Contaminated land investigation: detailed inspection of former Wisbech Canal, Norfolk

Prepared for

Borough Council of King's Lynn and West Norfolk
King's Court
Chapel Street
King's Lynn
Norfolk
PE30 1EX

Report reference: 60319R1D1. November 2010

Confidential

Prepared by
ESI Ltd

New Zealand House, 160 Abbey Foregate, Shrewsbury, SY2 6FD, UK
***Tel** +44(0)1743 276100 **Fax** +44 (0)1743 248600 **email** esi@esinternational.com*
Registered office: New Zealand House, 160 Abbey Foregate, Shrewsbury, SY2 6FD. Registered in England and Wales, number 3212832

Contaminated land investigation: detailed inspection of former Wisbech Canal, Norfolk

Principal Author(s)
Andy Tait/Andy Singleton

Checked by: Lisa Murray

Reviewed by: Hannah Fraser

Confidential

Prepared by

ESI Ltd

New Zealand House, 160 Abbey Foregate, Shrewsbury, SY2 6FD, UK
***Tel** +44(0)1743 276100 **Fax** +44 (0)1743 248600 **email** esi@esinternational.com*
Registered office: New Zealand House, 160 Abbey Foregate, Shrewsbury, SY2 6FD. Registered in England and Wales, number 3212832

CONTENTS

0. EXECUTIVE SUMMARY 1

1. INTRODUCTION 3

1.1 Background 3

1.2 Objectives 3

1.3 Scope of work 3

1.4 Relevant Legislation 4

1.5 Report structure 4

2. SITE LOCATION AND HISTORY 6

2.1 Site location and setting 6

2.2 History of the Site 6

3. CONSULTATIONS 9

4. ENVIRONMENTAL SETTING 11

4.1 Current land use and general site setting 11

4.2 Geology 11

4.3 Hydrogeology 12

4.4 Hydrology and drainage 13

4.5 Waste management/landfill sites 13

4.6 Ecology and wildlife 13

5. SITE INVESTIGATION WORKS 14

5.1 Summary of NCC ground gas monitoring (1992 to present) 14

5.2 NCC 2009 ground gas investigations 14

5.3 Summary of the NPL site investigation works (2009) 15

5.4 Summary of Kings Lynn and West Norfolk Council site investigation works (2010) 15

5.5 ESI site investigation works (2010) 15

5.5.1 Purpose of the site investigation 15

5.5.2 Drilling activities 16

5.5.3 Soil and water sampling and testing 21

5.5.4 Ground gas measurements 23

6. SITE INVESTIGATION RESULTS 24

6.1 Geology 24
6.1.1 Made Ground 24
6.1.2 Natural deposits 24

6.2 Hydrogeology 24
6.2.1 Groundwater levels 24

6.3 Soil quality data 27

6.4 Leachability test results 29

6.5 Groundwater quality data 30
6.5.1 ESI monitoring data 30
6.5.2 NCC monitoring data 31

6.6 Soil gas results 32
6.6.1 ESI monitoring data 32
6.6.2 NCC monitoring data 33

7. CONCEPTUAL MODEL 34

7.1 Conceptual ground model 34

7.2 Conceptual exposure model 35
7.2.1 Sources 35
7.2.2 Pathways 36
7.2.3 Receptors 37

7.3 Pollutant linkages 38

8. HUMAN HEALTH RISK ASSESSMENT 41

8.1 Methodology 41
8.1.1 Risk screening 41

9. SOIL GAS RISK ASSESSMENT 48

9.1 Methodology 48

9.2 Risks posed by bulk gases *(pollutant linkage: PL11)* 48

10. CONTROLLED WATERS RISK ASSESSMENT 51

10.1 Methodology 51

10.2 Level 2 RTM assessment 51
10.2.1 In-waste water quality 51
10.2.2 Off-waste water quality 54

10.3 Level 3 RTM assessment *(pollutant linkages: PL7 and PL8)* 56

11. CONCLUSIONS AND RECOMMENDATIONS 59

11.1 Conclusions 59

11.2 Recommendations 61

12. REFERENCES.. 62

FIGURES

Figure 1.1 Site location

Figure 4.1 Geological setting

Figure 4.2 Surface water drainage to the south west of the infilled canal

Figure 5.1 Location of Site sub sections

Figure 5.2 Site investigation locations: Section 1

Figure 5.3 Site investigation locations: Section 2

Figure 5.4 Site investigation locations: Section 3

Figure 5.5 Site investigation locations: Section 4

Figure 5.6 Site investigation locations: Section 5

Figure 7.1 Conceptual ground model: typical section through infilled canal

Figure 7.2 Conceptual exposure model

Figure 9.1 Bulk gas records for NCC borehole 3732 (1992 to 2010)

TABLES

Table 4.1 Summary of BGS boreholes 12
Table 5.1 Summary of ESI in-waste boreholes.. 18
Table 5.2 Summary of ESI boreholes drilled beyond the waste extents.. 19
Table 5.3 ESI groundwater samples.. 22
Table 6.1 Groundwater monitoring data: ESI boreholes.. 25
Table 6.2 Groundwater monitoring data: NCC boreholes.. 26
Table 6.3 Summary of soil quality: surficial soils (within 0.25 m of ground surface)............ 27
Table 6.4 Summary of soil quality data: waste materials.. 28
Table 6.5 Comparison of ESI groundwater quality and soil leachability test results............ 30
Table 6.6 Comparison of ESI and NCC groundwater quality data for in-waste BHs 31
Table 7.1 Pollutant Linkages.. 39
Table 8.1 Screening values adopted for the human health risk assessment....................... 42
Table 8.2 Exceedance of GACs: surficial soils 43
Table 8.3 Statistical assessment of soil quality data (superficial soils)............................... 46
Table 10.1 In-waste groundwater quality (aqueous contaminant source) 53
Table 10.2 Off-waste groundwater quality 55
Table 10.4 Source and pathway parameters 57

APPENDICES

Appendix A Sources of information
Appendix B Planning consent for canal infilling
Appendix C Historical land use mapping
Appendix D Historical photographs of the Wisbech Canal
Appendix E BGS borehole records
Appendix F NCC borehole logs
Appendix G NCC borehole coordinates
Appendix H NCC soil gas measurements (1992 to 2010)
Appendix I KLWN soil sampling and laboratory analyses
Appendix J ESI site investigation photographs (2010)
Appendix K ESI borehole logs
Appendix L ESI borehole location descriptions
Appendix M Site diary (ESI site investigations, July 2010)
Appendix N Grab sample details (ESI site investigations, 2010)
Appendix O Laboratory certificates (ESI site investigations, 2010)
Appendix P Summary of laboratory analyses
Appendix Q Laboratory analyses (NCC groundwater supply, 2010)
Appendix R ESI soil gas measurements (2010)
Appendix S Statistical Calculator output
Appendix T Modified BaP assessment criteria
Appendix U Ammonia dissociation calculations
Appendix V RTM worksheets

Glossary and Abbreviations

This glossary includes definition of key technical terms and abbreviations that may be used within the text.

aOD	Above Ordnance Datum
bgl	Below ground level
BGS	British Geological Survey
BaP	Benzo(a)pyrene
BOD	Biological oxygen demand
BTEX	Benzene, toluene, ethylbenzene, xylene
COD	Chemical oxygen demand
DO	Dissolved oxygen
DRO	Diesel range organics
EA	Environment Agency
GRO	Gasoline range organics
GAC	Generic assessment criterion
GSSV	Generic Soil Screening Value
MTBE	Methyl tertiary butyl ether
LOD	Limit of detection
NGR	National Grid Reference
PAH	Polycyclic Aromatic Hydrocarbons
SGV	Soil Guideline Value
SOM	Soil organic matter
SSAC	Site-specific assessment criterion
SVOC	Semi-volatile organic compound
TDS	Total dissolved solids
TOC	Total organic carbon
TPH	Total Petroleum Hydrocarbons
VOC	Volatile organic compound

0. EXECUTIVE SUMMARY

ESI Ltd. was appointed by Kings Lynn and West Norfolk Borough Council in March 2010 to undertake a contaminated land assessment of the infilled Wisbech Canal. The purpose of this work was to assess the potential risks posed by the current land quality to all identified environmental receptors, including risks to human health. As such, the work has been performed under the requirements of Part IIA of the Environmental Protection Act 1990.

The Wisbech Canal was conceived in the late eighteenth century as a link between Wisbech and the Old River Nene at Outwell. The canal, which was some 5.25 miles long, was formally completed in 1797. The subsequent operation of the canal was beset with various problems including competition from the Wisbech to Upwell tramway which was opened in 1883 and gradually displaced the canal as the preferred trading route. Canal traffic ceased in 1922 and the structure was officially abandoned in 1926. Following the demise of the canal, the structure was infilled with waste materials over a period of around 20 years. Two broad phases of infilling are understood to have occurred. Firstly, inert waste materials are reported to have been placed in the Wisbech section of the canal during the 1950's. Secondly, municipal wastes were deposited in the remaining (and far longer) canal section between 1962 and the mid 1970s. The infilled canal is currently occupied by a variety of land uses including public open space, the A1101 highway, agricultural land, pavement and roadside verges, some commercial land areas (including car parking) and a number of residential gardens.

A number of historical site investigation/environmental monitoring works have been performed along the former Wisbech Canal. The most significant of these relates to long-term ground gas monitoring conducted by Norfolk County Council along the length of the former canal structure. The County Council have recorded monthly gas measurements at up to 69 gas monitoring boreholes between 1992 and the present day.

Further site investigations were coordinated by ESI between July and November 2010, with the aim of developing a robust conceptual understanding of the infilled canal and thus enabling the quantitative assessment of environmental risks posed by observed land quality. A total of 30 percussive-rotary boreholes were drilled across the study area, of which 27 were installed with semi-permanent piezometers. A total of 55 soil samples and 15 groundwater samples were taken from various locations along the length of the former canal; these were all subjected to laboratory testing. Soil gas concentrations and borehole flow rates were measured at all ESI gas monitoring boreholes during six repeat monitoring rounds between August and November 2010.

The natural geological sequence comprises superficial tidal flat deposits (clay and silt with thin peaty layers) overlying the Ampthill Clay (soft grey mudstone). ESI's site investigations have confirmed that the Wisbech Canal formed a cutting into the superficial clays and silts. The waste materials reside directly upon these natural strata and are overlain by a clayey cover layer which is of the order 0.5 m thick.

The local lithologies are classified as Non productive Strata reflecting their limited water resource potential. Regardless, a number of private water wells exist within close proximity of the former canal; these are likely to abstract from sandier horizons within the tidal flat deposits. Shallow groundwater was routinely encountered within 3 m of the ground surface during the recent site investigations. The spatial variability in groundwater levels coupled with the low permeability of the natural lithologies suggest that rates of shallow groundwater movement are relatively limited in the vicinity of the former canal.

Numerous man-made drainage ditches and dykes are evident within 100m of the former canal; the extent to which these features are hydraulically connected to shallow groundwater occurring along the infilled canal is uncertain.

Potential contaminant sources include selected petroleum hydrocarbon compounds within the near surface soils and the underlying waste materials; dissolved phase sulphate, ammonia, chloride, manganese, phenol and various petroleum hydrocarbon compounds

within the shallow groundwater; and locally elevated methane and carbon dioxide concentrations within the waste mass.

Relevant receptors which may be impacted upon by any contaminated ground conditions include humans (i.e., members of the public using sections of the infilled canal for recreational purposes, and also occupants of nearby residential dwellings), residential and commercial buildings neighbouring the infilled canal, and to a lesser degree shallow groundwater (although this is debateable due to the non aquifer status of the local lithologies), nearby groundwater abstractions and local surface water drainage features.

A conservative screening exercise has been undertaken using the latest CLEA methodology to identify any contaminants which may pose a significant risk to human health. On the basis of the available site investigation data, it may be concluded that neither the observed surficial and sub surface soil quality or the shallow groundwater quality pose any significant health risks to informal users of the study area or the residents of properties which extend over the infilled canal.

An assessment of the potential risks from observed ground gas concentrations has been undertaken. This assessment suggests very low gas risks are associated with the observed gas regime in and around the infilled canal.

A conservative screening exercise has been undertaken to identify any contaminants which may cause pollution of controlled waters. The results of this exercise indicate that the majority of substances which were tested for do not pose a pollution risk. However, the landfill leachate present within the waste mass does represent a source of elevated ammonia and manganese plus moderately elevated chloride, phenol, diesel range petroleum hydrocarbons, and selected PAHs.

Elevated concentrations of sulphate, chloride, ammonia, phenol and manganese have similarly been measured in groundwater samples taken beyond the waste extents. As such, there appears to be localised impacts on shallow groundwater quality associated with landfill leachate. The exceedance of several drinking water quality standards suggests that the groundwater in close proximity to the infilled canal is unfit for potable consumption without some form of water treatment. It is however acknowledged that water quality improves rapidly with distance from the infilled canal, suggesting that the pollution effects may be relatively localised (i.e., potable quality water was proven at a private water well positioned some 30 to 40 m from the waste materials).

No significant pollution risks are considered to occur in relation to local surface water drains and ditches.

Based on the available site investigation data and associated interpretations it is not considered appropriate to determine the infilled Wisbech Canal under the Part IIA regime.

1. INTRODUCTION

1.1 Background

ESI Ltd. (ESI) was appointed by Kings Lynn and West Norfolk Borough Council (the Council) in March 2010 to undertake a contaminated land assessment of the infilled Wisbech Canal ('the Site'). Note: the Site lies within the administrative areas of King's Lynn and West Norfolk Borough Council and also Fenland District Council (the council boundary runs along the centre line of the canal for much of its length).

The purpose of this work was to assess the potential risks posed by the current land quality to identified environmental receptors, including risks to human health. As such, the work has been performed under the requirements of Part IIA of the Environmental Protection Act 1990 (the Site has been identified as being potentially contaminated and has been prioritised in accordance with the Council's Contaminated Land Strategy).

The Wisbech Canal was conceived in the late eighteenth century as a link between Wisbech and the Old River Nene at Outwell. The canal, which was some 5.25 miles long, was closed in 1926 due to a combination of factors, including competition for trade from the railways. The canal was infilled with predominantly domestic wastes during the 1960s and 1970s. The alignment of the former canal is shown on Figure 1.1.

This document presents details of the site investigation works undertaken by ESI and the subsequent risk assessment findings.

1.2 Objectives

The objective of the work was to undertake a comprehensive data review and targeted site investigations to aid consideration of whether an unacceptable risk to human health, buildings or property may exist and/or significant pollution of controlled waters is likely from observed ground gases or soil and groundwater quality across the Site.

As such, sufficient information was required from the site investigation and subsequent risk assessments to enable the Council to assess whether the Site should be determined as Contaminated Land under the Part IIA regime.

In addition, given the contribution of landfill gas emissions to global warming effects, a further objective of the proposed work was to provide a quantitative assessment of the total greenhouse gas emissions resulting from the former landfill site. The results of this monitoring work will be provided to the Environment Agency who have a responsibility for collating information regarding the magnitude of greenhouse gas releases from historical landfill sites. Note: the findings of the greenhouse gas assessment are presented in a separate report (ESI, 2010).

1.3 Scope of work

In order to achieve the objectives stated above, the scope of work carried out for this assessment included:

- Review of salient documentary information for the Site and surrounding area.
- Conduct an initial site walkover/familiarisation.
- Undertake intrusive site investigation works across the Site and surrounding land areas; these works were largely undertaken between 19th and 27th July 2010, with follow-up monitoring and sampling works performed between August and November 2010.
- Develop a conceptual site model including the understanding of all potential source-pathway-receptor linkages (i.e. relevant pollutant linkages).
- Quantify potential risks from contaminated land to relevant environmental receptors arising from the observed site conditions.

- Prepare a summary report in line with the approach advocated by relevant guidance (Environment Agency, 2004).

A summary of the information sources used to assist in the investigation and risk assessment works is presented in Appendix A.

