bedrock Aquifer map indicates that the underlying limestone aquifer is described as a locally important aquifer, with bedrock that is generally moderately productive.

According to the Geological Survey of Ireland's 1996 National Vulnerability Data, the vulnerability of the overlying strata at the site is rated as being typically low to high. An examination of the national vulnerability map for the site, which is presented as Drawing No. C4559/03 (Appendix A), indicates that for the majority of the site, particularly on the northern side, it is considered to be of low vulnerability whereas beyond the southern boundary of the site, it is considered to be of high vulnerability.

Available information indicates that there are no groundwater abstraction wells either on-site or within 500m of the site.

4. GROUND INVESTIGATION WORKS

4.1 General

Initial ground investigation works were carried out by Verde at the site between December 2010 and June 2011, at the request of Limerick City Council. These works took the form of a limited borehole and trial pit investigation.

A geophysical survey of the waste mass was also undertaken by Minerex Geophysics Limited in June 2011 to determine ground conditions, delineate any areas of gross landfill leachate, assess the thickness of the waste mass and determine the characteristics of the underlying overburden and depth to bedrock. Information with respect to the survey undertaken in presented in their geophysical survey report (Ref. 5550f-005, dated June 2011) although salient aspects of their investigation and findings have been summarised below.

A summary of the ground investigation works undertaken is presented in Table Error! No text of specified style in document..**1**.

Table Error! No text of specified style in document.**.1 - Summary of Ground Investigation**

Phase of Investigation	Date of Investigation	Exploratory Holes	SI Carried out by
1	2010	BH1 - BH6	Verde Environmental Consultants Ltd
2	2011	TP1 - TP14	
3	2011	Non-intrusive geophysical survey	Minerex Geophysics Ltd

The initial Tier 2 borehole investigation was completed in December 2010 by Verde at the request of Limerick City Council to facilitate the installation of groundwater monitoring wells. Six boreholes were completed to a depth of 5.5m bgl within the northern part of the landfill, penetrating into the underlying undisturbed alluvial soils. No boreholes or monitoring installations were located within the southern part of the landfill due to access constraints. A copy of the investigation logs is presented in Appendix B.

Subsequent trial pitting works were carried out on 16th June 2011 to allow more detailed inspection of the waste mass, confirm the depth and composition of the waste across the surface and at depth, and allow for samples to be collected for laboratory analysis. Fourteen trial pits were excavated using a tracked excavator, the locations of which are presented on Drawing No. C4559/04, within Appendix A.

The summary below refers to two distinct areas of waste at the site, the overall 'Northern' waste mass and the elevated, bulbous 'Southern' end of the waste mass, which combine to form the overall illegal landfill at the site.

4.2 Summary of Ground Conditions

For a detailed description of the actual ground conditions revealed during the investigation reference should be made to the individual trial pit and borehole records presented in Appendix B. The locations of the exploratory holes are presented on Figure C4559/04, Appendix A, whilst topographical survey data of the waste mass is presented on Minerex's geophysical survey location plan (Map 1), dated 13th June 2011, as presented in their report. On the basis of the ground investigation, the general soils profile, for both the northern and southern parts of the waste mass, can be summarised as follows.

Schematic cross-sections have been compiled and depict indicative soil profiles through the northern and southern parts of the waste mass along two transects designated A and B. This information is presented on Drawing Nos. C4559/05, 06 and 07, which are included within Appendix A.

<u>Northern Waste Mass</u>

Ground conditions within the northern part of the waste mass were found to vary along its length. Given the elongated nature of the waste mass and its inherent size, three distinct areas have been identified for ease of reporting: *Zone 1*, which occupies the northernmost part of landfill; *Zone 2*, which lies within the central part of the landfill; and, *Zone 3*, which occupies the southernmost part. The extent of these areas is shown on the Drawing No. C4559/08, presented in Appendix A. Properties of the defined zones are summarised in Table Error! No text of specified style in document..**2** to Table Error! No text of specified style in document..**4**, below.

Table Error! No text of specified style in document.**.2 - Summary of Generalised Soil Profile (Zone 1)**

Lithology	Typical depth (m bgl) to base of stratum	Character
Made Ground (stratified)	0.55-1.0	Large volume of mixed municipal waste with some brown sandy silt, aggregate and cobbles.
	1.1-1.2	Brown sandy silt, some clay, aggregate fill and occasional cobbles and waste. Slight organic odour noted.
	0.25-1.5	Dark brown/black organic (humic) silt with mild decomposition odour and discolouration (possible natural strata).
Alluvium (Clay)	>2.0	Grey and brown silty clay.

Table Error! No text of specified style in document.**.3 - Summary of Generalised Soil Profile (Zone 2)**

Lithology	Typical depth (m bgl) to base of stratum	Character
Made Ground (stratified)	0.5-0.6	Large volume of mixed waste on ground surface including horse manure, plastic, wood, demolition wastes, asbestos containing materials. Mild decomposition odour noted.
	0.75-1.2	Brown sandy silt, some clay, aggregate fill and occasional cobbles and waste. Slight organic odour noted.
	1.5-1.6	Dark brown/black organic (humic) silt with mild decomposition odour and discolouration (possible natural strata).
Alluvium (Silt/Clay)	>3.0	Grey and brown silty clay.

Table Error! No text of specified style in document.**.4 - Summary of Generalised Soil Profile (Zone 3)**

Lithology	Typical depth (m bgl) to base of stratum	Character
Made Ground (stratified)	0.1	Light waste scattered across the ground surface.
	0.45-0.55	Light brown sandy silt with occasional cobbles and waste materials. Soils typically clean with only slight organic odour.
	0.9-1.1	Dark brown/black silt with organic residues and waste materials including plastic, paper, tyres, wood, metal.
Alluvium (Silt/Clay)	>3.0	Grey and brown silty clay.

On the basis of available information, it is apparent that the waste materials deposited on the surface are typically present to a depth of 0.1m within Zone 3, becoming thicker to between approximately 0.5m - 0.6m within Zones 1 and 2, with localised areas of surface wastes to a maximum recorded depth of 1.0m (Zone 1). These materials comprised mixed municipal wastes of variable composition but were observed to include horse manure, plastic, wood, demolition wastes and asbestos-containing materials at various locations. Underlying the surface wastes, two distinct layers of buried made ground soils were proven.

The first layer comprised brown sandy silt with some clay, aggregate fill and occasional cobbles and municipal wastes. These were proven to between 0.5m bgl and 1.2m bgl and were observed to exhibit a slight organic odour, although the soils appeared to be visibly clean. Underlying these were dark brown/black organic silts which were proven to between about 1.1m bgl (Zone 3) and 1.6m bgl (Zone 2). A generally mild decomposition odour and discolouration was recorded across all three of the identified zones, although soils within Zone 3 were noted to include an element of waste including plastic, paper, tyres, wood and metal.

Alluvial deposits were found to underlie the made ground soils from a general depth of about 1.0m bgl within Zone 3, 1.5m bgl in Zone 2 (encroaching into the southern part of Zone 1) and at shallower depth (between 0.7m bgl and 0.25m bgl) in the northern part of Zone 1 where no, or very limited, waste tipping appears to have occurred. Typically the alluvial deposits comprised grey-brown silty clay with no visual and/or olfactory evidence of contamination. No bedrock was encountered during the ground investigation.

Southern Waste Mass

Ground conditions within the raised waste mass to the south were recorded within trial pits TP01, TP07 and TP08. The extent of the raised area and the position of the trial pits are shown on the Drawing No. C4559/08, within Appendix A, and the soil profile is summarised in Table Error! No text of specified style in document..**5**.

Table Error! No text of specified style in document..**5 - Summary of Generalised Soil Profile (Southern part of Landfill)**

Lithology	Typical depth (m bgl) to base of stratum	Character
Made Ground (stratified)	0.55 (localised)	Light brown sandy silt (possibly reworked natural soil).
	1.2-1.95	Large volume of mixed municipal waste including rocks, wood, plastic, rubber wheels, carpet, metal, household waste and demolition soils with some brown sandy silt, aggregate and cobbles. Soils are moist, discoloured and exhibit landfill odour.
	1.6-2.6	Moist, dark brown/black organic (humic) silt with decomposition odour and discolouration (possible natural strata).
Alluvium (Silt/Clay)	>3.0	Grey and brown silty clay.

Deposited waste materials within the southern part of the illegal landfill were proven to reach a maximum thickness of between 1.2m bgl (TP08) and 1.95m bgl (TP07). An overlying layer of reworked natural soil was present at the position of TP01 to a depth of 0.55m bgl, beneath which municipal waste materials were present to 1.8m bgl, although these overlying soils were absent from other investigation locations.

As with the northern part of the landfill, underlying the general waste materials were dark brown/black organic silts; these were proven to between 1.6m bgl and 2.6m bgl. These silty soils were noticeably discoloured and exhibited olfactory evidence of decomposition. Black, humic-rich water was present within these soils. The underlying, undisturbed natural soils comprised grey-brown silty clay with no visual and/or olfactory evidence of contamination. No bedrock was proven during the ground investigation.

4.3 Waste Composition

A physical inspection of the materials excavated during the recent trial pitting works identified a mixture of municipal waste, animal bedding, construction and demolition soils and materials that may be hazardous. A summary of the waste types encountered is presented in Table Error! No text of specified style in document..**6**.

Table Error! No text of specified style in document.**.6 - Summary of Principal Waste Types**

Waste Type	Information
Mixed Municipal Waste	Kitchen waste, paper, cardboard, clothes, textile, metal, furniture, glass, wood, combustion residue (ash and cinder), electrical goods
Animal Wastes	Bedding, sawdust and manure (manure being extensive given the keeping of horses on site)
Construction Materials	Soil, stones, concrete and metal
Hazardous	Electronic goods, fluorescent light fittings and other mercury containing material, refrigerants, paint, ink, adhesives, asbestos containing material

4.4 Groundwater & Flow Characteristics

During the ground investigation, groundwater strikes were noted at a depths of around 3.0m bgl in boreholes BH2 and BH3, with shallower strikes noted in boreholes BH4 (2.5m bgl) and in BH5 and BH6 (1.5m bgl).

The depth to groundwater was generally observed to correspond with the interface between the upper layers of softer alluvial soil, which comprised organic clay, silt and sand/gravel/cobbles and the deeper underlying alluvial soils which, on the basis of borehole information, typically comprised sandy silt/silty clay. Geophysical data for the site confirms that the underlying natural soils comprise softer strata (clay and silt rich saturated overburden) that are within *circa* 2.5m of the surface and that these are, in-turn, underlain by a greater thickness of firm/stiff alluvial clays that become increasingly competent with depth.

Groundwater levels at the site were measured within the monitoring boreholes completed in December 2010, the results of which were presented in the Verde Tier 2/3 Environmental Risk Assessment report (ref. 20476, July 2011). A summary of groundwater levels recorded within the boreholes is given in Table Error! No text of specified style in document..**7**. It should be noted that groundwater level data are only available for the northern part of the site, given that there are no installations towards the south.

Table Error! No text of specified style in document..**7 - Summary of Groundwater Levels**

Well ID	Casing Height (m)	Level at Base of Casing (m aOD)	Approximate Water Level (m bgl)	Approximate Reduced Water Level (m aOD)
BH1	0.38	2.97	0.90	2.07
BH2	0.25	3.42	0.75	2.67
BH3	0.19	3.54	1.23	2.31
BH4	No data due to damage			
BH5	0.28	2.95	0.54	2.41
BH6	No data due to damage			

Elevation data obtained from the geophysical survey plans have been used to calculate reduced water levels within the boreholes where measurements have been obtained. On the basis of available information, therefore, groundwater within the shallow alluvial soils appears to be at its deepest (2.07m aOD) in the north of the site and at approximately 2.5m aOD beneath the rest of the landfill (allowing for slight variations in height). The SAC wetland to the east lies at a general elevation of 2.0m aOD, thus indicating the relatively shallow nature of the groundwater beneath the site.

With respect to river level, it is estimated, in the absence of specific data for the immediate vicinity, that the surface water bodies adjacent to the site lie at an elevation of approximately 1.0m aOD. Groundwater levels beneath the site and SAC are likely to be similar, although they are anticipated to fluctuate according to seasonal variations, baseflow and other factors which affect groundwater flowing towards the rivers. The calculated elevations are, therefore, regarded as tentative.