1.4 Relevant Legislation

Part IIA of the Environmental Protection Act 1990 introduced a regulatory regime for the identification and remediation of contaminated land. Statutory Guidance (DEFRA Circular 01/2006) and the Contaminated Land (England) Regulations (2000) contain details of the regime relevant to the detailed inspection works.

Under Part IIA the local authority, when deciding on the determination of contaminated land, is required to undertake two steps; firstly, to satisfy itself that a source of contamination, a pathway and also a relevant receptor, all exist in relation to the site in question. This condition has been met for the Site as a consequence of initial desk top reporting conducted by the Council (and supported by soil gas monitoring data supplied by Norfolk County Council)

The second step required under the Part IIA regime is to establish an active linkage involving any identified source(s), pathway(s) and receptor(s) and to satisfy itself that the pollution linkage is resulting in significant harm being caused, presents a significant possibility of significant harm being caused, is resulting in the pollution of controlled waters, or is likely to result in such pollution. The results and interpretation contained in this report are designed to assist the Council in addressing the second step in the determination process.

1.5 Report structure

The information contained within this report comprises the following:

• Section 2:	Site location and history	:	Details of the current Site setting and historic Site land use
• Section 3:	Consultations	:	Records of consultations held with relevant third parties
• Section 4:	Environmental setting	:	Summary of physical characteristics of the Site and surrounding area, including geology, hydrogeology, hydrology and drainage
• Section 5:	Site investigation works	:	Summary of both historical site investigations performed at various locations along the Site and ESI's recent site investigation programme
• Section 6:	Site investigation results	:	Description of the salient site investigation findings relating to geology, hydrogeology, soil and groundwater quality and soil gas
• Section 7:	Conceptual site models	:	Description of both the prevailing Conceptual Site Model (the physical site setting) and the Conceptual Exposure Model, including details of relevant contaminant sources, pathways and receptors
• Section 8:	Human health risk assessment	:	Quantitative assessment of the risks posed to human health by observed soil and groundwater quality

- Section 9: Ground gas risk assessment : Quantitative assessment of the risks posed to local buildings and their occupants from the observed ground gas regime
- Section 10: Controlled waters risk assessment : Quantitative assessment of the risks posed to controlled waters by observed soil and groundwater quality
- Section 11: Project conclusions and recommendations : Salient project conclusions and recommendations

2. SITE LOCATION AND HISTORY

2.1 Site location and setting

The infilled Wisbech Canal is located between Wisbech and Outwell as shown on Figure 1.1. A variety of land uses now occupy the former route of the canal including public open space, the A1101, agricultural land, pavement and roadside verges, some commercial land areas (including car parking) and a number of residential gardens.

A site walkover was conducted by ESI on 10th June 2010. The length of the canal was accessed by foot and bicycle by Andy Singleton and Pete Moss. The following observations were made during the site walkover:

- There were no obvious signs of vegetation stress (i.e., indicating the presence of phyto-toxins in the local soils or depleted oxygen concentrations within the sub soils) along the length of the former canal.
- Reasonable access was available for intrusive site investigation works along the majority of the canal; drilling constraints were however identified along the stretch of infilled canal between Collett's Bridge and Outwell Bridge due to the presence of the A1122.
- Potential site investigation locations were identified in the most developed section of the former canal alignment (in south of Wisbech) despite a high density of commerce and residential buildings.
- The former alignment of the canal was evident along much of the route based on current topography, road alignments and the remains of former structures including bridge foundations and sluice gate mechanisms.
- Numerous buried services were identified alongside the infilled canal. Anglian Water marker posts were encountered along the grassed strip of land which marks the route of the former canal through Outwell.

2.2 History of the Site

As the rivers across North Norfolk 'fell into decay' during the 17th and 18th centuries transport across the area became increasingly difficult (Smith, 2002). In response to these difficulties the Wisbech Canal was conceived in the late eighteenth century as a trading link between Wisbech and the Old River Nene at Outwell (Boyes, 1977). The Wisbech Canal Company was formed in 1790 and the canal was authorised by an Act of Parliament in 1794.

Construction of the canal commenced in 1795. Works included remodelling of the existing Well Creek, including straightening and by-passing off the Emneth and Basin corners (Smith, 2002) Because of the low level of the Fens, the canal was constructed on embankments for some of its length. The canal did not have its own water supply, but was refilled with water at each high tide. On completion, in 1797, the canal was 5.25 miles long with a flood lock at each end.

The operation of the canal was beset with various problems including regular silting (due to the tidal infilling of the canal, silt was routinely carried into the canal by the waters of the Nene); ice damage to the locks (Boyes, 1977); water shortages; and competition from alternative trading routes, including both alternative water ways (Boyes, 1977) and the Wisbech to Upwell tramway. The tramway, which was opened in 1883, also ran from Wisbech to Outwell following a route along the course of the canal. Initially, there was some benefit to the canal, as coal was transported by the railway to Outwell, and loaded into boats by chutes. However, over time the railway displaced the canal as the preferred trading route.

Canal traffic ceased in 1922 and the structure was officially abandoned on 14th June 1926.

Following the demise of the canal, the structure was infilled with waste materials over a period of around 20 years. Two broad phases of infilling are understood to have occurred. Inert waste materials are reported (KLWN, 2010) to have been placed in the northern section of the canal (i.e., extending from the northern limit of the canal to the current alignment of the A141) during the 1950's (see: http://www.cambridgeshire.gov.uk/NR/rdonlyres/8A1BD7B5-C38A-4776-A5A3-B6C1C0E21494/0/EUSFenlandWisbech.pdf). Anecdotal reports suggest that the infill materials were either derived from river or basin dredgings or arisings from the installation of new sewers along the A1101 (KLWN, 2010). Infilling of the area to the north of Elm was largely completed by 1961.

The main phase of landfilling within the Wisbech Canal was given planning approval in January 1961 (see Appendix B). Under this planning permission 'controlled tipping of refuse' was enabled between Common Bridge (located north of Elm) and Outwell Sluice.

Specific planning conditions relating to the landfilling included:

- Waste was to be deposited in layers.
- Waste layers were to be no more than 6 feet (1.9 m) thick.
- Each layer was to be covered by at least 9 inches (0.23 m) of earth or anther suitable substance.
- If the material deposited at any one time consisted entirely, or mainly of fish, animal, or other organic refuse, it was to be covered with earth or other equally suitable substances at least 2 feet (0.6 m) in depth.
- No leakage of polluted drainage was to be allowed to reach any watercourse in the area.
- No building or other structures, including fencing, was to be erected on the land without the prior consent of the local planning authority.

Infilling commenced in June 1962. For the next ten years Mr (Speedy) Hills was responsible for infilling the canal from New Common Bridge in Wisbech to Gills (Scott's) Bridge in Outwell (Smith, 2002). The final section of canal was infilled in the reverse direction (i.e., from Outwell sluice in the south towards Scott's Bridge).

During the formal infilling of the canal, additional fly tipping of waste materials is understood to have occurred; 'in the 1960s the canal, which was almost devoid of water, attracted the dumping of all manner of rubbish' (Smith, 2002).

All landfilling activities were completed by 1978.

Note: further details of the Wisbech Canal history are presented in the Council's preliminary risk assessment report (KLWN, 2010). A schematic illustration of the Wisbech Canal, as taken from the Councils desk study report (KLWN, 2010) is reproduced over page.

Historical land use maps (as provided by KLWN) are reproduced in Appendix C. These maps confirm the sequencing of events described above.

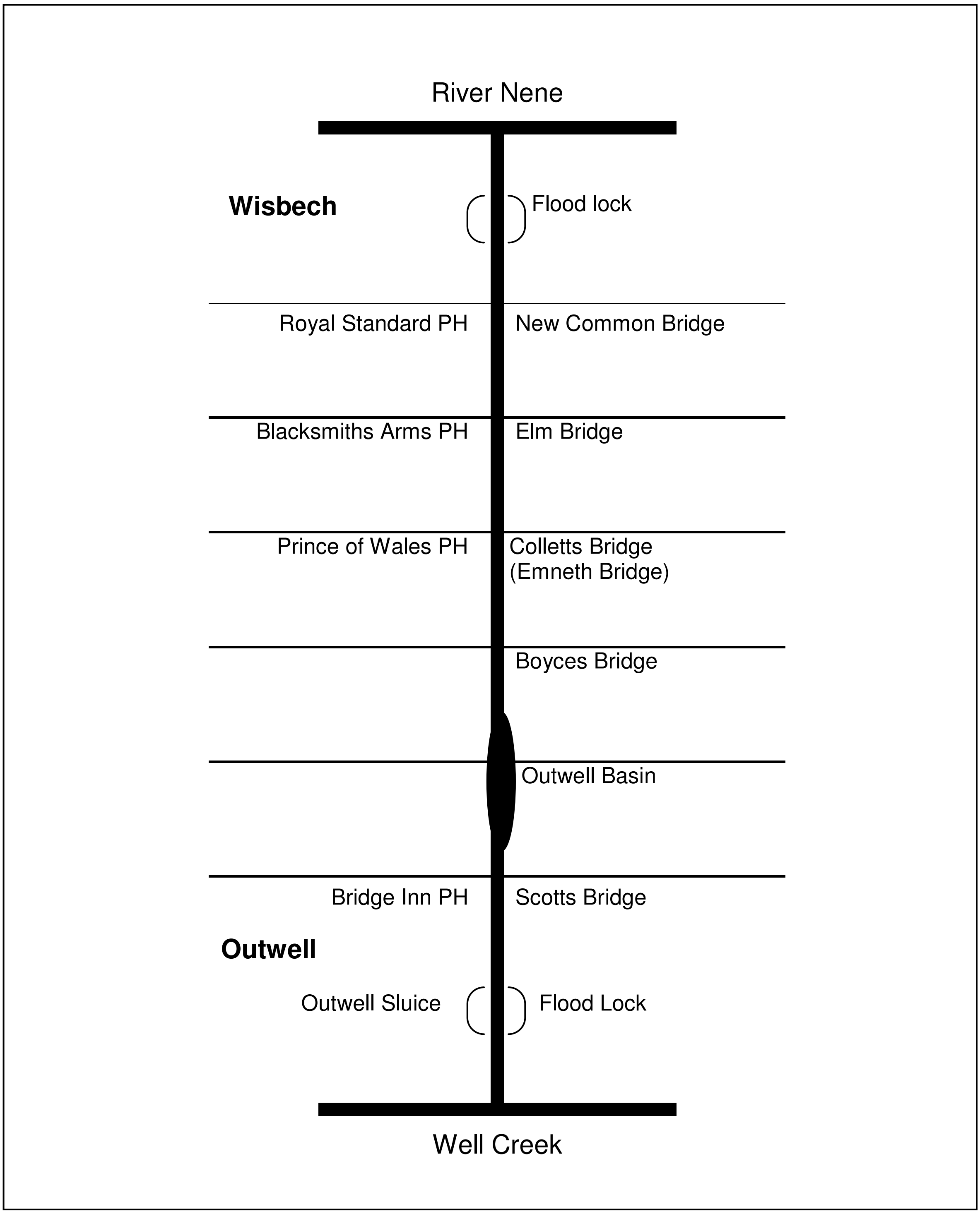


Diagram 1: Schematic diagram of the Wisbech Canal

3. CONSULTATIONS

Formal contact was made with the following organisations and individuals:

i) Environment Agency

Various data requests were also made to the EA in relation to groundwater levels and water quality, surface water quality, groundwater abstraction details, surface water flooding, etc.

ii) King's Lynn and West Norfolk Borough Council

As the project client, regular communications were held with King's Lynn and West Norfolk Borough Council. Close contact was thus maintained with the Council's project manager, Fabia Pollard (Senior Scientific Officer). Fabia supplied various documentary and anecdotal information throughout the project duration.

A project kick off meeting was held with representatives from the Council on 10th June 2010.

iii) Fenland District Council

Given that the former Wisbech Canal also falls within the boundaries of Fenland District Council, information was sought and exchanged with the Council's Laura Bradley (Environmental Protection Officer). Laura was also present at the kick off meeting on 10th June 2010.

iv) Norfolk County Council (NCC)

Des Holmes (NCC Waste Management Officer) provided information associated with the County Council's long term soil gas monitoring programme along the infilled Wisbech Canal, including borehole drill records, monthly bulk gas monitoring data and groundwater level information.

- NCC consider gas risks to local residents to be low on account of:
    - Time since deposition
    - Saturated conditions anticipated within the waste
    - Low permeability of the natural deposits surrounding the former canal.
    - Absence of any vegetation stress along the line of the canal

Robert Holden (NCC Street Works Officer) was also contacted to discuss the road construction techniques used during the development of the A1101 (most notably the section of road between Outwell and Collett's Bridge which was partly constructed on top of the infilled canal).

Mr Holden consulted with the County Council's highways department and was able to provide the following information:

- The section of the A1101 which runs from Outwell Basin northwards was completed during the early 1990s; the highways contractor was Roadworks 1952 Ltd (now Jacksons).
- No waste materials were removed during the road construction; rather, in situ materials were compacted using a sheepsfoot roller. A layer of sand c. 1 m thick was then placed over the compacted materials. A dynamic compaction with a flat steel weight was dropped from a predetermined height a set number of times. Above this the road was constructed using a conventional specification: 150 mm type 1 overlain by c. 250 mm of asphalt.

v) Local historian

Numerous correspondences were had with local historian, William Smith, who provided a valuable first hand insight into the former operation of the canal and the methods using for waste disposal and site reinstatement. Information provided by Mr Smith included:

- The Wisbech Canal was of variable width, although the structure was typically wider at its southern end (i.e. around Outwell). The canal was c. 20 m across at its widest point.

- The canal sides sloped down towards the base of canal (i.e., the sides were not vertical); this design avoided the need for any significant engineered support of the canal sides.
- The canal depth was typically no more than 2 m (i.e., from road level to the base of the canal).
- The canal was cut into the natural clays; no lining materials were subsequently used in the canal construction.
- The canal was dredged prior to infilling in order to both maximise the capacity for waste disposal and provide materials for capping the deposited wastes.
- No barrier was placed between the infilled materials and the surrounding natural silts and clays during the landfilling works.
- Collett's Bridge is likely to have received a greater thickness of wastes (c. 3 - 4 m) compared with other areas along the canal.
- Infilling of the canal commenced at Wisbech and progressed in a southerly direction to Scott's Bridge in Outwell. Waste disposal was then undertaken from the southern end of the canal back towards Scott's Bridge. This decision led to the accumulation of noxious sludge within the 'open' section of canal positioned between the two infilled sections. Following public pressure the sludge was tankered off site and the affected section (amounting to a stretch of up to 300m) was rapidly filled predominantly with 'inert' soil.

  Note: the available ESI and NCC borehole logs (see Appendices F and K) do not show any obvious deviation in waste composition around Scott's Bridge although this may reflect both the low density of ESI in-waste boreholes and the basic level of information presented on the NCC logs.

Selected historical photographs supplied by William Smith are presented in Appendix D.

vi) Wisbech museum

A telephone discussion was held with Robert Bell of the Wisbech Museum. Mr Bell arranged for relevant mapping and documentation associated with the operation and subsequent infilling of the Wisbech Canal to be made available to ESI. Andy Singleton (ESI's project manager) and Pete Moss (ESI's fieldwork supervisor) reviewed the available museum information on 10th June 2010. This information included:

- The Wisbech Corporation Plan 1973.
- Selected photographs of the canal infilling. *These images showed clear evidence of the use of imported topsoil in the reinstatement of the infilled canal. The photographs also indicated the relatively uncontrolled nature of the waste disposal.*
- Various financial account details, meeting minutes and share reports relating to the Wisbech Corporation.

4. ENVIRONMENTAL SETTING

4.1 Current land use and general site setting

The generic land use types which are evident along the length of the infilled canal are highlighted on Figures 5.2 to 5.6. These land uses include commercial, gardens, grazing, open space and roads.

In summary, the northern section of the Site (i.e., that between Wisbech and the junction between the A1122 and A47 (formerly New Common Bridge)) is currently occupied by a mixture of residential gardens and intermittent commercial activities (including petrol filling stations and a number of vehicle repair garages). The landfilled section between the former New Common Bridge and Collett's Bridge is now covered by grassed 'open space'; a footpath is evident along the route connecting Elm to Collett's Bridge. The surrounding land use between Elm and Collett's Bridge is dominated by arable agricultural with some localised housing (the agricultural land is characterised by a series of fields divided by a network of surface water drains).

The route of the infilled canal through Collett's Bridge is predominantly green open space; this strip of land has been informally 'adopted' by the local residents for their private use. Fencing has been used to mark various plots of land; vegetable cultivation is also evident at a number of locations. To the south, the infilled canal is presently occupied by rough grassed cover and increasingly the route of the A1122.

To the south of Outwell Basin the land use comprises grassed open space.

4.2 Geology

The entire study area is underlain by the Terrington Beds (BGS sheet 159, 1995) comprising saltmarsh deposits (dull reddish brown clays) and tidal creek deposits (silty fine grained sands).

These superficial deposits are underlain by the Ampthill Clay formation comprising soft grey mudstone and pale grey calcareous mudstone with some cementstone doggers. The Ampthill Clay is reported to be of the order 40 to 50 m thick across the region (BGS, 1995).

No significant geological faulting is evident in the locality of the Site. The regional geology is summarised on Figure 4.1.

The records of five historical boreholes located in the vicinity of the Site were obtained from the BGS (see Appendix E). Summary details of these boreholes are given in Table 4.1; the original borehole locations are also shown on Figure 4.1. Key observations relating to the BGS borehole records include:

- The information for borehole records 505690 and 505691 relate to seven discrete water wells (private water supplies) positioned in the Emneth locality.
- Groundwater level records from the 1930s indicate a shallow groundwater table, with water levels typically occurring within 2 m of the ground surface.
- Geological information confirms the presence of the Terrington Beds near to ground surface. For example, geological records for BH 505715 (located in Wisbech) show laminated brown to grey silty clays and grey silts to a depth of at least 13.6 m bgl. The Terrington Beds (referred to as tidal channel deposits) encountered in borehole 507280 (located in Outwell) appear to comprise slightly coarser deposits, being described as fine brown sand or fine shelly sand.

Table 4.1 Summary of BGS boreholes

Record ID	Borehole reference	Borehole name	Easting	Northing	Borehole depth: m	Groundwater level: m bgl
505685	TF40NE5	NEW COTTAGES, EMNETH 44	548820	306380	2.74	0.5 (1937)
505690	TF40NE10	HOLLYCROFT RD. EMNETH 38	549970	306230	2.4 to 5.6	0.5 to 2.8 (1937 and 1938)
505691	TF40NE11	HANSTEAD HOUSE, EMNETH 39				
505715	TF40NE35	WISBECH 6	546200	308990	13.72	/
507280	TF50SW1	HOMELANDS OUTWELL IGS	551110	304170	15	/

The superficial soil profile/characteristics across the Site were better defined during the site investigation works undertaken in July 2010. Details of the site-specific geology are presented in Section 6.1.

4.3 Hydrogeology

Both the superficial deposits and the underlying bedrock are classified as Non Productive Strata (formerly Non Aquifers). In support of this, the Environment Agency's Anglian Northern Groundwater team have confirmed that the local geological strata are unproductive and so do not hold groundwater in quantities that would make it a useful resource. In response to this situation, the Agency do not have any groundwater level or water quality monitoring points within at least 2 km of the Site. Furthermore, there are no source protection zones (SPZ) defined within a 2 km radius of the Site.

A recent phase 1 geoenvironmental and geotechnical report conducted by RSK (RSK, 2010) for a site off Elm High Road, Wisbech, concluded that the superficial deposits in this area are 'relatively impermeable' based on the 'failure' of various soakaway tests (i.e., water introduced to an excavation within the superficial Terrington Beds did not seep into these deposits at any meaningful rate). The RSK study site was located c. 80 m east of the infilled canal.

Regardless, a few private groundwater abstractions are known to be present in the vicinity of the infilled canal (based on both BGS records and the results of public consultations undertaken by the Council). A series of shallow water wells are known to have existed in the Emneth area to the north of the former canal during the early twentieth century (see Section 4.2). Public consultations undertaken during June 2010 revealed the presence of two additional wells within close proximity of the infilled canal. A 5.5 m deep, 2.5 m diameter well is still in use (predominantly for garden irrigation) at Birdbeck House, Basin Road, Outwell. This structure, which is understood to pre date 1742, is located between 30 and 40 m from the infilled canal. According to the home owner, static water levels in the Birdbeck House well are typically 2 to 2.5 m bgl. A second well is located at The Hazels property in Collett's Bridge; this feature is understood to be c. 8 m deep.

No licensed groundwater abstractions are presently located within the close proximity of the Site (i.e., within a 5.5 km of the centre point of the former canal).

Shallow groundwater is therefore known to occur, at least sporadically, within the superficial deposits. Historical water levels (taken during the 1930s) associated with the BGS supplied boreholes ranged from 0.5 to 2.8 m bgl. This is consistent with the recent water levels observed at the Birdbeck House well. The continuity of shallow water across the Terrington Beds is however unclear; i.e., appreciable groundwater may be constrained to areas of enhanced permeability.

Due to the low lying nature of the area, groundwater flows may be largely controlled by the location of surface water features (which likely act as points of discharge for the local groundwater). It is recognised that the presence of numerous man made drainage channels in the locality of the Site may well interfere with 'natural' groundwater flow behaviour. As such, the nature of any shallow groundwater flow directions in the vicinity of the Site is difficult to predict.

The hydrogeological conditions occurring in and around the Site were better defined as a result of ESI's recent site investigation works. Details of the site-specific hydrogeology are presented in Section 6.2.

4.4 Hydrology and drainage

The Fenland landscape is typified by its complex network of natural and man-made surface water drainage features, including numerous canals, ditches and dykes. The largest water features in the vicinity of the Site are the River Nene which passes through the western half of Wisbech and the Well Creek, which passes through Upwell and Outwell. The Wisbech Canal formerly connected these two tidal water courses.

A network of artificial drainage channels is evident directly north and south of the former canal alignment. These features are assumed to both remove access surface water runoff following rainfall and also control groundwater levels within the superficial deposits. As such, the superficial tidal flat deposits are likely to be in hydraulic continuity with the drainage features adjacent to the canal. The location of drainage channels to the south of the infilled canal are highlighted on Figure 4.2.

Field observations made during ESI's site investigation programme indicate that the drainage channels are often steeply sided and are cut between 2 and 5 m into the superficial deposits. Selected photographs of local drainage features are shown in Appendix J.

The EA hold records of 10 surface water abstraction licences within a 5.5 km radius of the centre point of the canal, nine of which relate to agricultural use (predominantly spray irrigation) with the final abstraction used for cooling purposes.

The EA have also supplied water quality data for five effluent discharges to local surface water courses. All data relate to the discharge of treated sewage effluent (non water company effluent). Four of the five discharges are within a 1 km radius of Outwell.

4.5 Waste management/landfill sites

Environment Agency records indicate the absence of any other active or historical landfill sites within a 2 km radius of the Site.

4.6 Ecology and wildlife

Within a 1000 m radius of the Site, there are no recorded Sites of Special Scientific Interest, Ramsar sites, National Nature Reserves, Special Areas for Conservation, Special Protection Areas or National Parks.

5. SITE INVESTIGATION WORKS

A number of site investigation/environmental monitoring works have been performed along the former Wisbech Canal in recent years.

Long-term ground gas monitoring has been conducted by Norfolk County Council (NCC) along the length of the former canal structure.

A limited programme of additional gas monitoring was undertaken along the northern section of the infilled canal in 2009 (i.e., that section not covered by NCC monitoring installations).

A programme of site investigations was undertaken along a short section of the former canal off Elm Low Road during October 2009. The investigation, performed by Norfolk Partnership Laboratory (NPL), was undertaken to aid the assessment of land quality across the 0.13 ha site prior to the intended land sale.

King's Lynn and West Norfolk Borough Council performed further limited trail pitting and soil sampling along the line of the former Canal during January 2010.

Subsequent comprehensive site investigations were coordinated by ESI between July and November 2010, with the aim of developing a robust conceptual understanding of the Site and thus enabling the quantitative assessment of environmental risks posed by observed land quality.

Further details of these various site investigations are presented below.

5.1 Summary of NCC ground gas monitoring (1992 to present)

Norfolk County Council (NCC) have responsibility for monitoring ground gases associated with the infilled Wisbech Canal as part of their Waste Disposal Authority duties (KLWN, 2010). Long-term ground gas monitoring has therefore been conducted by NCC along much of the infilled canal. A total of 69 gas monitoring boreholes were drilled along the canal alignment in 1992 by Dereham Water Supplies Ltd. All holes were drilled at 6 inch drill diameter to a depth of c. 3 m bgl. The boreholes were targeted on sections of the former canal which pass close to residential dwellings (i.e., no gas monitoring boreholes are positioned along the Outwell Road between Collett's Bridge and Outwell Basin). A notable exception to this is the northern stretch of the canal (i.e., that north of the Blacksmith Arms Public House; see Diagram 1) along which there are no NCC monitoring boreholes. The absence of boreholes in this area reflects the County Council's belief that 'the length of the canal north of monitoring point 3701 was believed to be filled with inert material' (KLWN, 2010).

All NCC monitoring holes were targeted at the waste materials. However, nine of the holes are reported to have encountered either no waste or very little waste (3709, 3710, 3718, 3725, 3735, 3736, 3760, 3763 and 3766). Where waste is present, the geological logs for the NCC boreholes show 0.5 m of 'soil' above the waste materials (it is noted that NCC have expressed reservations regarding the quality of the information presented on the logs, as generated by Dereham Water Supplies Ltd (see Appendix F)). The locations of the NCC monitoring boreholes are shown on Figures 5.2 to 5.6 (the location of the sub-areas depicted on each of these figures is shown on Figure 5.1). The coordinates for the NCC boreholes (as supplied by NCC) are tabulated in Appendix G.

Monthly bulk gas records are available for the majority of NCC boreholes since 1992 (see Appendix H). No borehole flow rates have however been recorded.

5.2 NCC 2009 ground gas investigations

In 1991 a series of trial pits approximately 3 m deep were excavated along a 200 m length of the infilled canal immediately north of the existing A47. The trial pits are reported to have encountered 'soils, rubble and some timber'. Gas monitoring probes were installed in the trial holes and monitored on around four separate occasions. Monitoring was stopped when no methane and only slightly elevated levels of carbon dioxide were detected (KLWN, 2010).

5.3 Summary of the NPL site investigation works (2009)

A programme of targeted site investigations were undertaken by Norfolk Partnership Laboratory (NPL) at a site on Elm Low Road in Wisbech (i.e., towards the northern end of the former canal structure) during October 2009; these works were designed to assist in land quality characterisation ahead of proposed site redevelopment.

The NPL works comprised the drilling of six window sampling boreholes to a depth of c. 3 m bgl; the installation of two monitoring boreholes (see Figure 5.2); collection of three soil samples for laboratory chemical testing; and soil gas monitoring on four occasions during October and November 2009 at four monitoring boreholes.

Made Ground was recorded in five of the six boreholes at thicknesses of between 0.9 and 3 m. The Made Ground included concrete, brick, ceramics, plastic, ash, coal, asphalt, glass and wood. The natural Terrington Beds were encountered beneath the Made Ground; these deposits comprised laminated light brown and greyish-brown silt and greyish-brown and black silty clay. Groundwater levels were typically c. 2.5 m bgl. Borehole recharge was observed to be ‘very slow’ following dewatering.

Ground gas monitoring data showed a general absence of methane, although 3.7% methane was measured at one location during a single monitoring round. Carbon dioxide results ranged between 1 and 5 %. No positive borehole gas flows were measured. The resulting ground gas risk assessment concluded a negligible gas risk.

The soils analyses undertaken indicated the absence of any appreciable land contamination. The PAH signature indicated that the source of the observed PAHs was coal or ash. The NPL report concluded that in situ soils posed a low risk to potential future site users.

5.4 Summary of Kings Lynn and West Norfolk Council site investigation works (2010)

In order to inform the conceptual site understanding the Council sampled sub surface soils at four locations along the line of the former canal (HA1 to HA4) using a hand auger. These works were undertaken during January 2010 (see Appendix I and also Figures 5.2 to 5.6). Eight grab samples were taken from the auger locations (two soils sample were collected at 0.2 and 0.5 m bgl from each location) and subject to laboratory testing. An additional sample was taken from waste materials evident at the ground surface.

Exposed soils were reported to vary from dark brown loam to orange/brown silty clay, reflecting the variability of fill and cover materials along the infilled canal. Waste materials, including brick and ash fragments, glass, fabric, clothing, shoes, bottles and plastic were encountered at three of the trial pit locations. Laboratory analyses showed no evidence of gross contamination associated with the waste deposits (the KLWN laboratory analyses are reproduced in Appendix I).

Further details of the KLWN sampling activities are presented in the preliminary risk assessment report (KLWN, 2010). This document also contains descriptions and photographs of the Site associated with a walkover performed by the Council during December 2009.

5.5 ESI site investigation works (2010)

A comprehensive programme of site investigations and repeat monitoring activities was conducted by ESI between July and November 2010.

5.5.1 Purpose of the site investigation

The outline aims of ESI’s site investigation works were as follows:

- To define any sources of contamination associated with the infilled canal (i.e., as demonstrated by the surficial soil quality above the line of the former canal, the extent and chemical quality of the waste materials themselves, leachate quality associated with the infilled materials, and also the ground gas potential of the wastes).
- To assess the ground conditions beyond the waste materials and thus the likelihood of lateral gas migration away from the landfilled materials.
- To monitor bulk gas concentrations beyond the boundary of the former canal (i.e., along the potential lateral gas migration pathway).
- To provide sufficient data in order to develop a robust conceptual site understanding and permit detailed quantitative risk assessment.

5.5.2 Drilling activities

In order to meet the aims stated above a series of boreholes were drilled both within the waste materials and within natural deposits located adjacent to the infilled canal.

The drill locations were targeted on areas of common land wherever possible in order to avoid disruption and unnecessary concern to local residents (as such, minimal drilling activities were scheduled within any residential gardens). The boreholes drilled within the waste materials were sited based on perceived gas potential (as indicated by existing NCC soil gas monitoring records), ease of access (for drilling and repeat monitoring) and the prevailing land use (i.e. proximity of residential properties).The positioning of 'off-waste' boreholes was constrained by the availability of safe and convenient drill locations. Working within these constraints, where possible the off-waste holes were situated along the potential gas migration pathway between the wastes and adjacent residential receptor and also in-line with new or existing in-waste boreholes.

i) Drilling preparations

The intrusive investigations planned for the Site posed a number of potential health and safety risks to both the site investigation team and possibly the wider public; these risks included the consequences of disturbing buried services and also the potential exposure to landfill gases and airborne contaminants, including asbestos fibres.

Prior to the undertaking of all site works, plans relating to buried services (including gas, electricity, water and telecoms) were obtained and factored into the site investigation designs..

Appropriate measures were taken to manage the risks posed by landfill gases, including the specification of appropriate drilling methods and the use of personal gas monitoring devices. Standard ESI health and safety procedures were followed regarding the response to elevated gas concentrations (note: no elevated landfill gas concentrations were encountered during the drilling activities) and also the management of asbestos risks. The latter included the use of field personnel with asbestos awareness training, specification of appropriate PPE and the use of suitable processes for handling suspected asbestos containing materials.

i) Drilling methods

All exploratory drilling was undertaken using a percussive Terrier drill rig (a relatively small and manoeuvrable rig which produces intact soil cores which enable accurate soil descriptions).