It has not been possible to draw conclusive groundwater contours for the site and adjacent SAC wetland given that groundwater data is available only for the immediate landfilled area. It is considered, however, that given available information with respect to the local groundwater body (GWB) for Limerick City North and Limerick City North West, the shallow alluvial groundwater body will most probably flow towards both the north-east (nearest point to the Abbey River being 68m) and east (across the SAC), towards the Abbey River (*circa* 220m distant). There may also be some flow in a general south-westerly direction beneath the estate (particularly from the southern end of the waste mass), if influenced by the regional groundwater flow. We note that regional groundwater flow direction is indicated to be towards the River Shannon but, on a local scale, flow will be determined by topography and drainage patterns.

General ground elevations within the waste mass are around 3.0m-3.5m aOD, whereas the SAC lies at a typical elevation of 2.0m aOD. Contours therefore drop relatively quickly from the waste mass before reaching a relatively uniform elevation across the SAC. Although reduced level data for the shallow groundwater is limited, it is estimated, assuming that groundwater across the SAC is at or around 1.0m aOD, that the initial mean hydraulic gradient (*i*) of the alluvial groundwater may be approximately 0.01 in the north and between approximately 0.005 and 0.007 to the east.

Verde do not consider the hydraulic gradients to be constant between and across the northern and southern parts of the landfill and the SAC, however, since this will most probably change locally, either becoming steeper or shallower depending on ground conditions, flow paths, permeability and other influencing factors. The values postulated are therefore regarded as tentative. Additional information relating to porosity and hydraulic conductivity of the underlying shallow alluvial soils is presented further in the report.

Groundwater flow within the limestone bedrock is understood to occur through fractures, faults and fissures, given that there is no significant intergranular permeability. Groundwater flux is thought to be concentrated towards the top 30m of the aquifer, with the GWB being considered to be generally unconfined.

There is considered to be an effective hydraulic interconnection between groundwater and surface water given that groundwater is discharged to the surface as baseflow to those rivers crossing the GWB. The volume of water flowing from the aquifer to the rivers is dependent on the water table elevation and topography however.

4.5 Waste Categorisation

Normal usage of land occupied by a residential housing estate would not ordinarily give rise to any significant potential sources of contamination that may pose a risk to the water environment, ecological habitats and/or the wider environment. Given, however, that the land to the rear of houses situated along St. Munchin's Street has been used for uncontrolled landfill, it is considered that such activities may present a potential risk of causing significant contamination of the surface water itself and the SAC. Most notably, such contamination could result from landfill-derived leachate.

In most instances, soil and waste are mixed together, particularly within the upper layers of the landfill. Sample analysis previously undertaken was therefore primarily based on analytical parameters specified in the European Union Council Decision establishing criteria and procedures for the acceptance of waste at landfill, pursuant to Article 16 of, and Annex to, Directive 1999/31/EC.

Waste Acceptance Criteria (WAC) testing was undertaken on six made ground and waste containing samples, these being:

- TP1 (0.6-1.5m bgl);
- TP7 (2.0-2.3m bgl);

- TP9 (0.0-0.5m bgl);
- TP14 (0.0-0.2m bgl); and two composite soil/waste samples
- Comp-A and Comp-B.

Laboratory test certificates are presented in Appendix C, whilst a summary of those contaminants which exceed the limit values for compliance (leaching test) is given in Table Error! No text of specified style in document..**8**.

Table Error! No text of specified style in document..**8 - Summary of Samples Exceeding Waste Acceptance Criteria**

Sample ID (**Depth in brackets - m bgl**)	**Determinand**	**A_2 10:1 leached concentration (mg/kg)**	**Limit Values for Inert Waste (mg/kg)**
TP1 (0.6-1.5)	Sulphate (Soluble)	2130	1000
TP7 (2.0-2.3)	Sulphate (Soluble)	1140	1000
TP14 (0.0-0.2)	Dissolved Organic Carbon	609	500
COMP-B*	Antimony	0.08	0.06
	Sulphate (Soluble)	2950	1000
	Total Dissolved Solids	5130	4000

* Composite sample for material taken from TP10, TP11, TP12 and TP13.

Laboratory test results for the WAC testing generally indicate that the on-site fill materials would be acceptable for disposal as inert waste, notwithstanding the limited number of elevated concentrations recorded in Table Error! No text of specified style in document..**8**. It should be noted, however, that the on-site wastes contain other materials such as metal, asbestos-containing materials and plastic, which may preclude their disposal as inert waste. The Council directive states that "...where wastes contain other materials, which, if present to an extent, increases the risk associated with the waste sufficiently to justify their disposal in other classes of landfill, they may not be accepted in a landfill for inert waste."

A degree of "sorting" would therefore be needed with respect to the on-site wastes before material could be potentially disposed as inert, given the presence of deleterious materials contained within the waste mass.

4.6 Analytical Results and Contaminant Distribution

Ground investigation works and groundwater monitoring completed between 2010 and 2011 identified the presence of elevated concentrations of metals, metalloids and other inorganic components within the made ground and groundwater. Copies of the relevant laboratory test certificates are presented in Appendix C and summary tables for potential contaminants of concern are presented within Appendix D.

Hazard plans showing a visual representation of the location, composition and concentration of the contaminant burden within soil and groundwater beneath the landfilled area are presented as Drawing Nos. C4559/09 and C4559/10, included within Appendix A.

For convenience, the landfilled area has been divided into two ("north" and "south") for the purposes of assessing soil contamination. Groundwater data are only available for the northern part of the landfill.

Northern Waste Mass - Soil

A total of 9 soil samples were tested.

Laboratory test results and comparison against initial Tier 1 generic assessment criteria (GAC) values indicate that there is only limited soil contamination within the made ground and mixed wastes in this area. An elevated lead concentration (694mg/kg) was recorded in the soil sample taken from TP4 at a depth of 0.1-0.8m bgl, whilst naphthalene was recorded at 1.44m/kg in the near-surface soils at TP14 in the far north The GAC values applied for these contaminants are 450mg/kg and 0.68mg/kg, respectively.

No elevated contaminant concentrations were measured within the natural ground samples analysed.

Southern Waste Mass - Soil

Five soil samples from within the southern waste mass were sent for analysis: three made ground and two from the underlying natural strata.

Of the samples recovered, no elevated contaminant concentrations above the initial Tier 1 screening values were measured.

Groundwater

Contaminant concentrations measured within the on-site soils and mixed wastes appear to be relatively low and WAC leaching test results for selected soil and waste samples were also relatively low.

Some elevated concentrations of metals/metalloids and other inorganic contaminants (including ammoniacal nitrogen) were recorded within the samples of shallow alluvial groundwater recovered from beneath the site.

A summary of the contaminants of concern that exceed the Tier 1 groundwater GAC values applied is given in Table Error! No text of specified style in document..**9**, below.

Table Error! No text of specified style in document.**.9 - Summary of Elevated Contaminant Concentrations Recorded in Shallow Alluvial Groundwater, 2010-2011**

Contaminant	Position	Concentration (µg/l)	Tier 1 GAC (µg/l)
Arsenic	BH1, BH5	18.5 (4.69*), 9.26	7.5
Chromium (Total)	BH1, BH2, BH3, BH4, BH5, BH6	117 (16.8*), 39.7, 93.8, 61.0, 51.5, 85.9	37.5
Chromium (VI)	BH1, BH3	(32.0*), (42.0*)	30
Manganese	BH1, BH2, BH3, BH5, BH6	1280, 467, 545, 2720, 74.8	300
Phosphorus	BH1, BH2, BH3, BH4, BH5, BH6	12200, 1860, 8520, 2820, 3560, 2850	35
Ammoniacal Nitrogen (as NH3)	BH1, BH3, BH5, BH6	482 (11500*), 278 (1700*), 758, 619	-
Ammoniacal Nitrogen (as N)	BH1, BH3, BH5, BH6	396 (9470*), 228 (1400*), 624, 509	65
Sulphate	BH2	(206*)^	187.5^
Total PAH (screen)^^	BH1	0.287*	0.075

* 2011 Groundwater data;
^ value expressed as mg/l;

^^ Total PAH concentration allowable is 0.075µg/l. PAH concentrations measured are accounted for by the naphthalene congener, which has an individual allowable concentration of 2.4µg/l (see MAC-EQS in SI No.272, 2009).

Although monitoring data are limited, given the elevated concentrations of certain contaminants of concern, it is considered that there may be a potential risk to groundwater, surface water and the GAC from the off-site migration of landfill leachate.

The composition of wastes deposited in a landfill and the physico-chemical parameters that result have a major influence on how chemical and biological processes operate within this and, consequently, the chemical composition of the leachate produced. Waste decomposition in a landfill containing putrescible wastes may typically comprise four stages, each characterised by different predominant microbial activity: aerobic, anaerobic, acetogenic and methanogenic (Göbbles and Püttmann, 1997, Water Research, 31, 1609-1618). However, the individual stages of decomposition may not occur within any particular landfill (Robinson, 1995, “A Review of the Comparison of Leachates from Domestic Wastes in Landfill Sites”. Department of the Environment Report No. CWM/072/95) and both gas and leachate production and composition will be directly controlled by various factors including the age and composition of the fill, the geological setting, climate and the degree of air and water ingress.

It is considered that the St. Mary's Park illegal landfill is indicative of relatively stable and mature waste decomposition, in that the leachate is characterised by the presence of relatively low COD, ammoniacal nitrogen, chloride and metals (e.g. zinc, calcium and sodium), whilst the underlying soils at the base of the landfill were noted to comprise humic substances the concentration of which typically increases as organic matter ages. Although the initial 2010 groundwater monitoring results detected reasonable concentrations of dissolved contaminants in groundwater (Table Error! No text of specified style in document..**10**), the 2011 data (Table Error! No text of specified style in document..**11**) show some significant changes that may result from changes in waste decomposition and dilution.

Table Error! No text of specified style in document.**.10 - Summary of 2010 Groundwater Monitoring Results**

Element	**Concentrations (mg/l)**						**Range for other European landfills (mg/l)**
	BH1	BH2	BH3	BH4	BH5	BH6	
BOD	2.94	<1	5.16	<1	1.36	1.98	100-200**
COD	1020	238	595	505	472	2240	-
Calcium	227	164	156	158	189	94	100-400**
Sodium	56	34	51	31	34	31	100-200**
Sulphate	141	131	73	72	19	103	10-1200*
Chloride	84	31	50	37	43	26	30-4000*
Ammoniacal Nitrogen (as NH_3)	0.5	<0.2	0.3	<0.2	0.7	0.6	1.0-1500*

* Andreottola *et al*. (1992) "Chemical and biological characteristics of landfill Leachate", in: Christensen, T. H., Cossu, R. & Stegmann, R. (eds.). Landfilling of Waste: Leachate, pp. 65-88. Elsevier, London.

** Tchobanoglous *et al*. (1993). "Integrated Solid Waste Management: Engineering Principles and Management Issues". McGraw-Hill, New York.

Table Error! No text of specified style in document.**.11 - Summary of 2011 Groundwater Monitoring Results**

Element	**Concentrations (mg/l)**					
	BH1	BH2	BH3	BH4	BH5	BH6
BOD	2.38	<1	<1	No data	<1	No data
COD	89	**286**	123		248	
Sulphate	130	**206**	29		**35**	

Ammoniacal Nitrogen (as NH3)	**11.5**	<0.2	**1.7**		<0.2	

[**bold**] denotes increase in contaminant concentration between 2010 and 2011.

It is anticipated that contaminants are entering the underlying groundwater as a result of either or both: direct contact at the lower depths of the waste mass; and, infiltration through the waste mass.

Surface Water

Three surface water samples were taken from positions along the Abbey River to the east and the River Shannon to the north. Components indicative of potential leachate contamination, such as BOD, COD and ammoniacal nitrogen, were measured. Copies of the individual test certificates are presented in Appendix C and the results summarised in Table Error! No text of specified style in document.**.12**.