A total of eight in-waste boreholes were drilled, seven of which were installed for groundwater sampling and ground gas monitoring (borehole references: W1 to W7). A further 22 boreholes were drilled beyond the waste extents, 20 of which have been installed (borehole references: A1 to A20). The locations of all drilled holes are shown on Figures 5.2 to 5.6. Summary information relating to each of these locations is presented in Tables 5.1 and 5.2.

Where fitted, the semi-permanent monitoring installations comprised 50 mm diameter HDPE piezometers. Slotted pipe sections (1 mm slot size) were typically specified below a depth of 1 m bgl; plain pipe was used to ground surface; details concerning individual response zones/screened intervals are presented in Tables 6.1 and 6.2. Each borehole annulus was backfilled with non-calcareous pea gravel and a bentonite cement seal was placed from c. 1 m bgl to ground surface. Gas taps were fitted to all installed boreholes and flush borehole covers were concreted into place at surface.

Note: care was used when designing each installation to prevent the creation of preferential pathways into the underlying superficial deposits; as such, the in-waste borehole installations were typically limited to the depth of waste encountered (i.e., where boreholes were drilled into the underlying natural deposits, these holes were backfilled with bentonite cement to the base level of the waste materials).

Those boreholes which were not installed (i.e., due to shallow drilling refusal or the absence of appreciable waste materials) were backfilled with bentonite.

All soils recovered during the drilling works were carefully logged according to current best practice. To assist in understanding the gas generation potential of the in-filled material, logging and inspection of the drill cores included careful inspection and recording of any putrescible material.

Selected photographs taken during the 2009 site investigation are presented in Appendix J.

Detailed geological logs for each of the borehole locations are presented in Appendix K. Furthermore, brief descriptions of the ESI borehole locations are shown in Appendix L.

A hand held PID meter was used during all site works to provide an indication of the presence of any volatile gases within both the Made Ground and natural deposits.

All borehole locations were estimated using a hand held GPS device.

All arisings from the drilling works were removed off site for appropriate disposal.

Information from the site diary maintained by ESI's site supervisor is presented in Appendix M.

Table 5.1 Summary of ESI in-waste boreholes

BH ref	Purpose	Drill date	Depth: m	Installation details	Easting[1]	Northing[1]	Datum[2]: m AOD	Location
W1	Characterising the extent and composition of cover materials, the waste extent and composition, and the nature of underlying lithologies. Enabling subsequent ground gas monitoring	27/07/10	2.0	Borehole not installed; limited waste thickness	546854	308416	3.7	Situated on grassed verge directly north of window showroom.
W1a		27/07/10	4.0	Response zone 1 to 3 m bgl (installed in waste materials)	546845	308418	3.7	
W2		27/07/10	4.0	Response zone 1 to 3.5 m bgl (installed in waste materials)	546961	307984	3.7	Borehole situated on southern edge of Shell garage land holding
W4		26/07/10	4.0	Response zone 1 to 4.0 m bgl (NO waste materials encountered)	547256	307539	3.7	Situated on grassed area in north of land occupied by Concorde Tyres
W4a		27/07/10	3.0	Response zone 0.5 to 2.5 m bgl (installed in waste materials)	547258	307539	3.7	
W5		23/07/10	4.0	Response zone 1 to 3.5 m bgl (installed in waste materials)	550823	304767	3.8	Situated on amenity land adjacent to Marcol Basin Road
W6		19/07/10	4.0	Response zone 1 to 4.0 m bgl (installed in waste materials)	551202	304314	3.85	Situated on amenity land adjacent to Wellsworth Isle Rd
W7		19/07/10	5.0	Response zone 1 to 4.5 m bgl (installed in waste materials)	551292	303903	3.7	Situated on amenity land adjacent to 46 Wisbech Rd

[1] *borehole coordinates taken using a GPS*

[2] *borehole elevations extrapolated from NCC survey data (see Appendix G)*

Note: borehole W3 was planned but not drilled due to access restrictions

Table 5.2 Summary of ESI boreholes drilled beyond the waste extents

BH ref	Purpose	Drill date	Depth: m	Installation details	Easting[1]	Northing[1]	Datum[2]: m AOD	Location
A1	Validating the lateral extent of waste materials. Enabling subsequent ground gas monitoring	27/07/10	4.0	Response zone 1 to 3 m bgl	546949	307962	3.7	Borehole located on strip of rough land directly north of recently constructed houses.
A2		26/07/10	4.0	Response zone 1 to 4 m bgl	547309	307516	3.7	Borehole located on grass verge to east of main road
A3		26/07/10	1.0	No installation Note: borehole abandoned at 1 m due to concrete obstruction	547354	307402	3.9	Boreholes situated on rough grass verge adjacent to Glenburn property
A3a		26/07/10	4.0	Response zone 1 to 4 m bgl	547354	307402	3.9	
A4		21/07/10	3.0	Response zone 1 to 3 m bgl	547970	307048	3.8	Situated in rear garden of 42 Outwell Road
A5		21/07/10	2.0	No installation	547970	307048	3.8	Boreholes located in corner of field
A5a		21/07/10	4.0	Response zone 1 to 4 m bgl	548055	306929	3.8	
A6		21/07/10	4.0	Response zone 1 to 4 m bgl	548199	306729	4.2	Situated in rear garden of Palmer residence, 2 Outwell Road
A7		21/07/10	4.0	Response zone 1 to 4 m bgl	548211	306611	4.2	Boreholes situated in middle of track to rear of residential properties
A8		22/07/10	4.0	Response zone 1 to 4 m bgl	548299	306429	4.2	
A9		22/07/10	4.0	Response zone 1 to 4 m bgl	549206	305914	4.3	Situated in verge in front of 185 Outwell Road

BH ref	Purpose	Drill date	Depth: m	Installation details	Easting[1]	Northing[1]	Datum[2]: m AOD	Location
A10	Validating the lateral extent of waste materials. Enabling subsequent ground gas monitoring	23/07/10	4.0	Response zone 1 to 4 m bgl	549803	305467	3.8	Situated in verge adjacent to 250 Outwell Road
A11		23/07/10	4.0	Response zone 1 to 4 m bgl	550264	305093	3.8	Situated in verge adjacent 318 Outwell Road
A12		22/07/10	4.0	Response zone 1 to 4 m bgl	550740	304755	4.0	Situated on land between 385 & 377 Wisbech Rd
A13		21/07/10	4.0	Response zone 1 to 4 m bgl	550787	304735	4.0	Situated adjacent to The Bungalow, Basin Road
A14		20/07/10	4.0	Response zone 2 to 4 m bgl	550885	304781	4.0	On central amenity land
A15		20/07/10	4.0	Response zone 1 to 4 m bgl	550957	304667	4.0	Situated on verge adjacent to Cedar Ridge
A16	To assess potential for former 'slacker' features to act as preferential gas migration pathways	22/07/10	4.0	Response zone 1 to 4 m bgl	551147	304485	3.7	Borehole positioned to intercept 'slacker'; former surface water channel connected to infilled canal
A17	Validating the lateral extent of waste materials. Enabling subsequent ground gas monitoring	20/07/10	4.0	Response zone 1 to 4 m bgl	551175	304427	3.7	Situated on verge adjacent to Beupre Ave
A18		20/07/10	4.0	Response zone 1 to 4 m bgl	551174	304311	3.7	Situated on verge adjacent to Birdbeck Drive
A19		19/07/10	4.0	Response zone 1 to 4 m bgl	551258	304186	3.7	Borehole situated on grassed area in front of Oak Drive
A20		19/07/10	4.0	Response zone 1 to 4 m bgl	551311	304006	3.7	Situated in village hall car park

[1] *borehole coordinates taken using a GPS*

[2] *borehole elevations extrapolated from NCC survey data (see Appendix G)*

5.5.3 Soil and water sampling and testing

i) Soil samples

A total of 12 soil samples were taken from the waste materials encountered during the borehole drilling (i.e., from borehole locations W1 to W7). The sample depths ranged from 1 to 4 m bgl. All samples were taken directly from the borehole cores using a clean stainless steel trowel and appropriate sampling containers. Note: all drilling and sampling equipment was cleaned using a portable water spray/jet wash and rolls of paper towel between each sampling location to minimise any risk of cross contamination.

The waste samples were dispatched under full chain of custody procedures to Alcontrol Laboratories for chemical testing. The following analyses were performed on the waste samples:

- Metals and metalloids (As, Cd, Co, Cr (III and VI), Cu, Hg, Mn, Mo, Ni, Pb, Se, V and Zn).
- Ammoniacal nitrogen
- Total sulphate
- Sulphide
- Total phenol (monohydric)
- Cyanide (total and free)
- Soil organic matter
- Fraction organic carbon
- pH
- Speciated PAHs
- TPH (fully speciated hydrocarbon analyses with aliphatic/aromatic split)
- Volatile organic compounds (VOCs), including BTEX
- Semi volatile organic compounds (SVOCs)
- Pesticides (organochloride suite)
- Asbestos screen

Separate leachability testing was also specified on each of the 12 waste samples in order to assess the current contaminant potential of landfilled materials within the unsaturated zone. The following soil leachability analyses were performed:

- Metals and metalloids (As, Cd, Co, Cr (III and VI), Cu, Hg, Mn, Mo, Ni, Pb, Se, V and Zn).
- Ammoniacal nitrogen
- Total sulphate
- Sulphide
- pH
- Hardness (total)
- Cations: calcium and magnesium

In addition to the soil samples derived from the drilling cores, a further 43 grab soil samples were taken during the investigation; 21 of these samples were taken from the gardens of private residences in south Wisbech (sample references H1A to H8C); a further 12 samples (H9A to H9L) were taken from the 'adopted garden' area in Collett's Bridge; the final 10 samples (H10 to H19) were taken from the grassed strip of land in Outwell which runs along the former canal alignment. All grab samples were taken at depths of between 0.15 and 0.2 m bgl using a clean stainless steel trowel. The locations of all grab samples are shown on Figures 5.2 to 5.6. Additional information relating to the grab sample locations is presented in Appendix N.

The grab soil samples were dispatched under full chain of custody procedures to Alcontrol Laboratories for chemical testing. The following analyses were performed on the grab samples:

- Metals and metalloids (As, Cd, Co, Cr (III and VI), Cu, Hg, Mn, Mo, Ni, Pb, Se, V and Zn).
- Total sulphate
- Soil organic matter
- Fraction organic carbon
- Speciated PAHs
- TPH (fully speciated hydrocarbon analyses with aliphatic/aromatic split)
- Asbestos screen

ii) Groundwater samples

Five groundwater samples were taken from the in-waste boreholes. A further nine water samples were taken from the A-series boreholes positioned beyond the waste extents. A single sample was also taken from a private water supply well located in the garden of Birdbeck House in Outwell (sample reference BB1).

Details of the 15 groundwater samples are presented in Table 5.3

Table 5.3 ESI groundwater samples

BH	Water level : mbgl	Sat thickness : m	Purge required (3 well vol): litres	Actual purged : litres	Comment
W2	2.38	1.12	6.72	10	Medium grey/brown silty water. Slight hydrocarbon odour and slight sheen present
W4a	1.89	0.91	5.46	6	Brown silty water
W5	3.1	0.7	4.2	5	Dark grey silty water. Very slight sheen for a short period during purging.
W6	2.25	1.65	9.9	10	Dark grey silty water. Slight sheen present
W7	1.58	2.92	17.52	18	Dark grey silty water. Slight oily sheen present
A1	2.46	0.59	3.54	1.5	Dry after 1.5 L
A2	2.7	1.2	7.2	3	Purge dry after 3 L. Medium brown silty water
A5a	2.5	0.5	3	3	Medium brown, very silty water. Quick recovery
A9	1.9	2.1	12.6	6	Medium brown/grey silty water. Purge dry
A11	3.6	0.4	2.4	1	Sediment at 3.9 m. Purge dry after 1 L. Brown silty water
A13	3.36	0.54	3.24	3	Very slow recovery. Purge dry and return later for sample. Brown silty water
A17	1.42	2.58	15.48	16	Brown/grey silty water. About 3 L of silt purged
A18	2.84	1.16	6.96	4	Sediment at 3.2 m when dipped. Medium brown/grey very silty water. Purged dry
A20	0.74	3.26	19.56	12	Green/grey silty water. Borehole dry after about 12 L
BB1	No access	/	/	None	Sample from well in garden of Birdbeck House, Basin Rd, Outwell. Clear water

All samples were taken on 13 September 2010 using dedicated sampling bailers. Where feasible, an amount of water equivalent to three well volumes was removed prior to sampling.

All water samples were dispatched under full chain of custody procedures to Alcontrol Laboratories for chemical testing. The following analyses were performed:

- Metals and metalloids (As, Cd, Co, Cr (III and VI), Cu, Hg, Mn, Mo, Ni, Pb, Se, V and Zn).
- Ammoniacal nitrogen
- Total sulphate
- Sulphide
- Total phenol (monohydric)
- Cyanide (total and free)
- Thiocyanate
- Chloride
- Hardness (total)
- pH
- Speciated PAHs
- TPH (fully speciated hydrocarbon analyses with aliphatic/aromatic split)
- Volatile organic compounds (VOCs), including BTEX
- Semi volatile organic compounds (SVOCs)
- Pesticides (organochloride suite)
- Cations: calcium and magnesium

5.5.4 Ground gas measurements

Soil gas concentrations (methane, oxygen, carbon dioxide, carbon monoxide and hydrogen sulphide) and borehole flow rates were measured at all ESI gas monitoring boreholes (including both the W and A-series boreholes) during six repeat monitoring rounds between August and November 2010.

Soil gas measurements were made using a potable soil gas analyser (LMSxi Type G3.18). This meter uses an infra-red detector to quantify soil gas concentrations. Additional in built sensors also provide information on atmospheric pressure, temperature and borehole flow rates. The typical accuracy of the LMSxi gas analyser with regard to methane detection is 0.2 % at 5% methane and 3% at 100% methane; with regard to carbon dioxide, the accuracy figures are 0.1 % at 10% carbon dioxide and 3% at 100% carbon dioxide. A flow range of between 0.1 and 20 l/hr can be recorded.

Measurements of volatile gases were also periodically taken using a Photo Ionisation Detector (PID).

6. SITE INVESTIGATION RESULTS

6.1 Geology

6.1.1 Made Ground

Made Ground was encountered within all ESI boreholes located over the infilled canal. The Made Ground was found to consist of two distinct types: domestic waste material and an overlying cover material.

The cover layer was of variable composition ranging from clayey slightly gravelly sand to sandy gravelly clay. This material also included some inert 'waste' such as brick and concrete fragments and occasional pieces of plastic. The thickness of the cover layer also appears to vary across the Site; observed thicknesses ranged between 0.4 and 0.8 m (including topsoil).

The Made Ground deposits underlying the cover layer appear typical of domestic waste materials across much of the Site. The waste composition typically included a slightly silty gravelly sand matrix containing assorted brick, ceramics, glass, clinker, fabric, plastic, metal and wood.

The borehole logs for the three northern most in-waste boreholes (W1a, W2 and W4a, see Appendix K) show the possible absence of domestic waste materials. The Made Ground encountered at these locations is described as a gravelly sand with some brick and concrete and occasional glass and pottery. These descriptions are consistent with anecdotal reports that the stretch of canal from Wisbech to Elm was infilled with inert wastes.

The thickness of waste materials observed within the ESI boreholes ranged from 2.0 to 3.6 m. With only a limited number of drill locations it is not possible to establish any spatial variation in waste thickness along the Site.

6.1.2 Natural deposits

The in-waste borehole logs indicate that the waste materials reside directly upon the natural geological horizons; these are described as brown to grey silty clay and slightly sandy clay. Peat lenses were also observed within the silts.

The off-waste borehole records confirm the presence of superficial tidal flat deposits within close proximity of the ground surface (unsurprisingly miscellaneous Made Ground materials are evident above the natural deposits across the urbanised sections of the infilled canal). The tidal flat deposits comprised soft to firm grey-brown slightly sandy silt and slightly sandy clay. Peaty lenses were also occasionally encountered; these were typically less than 0.2 m in thickness. More frequent sand lenses were also observed; these were often less than 0.5 m thick.