Table Error! No text of specified style in document.**.12 - Summary of 2011 Surface Water Analysis**

Element	**Concentrations (mg/l)**			**2010-2011 Groundwater Average on site (mg/l)**	**EQS* (mg/l)**
	SW1 (upstream)	SW2 (downstream - Abbey River)	SW3 (downstream - River Shannon)		
COD	22.5	21.8	21	582	-
BOD	1.08	<1	<1	2.8	-
Ammoniacal Nitrogen (as NH_3)	<0.2 (0.16)	<0.2 (0.16)	<0.2 (0.16)	2.6 (2.1)	0.065*

* S.I. No.9, 2010 value for Ammoniacal Nitrogen as N. Ammoniacal nitrogen results in brackets are the equivalent concentration, as N.

5. CONCEPTUAL SITE MODEL

An initial Conceptual Site Model (CSM) was presented as part of the Tier 1/2 risk assessment and was based on third party information from Limerick City Council, historical data, site location, likely contamination status and the overall risk it presented to the identified receptors through various pollution pathways. A revised CSM was developed and presented in Section 6 of the Verde Tier 2/3 Environmental Risk Assessment report, ref. 20476, July 2011.

In this present report, we have refined the CSM taking specific account of assessing the risks to the water environment, the designated ecosystem and human health receptors. The CSM therefore summarises our understanding of surface and sub-surface features, the potential contaminant sources, transport pathways and receptors in order to assess potential pollutant linkages.

The CSM is presented in schematic form as Drawing No. C4559/11, presented in Appendix A. Table Error! No text of specified style in document..**13** gives a summary of the potential residual pollutant linkages identified in the CSM.

Table Error! No text of specified style in document.**.13 - Potential Pollutant Linkages**

	Source	Pathway	Receptors
1	Solid waste material and any made ground / overburden containing waste or waste-derived organic and inorganic contaminants.	Direct dermal contact, ingestion and inhalation of dust and vapours	Members of the public (including occupants of adjacent properties); animals/wildlife.
		Vertical and Lateral migration via drainage/runoff	Abbey River, Shannon River and SAC.
2	Leachate and groundwater potentially containing a variety organic and inorganic contaminants.	Direct dermal contact and ingestion	Members of the public (including occupants of adjacent properties); site maintenance workers; animals/wildlife.
		Vertical and lateral migration	Abbey River, Shannon River and SAC.
3	Landfill gases being generated within the waste body.	Vapour inhalation	Members of the public (including occupants of adjacent properties); site maintenance workers.

		Accumulation in confined spaces	Adjacent residential properties.

5.1 Contaminant Sources

Northern Waste Mass

Ground conditions within the northern part of the landfill comprise waste materials to a maximum recorded depth of 1.0m bgl (Zone 1). These materials comprise mixed municipal wastes of variable composition including horse manure, plastic, wood, demolition wastes and asbestos-containing materials.

The underlying soils comprised brown sandy silt with some clay, aggregate fill and occasional cobbles and municipal wastes to a depth of between 0.5 and 1.2m bgl. These soils exhibited a slight organic odour, although appeared to be visibly clean. Deeper soils comprised dark brown/black organic silts to a depth of between 1.1 and 1.6m bgl: these exhibited a generally mild decomposition odour and discolouration, although some soils were noted to include an element of waste, including plastic, paper, tyres, wood and metal.

Other than the evidence of waste components and organic matter decomposition, no visual and/or olfactory evidence of contamination was noted during the investigation. The only measured concentrations of contaminants of concern that exceeded the Tier 1 GAC values applied were for lead, the concentration of which only marginally exceeded the GAC.

Alluvial deposits were found to underlie the made ground soils from a general depth of about 1.0m bgl within Zone 3, 1.5m bgl in Zone 2 and at between 0.25 and 0.7m bgl in the northern part of Zone 1 where no, or limited, waste tipping appeared to have occurred.

Southern Waste Mass

Waste materials within the southern part of the landfill were proven to a maximum thickness of between 1.2 (TP08) and 1.95m bgl (TP07). Locally, reworked natural soils were present at surface and underlain by municipal waste materials to about 1.8m bgl. Reworked natural soil cover was absent from other investigation locations.

As with the northern part of the landfill, underlying the general waste materials were dark brown/black organic silts were proven to between 1.6m bgl and 2.6m bgl. These silty soils were noticeably discoloured (humic-containing) and exhibited strong olfactory evidence of decomposition: black, discoloured "humic" water was noted within the soils during the investigation.

Other than the evidence of waste components and organic matter decomposition, no visual and/or olfactory evidence of contamination was noted.

Laboratory test results did not indicate any contaminant concentrations above the initial Tier 1 GAC screening values.

5.2 Pathways

Potential Pathways to Water Environment and SAC

Information presented on the National Draft Bedrock Aquifer map indicates that the underlying limestone aquifer is described as a locally important aquifer, with bedrock that is generally moderately productive.

Investigation works have highlighted the presence of contaminants, representative of landfill leachate, at elevated concentrations within the shallow groundwater beneath the site. The unsaturated zone and underlying natural deposits at the base of the landfill are considered to represent a migration pathway through which the observed contamination has entered the shallow alluvial groundwater body. Given that there are no confining layers between the waste mass and the underlying shallow strata, a complete source-pathway-receptor pollutant linkage has been created.

Although there has been no evidence obtained that this contamination has actually impacted the adjacent SAC or watercourses, it is considered that shallow groundwater represents a potential pathway by which dissolved contamination may migrate laterally across the site and out into the wider groundwater environment. The landfilled material also poses a potential direct risk to surface water at times of flood.

Hydrogeological conditions at the site and beneath the SAC to the east indicate that groundwater most probably flows towards the north-east and east towards the Abbey River: true groundwater is present at depth within the underlying Dinantian Pure Unbedded Limestone strata, with regional groundwater flow directions being towards the River Shannon (i.e. mainly southwards). The River Shannon is not however considered to be at direct risk given the position of the site relative to the river and surface water flow directions. The Abbey River does converge with the River Shannon but this is at the southernmost point on King's Island, approximately 1.4km away, and therefore this does not represent a viable pathway that could pose significant risk to the River Shannon.

It is considered that the shallow alluvial groundwater is in hydraulic continuity with the Abbey River, which lies, at its nearest point, approximately 68m to the north-east of the northern landfill area. Given the anticipated direction of groundwater flow beneath the SAC to the east, the distance to the Abbey River, at which point any site-derived contamination could potentially discharge, is approximately 220m. At times of flood, the distance between the waste mass and the Abbey River may be reduced to only a few metres.

The hydraulic gradient with respect to the northern part of the landfill (i.e. the shortest distance to the Abbey River) has been calculated to be approximately 0.01, whilst the gradient for the remainder of the site (for water flowing eastwards towards the Abbey River) is between approximately 0.005 and 0.007.

With regard to the deeper limestone aquifer, the site is underlain by a substantial thickness of low permeability cohesive soils, which afford protection. Consequently, it is unlikely that significant pathways exist for contaminants to impact on the underlying bedrock.

Human Health

Both those accessing the site and residents of the adjacent properties could be exposed to contamination derived from the landfilled materials. Several active pathways can be recognised:

- Direct dermal contact with landfill soils;
- Indirect dermal contact with landfill soils *via* household dust;
- Direct ingestion of landfill soils;
- Indirect ingestion of landfill soils *via* household dust;
- Inhalation of landfill soil-derived dust in indoor and outdoor air;

- Inhalation of volatile vapours in indoor and outdoor air.

5.3 Receptors

Water Environment and Ecological Receptors

The following potential receptors are considered to be potentially vulnerable as a result of the contaminant sources and pathways identified:

Abbey River: it is possible that the river may be at risk of impact through the migration of dissolved contaminants *via* the alluvial groundwater or flood drainage.

SAC: the site setting is sensitive given the presence of legally designated habitats. There remains the potential for contamination to migrate in groundwater and flood water to the SAC wetland.

Human Health

Due to prolonged periods of occupancy, the most sensitive receptors within the conceptual site model are considered to be residents of St. Munchin's Street located immediately adjacent to the landfilled area. In accordance with best practice guidance, the most sensitive receptor group in a normal residential setting will be females within the 0 to 6 year old age class.

It has been assumed that this receptor group may have some direct contact with the landfill soils due to playing on or walking through the area as well as being indirectly exposed *via* dust and vapours.

There is also a potential risk to maintenance workers or council employees visiting or working on the site although this is likely to be less significant than for the adjacent residents due to the limited exposure duration of such activities and the fact that such works will be undertaken under health and safety procedures. These receptors are therefore not considered further.

6. DETAILED QUANTITATIVE RISK ASSESSMENT FOR WATER RECEPTORS

6.1 Methodology

On the basis of the CSM outlined in Section 5, above, a groundwater DQRA has been carried out in accordance with the Environment Agency of England and Wales (EA) “Remedial Targets Methodology” (RTM) for assessing risk to the water environment. This assessment was undertaken using the EA's RTM Worksheet model.

As discussed above, a potential risk to both the SAC and adjacent stretch of the Abbey River may exist from the presence of leachable contaminants within soil and groundwater at the site. An assessment of risk associated with the lateral migration of this contamination *via* shallow alluvial groundwater to the adjacent Abbey River is presented in this section. The data obtained in this assessment also informs the assessment of potential risk to the SAC, which will be discussed in Section 7, below.

In assessing potential risk to the Abbey River, a Level 3a RTM assessment has been undertaken, using the groundwater beneath the landfill as the source term. The Level 3a assessment allows for contaminant concentrations to be directly entered into the model, without the need to simulate their passage through the unsaturated zone, which is the most appropriate approach in this case given the presence of landfilled wastes within the (permanently or temporarily) saturated zone and the measured concentrations of contamination within the shallow groundwater at the source.

6.2 Parameterisation

<u>Contaminants of Concern</u>

Given the relatively limited number of boreholes from which representative groundwater samples have been obtained, the groundwater source term with respect to the model is based on the complete waste body, rather than it being divided into smaller parcels. In this instance the source is therefore 600m long by 70m wide (at its widest point). By modelling the source as a single entity, it is considered to provide a conservative overall assessment of potential impacts from several contaminants of concern, which may have varied and sporadic spatial distributions within the fill. It is also considered that this averaging approach is the most appropriate given the limited dataset for the groundwater leachate concentrations available.

All of the available elevated groundwater data associated with the site has been used to derive representative contaminant input concentrations for the RTM Worksheets wherever possible. A full summary of the contaminant input parameters used within the model is given in Table Error! No text of specified style in document..**14**, below, whilst the spatial distribution of groundwater contaminants of concern are shown on the appended groundwater hazard plan, Figure C4559/09. Individual groundwater laboratory test results are presented in Appendix C.

Table Error! No text of specified style in document..**14 - Contaminant Concentrations Used in Modelling**

Contaminant of Concern	**Groundwater Concentrations (µg/l)**		
	Minimum	**Maximum**	**95th %ile**
Arsenic	0.4	18.5	14.3
Chromium (Total)*	13.3	117	106
Chromium (VI)	32.0	42.0	41.5
Manganese	7.4	2720	2360
Phosphorus**	1860	12200	11280
Ammoniacal Nitrogen (as N)	228	9470	7453
Sulphate	18700	206000	176750

* Modelled as Cr (III);
** Modelled as Phosphate.

Input concentrations for contaminants of concern within the groundwater leachate have been defined as the "most likely", which is defined as the 95th percentile upper confidence limit (UCL) estimate of the true mean value of the data-set. This is in line with current best practice.

Three compliance points for assessment have been determined, as shown on Drawing No. C4559/12, included in Appendix A. These are:

a) the Abbey River, located 68m to the north-east of the northern end of the landfill;

b) the Abbey River, located 220m to the east of the landfill, and;

c) an arbitrary distance of 2m from the eastern edge of the landfill to the western edge of the SAC, assuming the Abbey River is in flood and in near direct contact with the waste mass.

It has been conservatively assumed that degradation of contaminants will take place within the dissolved phase only.

Geology and Hydrogeology

Models such as the RTM require the input of certain geological and hydrogeological parameters to determine the fate and transport of contaminants within the subsurface. At the site, it is considered that the primary pathway for the transport of dissolved contaminants of concern to the compliance points is within the shallow alluvial groundwater.

Table Error! No text of specified style in document..**15** presents the geological and hydrogeological parameter values that were used in the model. These were based upon site data, where available, and literature-derived values. A degree of conservatism was applied in the selection of values.

Table Error! No text of specified style in document.**.15 - Summary of Alluvial Aquifer Soil Input Parameters**

Matrix	Fraction of Organic Carbon	Moisture Content (%)	Bulk Density (g/cm^3)	Effective Porosity (fraction)	Hydraulic Conductivity (m/d)*
Alluvium (Silty Clay)	0.001 - 0.004	17 - 34**	2.5	0.03 – 0.2	~0.0004 (4.7E-09m/s)

Data from EA ConSim 2.5 database unless otherwise stated;
* Domenico, P.A. and Schwartz, F.W. (1990) Physical and Chemical Hydrogeology;
** Site-specific soil moisture contents.

Source Zone & Aquifer Input Parameters

Input parameters specific to the identified groundwater source zone are given in Table Error! No text of specified style in document..**16** to Table Error! No text of specified style in document..**18**.

Table Error! No text of specified style in document.**.16 - Summary of Input Parameters - Compliance Point 'A'**

Parameter	Unit	Distribution	Justification
Hydraulic gradient	*i*	0.01	Estimated from contour elevations, anticipated groundwater levels and distance to compliance point
Aquifer thickness	m	6.0 – 8.0	Approximate depth to underlying bedrock from geophysical survey data
Maximum width of contaminated zone perpendicular to groundwater flow	m	50	Approximate site dimensions from topographical survey. Length of contaminated site taken to be the whole site, thus presenting worst-case scenario. Thickness of contaminated zone assumed to be max. thickness of made ground (2m)
Length of contaminated site	m	600	
Groundwater flow direction	º	35	Approximate flow path direction of groundwater to Abbey River. Value taken from topographical survey plan
Down-gradient distance to receptor	m	68	Shortest distance measured from site plans to Abbey River
Longitudinal dispersivity (ax)	m	6.8	10% distance to compliance point
Transverse dispersivity (az)	m	0.68	1% distance to compliance point
Vertical dispersivity (ay)	m	0.068	0.1% distance to compliance point

Table Error! No text of specified style in document.**.17 - Summary of Input Parameters - Compliance Point 'B'**

Parameter	Unit	Distribution	Justification
Hydraulic gradient	*i*	0.005 - 0.007	Estimated from contour elevations, anticipated groundwater levels and distance to compliance point
Aquifer thickness	m	6.0 – 8.0	Approximate depth to underlying bedrock from geophysical survey data
Maximum width of contaminated zone perpendicular to groundwater flow	m	600	Approximate site dimensions from topographical survey. Length of contaminated site taken to be the whole site, thus presenting worst-case scenario. Thickness of contaminated zone assumed to be max. thickness of made ground (2m)
Length (depth) of contaminated site	m	70	

Parameter	Unit	Distribution	Justification
Groundwater flow direction	º	90	Approximate flow path direction of groundwater to Abbey River
Down-gradient distance to receptor	m	220	Shortest distance measured from site plans to Abbey River
Longitudinal dispersivity (ax)	m	22.0	10% distance to compliance point
Transverse dispersivity (az)	m	2.2	1% distance to compliance point
Vertical dispersivity (ay)	m	0.22	0.1% distance to compliance point

Table Error! No text of specified style in document.**.18 - Summary of Input Parameters - Compliance Point 'C'**

Parameter	Unit	Distribution	Justification
Hydraulic gradient	*i*	0.005 - 0.007	Estimated from contour elevations, anticipated groundwater levels and distance to compliance point
Aquifer thickness	m	6.0 – 8.0	Approximate depth to underlying bedrock from geophysical survey data
Maximum width of contaminated zone perpendicular to groundwater flow	m	600	Approximate site dimensions from topographical survey. Length of contaminated site taken to be the whole site, thus presenting worst-case scenario. Thickness of contaminated zone assumed to be max. thickness of made ground (2m)
Length (depth) of contaminated site	m	70	
Groundwater flow direction	º	90	Approximate flow path direction of groundwater to Abbey River
Down-gradient distance to receptor	m	2.0	Shortest distance measured from site plans to Abbey River
Longitudinal dispersivity (ax)	m	0.2	10% distance to compliance point
Transverse dispersivity (az)	m	0.02	1% distance to compliance point
Vertical dispersivity (ay)	m	0.002	0.1% distance to compliance point

Contaminant Properties

The input parameters presented in Table Error! No text of specified style in document..**19** were used to describe the physico-chemical properties of each contaminant of concern.

Given that only inorganic contaminants of concern were identified at concentrations exceeding the GAC values applied in screening, biodegradation of the contaminants of concern was not relevant.

Table Error! No text of specified style in document.**.19 - Summary of Contaminant Specific Input Parameters**

Contaminant of Concern	Half-Life (Years)	Soil Water Partition Coefficient (K_d) (l/kg)	Target concentration (mg/l)
Arsenic	9.9E+99^	5.0E+02	0.0075^^
Chromium*		4.8E+03	0.0375^^
Chromium (VI)		1.8E+01	0.03^*
Manganese		5.0E+06	0.3^**
Phosphate		0	0.035^^
Ammonium		5.0E-01 to 2.0E+00**	0.065^^
Sulphate		0	187.5^^

Data sourced from EA ConSim 2.5 database and Nathanail *et al* (2009), unless otherwise specified;
* Chromium (III) dominates in most redox environments unless a specific source of Cr (VI) exists;
^ Half-life set to maximum to represent no degradation;
** EA NGWCLC Report, NC/02/49, Review of Ammonium Attenuation in Soil and Groundwater, 2003;
^^ EC Groundwater' Regulation 2010 (S.I. No.9, 2010);
^* EC 'Surface Water' Regulations 2009 (S.I. No. 272, 2009);
^** EQS (Freshwater), October 2004, Issue No.1, WRc - NSF National Centre for Environmental Toxicology.

6.3 Results

The three compliance point cases were modelled in individual RTM Worksheets to assess the predicted impact of the identified potential contaminants of concern at the Abbey River receptor. Results for each case are presented in Table Error! No text of specified style in document..**20** to Table Error! No text of specified style in document..**22**, below, and copies of the RTM Worksheets are provided in Appendix E.

Results are assessed against the Generic Assessment Criteria for the compliance points. These are, wherever possible, the EQS values.

Table Error! No text of specified style in document.**.20 - Predicted Impacts to Abbey River: Compliance Point 'A' (~68m)**

Contaminant of Concern	Target Concentration (mg/l)	Predicted Concentrations at Abbey River Receptor (mg/l)	On-site Remedial Target Concentration (RTC) (mg/l)
Arsenic	0.0075	0.007	0.01
Chromium (III)	0.0375	0.05	0.07
Chromium (VI)	0.03	0.02	0.06
Manganese	0.3	1.14	0.62
Phosphate	0.035	5.47	0.07
Ammoniacal Nitrogen (as N)	0.065	3.61	0.13
Sulphate	187.5	85.7	387

Shaded cells indicate that the predicted concentration exceeds the GAC;
Data used are the 95th percentile value for groundwater source concentration.

Table Error! No text of specified style in document.**.21 - Predicted Impacts to Abbey River: Compliance Point 'B' (~220m)**

Contaminant of Concern	Target Concentration (mg/l)	Predicted Concentrations at Abbey River Receptor (mg/l)	On-site Remedial Target Concentration (RTC) (mg/l)
Arsenic	0.0075	0.002	0.05
Chromium (Total)	0.0375	0.02	0.23
Chromium (VI)	0.03	0.006	0.19
Manganese	0.3	0.38	1.86
Phosphate	0.035	1.82	0.22
Ammoniacal Nitrogen (as N)	0.065	1.2	0.44
Sulphate	187.5	28.5	1160

Shaded cells indicate that the predicted concentration exceeds the GAC;
Data used are the 95th percentile value for groundwater source concentration.

Table Error! No text of specified style in document.**.22 - Predicted Impacts to Abbey River during Flood Conditions: Compliance Point 'C' (~2m)**

Contaminant of Concern	Target Concentration (mg/l)	Predicted Concentrations at Abbey River Receptor (mg/l)	On-site Remedial Target Concentration (RTC) (mg/l)
Arsenic	0.0075	0.01	0.0075
Chromium (Total)	0.0375	0.1	0.0375
Chromium (VI)	0.03	0.04	0.03
Manganese	0.3	2.36	0.3
Phosphate	0.035	11.3	0.035
Ammoniacal Nitrogen (as N)	0.065	7.45	0.065
Sulphate	187.5	177	188

Shaded cells indicate that the predicted concentration exceeds the GAC;
Data used are the 95th percentile value for groundwater source concentration.

6.4 Sensitivity Analysis

Further to the modelling of groundwater contaminant concentrations for compliance points 'A', 'B' and 'C', consideration was given to the sensitivity of the model to variation in the selected parameters. Sensitivity analysis is used to identify those parameters whose input values have the most impact on the model results.

The sensitivity analysis has been completed for one of the most persistent contaminants associated with municipal and mixed-waste landfill sites, ammonium, for the compliance model 'B'. Predicted model concentrations for ammonium in the base case Model 'B' were 1.2mg/l, which compares to an EQS of 0.065mg/l. The results of the sensitivity analysis are presented in Table Error! No text of specified style in document.**.23**.

Given the shallow hydraulic gradient and short flow path, reasonable ranges of hydraulic conductivity and hydraulic gradient did not significantly affect the results of the model.

Table Error! No text of specified style in document.**.23 - Results of Sensitivity Analysis - Ammoniacal Nitrogen - Model 'B'**

Parameter	Input Values		Predicted Impact at Receptor (mg/l)	Sensitivity
	Initial	Revised		
K_d	2.00E+00	5.00E-01	No change	Unimportant
		1.00E+00	No change	
		1.50E+00	No change	
Plume thickness at source (m)	2.00E+00	2.50E+00	1.49	Moderate to High
		1.50E+00	0.90	
		1.00E+00	0.60	
Initial contaminant concentration in groundwater at plume core (mg/l)	7.45E+00	5.55 (25%)	0.89	Moderate to High
		3.70 (50%)	0.59	
		1.85 (75%)	0.29	
Distance to compliance point (m)	2.20E+02	1.10E+02	2.35	High
		5.50E+01	4.35	
		2.80E+01	6.63	

On the basis of the sensitivity analysis, it is evident that the most sensitive parameters are physical. However, the waste mass at the site is variable in its length, width, thickness, depth and distance to the SAC wetland to the east. To model the site in 3-dimensional detail is not readily feasible, would require a large amount of additional site investigation data, and probably would yield relatively minor differences in *local* predicted compliance point concentrations given the pathway length.

The three models run within the remit of the groundwater DQRA are therefore considered to be reasonably “representative” of the available dataset and to provide a reasonable “worst-case” assessment.

6.5 Risk Evaluation

We present below an evaluation of the risk to water environments for each of the modelled scenarios.

Model 'A'

1. With respect to Model 'A' (approximately 68m to the Abbey River from the northern end of the waste mass), concentrations of chromium (III), manganese, phosphate, ammoniacal nitrogen and chloride within the shallow alluvial groundwater beneath the site are predicted to present a potentially unacceptable risk to the Abbey River, assuming that discharge of groundwater into that receptor takes place. Model 'A' is considered to be a conservative model;

2. In comparing the predicted concentrations against relevant quality standards, concentrations of chromium, at the river, were predicted to be 0.05mg/l. Surface water monitoring results for works undertaken in 2011 indicate however that the concentration for chromium (total) within the river water is 0.005mg/l, an order of magnitude less: risk from chromium is therefore considered to be **low**;

3. Concentrations of manganese at compliance point 'A' were predicted to be 1.14mg/l. Considering the conservative assumptions in the model, the risk is considered to be **low to moderate;**

4. Phosphate concentrations at the compliance point were predicted to be 5.47mg/l. Surface water test results for phosphate yielded concentrations of <0.05mg/l in all three samples. Given these data and the fact that a significant proportion of the measured phosphorus at the source may be in forms less mobile than phosphate, the risk is therefore considered to be **low to moderate**;

5. Ammoniacal nitrogen concentrations (as N) were predicted to be 3.61mg/l with respect to Model 'A', which exceeds the groundwater quality standard of 0.065mg/l (65µg/l). Ammoniacal nitrogen concentrations within the surface water (as NH_3) were below laboratory detection limits. Ammoniacal nitrogen, given its persistence in landfill-derived leachate sources, may present a long-term threat to water quality and, as such, is considered to be a **moderate** risk.