6.2 Hydrogeology

6.2.1 Groundwater levels

Shallow groundwater levels were monitored at all available ESI boreholes on two occasions (13/09/10 and 18/10/10). The water levels records are presented in Table 6.3.

Table 6.1 Groundwater monitoring data: ESI boreholes

Location	Groundwater level			
	13/09/2010		18/10/2010	
	m bgl	m AOD[1]	m bgl	m AOD[1]
A1	2.46	1.24	2.4	1.3
A2	2.69	1.01	2.56	1.14
A3a	2.17	1.73	2.02	1.88
A4	Dry	/	Dry	/
A5a	2.5	1.3	2.24	1.56
A6	3.31	0.89	3.08	1.12
A7	1.98	2.22	1.95	2.25
A8	1.8	2.4	1.64	2.56
A9	1.9	2.4	1.83	2.47
A10	3.46	0.34	3.22	0.58
A11	3.6	0.2	3.37	0.43
A12	2.89	1.11	2.63	1.37
A13	3.36	0.64	3.12	0.88
A14	2.17	1.83	2.11	1.89
A15	3.23	0.77	2.98	1.02
A16	1.55	2.15	1.42	2.28
A17	1.42	2.28	1.29	2.41
A18	2.84	0.86	2.62	1.08
A19	1.84	1.86	1.52	2.18
A20	0.74	2.96	0.7	3.0
W1a	3.0	0.7	2.87	0.83
W2	2.38	1.32	2.34	1.36
W4 *	1.93	1.77	1.69	2.01
W4a	1.89	1.81	1.76	1.94
W5	3.1	0.7	2.92	0.88
W6	2.25	1.6	2.26	1.59
W7	1.58	2.12	1.47	2.23

[1] Borehole datum elevations extrapolated from NCC level survey (see Tables 5.1 and 5.2)

Selected NCC boreholes were also dipped by the County Council on one occasion (22/06/2010); the water level data for 16 NCC boreholes are presented in Table 6.4.The NCC records are broadly consistent with the ESI groundwater level data set.

Table 6.2 Groundwater monitoring data: NCC boreholes

Borehole	Date	Water level: m bgl	Water level: m AOD
3729	22/06/10	1.8	2.30
3733	22/06/10	1.95	2.54
3739	22/06/10	2.15	1.35
3740	22/06/10	2.10	2.00
3743	22/06/10	2.65	1.45
3744	22/06/10	2.2	2.10
3748	22/06/10	2.2	1.70
3751	22/06/10	Dry	Dry
3754	22/06/10	Dry	Dry
3755	22/06/10	1.45	2.35
3756	22/06/10	1.5	2.40
3757	22/06/10	1.6	2.00
3758	22/06/10	1.8	2.00
3760	22/06/10	Dry	Dry
3767	22/06/10	1.6	2.30
3768	22/06/10	1.8	1.70

The water levels recorded in Tables 6.1 and 6.2 indicate that groundwater was routinely encountered within 3 m of the ground surface. The observed water levels range was 0.2 to 3.0 m AOD, with the majority of records falling within the range 1 to 2 m AOD.

The ESI monitoring records (Table 6.1) show a modest increase in water levels across the monitoring period (there was a typical rise in levels of between 0.1 and 0.2 m); this presumably represents the effects of rainfall recharge.

Water levels within those boreholes positioned over the waste deposits indicate that the majority of the waste is partly saturated; saturated thicknesses in the ESI W-series boreholes range between 0.4 and 2.2 m. Given that water levels within the wastes are relatively consistent (around 1.5 to 2.5 m bgl) the saturated thickness is controlled by the depth (base elevation) of the waste materials.

Relative groundwater levels between the waste materials and the surrounding natural deposits show a mixed picture. Four pairs of in-waste (W-series) and out of waste (A-series) boreholes are located along the length of the Site (i.e., A18 and W6, A13 and W5, A2 and W4, A1 and W2). The relative water levels observed within these borehole pairs show some evidence of consistent water levels between the waste and natural materials (i.e., A1 and W2; A13 and W5), indicating reasonable hydraulic continuity, whereas other locations show a significant water level variation (i.e., there is a 0.8 m difference between the average observed water levels at boreholes A2 and W4).

No obvious spatial trends in shallow groundwater levels are evident from the wider data set. Indeed, water levels often show considerable variation across relatively short distances (i.e., there is a c. 1 m difference in water levels between A19 and A20 despite their relative proximity and similar locations relative to the infilled canal; similarly, there is a 0.5 m water level change between A12 and A13 despite their close proximity).

Note: due to the linear nature of the Site it is not possible to construct any meaningful groundwater contours from the available water level records.

6.3 Soil quality data

Summary soil quality data from the recent ESI site investigation are presented in Table 6.3 and Table 6.4. The original laboratory certificates are presented in Appendix O. In addition, a summary of all soil quality data is shown in Appendix P.1.

Table 6.3 includes summary statistics from all samples taken within 0.25 m of the ground surface (i.e., the grab samples results), whereas Table 6.4 includes the results for the deeper waste materials.

The rationale for dividing the soil data set according to sample depths and horizons relates in part to the subsequent human health risk assessment; i.e. direct contact risks (those associated with soil ingestion, dust inhalation and dermal contact) are likely to be confined to near surface soils.

Note: only those organic substances detected above the limits of laboratory detection (LOD) are included in Tables 6.3 and 6.4. In the calculation of the summary statistics, any results reported as being below the LOD are conservatively assumed to be equal to the relevant LOD concentration.

Surficial soils (grab samples taken from depths of less than 0.25 m bgl)

The summary of surficial soil quality data presented in Table 6.3 indicates that the near surface grab samples (H1 to H19) provide no evidence of significant contamination within the cover materials overlying the waste materials.

Note: the ESI near surface sample results are entirely consistent with the data provided by the Council in relation to eight shallow samples taken during January 2010 (see Section 5.4).

Table 6.3 Summary of soil quality: surficial soils (within 0.25 m of ground surface)

Determinand	Nr samples	Unit	Min	Max	Mean	Nr > LOD
Inorganics						
Total Sulphate as SO_4	43	mg/kg	190	1100	561	43
Soil organic matter	43	%	1.9	8.1	4.18	43
Metals						
Arsenic	43	mg/kg	4.6	35	11.3	43
Cadmium	43	mg/kg	< 0.2	0.8	0.2	19
Chromium (hexavalent)	43	mg/kg	< 1.2	2.1	0.7	2
Chromium (III)	22	mg/kg	11	23	14.7	22
Chromium (total)	43	mg/kg	12	31	18.5	43
Cobalt	43	mg/kg	4.9	12	6.8	43
Copper	43	mg/kg	9.9	110	30.3	43
Lead	43	mg/kg	15	370	87.9	43
Manganese	43	mg/kg	260	550	347	43
Mercury	43	mg/kg	< 0.3	0.4	0.2	1
Molybdenum	43	mg/kg	0.4	2	0.9	43
Nickel	43	mg/kg	11	29	17.3	43
Selenium	21	mg/kg	<1.0	<1.0	<1.0	0
Vanadium	43	mg/kg	20	62	32.8	43
Zinc	43	mg/kg	39	280	108	43
Petroleum hydrocarbons						
Benzene	37	*ug/kg*	<1.0	28	2.1	4
Toluene	37	*ug/kg*	<1.0	18	1.6	3
TPH - Aliphatic >C21 - C35	37	mg/kg	< 8.0	30	5.3	3
TPH - Aromatic >C10 - C12	37	mg/kg	< 1.0	11	2.7	20
TPH - Aromatic >C12 - C16	37	mg/kg	< 2.0	8.7	2.3	16

Determinand	Nr samples	Unit	Min	Max	Mean	Nr > LOD
TPH - Aromatic >C16 - C21	37	mg/kg	< 10	92	10.6	8
TPH - Aromatic >C21 - C35	37	mg/kg	< 10	690	66.0	20
Naphthalene	43	mg/kg	< 0.05	< 0.05	< 0.05	0
Acenaphthylene	43	mg/kg	< 0.20	0.46	0.11	1
Acenaphthene	43	mg/kg	< 0.10	< 0.10	< 0.10	0
Fluorene	43	mg/kg	< 0.20	< 0.20	< 0.20	0
Phenanthrene	43	mg/kg	< 0.20	4.1	0.36	6
Anthracene	43	mg/kg	< 0.10	1.5	0.12	5
Fluoranthene	43	mg/kg	< 0.20	15	2.23	35
Pyrene	43	mg/kg	< 0.20	13	1.97	35
Benzo(a)anthracene	43	mg/kg	< 0.20	6.9	1.07	35
Chrysene	43	mg/kg	< 0.05	6.9	0.94	33
Benzo(b)fluoranthene	43	mg/kg	< 0.10	11	1.65	37
Benzo(k)fluoranthene	43	mg/kg	< 0.20	4.2	0.66	31
Benzo(a)pyrene	43	mg/kg	< 0.10	8.3	1.38	34
Indeno(1,2,3-cd)pyrene	43	mg/kg	< 0.20	4.7	0.76	27
Dibenz(a,h)anthracene	43	mg/kg	< 0.20	0.97	0.19	12
Benzo(ghi)perylene	43	mg/kg	< 0.05	5.2	0.86	30

Waste materials (samples taken between 1 and 4 m bgl)

A summary of the observed chemical quality associated with samples taken from the waste materials is presented in Table 6.4. This table indicates that measured concentrations of monohydric phenols, BTEX, the lighter end petroleum hydrocarbons (<C10), organochlorine pesticides, selected PAHs and the majority of target list VOCs and SVOCs were below the limits of laboratory detection. Furthermore, the detectable metals, petroleum hydrocarbons (including PAHs), VOCs and SVOCs generally occurred at relatively modest concentrations.

Several moderate/high soil organic matter percentages were recorded (up to 15%) indicating a potential propensity for ground gas production.

Unsurprisingly, the waste results show somewhat higher analyte concentrations in comparison with the surficial soil data.

Table 6.4 Summary of soil quality data: waste materials

Determinand	Nr samples	Unit	Min	Max	Mean	Nr > LOD
Inorganics						
pH	12	pH units	6	8.1	7.4	12
Total Cyanide	12	mg/kg	<1.0	4.2	1.5	5
Free Cyanide	12	mg/kg	<1.0	<1.0	0.5	0
Total Sulphate as SO_4	12	mg/kg	710	16000	3968	12
Sulphide	12	mg/kg	6.1	990	139.4	12
Ammoniacal Nitrogen as N	12	mg/kg	<5.0	410	65.1	7
Soil organic matter (%)	12	%	2.5	15	6.4	12
Metals						
Arsenic	12	mg/kg	7.6	78	22.5	12
Cadmium	12	mg/kg	<0.3	2.1	0.9	11
Chromium (hexavalent)	12	mg/kg	<0.6	4	0.9	1
Chromium (III)	4	mg/kg	14	38	24.8	4
Chromium (total)	12	mg/kg	14	210	41.5	12

Determinand	Nr samples	Unit	Min	Max	Mean	Nr > LOD
Cobalt	12	mg/kg	6.4	31	11.8	12
Copper	12	mg/kg	26	270	101	12
Lead	12	mg/kg	31	1300	292	12
Manganese	12	mg/kg	230	770	4412	12
Mercury	12	mg/kg	<0.15	0.6	0.2	2
Molybdenum	12	mg/kg	0.7	16	4.2	12
Nickel	12	mg/kg	16	98	39.7	12
Selenium	2	mg/kg	<1.0	<1.0	<1.0	0
Vanadium	12	mg/kg	21	73	37.7	12
Zinc	12	mg/kg	72	2900	555	12
Petroleum hydrocarbons						
TPH - Aliphatic >C10 - C12	12	mg/kg	< 1.0	2.2	0.9	3
TPH - Aliphatic >C12 - C16	12	mg/kg	< 2.0	26	4.7	5
TPH - Aliphatic >C16 - C21	12	mg/kg	< 8.0	220	52.7	6
TPH - Aliphatic >C21 - C35	12	mg/kg	< 8.0	3300	560	7
TPH - Aromatic >C10 - C12	12	mg/kg	< 1.0	13	6.34	10
TPH - Aromatic >C12 - C16	12	mg/kg	< 2.0	21	5.9	10
TPH - Aromatic >C16 - C21	12	mg/kg	< 10	350	59.8	8
TPH - Aromatic >C21 - C35	12	mg/kg	< 10	2500	358	10
Acenaphthene	12	mg/kg	< 0.1	1.7	0.2	1
Anthracene	12	mg/kg	< 0.1	3.8	0.4	3
Benzo(a)anthracene	12	mg/kg	< 0.2	11	1.7	9
Benzo(a)pyrene	12	mg/kg	< 0.1	11	1.8	8
Benzo(b)fluoranthene	12	mg/kg	< 0.1	15	2.4	9
Benzo(ghi)perylene	12	mg/kg	< 0.1	6.5	1.0	6
Benzo(k)fluoranthene	12	mg/kg	< 0.2	5.3	0.9	9
Chrysene	12	mg/kg	< 0.1	9.8	1.4	9
Dibenz(a,h)anthracene	12	mg/kg	< 0.2	1.1	0.2	3
Fluoranthene	12	mg/kg	< 0.2	25	3.7	9
Fluorene	12	mg/kg	< 0.2	2.4	0.4	2
Indeno(1,2,3-cd)pyrene	12	mg/kg	< 0.2	6.1	1.0	7
Phenanthrene	12	mg/kg	< 0.2	13	1.7	4
Pyrene	12	mg/kg	< 0.2	21	3.1	9
VOCs						
Chlorobenzene	12	*ug/kg*	< 7.0	160	26.2	2
Isopropylbenzene	12	*ug/kg*	< 7.0	14	4.8	2
N-Propylbenzene	12	*ug/kg*	< 5.0	13	4.0	2
1,3,5-Trimethylbenzene	12	*ug/kg*	< 4.0	14	3.8	2
1,2,4-Trimethylbenzene	12	*ug/kg*	< 5.0	110	18.0	3
1,2-dichlorobenzene	12	*ug/kg*	< 5.0	38	7.7	2
SVOCs						
Dibenzofuran	12	mg/kg	<0.2	0.7	0.15	1
Carbazole	12	mg/kg	<0.3	1.2	0.24	1

6.4 Leachability test results

Twelve duplicate waste samples were subjected to leachability testing. A summary of all leachability results is presented in Appendix P.2 (the laboratory certificates are also presented in Appendix O). The data presented in Appendix P.2 suggest that, in the context of heavy metals and metalloids, there is relatively limited potential for leachate generation within the waste materials.

However, some elevated sulphide (15 microg/l) and ammoniacal nitrogen (24 mg/l) concentrations were recorded which suggests that the waste materials do represent a potential source of aqueous contamination.

6.5 Groundwater quality data

6.5.1 ESI monitoring data

A total of 15 groundwater samples were taken from boreholes installed both on and off the Site, including a single private abstraction well.

A summary of all groundwater quality results is presented in Appendix P.3 (the complete set of laboratory certificates is also presented in Appendix O).

The data presented in Appendix P.3 suggest that no detectable concentrations of pesticides (organochlorine), VOCs or BTEX compounds were found in shallow groundwater, either within the waste materials or beyond them. Metal concentrations were generally moderate and only occasional SVOCs were detected (predominantly PAHs with some chlorinated hydrocarbons and phthalates) although these were at relatively modest concentrations. Interestingly, the majority of detections were associated with samples taken from beyond the waste materials (despite a greater number analyses performed on samples derived from the ‘in waste’ borehole).

The groundwater TPH results showed detectable concentrations in only a single sample (taken from an in waste borehole); only the mid to heavier end (non volatile) fractions were present in this sample. The measured Aromatic C21-35 concentration exceeded its solubility limit possibly suggesting some localised free product or solid phase hydrocarbons.

Locally elevated sulphate and chloride concentrations were detected; once again, average concentrations were surprisingly higher in the ‘off waste’ samples. In contrast, ammoniacal nitrogen concentrations were significantly higher for those results associated with the in waste samples.

No significant water quality issues have been identified with the sample taken from Birdbeck House, Basin Rd, Outwell (sample reference BB1).

A comparison between measured groundwater concentrations (associated with in-waste boreholes) and leachability test results is presented in Table 6.5. This shows a reasonable correlation between the metals data sets, with some variability which may in part be attributed to heterogeneity within the waste. The comparison for sulphate and ammoniacal nitrogen is less convincing; the divergence in these results (particularly for ammoniacal nitrogen) may be associated with the leachability test method (i.e., although the observed ammonia concentrations in groundwater are generally higher than the leachability results, it is considered unlikely that the observed ammonia concentrations in groundwater are associated with any contaminant source other than the waste deposits).

Table 6.5 Comparison of ESI groundwater quality and soil leachability test results

Determinand	Unit	Average groundwater quality	Average leachability test result	Comment
Sulphate as SO_4	µg/l	39900	152500	Leachability results typically higher
Sulphide	µg/l	5	8.8	
Ammoniacal Nitrogen as N	µg/l	67600	4772.4	Groundwater results typically higher
Ammonia	mg/l	0.61	0.035	Calculated values
Hardness Total	mgCaCO3/l	664	213.3	
Cadmium	µg/l	0.3	0.5	
Chromium	µg/l	2.6	1.2	

Determinand	Unit	Average groundwater quality	Average leachability test result	Comment
Cobalt	µg/l	2.4	1.6	
Copper	µg/l	4.8	13.1	
Lead	µg/l	12.8	7.8	
Manganese	µg/l	666	145.3	
Mercury	µg/l	1.5	1.5	
Molybdenum	µg/l	3.0	11.3	
Nickel	µg/l	2.9	2.4	
Selenium	µg/l	10	10.0	
Vanadium	µg/l	2.5	6.3	
Zinc	µg/l	12.2	6.3	

6.5.2 NCC monitoring data

Norfolk County Council (NCC) took shallow water samples from five NCC gas monitoring boreholes on 22nd June 2010 (it is noted that all five sampled boreholes are located in Outwell). These samples were dispatched by NCC for chemical testing. The laboratory certificates are presented in Appendix Q; a summary of this data is also shown in Appendix P.4.

The NCC groundwater quality data summarised in Appendix P.4 show some considerably higher analyte concentrations compared with the ESI water quality data (see Appendix P.3). A comparison of the average in-waste groundwater concentrations for the ESI and NCC data sets is shown in Table 6.6. This clearly shows that the NCC water analyses report significantly higher sulphate, cadmium, copper, lead, nickel, vanadium and zinc concentrations.

Table 6.6 Comparison of ESI and NCC groundwater quality data for <u>in-waste</u> BHs

Determinand	Unit	Average groundwater quality (ESI)	Average groundwater quality (NCC)	Comment
pH	pH units	7.9	7.2	
Sulphate as SO_4	mg/l	39.9	505.6	NCC results significantly higher
Chloride	mg/l	348.9	525.2	
Ammoniacal Nitrogen as N	mg/l	67.6	52.0	
Hardness - Total	mgCaCO3/l	664.0	1298.6	
Cadmium	µg/l	0.3	2.1	
Chromium	µg/l	2.6	12.4	
Cobalt	µg/l	2.4	17.6	NCC results significantly higher
Copper	µg/l	4.8	123.8	NCC results significantly higher
Lead	µg/l	12.8	205.3	NCC results significantly higher
Manganese	µg/l	666.0	1282.4	
Molybdenum	µg/l	3.0	13.8	
Nickel	µg/l	2.9	51.2	NCC results significantly higher
Vanadium	µg/l	2.5	26.4	NCC results significantly higher
Zinc	µg/l	12.2	8821.2	NCC results significantly higher
Calcium	mg/l	198.0	393.6	
Magnesium	mg/l	40.9	76.7	

It is noted that, when taken in isolation, the ESI water quality results associated with the southern end of the canal (i.e., samples taken from locations W6 and W7 in Outwell) also differ considerably from the NCC data (which relate exclusively to samples taken from Outwell). The water quality differences highlighted in Table 6.6 do not therefore appear to relate to differences in sampling location. The explanation for these differences is uncertain, but may relate either to different sampling practises (i.e., different levels of borehole purging may have been performed during the ESI and NCC sampling activities) and/or analytical methods (i.e., it is possible that the NCC samples were unfiltered, leading to potentially exaggerated laboratory results; this would not however explain the difference in sulphate results).

6.6 Soil gas results

6.6.1 ESI monitoring data

Ground gas monitoring data was collected from all of ESI's installed boreholes on six separate occasions between August and November 2010. The monitoring records, including bulk gas concentrations and borehole flow rates, are summarised in Appendix R.

The data presented in Appendix R indicate that minimal methane gas has been measured within those installations positioned beyond the boundaries of the infilled canal. This is unsurprising given that typically no or low methane concentrations were observed within the in-waste boreholes, with the exception of borehole location W2 where readings of 4.4%, 9.9% and 15.5% were measured (note: all other methane results at borehole W2 were below 1%).

The gas monitoring records show more variable carbon dioxide concentrations (ranging between 0% and 20%) with elevated concentrations associated with both on and off-waste borehole locations. Unsurprisingly, the highest concentrations were however associated with the in-waste boreholes; the average carbon dioxide concentration for the in-waste boreholes was 9.3%, compared with a value of 4.9% for the off-waste locations. There are no apparent spatial trends with regard to the distribution of carbon dioxide concentrations along the infilled canal.

PID readings were measured in all ESI boreholes on two occasions (02/08/10 and 13/09/10); the readings, which offer a measure of the total concentration of volatile organic compounds within the soil gas, were generally low (i.e., typically less than 20 ppm, with a maximum concentration of 32.5 ppm at borehole W6).

Measured gas flow rates were generally low across the Site; average flows were c. 0.06 l/hr within the waste boreholes and 0.09 l/hr in those boreholes located beyond the waste materials. Hence, of the 42 measurements taken from the in-waste boreholes, only eight (c. 19%) showed positive borehole flows (indicating a flow of soil gas from the sub surface to atmosphere), with a maximum flow of 1.31 l/hr measured at borehole W4a. Similarly, only 15 positive flows were recorded from 120 measurements at the off-waste boreholes; the maximum flow rate for the A-series boreholes was 2.51 l/s.

A closer inspection of the flow records for the in-waste boreholes suggests that there are no apparent spatial or temporal trends to the positive monitoring results. As such, the positive readings were associated with a spread of boreholes and a number of different monitoring rounds.

During the repeat ground gas monitoring rounds, gas measurements were also taken at a selection (a total of 13) of NCC boreholes. These results, which are also presented in Appendix R, compare favourably with both the monitoring data for ESI's in-waste boreholes and also the corresponding NCC monitoring results (see Appendix H). Hence, the measurements taken at the 13 NCC boreholes show minimal methane concentrations and moderate carbon dioxide concentrations (average carbon dioxide of 3.3%; maximum of 8%). The close correlation between the recent NCC monitoring data (see Appendix H) and the ESI records offers validation of the accuracy of both datasets and enables us to use the NCC monitoring records with greater certainty within the subsequent ground gas risk assessment.

6.6.2 NCC monitoring data

The NCC gas records show low methane concentrations for those boreholes which appear to have been drilled beyond the main body of waste. Given that all NCC were drilled in relatively close proximity to the former canal, the County Council suggest that lateral gas migration is therefore limited (personal comms., Des Holmes).

Considering the complete soil gas data set, methane concentrations in excess of 10% by volume have occasionally been observed, although measurements in the range 0 to 3% are more common, with the vast majority of results recorded as 0%. Elevated methane concentrations have typically not been observed in boreholes 3701 to 3726 (i.e. those located between Elm in the north and the mid-point of Collett's Bridge in the south). There is also clear evidence for reduced methane production between 1992 and 2000. This observation agrees with the County Council's verdict that gas production has slowed considerably in the years following waste disposal.

The NCC carbon dioxide records are more variable; numerous carbon dioxide readings in excess of 10% by volume have been recorded across the entire length of monitored landfill. The long term monitoring records provide evidence of declining carbon dioxide concentrations since the early 1990s.

The NCC soil gas records for the period July 1992 to August 2010 are presented in Appendix H

7. CONCEPTUAL MODEL

7.1 Conceptual ground model

The key findings from the desk study and site investigation works have been used to form an understanding of the physical site setting which may influence the presence and movement of contaminants in and around the infilled canal. The main elements of this conceptual ground model are described below:

- The infilled Wisbech Canal is c. 8.4 km in length; the topography along the Site is flat with ground elevations typically between 3.5 and 4.5 m AOD.
- The natural geological sequence comprises superficial tidal flat deposits (a limited thickness of clay and silt with thin peaty layers) and the Ampthill Clay (comprising soft grey mudstone and pale grey calcareous mudstone of approximate 50 m thickness).
- Domestic type waste materials exist along the majority of the infilled canal; it is likely however that the infilled materials in the north of the Site (i.e., to the north of the Blacksmith Arms PH) contain predominantly inert materials.
- The domestic waste materials included assorted brick, ceramics, glass, clinker, fabric, plastic, metal and wood within a slightly silty gravelly sand matrix. The presented of putrescible materials within the waste has therefore been confirmed; these materials represent a potential ground gas source.
- The typical thickness of the infilled materials is thought to range between 2 and 4 m, although thicker deposits may occur locally.
- The infilled materials reside directly upon natural silts and clays. The waste is overlain by a clayey cover layer which is of variable thickness (0.4 to 0.8 m) and composition. The cover materials are not considered to form a robust landfill cap and as such will allow the infiltration of rainwater into the waste materials and will likely permit the release of any ground gases generated by the infilled materials.
- The local geological strata within the Site area are described by the Environment Agency as a Non Aquifer.
- Regardless a number of private (unlicensed) and agricultural groundwater abstractions are known to exist within 1 km of the former canal. No source protections zones have however been defined for the local area reflecting the low water resource potential of the area.
- Shallow groundwater was routinely encountered within 3 m of the ground surface during the recent site investigations.
- Water levels within those boreholes positioned over the waste deposits indicate that the majority of the waste is partly saturated; saturated thicknesses range between 0.4 and 2.2 m.
- Considerably variability in groundwater levels is evident across relatively short distances. Coupled with the low permeability of the natural lithologies which underlie the study area, this may suggest that shallow groundwater movements are relatively limited in the vicinity of the former canal.
- The observed hydraulic gradient is consistently towards the south west along the stretch of former Canal through Outwell. This flow direction may reflect the influence of the network of surface drainage features to the south of the Canal (see Figure 4.2).
- The infilled canal is located adjacent to numerous surface water features (predominantly man made ditches and dykes). By definition, the superficial tidal flat and peat deposits are likely to be in reasonable hydraulic continuity with these

drainage features. The degree of baseflow contribution (opposed to rainfall runoff inflows) to these drainage features is however unclear.

- No licensed surface water abstractions are reported by the Environment Agency within 1 km of the Site.
- Multiple residential properties are located within 10m of the waste materials contained within the infilled canal.

A schematic cross section across the infilled canal is shown on Figure 7.1.

7.2 Conceptual exposure model

A conceptual exposure model has been developed for the Site which describes the likely contaminant sources present across the Site, potential receptors and the possible pathways linking sources and receptors. In order for harm or pollution to be caused to identified receptors there must be three essential elements present:

A contaminant: a substance that is in, on, or under the land and has the potential to cause harm or to cause pollution of controlled waters;

A receptor: in general terms, something that could be adversely affected by a contaminant, such as people, an ecological system, property or a water body;

A pathway: a route or means by which a receptor can be exposed to or affected by a contaminant.

An environmental hazard is identified where all three of these elements are present, and there is consequently the potential for a contaminant to affect a particular receptor through a particular pathway. The risk assessments presented in Sections 8, 9 and 10 aim to assess, in quantitative terms, the likelihood of significant harm or pollution occurring to identified receptors.

7.2.1 Sources

Based on our current understanding of the Site's history and the recent site investigation results, relevant contaminant sources include:

- *Contaminants present within the infilled materials*

  Although surficial soil quality data (associated with the cover materials evident above the waste deposits) show no gross contamination with only modest metal and total petroleum hydrocarbon concentrations and, locally moderate PAH concentrations (maximum BaP of 8.3 mg/kg) were detected.

  The chemical quality of the waste materials was also reasonable. However, moderate TPH and PAH concentrations have been recorded at certain locations, along with modest concentrations of selected VOCs and SVOCs.

- *Aqueous phase contaminants within/below the waste*

  Sulphate, chloride, ammoniacal nitrogen, phenol, manganese and selected petroleum hydrocarbon concentrations have been detected within shallow groundwater associated with the infilled waste. Note: NCC test results also suggest that landfill leachate may contain elevated heavy metal concentrations.

  There is a reasonable correlation between soil leachability test results and the observed groundwater quality data suggesting that the prevailing groundwater chemistry is a consequence of diffuse contamination occurring from the waste deposits.

- *Soil gas concentrations within the waste materials*

  Field data indicate that locally elevated methane and carbon dioxide concentrations occur within the infilled canal (maximum 15.5% methane and 20% carbon dioxide). It is however acknowledged that the vast majority of gas monitoring results indicate the absence of a significant methane source associated with the waste materials.

7.2.2 Pathways

The potential pathways along which contamination may move from a source area to possible receptors are unique to specific receptor types, as discussed below.

i) Human health receptors

Dermal contact and ingestion of contaminants may occur where the ground materials are readily accessible to humans; in theory these exposure routes may be present across the public access areas of the Site and within residential gardens.

Disturbance of surficial or sub surface soils (by either natural forces such as wind or animal activity, or through anthropogenic activities such as walking or digging) offers the potential for dust generation which may lead to contaminant exposure via dust inhalation.

Exposure to landfill gasses (principally following gas accumulation within confined spaces) may pose acute health risks from asphyxiation and explosion, and chronic health risks due to long-term exposure of toxic gases. The potential risks posed by landfill gas production and migration will be greatest at those properties directly neighbouring the infilled canal, although the extent of the risk will be determined by the nature of the gas source and the presence of any lateral gas migration pathways.

Note: based on the responses given to the Council during a public consultation exercise, certain properties located close to the infilled canal are known to have cellars (i.e., 44 Elm High Road). Due to the subterranean nature of cellars (potentially enabling more ready gas ingress) and their typically limited rates of ventilation/air exchange, buildings which incorporate cellar structures may be more sensitive to ground gas risks.

ii) Controlled waters receptors

Potential controlled waters receptors include groundwater present within the superficial deposits and also the network of surface water drainage channels which are evident in close vicinity of the Site.

It is acknowledged that the local superficial and solid lithologies are classified as non productive strata, suggesting a low resource value and thus environmental sensitivity. However, a number of private water wells are known to exist within close proximity to the infilled canal; consideration of the pollution risks to these features (and by definition the local shallow groundwater system) should therefore be given. It is noted that during the recent site investigations water quality in a private water well (Birdbeck House) located c. 30 to 40 m from the infilled canal was found to be good, with no obvious contamination.

The presence of a continuous shallow groundwater system along the length of the Site is uncertain. The degree of interaction between landfill leachate associated with the infilled canal and local surface water features is therefore unclear. It is assumed that shallow groundwater within the Terrington Beds will be in hydraulic continuity with the local network of surface water channels (not least since these channels are anticipated to have a drainage function), although the rate of movement through the superficial silts is anticipated to be low.

The risk of pollution to local controlled waters is somewhat exacerbated by the absence of any landfill liner (which would act to contain leachate within the waste materials) and the absence of an engineered cap (which would minimise infiltration and thus leachate generation).

7.2.3 Receptors

Under the Part IIA regime the Local Authority is required to consider potential risks to a number of receptor categories, including risks to human health, controlled waters, ecological systems/living organisms, property in the form of crops, livestock etc., and property in the form of buildings.