Model 'B'

1. With respect to Model 'B' (~220m to the east at Abbey River), predicted concentrations for arsenic, chromium and sulphate were below the relevant quality standards with respect to risk to the Abbey River surface water receptor. Model 'B' is considered to be the most representative of the three models as it allows for a greater degree of attenuation, given the increased distance between source and receptor under normal circumstances;

2. Manganese concentrations (0.38mg/l) are predicted only to marginally exceed the Freshwater EQS of 300µg/l (0.3mg/l), whilst elevated concentrations of phosphate (1.82mg/l) and ammoniacal nitrogen (1.2mg/l) were predicted at the receptor above guidance levels. Given the elevated nature of their predicted concentrations in both models, 'A' (short attenuation potential) and 'B' (long attenuation potential), **manganese, phosphorus and ammoniacal nitrogen are considered to be the primary risk drivers** with respect to any remedial works that may be required at the site.

Model 'C'

1. Predicted concentrations for each of the eight individual contaminants of concern modelled within the risk assessment were noted to be in excess of relevant groundwater and/or surface water assessment criteria. Model 'C' was run to mimic flood conditions, assuming that the distance to the receptor was dramatically reduced (to *circa* 2m). No allowance for dilution effects within the accumulated surface water were made under this scenario, which is consistent with EA RTM guidance. **All contaminants of concern are therefore considered to present a potential risk to the water environment in times of flood**.

2. In assuming that there could be direct contact between the waste and the receptor, the model predicts that legislative limits for the protection of the water environment will be directly applicable. This is to be expected.

3. Although the waste mass at the site is most probably in direct contact with the underlying groundwater (including for models 'A' and 'B' above), it is the 'flood' scenario which demonstrates the greatest risk for contaminant transport to surface water given the lack of

attenuation between the source and the receptor: predicted receptor concentrations directly reflect those of the source.

Overall

Surface water monitoring, albeit limited in extent, along the Abbey River and River Shannon provides basic “off-site” data with which the predicted contaminant concentrations for Models 'A' and 'B' may be compared. Although contamination, once in these surface water bodies, will be significantly diluted, this comparison allows for an assessment to be made as to whether the RTM models are overestimating or underestimating contaminant concentrations at the receptor.

The nature of the site, particularly the potentially discrete distribution of the individual contaminants and the unavoidable “simplification” of the source zone represented in the model, will almost certainly have contributed to a conservative assessment, despite our best endeavours to apply realistic input parameters. **Given the limitations of the models, therefore, the predicted contaminant concentrations should be regarded as a realistic “worst-case” but may never be realised in reality.** This is particularly the case since, in line with current guidance, there is no consideration of the potential for dilution within the receptor itself.

Reductions to waste mass and/or contaminant concentrations would result in a reduced potential for the contamination of the water environment and effect on sensitive wetland species. However, it should be noted that in times of flood (when the Abbey River and River Shannon encroach onto the wetland and, potentially, make contact with the landfilled waste), contaminant concentrations at the receptor increase significantly, this being a function of distance and a reduction in the potential for attenuation. However, in reality, there will be significant dilution within the surface water and **the likelihood of the site having a significant detrimental effect on general surface water quality is low**.

7. RISK TO ECOLOGICAL RECEPTORS

7.1 Special Area of Conservation

The Lower River Shannon SAC is the second largest SAC in Ireland with an overall area of approximately 64,000ha that encompasses the lower River Shannon and Shannon Estuary from Killaloe to Loop and Kerry Head. The SAC includes the lower freshwater reaches of the Cloon, Fergus Kilmastulla and Mulkear rivers and the Shannon Fergus Estuary cSPA and Loop Head cSPA.

The SAC is of international ecological importance and contains eighteen important habitats, six protected bird species and six other protected vertebrate species. Overall, the Shannon and Fergus Estuaries support the largest numbers of wintering waterfowl in Ireland. Species listed on Annex I of the EU Birds Directive include the Great Northern Diver, Whooper Swan, Brent Goose and Bar-tailed Godwit.

Flowing into the estuary are a number of tidal rivers, including the River Shannon which runs from Killaloe in the north-east to Limerick, along with some of its tributaries and the Abbey River. The River Shannon is typically broad and slow flowing, being naturally eutrophic (nutrient-rich) water that encourages the growth of algae. Semi-natural habitats including wet grassland, wet woodland and marsh occur along the length of the river although “improved grassland” or “reclaimed” land is most common, this being protected by embankments.

Five species of fish are recorded to be important within the SAC: Sea Lamprey (*Petromyzon marinus*); Brook Lamprey (*Lampetra planeri*), River Lamprey (*Lampetra fluviatilis*); Twaite Shad (*Allosa fallax fallax*); and, Salmon (*Salmo salar*). Each of the lampreys and the salmon have been observed in the lower Shannon river or its tributaries.

Water quality within the upper reaches/upper estuary of the Shannon around Limerick City is generally regarded as poor, although water quality elsewhere is generally satisfactory. Available information suggests that the poor quality is due to sewage discharge.

7.2 Ecological Survey - St. Mary's Park

We understand that ecological survey of the wet grassland within the SAC area to the east of the site has recorded that the site is moderately species rich, with flora dominated dominated by iris (*Iris pseudacorus*), reed canary grass (*Phalaris arundinacea*), creeping bent (*Agrostis stolonifera*) and creeping buttercup (*Ranunculus repens*). In addition, there are other typical wet grassland species such as spearwort (*Ranunculus flammula*) and marsh bedstraw (*Galium palustre*) present. Due to the season in which that survey was undertaken it was not possible to compile a more detailed species inventory.

As described above, a series of shallow linear land drains run in a grid pattern across the area of SAC located within St Mary's Park, which is situated between the eastern edge of the landfill and the Abbey River to the east. These drain into a single drain which runs parallel with the river bank before discharging through a tidal flap into the Abbey River at the northern end of Kings Island. The ecological survey indicates that there appears to be limited variation in the vegetation within the drains, as opposed to the overall site, whilst the sides of the embankment have patchy briar (*Rubus fruticosus*) and willow (*Salix* spp.) scrub along its flanks.

To the south of the illegal landfill, an elevated area comprising overburden material has been partially vegetated by the invasive species butterfly bush (*Buddleia davidii*) and Japanese Knotweed (*Fallopia japonica*).

We understand that the St Mary's Park land area is used by a variety of wintering birds for feeding purposes including snipe, redshank, mallard and black-headed gull, which were all present in small numbers during the survey.

7.3 Risk Evaluation - Impact on the Ecosystem of Contamination in Soil

The St Mary's Park area is used by a variety of wintering birds for feeding purposes. It is therefore pertinent to consider the potential impacts of soil-associated contamination on those species and their food sources.

The landfilled area itself is poorly and sparsely vegetated, which can be attributed to a combination of disturbance, poor soil quality and, potentially, contamination. However, these do not themselves form part of the SAC.

Since the landfilled area approaches, but does not actually encroach upon, the area of the SAC, the exposure of the ecosystem to soil-associated contamination will be confined to wind-blown dust or other tracked soil migrating onto that area, which will make a negligible contribution to risk.

However, bird and mobile invertebrates from the SAC may enter the landfilled area for feeding purposes and it is pertinent to consider what exposure may result.

Considering first of all the measured soil concentrations (Appendix D), it is noteworthy that the recorded values are relatively low. Comparing these to the EA's highly conservative Soil Screening Values (SSVs) designed to be applied for area-averaged soil concentrations within a protected ecosystem site itself (Environment Agency "Guidance on the Use of Soil Screening Values in Ecological Risk Assessment", Science Report SC070009/SR2b, 2008), it is apparent that only a limited number of spatially discrete samples exceed those screening values, specifically:

- one sample for benzo(a)pyrene (TP01, 0.6-1.5m, measured concentration 0.54mg/kg relative to SSV of 0.15mg/kg);
- three samples for cadmium (maximum measured concentration of 1.5mg/kg in TP04, 0.1-0.8m against a SSV of 1.15mg/kg);
- nine samples for chromium (maximum measured concentration of 43.1mg/kg in TP04, 0.1-0.8m against a SSV of 21.1mg/kg);
- one sample for lead (TP04, 0.1-0.8m, measured concentration 694mg/kg relative to SSV of 167.9mg/kg);
- seven samples for nickel (maximum measured concentration of 34.8mg/kg in TP04, 1.2-2.0m , against a SSV of 21.1mg/kg); and,
- three samples for zinc (maximum measured concentration of 1170mg/kg in TP11, 1.2-1.5m, against a SSV of 90.1mg/kg).

Moving on to consider the exposure frequency, any entry of protected species onto this small and sparsely vegetated area of land within the SAC will be transient and intermittent. For both reasons, **the risk posed directly by soil-borne contamination to the ecosystem will be negligible**.

7.4 Risk Evaluation - Impact on the Ecosystem of Contamination Entering Surface Water

It was noted above that there appears to be limited variation in the vegetation within the drains, as opposed to the overall site. Since these form a small proportion of the surface area of St Mary's Park, the risk posed by contamination on the ecosystem within those is considered to be low.

With regards to the general area of St Mary's Park and the wider SAC, the water environments DQRA provides a robust basis for determining the significance of contamination that could migrate from the illegally landfilled area to enter surface water and thereby impact the protected ecosystem associated with this.

Seven potential contaminants of concern were identified as being present in the shallow alluvial groundwater beneath the site (in effect within landfill leachate) at concentrations in excess of regulatory groundwater and surface water guideline values. The contaminants of concern were found to be arsenic, chromium (total and Cr (VI)), manganese, phosphorus, ammoniacal nitrogen and sulphate.

Subsequent DQRA, assuming the Abbey River to be the principal surface water receptor, indicated the potential for contamination to enter the surface water at concentrations that exceed the applicable target concentrations for surface water. A summary of the findings of the risk assessment are presented in Table Error! No text of specified style in document..24 below.

Table Error! No text of specified style in document.**.24 - Predicted Groundwater Contaminant Concentrations at Compliance Points 'A', 'B' and 'C'**

Contaminant of Concern	Concentration at Receptor (mg/l)			Target Concentration (mg/l)	Pass/Fail
	Model 'A'	Model 'B'	Model 'C'		
Arsenic	0.007	0.002	0.01	0.0075	Fail
Chromium (total)	0.05	0.02	0.1	0.0375	Fail
Chromium (VI)	0.02	0.006	0.04	0.03	Fail
Manganese	1.14	0.38	2.36	0.3	Fail
Phosphorus**	5.47	1.82	11.3	0.035	Fail
Ammoniacal Nitrogen (as N)*	3.61	1.2	7.45	0.065	Fail
Sulphate	85.7	28.5	177	187.5	Pass

Shaded cells indicate that the predicted concentration exceeds relevant GAC by the greatest amounts;
* Ammoniacal Nitrogen as NH_3-N given that EQS values are expressed on that basis.
** Total phosphorus modelled as phosphate.

Following completion of the risk assessment, it was noted that sulphate was the only potential contaminant of concern that did not exceed the groundwater/surface water quality standards with which the data were compared. Given that the EQS values are designed to protect ecosystems in water bodies from unacceptable impact, these provide a sound basis for the assessment of risk to the SAC.

Therefore, it is considered that **sulphate is unlikely to cause a detrimental impact on the wider ecosystem.**

Contaminant concentrations for each of the other six contaminants of concern were elevated under one or more of the test scenarios modelled and the relative risk posed by these will be discussed below.