Based on the knowledge of the Site setting and the current conceptual site model the potential receptors which may be impacted upon by any contaminated ground conditions include:

- Humans (including members of the public using parts of the infilled canal for general recreational purposes, and also occupants of nearby residential dwellings).
- Shallow groundwater associated with the Terrington Beds (although this horizon is classified as a non aquifer, a number of private water wells are known to occur in the vicinity of the Site).

- Private water wells in the close vicinity of the infilled canal.
- Residential buildings neighbouring the infilled canal (a number of which are known to have basement structures).
- Miscellaneous drainage features which are evident to the north and south of the Site.

7.3 Pollutant linkages

A summary of the potential pollutant linkages associated with the Site is presented in Table 7.1; these are graphically illustrated on Figure 7.2.

Table 7.1 Pollutant Linkages

Ref	Sources	Pathways	Receptors	Comments
Contaminants present within the infilled materials				
PL1	Various metals and petroleum hydrocarbons, including PAHs, plus selected VOCs and SVOCs present in surficial soils	Ingestion of soils and soil dust; inhalation of soil dust and dermal contact with contaminated soils	Residents (with gardens extending over the infilled canal) and members of the public using open access areas of the Site for recreational purposes (dog walking, etc.)	*Linkage worthy of further consideration*
PL2		Volatilisation of selected PAHs and subsequent inhalation		*Linkage worthy of further consideration* It is acknowledged however that any risks are likely to be low due to the modest volatility of the observed PAHs
PL3		Dissolution of soil phase contaminants into pore water or shallow groundwater and subsequent migration via shallow groundwater system	Shallow groundwater and local surface water drainage features plus local groundwater abstractions	*Linkage worthy of further consideration* It is acknowledged however that any risks are likely to be low due to the modest solubility and relatively low concentrations of the observed PAHs
PL4	Waste materials containing some moderate metal concentrations, mid to heavier-end petroleum hydrocarbons and PAH concentrations, plus selected VOCs and SVOCs	Ingestion of soils and soil dust; inhalation of soil dust and dermal contact with contaminated soils	Residents (with gardens extending over the infilled canal) and members of the public using open access areas of the Site for recreational purposes (dog walking, etc.)	*Linkage worthy of further consideration* It is acknowledged however that direct contact exposures will be limited due to the presence of a 0.4 to 0.8 m cover layer above the waste materials
PL5		Volatilisation of mid-range petroleum hydrocarbon fractions and selected PAHs and subsequent inhalation		*Linkage worthy of further consideration* It is acknowledged however that any risks are likely to be low due to the modest volatility of the observed petroleum hydrocarbons
PL6		Dissolution of soil phase contaminants into pore water or shallow groundwater and subsequent migration via shallow groundwater system	Shallow groundwater and local surface water drainage features plus local groundwater abstractions	*Linkage worthy of further consideration*

Table 7.1 Pollutant linkages (cont.)

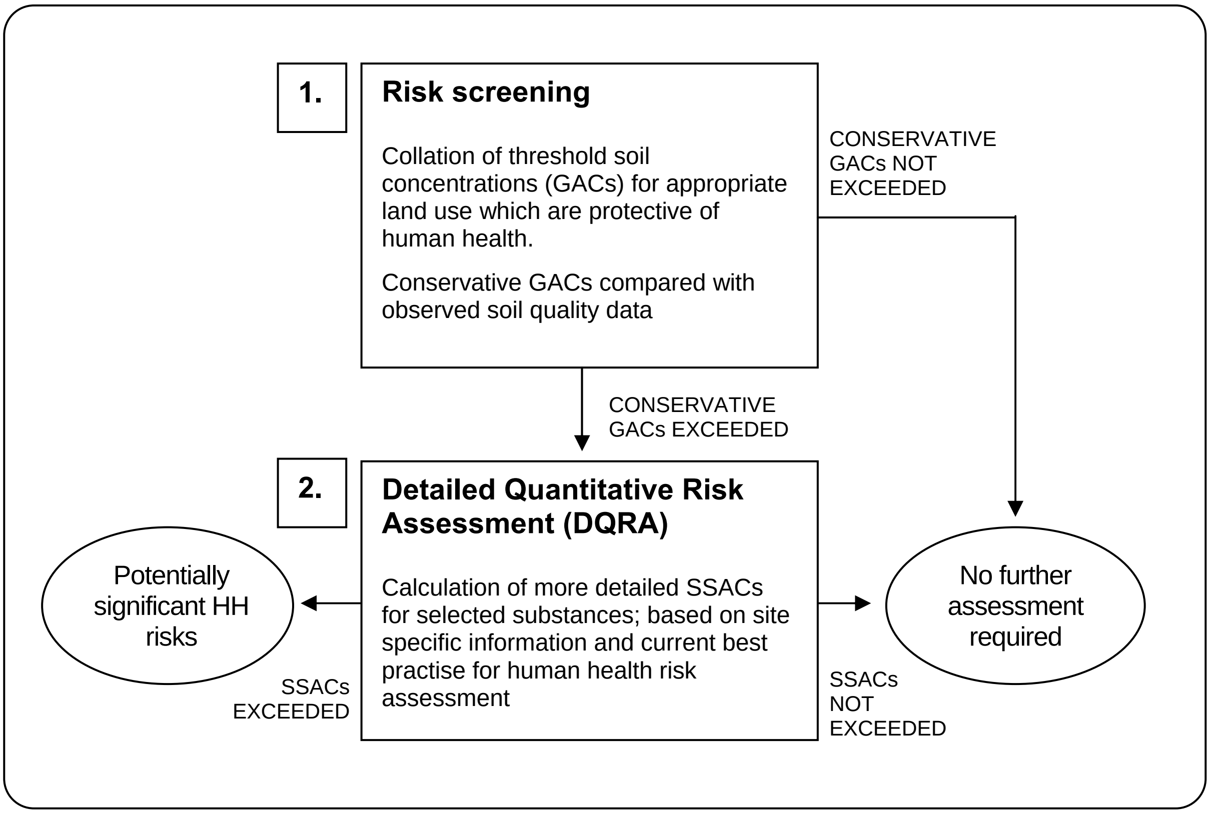
Ref	Sources	Pathways	Receptors	Comments
Aqueous phase contaminants within/below the waste				
PL7	Locally elevated sulphate, chloride ,ammoniacal nitrogen, manganese, phenol and petroleum hydrocarbon concentrations within landfill leachate	Migration via the shallow groundwater system (the degree of hydraulic continuity between the landfill leachate and the shallow groundwater system is uncertain)	Shallow groundwater and local surface water drainage features	*Linkage worthy of further consideration*
PL8	The landfill leachate may also contain elevated heavy metal concentrations (as indicated by limited water quality testing performed by NCC)		Shallow groundwater and local surface water drainage features	*Linkage worthy of further consideration*
PL9	Locally elevated sulphate, chloride, ammoniacal nitrogen, phenol, petroleum hydrocarbons and potentially selected heavy metals		Local residents abstracting shallow groundwater for potable use (note: this is unlikely to be occurring on any significant scale)	*Linkage worthy of further consideration*
PL10	Modest SVOC concentrations within shallow groundwater/ landfill leachate	Volatilisation of organic compounds and subsequent inhalation	Neighbouring residents and members of the public using open access areas of the Site for recreational purposes (dog walking, etc.)	No significant risks anticipated due to the absence of any appreciable VOCs (including BTEX) and the modest observed concentrations of SVOCs.
Soil gas concentrations within the waste materials				
PL11	Locally elevated carbon dioxide concentrations (and occasional methane concentrations) associated with the landfilled waste materials	Potential for lateral migration through sub surface soils to neighbouring properties; potential accumulation in basement structures	Occupants of neighbouring properties, particularly those in Outwell and Collett's Bridge	*Linkage worthy of further consideration*

8. HUMAN HEALTH RISK ASSESSMENT

Potential pollutant linkages have been assessed in Section 7.3 to identify those which may pose potential risks to key receptors. Having identified key linkages a quantitative assessment of the potential risks posed to the identified human health receptors by current contaminant concentrations across the site must now be performed.

8.1 Methodology

The process adopted for assessing risks to human health is summarised in the following flow diagram:



Hence, the assessment of risks posed to human health receptors by the exposure to potentially contaminated soil has been conducted through a tiered process, whereby an initial screening exercise has been employed to identify any potentially hazardous contaminants. Where any such contaminants are identified, these are then subject to a detailed quantitative risk assessment (DQRA) utilising as much site specific information as possible in order to generate representative site specific assessment criteria (i.e., threshold soil and groundwater concentrations, above which there is considered to be a potentially significant risk to human health for the prevailing conceptual model).

8.1.1 Risk screening

The initial screening exercise was conducted by comparing maximum observed soil quality results with a set of generic human health screening values (collectively termed Generic Assessment Criteria (GAC)).

The adopted GACs have been derived from published sources, including the Environment Agency's updated Soil Guideline Values, plus assorted assessment criteria developed by LQM (2009) and the EIC (CL:AIRE, 2010). All assessment criteria used in the human health risk assessment are therefore entirely consistent with the latest CLEA methodology (Environment Agency; 2009b, 2009c, 2009d).

All adopted GACs have been conservatively based on a standard residential land use including the consumption of home-grown produce. Soil organic matter content (which can influence the mobility of organic contaminants) has been set at 6% in the derivation of all GACs.

A listing of all GACs adopted for the screening exercise is presented in Table 8.1.

Table 8.1 Screening values adopted for the human health risk assessment

Parameter	Units	Screening value	Source	Comment
Metals				
Arsenic	mg/kg	32	SGV	SGV report; EA, 2009e
Cadmium	mg/kg	10	SGV	SGV report; EA, 2009f
Chromium (hexavalent)	mg/kg	4.3	LQM	
Chromium (III)	mg/kg	3000	LQM	
Copper	mg/kg	2330	LQM	
Lead	mg/kg	450	SGV	Based on former SGV in absence of approved method for deriving lead assessment criteria; Defra &EA, 2002
Mercury	mg/kg	1	SGV	Conservatively based on elemental mercury parameterisation; EA, 2009g
Molybdenum	mg/kg	370	EIC	
Nickel	mg/kg	130	SGV	SGV report; EA, 2009h
Selenium	mg/kg	350	SGV	SGV report; EA, 2009i
Vanadium	mg/kg	75	LQM	
Zinc	mg/kg	3750	LQM	
Petroleum hydrocarbons				
Benzene	mg/kg	0.33	SGV	SGV report; EA, 2009j
Toluene	mg/kg	610	SGV	SGV report; EA, 2009k
TPH Ali >C10 - C12	mg/kg	283	LQM	GAC set at vapour saturation limit
TPH Ali >C12 - C16	mg/kg	142	LQM	GAC set at solubility saturation limit
TPH Ali >C16 - C21	mg/kg	76000	LQM	
TPH Ali >C21 - C35	mg/kg	76000	LQM	
TPH Aro >C10 - C12	mg/kg	346	LQM	
TPH Aro >C12 - C16	mg/kg	593	LQM	
TPH Aro >C16 - C21	mg/kg	770	LQM	
TPH Aro >C21 - C35	mg/kg	1230	LQM	
Naphthalene	mg/kg	8.7	LQM	
Acenaphthylene	mg/kg	850	LQM	
Acenaphthene	mg/kg	1000	LQM	
Fluorene	mg/kg	780	LQM	
Phenanthrene	mg/kg	380	LQM	
Anthracene	mg/kg	9200	LQM	
Fluoranthene	mg/kg	670	LQM	
Pyrene	mg/kg	1600	LQM	
Benzo(a)anthracene	mg/kg	5.9	LQM	
Chrysene	mg/kg	9.3	LQM	
Benzo(b)fluoranthene	mg/kg	7	LQM	
Benzo(k)fluoranthene	mg/kg	10	LQM	
Benzo(a)pyrene	mg/kg	1.0	LQM	The equivalent allotment GAC is 2.1 mg/kg
Indeno(1,2,3-cd)pyrene	mg/kg	4.2	LQM	
Dibenz(a,h)anthracene	mg/kg	0.9	LQM	
Benzo(ghi)perylene	mg/kg	47	LQM	

Parameter	Units	Screening value	Source	Comment
VOCs				
Chlorobenzene	*µg/kg*	1700	LQM	
Isopropylbenzene	*µg/kg*	64000	EIC	
N-Propylbenzene	*µg/kg*	190000	EIC	
1,3,5-Trimethylbenzene	*µg/kg*	2000	EIC	Based on GAC for 1,2,4-Trimethylbenzene
1,2,4-Trimethylbenzene	*µg/kg*	2000	EIC	
1,2-dichlorobenzene	*µg/kg*	91000	LQM	

NB: no screening values/GACs are presented for cobalt or manganese in response to their modest observed concentrations and limited toxicity. No published GACs are available for the SVOCs dibenzofuran and carbazole; this is however not considered to be significant owing to the minimal observed concentrations of these substance (see Appendix P.1) and their limited volatility

i) Risks posed by surficial soil quality *(pollutant linkages: PL1 to PL3)*

The surficial soil quality data can be divided into two broad categories; firstly, those sample results associated with the public open spaces and secondly the results for grab samples taken from residential gardens

Table 8.2 lists those substances for which the maximum observed concentrations exceed the adopted GACs.

Table 8.2 Exceedance of GACs: surficial soils

Location	Parameter	Max observed concentration: mg/kg	GAC: mg/kg	Comment
Public open spaces				
Samples taken from grassed public access area along the centre of Outwell	Benz(a)pyrene	8.3	2.1 (based on allotment land use)	No risks posed by metals, BTEX or broad spectrum TPHs (all screened out)
Samples from 'adopted gardens' in Collett's Bridge	*None*	*N/A*	2.1 (based on allotment land use)	No risks identified based on measured soil quality (maximum BaP less than allotment GAC)
Private gardens				
14 Elm High Rd	Benz(a)pyrene	2.6	1.0 (based on residential land use)	No risks posed by metals, BTEX or broad spectrum TPHs (all screened out)
163 Elm Low Rd	Benz(a)pyrene	2.2	1.0	
34,36,38 Elm High Rd	Benz(a)pyrene	2.1	1.0	
44 Elm High Rd	Benz(a)pyrene	1.4	1.0	No risks from BTEX or broad spectrum TPHs (all screened out)
	Arsenic	35	32	
Blakeney	Benz(a)pyrene	1.5	1.0	No risks posed by metals, BTEX or broad spectrum TPHs (all screened out)
Elm Lodge	Benz(a)pyrene	4.7	1.0	
339a Elm Low Rd	Benz(a)pyrene	3.0	1.0	

Table 8.2 indicates that the vast majority of substances contained in the surficial soil test suite do not exceed the relevant assessment criteria. Indeed, only benzo(a)pyrene and arsenic exceed the assessment criteria. This result does not indicate that these substances pose a health risk, rather that they require further consideration.

The next stage in assessing the potential risks from observed benzo(a)pyrene and arsenic concentrations is to undertake a statistical assessment of the available soil quality results.

Detailed guidance on the statistical tests that can be used to compare soil quality data to human health screening values (critical concentrations) is given by CIEH and CLAIRE (2008). Importantly, the statistical tests are structured according to the reason for the assessment. As the purpose of this investigation is to establish whether the Site falls within the scope of Part IIA, the statistical tests are structured to conclude whether we can confidently say that the level of contamination at the Site is high relative to an appropriate measure of risk.

It is recognised that the observed soil quality data set will only represent a very small fraction of the entire soil mass. Hence, the statistical tests allow an estimated mean soil concentration of a given substance to be calculated with an associated confidence level that the true mean soil concentration is above the critical concentration (i.e. GAC value).

For a Part IIA assessment, the test is to determine if there is sufficient probability that the true mean soil concentration falls above the critical concentration. A 95% probability is generally considered as robust in the context of contaminated land investigation. However, under Part IIA a decision can also be made on the ‘balance of probabilities’ which is at the lesser but still defensible confidence level of 51% or more.