Arsenic and Chromium

The concentrations of arsenic, chromium (total) and hexavalent chromium only marginally exceeded the assessment criteria and consequently are considered to be minor constituents of the groundwater leachate. Indeed, given that the three models were conservative in nature, it is reasonable to assume that they will pose little to no adverse effect on the water environment and the SAC. Since the landfilled area is small in relation to the size of the SAC, and considering that there will be significant dilution of any leachate-derived contamination entering the surface water network, **risk from arsenic and chromium is considered to be low**.

Phosphorus

Although total phosphorus was detected in the groundwater at elevated concentrations, the most mobile form, inorganic phosphate, was present at concentrations below laboratory detection limits in all but one groundwater sample tested and was not detected in surface water samples. Further, the DQRA, by necessity, conservatively modelled phosphorus impact as phosphate. For these reasons, **phosphorus is considered to pose a low risk to the SAC**, particularly considering the significant degree of dilution that will take place within the receptor itself.

Manganese

Modelled concentrations of manganese at the compliance point exceeded the EQS in all three scenarios.

In oxygenated water, manganese is typically present in the form of insoluble manganese oxide-hydroxide complexes, although under reducing conditions Mn^{2+}, soluble inorganic complexes or insoluble $MnCO_3$ and MnO_2 may be present. Organic complexation of manganese may occur in higher alkalinity waters (e.g. Limerick GWB), where organic ligands are present, whilst at near neutral pH a large percentage of insoluble manganese will be associated with colloids and particulates such as clay and microorganisms.

Manganese can be bioaccumulated by aquatic biota, with bioaccumulation being greatest at lower trophic levels. It is known to affect fish and other organisms due to the formation and precipitation of low solubility organic complexes that can bind to fish skin and/or mucus membranes. However, conversely, manganese is an essential nutrient for microorganisms, plants and animals.

Considering the relative level of conservatism in the DQRA model, the modelled concentrations of manganese at the compliance point do not indicate a major risk to the ecosystem, particularly considering the relatively small mass flux from the landfilled area relative to the size of the receptor. Further, there will be significant amount of dilution and dispersal within flood water and in the surface water course. Consequently, **the risk to the ecosystem from manganese is considered to be low**.

Ammonium

Ammonium is a common contaminant that originates from such sources as foul sewerage systems/sewage outfalls, agriculture, landfills and contaminated industrial sites. It is also generated by the decomposition of natural proteinaceous organic matter. As such, it is ubiquitous in surface water.

In solution, ammonia may be present in ionised form (as the ammonium ion, NH_4^+) and as un-ionised ammonia (free ammonia, NH_3). The relative proportion of these two forms depends primarily on the pH of the receiving water and, to a much lesser extent, on temperature and salinity. The toxicity of ammonia to fish and aquatic invertebrates is principally attributable to NH_3, the proportion of which increases with increasing pH: at pH 8.5, for example, the concentration of free ammonia is approximately 10x that at pH 7.5.

Ammonia is not expected to adsorb significantly to sediments in water bodies nor to bioaccumulate, although it is assimilated by aquatic plants for use as a nitrogen source. It may be lost from water through volatilisation and will be oxidised by bacteria to nitrite and nitrate ("nitrification").

In this assessment, the DQRA has indicated a potential exceedence of the EQS in all three modelled cases by at least an order of magnitude. Under flood conditions (Model 'C') the EQS is exceeded by more than two orders of magnitude. Considering the relative level of conservatism in the DQRA model, the modelled concentrations of ammonia at the compliance point do not indicate a major risk to the ecosystem, particularly considering the relatively small mass flux from the landfilled area relative to the size of the receptor. Further, there will be significant amount of dilution and dispersal within flood water and in the surface water course. However, the modelled concentrations are such that **the potential risk to the ecosystem from ammonia is considered to be low to moderate but any impact would be confined to a very small area**.

8. DETAILED QUANTITATIVE RISK ASSESSMENT FOR HUMAN HEALTH RECEPTORS

This DQRA has been carried out to establish with greater confidence the levels of risk associated with the on-site contaminant source and to determine appropriate target levels for any future remediation.

The potential exposure scenario present at the site does not readily conform to any of the generic exposure scenarios described within commonly used frameworks for human health risk assessment. Therefore, generation of site-specific assessment criteria has been undertaken to establish more accurately the potential risks associated with the identified contamination source, taking account of the exposure pathways operating.

8.1 Methodology

The generic quantitative risk assessment carried out within the previous contamination investigation was based on generic assessment criteria (GAC) for a residential land use scenario, excluding consumption of site-grown produce. The assumptions contained within that scenario are not directly applicable to the exposure scenario identified associated with the subject site and may either over or under estimate the level of risk. It has therefore been necessary to formulate site-specific assessment criteria (SSAC) values based on an exposure scenario derived for the subject site.

The CSM demonstrates that several operational human health exposure pathways are present given the existing (and foreseeable future) site condition.

Assessment of the risk to end users has been carried out using the UK CLEA v1.06 model. The CLEA v1.06 model applies current UK best practice guidance, as described within EA Science Report SC050021/SR3, 2009. The model is appropriate for assessment of all of the potential pollutant linkages identified in connection with the site.

The standard CLEA v1.06 residential land-use parameter values were applied as a starting point but were modified to represent the site-specific exposure scenario detailed below. The residential end use scenario was used as a starting point for this assessment as the most sensitive receptor groups are considered to be residents of the properties on St. Munchin's Street, which back onto the landfilled area.

8.2 Detailed Conceptual Site Model for Human Health Risk

A summary of the conceptual site model is provided as Drawing No. C4559/11 within Appendix A. The model, which has been used as the basis for the CLEA v1.06 assessment, is described in the following paragraphs in terms of sources, pathways and receptors.

<u>Sources</u>

The contaminant source comprises the illegally tipped waste materials within the landfill body as described in Section 4. On the basis of the previous generic quantitative assessment, localised elevated concentrations of lead and naphthalene were identified which could potentially adversely affect human health. SSAC have therefore been derived for a range of potential contaminants of concern to allow re-evaluation of the soil and waste characterisation data.

Asbestos-containing materials have been identified within the landfilled material and constitute a source contaminant. However, it is not currently technically feasible to carry out a modelled exposure assessment for asbestos. The potential risk to receptor from asbestos containing materials is therefore considered separately.

This risk assessment does not include consideration of risk from hazardous landfill gas.

<u>Pathways</u>

The pathways considered to be active in the site-specific exposure scenario are summarised and explained within Table Error! No text of specified style in document..**25** below.

Table Error! No text of specified style in document.**.25 - Description of Pathways Included Within Human Health CSM**

Pathway	**Detailed Description**
Dermal contact with soils outdoors and soil dust	Direct dermal contact with waste soils is considered possible due to adjacent residents walking/playing/handling livestock on the adjacent landfill site. Exposure frequency will be determined to account for time spent on the site itself.
Dermal contact with soil dusts indoors	Assumes 365 days a year exposure for adjacent residents with some indoor dust derived from site soils tracked back to the property.
Direct ingestion of soil and soil dust	Direct dermal contact with waste soils is considered possible due to adjacent residents walking/playing/handling livestock on the adjacent landfill site. In addition it is likely that a component of the household dust within adjacent properties may be derived from the source soils and will form an element of the ingested soil component. This is possible due to both airborne transport of dust and tracking back of soils on shoes, clothing, etc. Exposure frequency will be modified to reflect time spent on site and relative contribution from ingestion of dust.
Inhalation of soil dust - Indoors	Dust generated from the source soils is likely to form a component of the indoor dust inhaled by adjacent residents.
Inhalation of soil dust - Outdoors	Dust generated from the source soils is likely to form a component of the outdoor dust inhaled by adjacent residents.
Inhalation of vapours in indoor and outdoor air	Volatile source chemicals have the potential to be present in outdoor air forming a component of inhaled air during time spent on site and in adjacent gardens. There is a small possibility that volatile vapours could migrate within the subsurface into adjacent properties which are located within close proximity to the landfill site.

It is not considered that ingestion of site grown produce is a significant exposure pathway at this site.

Receptors

The most sensitive receptor within the site-specific exposure model is considered to be a female 0 to 6 year old child resident within a residential property immediately adjacent to the landfill site. It is assumed that, in addition to being permanently resident within this location, the child may spend some time in direct contact with the landfill, walking, playing or feeding horses, etc.

Maintenance workers carrying out tasks such as grass cutting and path maintenance have been identified as potential receptors within the current conceptual site model. Whilst this receptor group are likely to come into contact with site soils, there is not a permanent staff for the site. Given that this receptor group will comprise adults of working age and exposure frequencies will be limited it is considered that any SSAC derived for the adjacent residents will also be protective of ground and maintenance workers at the site. The exposure duration included within the residential scenario of 86 contact days per year is sufficient to account for approximately 258 eight-hour shifts on site for an individual worker over the course of a year. This is considered sufficiently conservative. Furthermore, all of these visits are unlikely to be undertaken by the same individual. For more major works (e.g. remediation), potential exposures will, in any case, be managed under appropriate health and safety legislation.

8.3 Input Parameters

The input parameters used within the CLEA v1.06 model to reflect the site-specific CSM are described and justified below.

Exposure Frequency

These parameters are presented in Table Error! No text of specified style in document..**26**.

Table Error! No text of specified style in document.**.26 - Exposure Frequency Justification**

Parameter	**Value**	**Justification**
Exposure frequency (direct ingestion) (day/yr)	86	Based on visits to the landfill 2 days per week throughout the year and assuming 33% of ingested soil dust is derived from the landfill soil, as opposed to others sources such as garden soils or household dust. Includes a time weighted factor to allow for direct ingestion of household dust 365 days/year. For detailed calculation see Appendix F.
Exposure frequency (Dermal contact outdoors) (days/yr)	52	Visit to the landfill area on 2 days per week throughout the year and assuming 50% of dermal contact on these days is with soils from this source, as opposed to other sources such as garden soils. For detailed calculation see Appendix F.
Soil to indoor dust transport factor	0.33	Default soil to dust transport factor is 0.5, indicating a 50% site soil contribution to household dust. Modified to 33% for contribution of landfill soils to indoor dust. This is a conservative assumption for on the site and allows for the fact that a proportion of the landfill soils have no significant cover and may be a significant source of household dust. (Applies to indoor dust only and inhalation and dermal contact pathways only).

Soil Properties

The sandy loam/silt soil type was used within the site-specific model as this is most representative of most of the shallow landfilled soils. A soil organic matter value of 5% was used for the exposure scenario based on three site-specific TOC results (4.89-10.65%) obtained for the shallow waste soils.

Depth to contaminated soils has been adjusted to 0.0m in order to represent exposed surface materials. This parameter only influences the modelled exposure to vapours resulting from potentially volatile contaminants of concern. For pathways *via* direct contact and generated dusts the assumption is already made that the contaminants may be present at the ground surface.

The proportion of vegetative cover allowed for in the model is important in determining the potential for dust generation and subsequent exposure. The default CLEA setting within a residential exposure scenario is 0.75, allowing for 25% surface area free from cover by vegetation or hardstanding. This figure has been modified to 0.0 within the site-specific scenario to reflect the absence of significant vegetative cover over large parts of the landfill exposed at the ground surface.

<u>Contaminant Properties</u>

Input parameters for each of the contaminants of concern are summarised within the CLEA output reports presented in Appendix G.

Chemical properties for polycyclic aromatic hydrocarbons (PAHs) have been taken from "The LQM/CIEH Generic Assessment Criteria for Human Health Risk Assessment" (2nd Edition), 2009. Input parameters from this source have been selected in accordance with the recommended hierarchy for UK risk assessment in accordance with up to date guidance (EA, 2009) and have been thoroughly peer reviewed. No site-specific adjustments have been made to any of the contaminant properties from the above sources within this assessment as there is no basis for any changes within the modelled site-specific exposure scenario.

8.4 Exposure to Lead

<u>Approach to Risk Assessment for Lead in Soils</u>

Elevated concentrations of lead have been detected within localised soils at the site surface. To date in the UK, risk assessment for lead has been carried out using an approach based on empirical relationships between environmental lead exposure and human blood lead levels. Different models are used to estimate likely correlations for child and adult populations (DEFRA and EA, 2002).

At the time of writing this report it is understood that the Environment Agency are updating the basis for risk assessments for lead in soils, however, no publication date for this updated guidance has been announced. Consequently, the most appropriate basis for undertaking risk assessment for lead in soils in the UK remains the previously published report. The UK data available for lead is not compatible with the CLEA v1.06 model and consequently risks from lead in soil are considered separately within this section of the report.

The previously published SGV for lead in a residential setting, which considers the child aged 0-6 years to be the critical receptor, is based on modelling the relationship between environmental and blood lead for children in a residential setting. This model is therefore not appropriate for assessing the relationship within an area of public open space where contact with soils is limited in frequency and duration. It is therefore not possible to modify the residential model to account for a reduced exposure frequency.

The previously published SGV for lead within the commercial and industrial exposure scenario is based on similar empirical relationships between blood lead and environmental exposure for adult populations and does include provision for factoring in an exposure duration which accounts for time spent outside of the contaminant contact environment. It is therefore possible to use this model to indicate likely levels of risk associated with the soils at the site.

It must be considered that using this approach would not directly result in a residential SSAC in complete accordance with UK guidance, as the exposure scenario includes younger children. Consequently, the calculation has been adjusted to include the most up to date soil ingestion rate for young children in a residential scenario.

On the balance of probabilities and given the likely uses of the site and the absence or minimal nature of some of the other significant direct pathways, the results of this assessment are still considered sufficiently robust to allow a pragmatic conclusion to be drawn regarding the likely magnitude of risk associated with lead in soils and the likely necessity of undertaking further more detailed assessment into potential risks from lead in the soils at this site.

Risk Assessment for Lead in Soil

An indicative SSAC for lead in soil has been calculated based on Equation 2.2 in UK guidance document SGV10 (DEFRA and EA, 2002) and supporting discussion. The site-specific assumptions with regard to exposure duration and frequency discussed above have been used within the equation. together with an assumed exposure duration of 65 years to represent a lifetime exposure period. As discussed above, current soil ingestion rates for young children in a residential scenario have also been used in the calculation for additional conservatism. The site-specific calculation is included in Appendix H.

8.5 DQRA Results

The results of the CLEA model are summarised in Table Error! No text of specified style in document.**.27**, below. The model was applied to calculate SSAC to re-evaluate the potential risks from contaminants present at the site. The residential GAC for each contaminant is included in the table for comparison purposes only. Printed results from CLEA v1.06 are included within Appendix G.

Table Error! No text of specified style in document.**.27 - Results of Detailed Quantitative Risk Assessment**

Determinand	GAC (mg/kg) 5%SOM	SSAC (mg/kg)
Metals		
Inorganic Arsenic*	32	120
Cadmium	10	36
Chromium (III)	3000	4700
Lead	450	790**
Inorganic Mercury	170	850
Selenium+	350	2500
Copper	2300	12000
Nickel*	130	180
Zinc	3700	17000
PAHs		
Acenaphthene	840	9900
Anthracene	8200	96000
Acenaphthylene	710	9500
Benzo(a)anthracene	5.8	13
Benzo(b)fluoranthene	7.0	19
Benzo(k)fluoranthene	10	26
Benzo(g,h,i)perylene	47	120
Benzo(a)pyrene	1.0	2.6
Chrysene	9.1	25
Dibenzo(a,h)anthracene	0.9	2.3
Fluoranthene	630	4700
Fluorene	660	9000

Determinand	GAC (mg/kg) 5%SOM	SSAC (mg/kg)
Indeno(1,2,3-cd)pyrene	4.1	11
Naphthalene	3.2	7.7
Pyrene	1500	11000
Phenanthrene	330	4000
Phenol	840	1400
Other Hydrocarbons		
Benzene	0.2	0.88
Ethylbenzene	200	770
Toluene	410	2600
Xylene (total)	92	250
Aliphatic EC 5-6	17	93
Aliphatic EC >6-8	36	300
Aliphatic EC >8-10	8.8	88
Aliphatic EC >10-12	43	450
Aliphatic EC >12-16	350	3600
Aliphatic EC >16-35+	29000	22000
Aromatic EC 5-7	0.054	870
Aromatic EC >7-8	92	2600
Aromatic EC >8-10	14	160
Aromatic EC >10-12	54	840
Aromatic EC >12-16	140	6000
Aromatic EC >16-21+	250	6000
Aromatic EC >21-35+	890	6300

SSAC are rounded to 2 significant figures
*SSAC based on inhalation exposure only
+SSAC based on ingestion exposure only
**Indicative SSAC based on calculation in Appendix H

The CLEA model outputs include a summary of contributions from each active exposure pathway. A summary of the results of pathway contributions for the site-specific exposure scenario is provided in Table Error! No text of specified style in document.**.28**. The pathway contributions are very similar for all of the poorly volatile PAHs (i.e. those other than naphthalene) and these have therefore been considered together.

Table Error! No text of specified style in document.**.28 - Pathway Contributions (%) to SSAC**

Determinand	**Direct Ingestion**	**Dermal contact with soil and dust**	**Inhalation of dust**	**Inhalation of vapour (indoor)**	**Inhalation of vapour (outdoor)**	**Background (Oral)**	**Background (Inhalation)**
Metals							
Inorganic Arsenic	89.68	9.45	0.87	0	0	0	0
Cadmium	49.35	0.17	0.48	0	0	49.52	0.48
Chromium (III)	70.15	0	0.68	0	0	29.03	0.14
Lead	NA	NA	NA	NA	NA	NA	NA
Inorganic Mercury	95.45	0	0.92	0	0	3.63	0
Selenium	68.51	0	0.66	0	0	30.82	0
Copper	49.71	0	0.48	0	0	49.71	0.1
Nickel	48.22	0.85	0.47	0	0	49.53	0.47
Zinc	49.75	0	0.48	0	0	49.75	0.02
PAHs							
Acenaphthene	28.77	13.14	0.28	57.69	0.03	0.09	0
Anthracene	56.06	25.60	0.54	17.77	0.03	0	0
Acenaphthylene	27.76	12.68	0.27	59.25	0.03	0.01	0
Benzo(a)anthracene	67.86	30.99	0.65	0.48	0.01	0	0
Benzo(b)fluoranthene	68.17	31.13	0.66	0.03	0.01	0	0
Benzo(k)fluoranthene	68.18	31.13	0.66	0.02	0.01	0	0
Benzo(g,h,i)perylene	68.19	31.14	0.66	0.01	0	0	0
Benzo(a)pyrene	68.18	31.13	0.66	0.02	0.01	0	0
Chrysene	68.13	31.11	0.66	0.09	0.01	0	0
Dibenzo(a,h)anthracene	68.17	31.13	0.66	0.04	0	0	0
Fluoranthene	65.79	30.04	0.63	3.31	0.02	0.16	0.04
Fluorene	39.54	18.06	0.38	41.88	0.03	0.08	0.01
Indeno(1,2,3-cd)pyrene	68.17	31.13	0.66	0.04	0.01	0	0
Naphthalene	1.51	0.69	0.01	76.70	0.01	2.20	18.88
Pyrene	65.77	30.03	0.63	3.47	0.02	0.07	0.01
Phenanthrene	56.66	25.87	0.55	15.95	0.03	0.69	0.25
Phenol	16.29	17.17	0.16	33.64	0.07	16.29	16.39
Other Hydrocarbons							
Benzene	0.11	0.04	0	99.84	0.01	0	0
Ethylbenzene	0.61	0.22	0.01	95.40	0.02	0.13	3.61
Toluene	0.33	0.12	0	97.20	0.01	0.04	2.3
Xylene (total)	0.70	0.25	0.01	84.16	0.02	0.95	13.91
Aliphatic EC 5-6	0	0	0	49.99	0	0	50
Aliphatic EC >6-8	0.01	0	0	49.98	0	0.01	49.99
Aliphatic EC >8-10	0.05	0.02	0	49.92	0	0.07	49.93

Determinand	Direct Ingestion	Dermal contact with soil and dust	Inhalation of dust	Inhalation of vapour (indoor)	Inhalation of vapour (outdoor)	Background (Oral)	Background (Inhalation)
Aliphatic EC >10-12	0.27	0.09	0	49.62	0.01	0.36	49.64
Aliphatic EC >12-16	2.15	0.75	0.02	47.05	0.03	2.90	47.10
Aliphatic EC >16-35	18.91	6.64	0.18	24.21	0.06	50	0
Aromatic EC 5-7	0.11	0.04	0	98.96	0.01	0.01	0.87
Aromatic EC >7-8	0.33	0.12	0	97.20	0.01	0.04	2.3
Aromatic EC >8-10	0.45	0.16	0	49.37	0.01	0.61	49.39
Aromatic EC >10-12	2.36	0.83	0.02	46.76	0.03	3.19	46.81
Aromatic EC >12-16	15.91	5.59	0.15	28.29	0.06	21.5	28.50
Aromatic EC >16-21	35.46	12.46	0.34	1.72	0.02	50	0
Aromatic EC >21-35	36.72	12.90	0.35	0.02	0.01	50	0

The primary contribution for most non-volatile substances within the exposure scenario is *via* direct ingestion of soil. Time spent on the site and the contribution of site generated dust to indoor dust within adjacent houses are therefore likely to be of potential significance in determining SSAC for the majority of non-volatile substances. For PAHs, dermal contact with soil and dust is also a significant pathway that could be influenced by exposure to site derived dust.

Inhalation of dusts is not generally a significant pathway within the model, accounting for less than 1% of exposure in all cases. Despite a low overall contribution to exposure, dust inhalation is a significant pathway for arsenic and nickel exposure due to the very low acceptable exposures *via* this pathway for these substances.

For potentially volatile hydrocarbons and PAHs, the most significant pathway determining the SSAC is volatilisation to indoor air. The assumption has been made within the CSM that these substances could potentially migrate beneath properties and volatilise to indoor air. This is considered to be a very conservative assumption and will result in sufficiently conservative SSAC for these potentially volatile substances.

8.6 Sensitivity Analysis

A sensitivity analysis has been undertaken to assess the response of the modelled exposure scenarios to changes in input parameters. Sensitivity analysis has primarily been undertaken for exposure parameters which include site-specific information. Input parameters for contaminants of concern and receptor characteristics have generally not been adjusted from the accepted defaults as presented in Environment Agency (2009) and Nathanail *et al*. (2009, "The LQM/CIEH Generic Assessment Criteria for Human Health Risk Assessment", 2md edition. Land Quality Press, Nottingham) and are therefore considered appropriate.

Sensitivity analysis has been carried out for four representative substances, inorganic mercury, inorganic arsenic, naphthalene and benzo(g,h,i)perylene. The rationale behind the selection of these substances is detailed in Table Error! No text of specified style in document..**29** and the sensitivity analysis itself in Table Error! No text of specified style in document..**30**.

Table Error! No text of specified style in document..**29 - Selection of Representative Substances for Sensitivity Analysis**

Substance	**Rationale**
Inorganic Mercury	Highest proportional exposure due to direct ingestion (95%) and inhalation of dust (0.92%).
Inorganic Arsenic	SSAC based on inhalation exposure only. High relative exposure due to inhalation of dust (0.87%).
Naphthalene	Volatile organic compound. High relative exposure due to vapour inhalation.
Benzo(g,h,i)perylene	Low volatility PAH with highest proportional contribution from dermal contact with soils.

Table Error! No text of specified style in document.**.30 - Results of Sensitivity Analysis**

Input parameter	**Contaminant of concern**	**Adopted value**	**Variation 1**	**Variation 2**	**Sensitivity**
		0.33	0.5	0.125	
Soil to indoor dust transport factor (fraction)	Inorganic Mercury Inorganic Arsenic Naphthalene Benzo(g,h,i)perylene	850 120 7.7 120	760 81 7.7 93	980 270 7.7 190	Moderate High Negligible High
		86	65	110	
Exposure frequency (direct ingestion) (days/yr)	Inorganic Mercury Inorganic Arsenic Naphthalene Benzo(g,h,i)perylene	850 120 7.7 120	1000 120 7.7 130	600 120 7.7 110	High Negligible Negligible Low
		52	40	65	
Exposure frequency (dermal contact outdoors) (days/yr)	Inorganic Mercury Inorganic Arsenic Naphthalene Benzo(g,h,i)perylene	850 120 7.7 120	850 120 7.7 130	850 120 7.7 120	Negligible Negligible Negligible Low
		Sandy loam	Sand	Clay	
Soil Type	Inorganic Mercury Inorganic Arsenic Naphthalene Benzo(g,h,i)perylene	850 120 7.7 120	850 120 7.7 120	850 120 7.7 120	Negligible
		5%	4%	10%	
Soil Organic Matter	Inorganic Mercury Inorganic Arsenic Naphthalene Benzo(g,h,i)perylene	850 120 7.7 120	850 120 6.2 120	850 120 15 120	Negligible Negligible High Negligible

Negligible = no appreciable effect
Low = Marginal effect (i.e. <10%)
Moderate = Effect is >10% but less than 50% proportional to change in input parameter
High = Effect is > 50% proportional to change in input parameter

The sensitivity analysis demonstrates that the key variables within this assessment vary for different substances according to the critical exposure pathways as predicted by the CLEA results for pathway contribution.

The critical exposure pathway for the majority of inorganic contaminants (metals) is *via* the direct ingestion of soils and soil dust. This exposure pathway has been represented within the model in the same way as for the generic residential exposure scenario; however, the exposure frequency has been reduced to reflect the relatively lower exposure to landfill soils compared to garden soils. The assumptions made with regard to frequency of visits to the landfill, although not based on site-specific data, are considered to be sufficiently conservative for this assessment.

Inorganic substances showed moderate to high sensitivity to the soil to indoor dust transport factor. This parameter is important in modifying the exposure to contaminants via ingestion and inhalation of indoor dust. High sensitivity to this parameter is shown where inhalation of dust is the critical pathway for calculation of the SSAC. (i.e. arsenic and nickel). Low volatility PAHs also showed high sensitivity to this parameter as dermal contact with indoor dust is an important transport pathway for these substances.

The exposure scenario has allowed for up to 33% of household dust to be composed of site-derived soil. The soil to indoor dust concentration factor has been necessarily assumed in the absence of site-specific data. It is unlikely to be possible or practical to obtain site-specific values for this parameter. However, the majority of tracking back of dust occurs over a short distance and is frequency dependant (EA, 2009, p.65) and the assumptions made are considered sufficiently conservative to account for this potential pathway. In reality, the majority of soil in indoor dust is likely to be derived from residential gardens. Organic contaminants preferentially adsorb to organic soil material rather than the smaller clay and silt particles which are more likely to form dusts. It is therefore likely that the exposure to organic substances *via* the dust pathways will be overestimated.

Sensitivity to soil type and SOM is negligible, with little change to the calculated SSAC for different soil types and SOM values for inorganic and low volatility organic substances. This is because these parameters primarily determine the partitioning behaviour of contaminants within the soil, which predominantly affects plant uptake and vapour transport pathways that are not significant within the modelled exposure scenarios for these substances.

Naphthalene shows high sensitivity to changes in SOM which have a significant effect on the partitioning behaviour of volatile organic substances. Within the context of this exposure assessment the SOM value chosen is representative of the lower range and hence more conservative of reported site-specific values. Furthermore, due to the assumptions regarding the lateral migration of such volatile organic substances, it is considered that the modelled exposure scenario is very conservative with regard to the volatilisation to indoor air pathway.

In summary, it is considered that the sensitivity analysis demonstrates that the assessment is sufficiently conservative in addressing potential risk from the historic landfill site.

8.7 Conclusions

General

This DQRA has been performed to evaluate whether the illegal landfill at St. Mary's Park, Limerick, could present a significant risk to the health of adjacent residential receptors or site workers.

Existing analytical characterisation of the landfill wastes is relatively limited and there remains the potential for as yet unidentified sources of contamination to be present at the site. With this in mind, a site-specific exposure model has been developed using the CLEA v1.06 model framework to determine the risks associated with identified and potential contaminating substances. A suite of SSAC values have been derived for the exposure scenario against which to assess potential risks to human health.

Risk Evaluation

Although potential pollutant linkages have been identified for the site, none of the observed concentrations of potential contaminants of concern within the landfill materials exceeded their respective SSAC. The maximum observed concentration of lead (694mg/kg) identified in TP4 falls below the indicative SSAC of 790mg/kg calculated for the site. On this basis it is concluded that the risk to end users from this localised area of elevated lead concentrations is low.

The DQRA has demonstrated that the potential risks to human health associated with contaminants recorded in soil, based on the existing chemical characterisation of the landfilled materials for substances excluding asbestos, are not significant.

However, based on the physical description of the wastes, there may be areas of soil which contain higher concentrations of specific contaminants e.g. mercury or PAHs. SSAC values have been determined for a range of potential substances which can be used to assess the risk associated with the landfill if further characterisation or remediation works are to be carried out. SSAC values are suitable for the assessment of potential risks to adjacent residents and construction/maintenance workers on the site.

8.8 Risk from Asbestos

Physical descriptions of the landfill wastes have identified asbestos containing materials. These were predominantly noted within zone 2 of the landfill site (Appendix A, Drawing No. C4559/08).

The risk to adjacent residents and construction or maintenance workers from asbestos fibres cannot be modelled using exposure modelling software. The level of risk will largely depend on the form of the asbestos and its potential to be mobilised as inhalable dust.

Based on the current level of information regarding the form of asbestos present and considering the proximity and sensitivity of the receptors, it is advised that asbestos within the landfill should be considered to present an unacceptable risk to human health.

It is recommended that further assessment of the risk from asbestos and appropriate remedial measures be undertaken to address the potential risk to adjacent residents and potential workers on site.

9. CONCLUSIONS

We have undertaken DQRA in accordance with current guidance to assess the potential risk posed by materials deposited within the illegally landfilled area of St Mary's Park to human health, surface water and groundwater and the adjacent portion of the Lower River Shannon SAC.

9.1 Risk to Water Environments

Underlying Aquifer

Given that shallow soils at the site are underlain by a substantial thickness of low permeability cohesive soils, it is unlikely that significant pathways exist for contaminants to impact on the underlying Dinantian Pure Unbedded Limestone aquifer. Consequently, the risk posed by the site aquifer is **negligible**.

Abbey River

We have modelled three scenarios with regard to potential risk posed by the migration of landfill-derived contamination in shallow groundwater to the adjacent Abbey River. These scenarios consider the shortest and most probable pathway distances under normal conditions plus the very short transport pathway operating under flood conditions.

The principal contaminants of concern identified from previous site investigation are those which have been detected at concentrations in on-site leachate or groundwater at concentrations above the GAC values applied for screening purposes: chromium (both as Cr(III) and Cr(VI)), manganese, phosphorus, ammoniacal nitrogen, and sulphate.

Under normal conditions and taking account of the conservatism in the model, the risk posed to the Abbey River, *at the point of groundwater entry into that water course*, by sulphate and chromium is considered to be negligible to low, that posed by manganese and phosphorus (modelled as phosphate) is considered low to moderate, and that posed by ammoniacal nitrogen to be moderate.

Under flood conditions, surface water encroaches onto the wetland and will be very close to, and possibly locally in contact with, the deposited waste. Concentrations of the defined contaminants entering the flood water *at the point of discharge* will exceed the EQS-based target concentrations applied. The risk under flood conditions is therefore assessed to range from low to moderate for all of the defined contaminants of concern.

The nature of the site, particularly the spatially discrete distribution of the individual contaminants of concern, and the model parameters employed mean that the risk assessment models will be conservative. Further, in line with good practice, the assessments have been made on the basis of the contaminant concentration at the point of discharge to the Abbey River, i.e. they take no account of mixing and dilution within the water course. Given these considerations, the small total mass flux of contamination and the relatively low risk identified by the model, **we conclude that the overall risk posed by measured leachable concentrations of chromium, manganese, sulphate and phosphorus is negligible to low and that posed by ammoniacal nitrogen is low to moderate**. However, any elevated contaminant concentrations realised at the receptor will be minor and highly localised.

River Shannon

Given the groundwater transport pathways operating, the risk to the River Shannon is assessed as **negligible**.

9.2 Risk to SAC

We have considered whether the measured concentrations of contaminants in near-surface soils immediately adjacent to the SAC could have a direct impact on the ecosystem. Considering the relatively low concentrations recorded and the insignificant exposure intensity, we conclude that this risk is **negligible**.

Using the data from the water environments risk assessment, we have also assessed whether the risk posed by the contaminants of concern entering flood water, drainage water and the Abbey River itself could detrimentally impact individual species or ecosystem functionality within the SAC. Given the low concentrations and mass flux, we consider that **the risk is negligible to low for all contaminants except ammonia, for which the potential risk is considered to be moderate, although any impact would be confined to a very small area**.

9.3 Risks to Human Health

Inorganic and Organic Contamination

The concentrations of identified contaminants of concern are generally low and elevated concentrations are spatially discrete. Given the site setting, human exposure frequency and intensity will be low. Consequently, the human health DQRA has demonstrated that **the potential risks to human health associated with inorganic and organic contaminants present in near-surface soils is insignificant**.

Asbestos

Asbestos-containing materials have been recorded within near-surface soils in some parts of the landfilled area. Since there is limited information regarding the forms of asbestos present ,and considering the proximity and sensitivity of receptors, we consider that **near-surface asbestos within the landfill should currently be considered to present a potentially unacceptable risk to human health**.

It is recommended that further assessment of the risk from asbestos and appropriate remedial measures be undertaken to address the potential risk to residents and persons working on the site.

9.4 Risks from Ground Gas

Vapour exposure risk, assessed within the human health DQRA, is **negligible**.

The risk posed by landfill-derived bulk ground gases (methane and carbon dioxide) has not been separately assessed in this present report but we note that current concentrations of these gases within the landfilled area are very low and that there may not be a viable ground gas transport pathway towards adjacent properties (Verde "Tier 2/3 Environmental Risk Assessment" report, ref. 20476, July 2011). Current risk is therefore assessed as **negligible** but may change if there are future alterations to ground cover in the landfilled area or if further putrescible waste is illegally deposited.

10. RECOMMENDATIONS

The Tier 3 DQRA has identified the risk is negligible to low for all contaminants except ammonia, for which the potential risk is considered to be moderate, although any impact would be confined to a very small area. In accordance with EPA cop the site will need to be remediated due to its Class A rating. The EPA COP also references the Ministerial Direction (WIR 04/04) stating that sites proximate to residential development and SAC should at all times be remediated; it is to be "assumed that the waste shall be removed from the site except only where it can be shown that an alternative solution provides greater protection to the environment and the health of the local population."

Remediation of the site will first require the segregation and removal of all mixed waste items such as plastic, wood, metal, electronic items etc. Once these are removed, it is considered that much of the remaining soils may be suitably categorised as inert fill if a diligent segregation process is undertaken. This however will require further verification during the remediation process including consultation with the EPA.

Before undertaking any remediation programme a full ecological assessment will need to be undertaken at the site according to requirements in relation to protection of the SAC. This includes:

- Preparation of habitat map defining principle habitat types in vicinity of landfill and wet grassland east to the Abbey River based on field survey

- Consultation with National Parks & Wildlife Service regarding proposed remediation works and potential impacts and mitigation requirements during the remediation process

- Preparation of Screening Report for Appropriate Assessment (AA) with Natura Impact Statement as required assessing potential impacts on the Natura 2000 network in general and on the Lower River Shannon SAC in particular, including cumulative impacts with other plans or projects

- Development of plan to re-vegetate all disturbed land to tie in with existing marsh vegetation and to avoid the establishment of weed species or invasive alien species that could compromise the integrity of the SAC in the vicinity of the works. This element will need to be addressed as part of the AA process.

- Mapping of habitats will be undertaken in the first phase as this will be required as part of the AA process. This will include mapping of invasive alien species which would present a risk of accidental transfer during remediation works.

- Defining of working area to avoid unnecessary disturbance to adjacent wet grassland habitats Avoidance of direct site run-off to the Abbey River which may carry elevated loads of suspended solids or pollutants.

- Monitoring of run-off water quality.

- Establishment of vegetation efficiently following removal of waste and final re-profiling of ground

- Any soil imported to the site (if required) will need to be screened to be certified free of invasive alien species.