The statistical tests are presented in terms of a Null and an Alternative Hypothesis. The tests are structured to show, at the defined level of confidence, which of the two hypotheses is most likely to be true in a particular case. By convention, the Null Hypothesis is the starting proposition against which the key question (i.e. can we confidently say that the level of contamination at the Site is high relative to an appropriate measure of risk?) can be tested. Hence, for the Part IIA assessment:

- The Null Hypothesis is that the level of contamination in the study area is the same as or lower than the critical concentration; and
- The Alternative Hypothesis is that the level of contamination is higher than the critical concentration.

Prior to calculating the statistics, the observed soil quality data sets for each substance must be reviewed. The guidance outlines the following steps:

- *Check data quality* – the guidance details the importance of the quality and sufficiency of the data collected and used in the assessment of contaminated land. The data collected have been reviewed and discussed in Section 6. It is noted that the assumptions that underlie the statistical tests rely on the use of unbiased sampling data.
- *Identify and deal with non-detects* - the presence of non-detects within a data set and how they are treated (i.e. the choice of any substitute values) may affect the outcome of the statistical tests. This is particularly important if the detection limit is close to the critical concentration or there are a high proportion of non-detects within a data set. In this case, non-detect values have been conservatively set at the detection limit.
- *Identify and deal with outliers* – soil quality data can comprise contaminant concentrations spanning several orders of magnitude. This may reflect heterogeneity of the soil conditions, variability of contaminant distributions or uncertainty associated with sampling/laboratory analysis. The identification and appropriate treatment of outliers in a data set is important as it will have consequences for the outcome of the statistical tests. The guidance includes an ‘outlier’ test known as Grubb’s Test, which can be used to identity statistical outlier values.

- *Data distribution* - the guidance includes two statistical approaches to calculate the 95th lower confidence limit (LCL) depending on the underlying distribution of the data set. The one sample t-test should be used for normally distributed data and the Chebychev Theorem should be used for non-normal data.

In addition, prior to conducting the statistical tests an averaging area must also be specified; this is essentially the land area from which soil quality data will be analysed and subsequently compared to soil screening values. For the purpose of the screening exercise the averaging areas have been specified as the entire grassed strip along the centre of Outwell and the individual properties.

Table 8.3 contains a summary of the statistical test results performed on each of the potential contaminants of concern for each averaging area; populated versions of the Statistical Calculator are presented in Appendix S. Table 8.3 includes the findings of the review steps, outcome of the statistical tests, and the calculated levels of evidence. Note: the upper and lower bounds of evidence are calculated when the Chebychev Theorem is used; the actual level of evidence is a value within this range.

The information presented in Table 8.3 shows that there is insufficient evidence to reject the Null Hypothesis for the Part IIA scenario at either the 95% confidence limit or on the balance of probabilities (i.e. >51%) in relation to either the observed B(a)P concentrations at Outwell or the arsenic results at 44 Elm High Rd. As such, the observed concentrations of these substances within the superficial deposits do not pose a significant risk to human health.

With regard to the remaining BaP soils data, the statistical results suggest that we may decide to reject the Null Hypothesis at either a 95% confidence level or on the balance of probability. Once again, this does not indicate that the observed BaP data sets (for each garden area) present a significant risk to human health, rather that there are grounds for looking at this potential contaminant in more detail. With regard to revisiting the statistical interpretation, the principal area which warrants further consideration is the choice of the critical concentration (or GAC).

The benzo(a)pyrene critical concentration used in the screening assessment is based on a highly conservative LQM Generic Assessment Criteria (1 mg/kg). This GAC is however widely accepted to be overly conservative in the context of Part IIA and certainly not representative of significant possibility of significant harm (SPOSH). The general consensus within the human health risk assessment community is that a reasonable SPOSH concentration for BaP (based on a residential land use) is likely to be in excess of 4 mg/kg. Justification for this value is available from sensitivity analyses undertaken using the latest CLEA software (version 1.06) (Environment Agency, 2009a). Appendix T presents alternative BaP GAC concentrations using various modified input parameterisation. The revised GACs range from 1.0 mg/kg (i.e., no change) to 131 mg/kg. Amongst these, the most relevant sensitivity runs are ‘exposure scenarios’ 2 and 8. Exposure scenario 2 relates to an increase in BaP health criteria values by a factor of 10 (this relaxation in the modelled toxicological thresholds is considered a justifiable approach for better representing SPOSH conditions); the resulting modified GAC is 10 mg/kg. Exposure scenario 8 (see Appendix T) incorporates a number of revised exposure parameters (including justifiable changes to exposed skin fraction, soil ingestion rate and exposure frequency); the resulting modified GAC is 3 mg/kg.

The critical concentrations (or GACs) which would be required for each averaging area (i.e., each residential property investigated) to register no statistically significant health risk are listed in Table 8.3. Given that all of these concentrations are less than 3 mg/kg it may be concluded that the observed soil quality is unlikely to pose significant harm to local residents.

Table 8.3 Statistical assessment of soil quality data (superficial soils)

Location	Determ-inand	Non-detects	Outliers	Distribution	Statistical test	Units	Screening value: mg/kg	95th LCL: mg/kg	Estimated mean: mg/kg	Level of evidence against Null Hypothesis[1]	Test outcome	GAC required for no health risk: mg/kg
Outwell public open space	B(a)P	1	Yes (1)	Non-normal	Chebychev	mg/kg	2.1	<0	2.1	0% to 49%	**μ ≤ Cc**	/
14 Elm High Rd	B(a)P	0	No	Normal	One-sample test	mg/kg	1.0	1.53	2.2	**98%**	**μ > Cc**	2.2
163 Elm Low Rd	B(a)P	0	No	Normal	One-sample test	mg/kg	1.0	0.51	1.7	**89%**	**μ > Cc (BoP)**	1.7
34,36,38 Elm High Rd	B(a)P	0	No	Normal	One-sample test	mg/kg	1.0	1.17	1.8	**97%**	**μ > Cc**	1.8
44 Elm High Rd	B(a)P	0	No	Normal	One-sample test	mg/kg	1.0	1.13	1.3	**98%**	**μ > Cc**	1.3
	Arsenic	0	No	Normal	One-sample test	mg/kg	1.0	6.11	10.2	14%	**μ ≤ Cc**	/
Blakeney	B(a)P	0	No	Normal	One-sample test	mg/kg	1.0	0.25	1.1	**60%**	**μ > Cc (BoP)**	1.1
Elm Lodge	B(a)P	1	No	Normal	One-sample test	mg/kg	1.0	<0	2.2	**77%**	**μ > Cc (BoP)**	2.2
339a Elm Low Rd	B(a)P	0	No	Normal	One-sample test	mg/kg	1.0	<0	1.5	**71%**	**μ > Cc (BoP)**	1.5

[1] the upper and lower bounds of evidence are calculated when the Chebychev Theorem is used. The actual level of evidence is a value within this range

ii) Risks posed by waste materials *(pollutant linkages: PL4 to PL6)*

In-waste samples show no appreciable concentrations of pesticides, phenols, free cyanide or BTEX. As such, these substances present no significant health risks in the context of the infilled Wisbech Canal.

Metal and petroleum hydrocarbon concentrations were generally modest. No health risks in any case are ascribed to highly localised lead and arsenic concentrations within the waste materials, owing to the absence of any exposure mechanisms acting between these substances and relevant human receptors. The same principal applies to locally observed concentrations of benzo(a)pyrene and TPH C21-C35; i.e., since neither of these substances/categories are volatile (to any significant degree) they do not pose any health risks when present at depths in excess of 1 m bgl.

The main potential human health risks associated the waste deposits therefore relate to the presence and possible migration of any VOCs. All observed VOC concentrations are either below the limits of laboratory detection or below highly conservative GACs derived for a residential land use. As such, no human health risks are anticipated from the in situ waste materials.

iii) Risks posed by groundwater quality *(pollutant linkage: PL9)*

The potential risks to human health from exposure to contaminated groundwater include direct ingestion and dermal contact with impacted water, and also the inhalation of vapours originating from polluted groundwater.

A number of shallow water wells are known to exist within 100 m of the infilled canal; this offers potential human exposure to dissolved phase contamination.

The available groundwater quality data have been compared with current UK drinking water standards. This comparison suggests that the shallow groundwater is of a moderate quality with no evidence of any gross contamination. The concentrations of several analytes (including, sulphate, chloride, monohydric phenols, manganese, calcium, magnesium, and selected speciated PAHs)) do however exceed drinking water standards in one or more samples. Whilst these results do not necessarily indicate that health effects would result from drinking the shallow groundwater (for reasons including the spatially variability in water quality, and the fact that various drinking water standards are specified for aesthetic and practical purposes (such as the avoidance of staining clothes washing) opposed to strictly health based considerations), some health risks cannot be ruled out as a consequence of medium to long term ingestion of untreated groundwater, particularly in relation to observed phenol concentrations.

It is noted that a water sample was taken from a private water well located in the garden of Birdbeck House, in Outwell. The laboratory results for this sample are indicative of a good water quality (i.e., no tested analytes exceed current drinking water standards at this location).

With regard to vapour inhalation risks, inspection of the groundwater quality results indicates that the measured concentrations of BTEX, lighter end/volatile range petroleum hydrocarbon fractions (i.e. C16 and below), and target list VOCs were all below the limits of laboratory detection. Hence, in the absence of any volatile sources of aqueous contamination, there are no identified risks to local residents and recreational users of the Site, as a consequence of volatilisation and subsequent inhalation of aqueous phase volatile substances.

9. SOIL GAS RISK ASSESSMENT

9.1 Methodology

In general, hazardous ground gases may pose a variety of risks to human health and property through acute effects including asphyxiation and explosion. In the context of the infilled Wisbech Canal, the principal hazards from the generation and possible migration of ground gases associated with Site relate to potential impacts on properties (and their occupants) located within close proximity to the former canal structure.

The most common hazardous ground gases in the context of risks to buildings are methane, carbon dioxide, radon and hydrocarbon vapours. Methane and carbon dioxide are common landfill gases, generated through the degradation of organic material. Typical gas concentrations ranges for contemporary and some historical landfills are 20% to 60% in the case of methane and 15% to 40% for carbon dioxide (CIRIA, 2007); it is noted that the observed gas concentrations associated with the infilled Wisbech Canal are typically much lower than this.

Note: no appreciable petroleum hydrocarbon vapours are anticipated at the Site in the absence of any of the lighter-end hydrocarbon fractions within the analysed soil samples (it is assumed that due to the age of the waste tip, any volatile hydrocarbons have largely disappeared).

An assessment of the potential risks from gas accumulation within local buildings has been undertaken using CIRIA publication C665 (CIRIA, 2007). The assessment methodology advocated by CIRIA is based on the Wilson and Card classification system which determines a gas screening value (GSV) for a particular site based on the multiplication of the maximum observed borehole flow rate (expressed as l/hr) and the maximum gas concentration (% of either methane or carbon dioxide, whichever is greater). The use of maximum flow rates and concentrations is justified since the assessment of ground gas risks is focussed on acute effects such as asphyxiation and explosion. Since these are ‘one off’ events it is important to consider the reasonable worst case scenario that may occur, as this is when such effects are most likely to be manifested. Once calculated, the GSV can be related to one of six characteristic situations, each of which is ascribed a risk classification and associated recommendations for appropriate gas protection measures.

It is noted that the gas risk assessment presented below deviates from the CIRIA methodology since the later relates primarily to the construction of buildings on potential ground gas sources. However, the actual gas risks posed by the Site relate to potential impacts of off-site gas migration to nearby housing. Regardless, given the presence of various off-waste monitoring boreholes (constructed by both NCC and ESI) there is considered to be adequate soil gas data with which to undertake an assessment of the risks posed by off-site gas migration.

9.2 Risks posed by bulk gases *(pollutant linkage: PL11)*

Due to the linear nature of the Site, GSVs have been calculated for each individual borehole; these are presented in Appendix R. The GSVs described in Appendix R all indicate a ‘low’ or ‘very low’ gas risk (even if buildings were present directly on top of the monitoring locations). These results are a reflection of both low to modest absolute bulk gas concentrations and low to negligible borehole flow rates.

Further lines of evidence supporting the absence of any significant ground gas risks include:

- The NCC gas monitoring records (1992 to 2010) show a consistent reduction in methane concentrations between 1992 and 2000 (see attached Figure 9.1), clearly indicating a decline in gas production potential. Similar, albeit less pronounced, reductions in carbon dioxide through time are also evident.
- NCC gas data compiled since January 2009 show minimal methane gas concentrations along the length of the canal, again indicating the absence of any significant methane source. Of the 859 gas measurements taken during 2009 and 2010 only 11 readings show positive methane concentrations (maximum, 4.8%). Of

these detections, the majority are less than 1.5%. Six of the positive readings, including the two highest concentrations, were measured at location 3768 at the southern end of the former canal.

Note: the complete NCC gas records show generally minimal methane readings for those BHs which appear to have been drilled beyond the main body of waste (boreholes 3709, 3710, 3718, 3725, 3735, 3736, 3760, 3763 and 3766), even during the early 1990s (when high methane concentrations were recorded in selected in-waste boreholes; see Figure 9.1). Given that all NCC boreholes were drilled in relatively close proximity to the former canal this suggests that lateral gas migration is limited.

In summary, the recent NCC gas records suggest the absence of any appreciable methane gas source associated with the landfilled materials. The longer term records suggest that there is limited potential for lateral gas migration away from the landfill.

- The NCC carbon dioxide records for the equivalent period (2009 to 2010) range between 0 and 16%, although over 90 percent of measurements were less than 5%. Furthermore, the average carbon dioxide concentration across all NCC monitoring locations since 2009 was around 2%. The higher carbon dioxide measurements appear to be clustered in three locations; approximately adjacent to Wellsworth Isle Road in Outwell (NCC boreholes: 3755 and 3756), directly south of Collett’s Bridge (3732 and 3733) and behind the row of properties (42 to 62 Outwell Road) located north of Collett’s Bridge (3713 to 3715). All of these NCC monitoring boreholes are screened within the waste materials. It is noted that no significant carbon dioxide concentrations (i.e., in excess of 5%) have been recorded over the last two years in any of the nine NCC boreholes located directly adjacent to the waste materials; indeed, carbon dioxide concentrations at these locations were typically less than 2%.
- Detectable concentrations of methane were only recorded in three of the 22 ESI monitoring boreholes (A9, A17 and A20) positioned a short distance beyond the landfilled waste.
- There is some evidence from the ESI monitoring data of declining bulk gas concentrations with distance from the infilled canal (i.e., those A-series boreholes positioned in excess of c. 5 m from the waste materials exhibit lower carbon dioxide concentrations than those boreholes located directly adjacent to the waste).
- The evidence of declining gas concentrations with distance from the infilled canal is entirely consistent with the conceptual site model which suggests that the presence of natural silts and clays adjacent to the waste materials will inhibit lateral gas migration.
- The potential influence of former canal drainage connections (referred to as ‘slackers’) on the migration of ground gases has been partially explored by the drilling of borehole A16, positioned deliberately on or directly adjacent to one such slacker feature. The absence of any methane and only modest carbon dioxide concentrations at borehole A16 suggests that these former drainage connections are unlikely to represent preferential gas migration pathways.
- Recent greenhouse gas assessment works (including an FID walkover survey and a subsequent flux box survey) have been undertaken along the length of the infilled canal to assess the surface emissions of methane gas (ESI, 2010). The FID survey transects plus the locations of the 15 flux box measurements are presented on Figures 5.2 to 5.6. The flux box results show that no appreciable gas emissions (typically defined as exceeding 0.5 mg/m^3) were detected at any of the flux box monitoring locations. As such, it may be assumed that the surface gas emissions associated with the former Wisbech Canal are less than the ‘lower detection limit value’ (i.e., negligible); this equates to a flux of less than 5 x 10^{-5} mg/m^2/second for

the flux box design used during the monitoring activities. These results were validated by the FID walkover survey, which also showed negligible surface gas emissions.

Given the absence of any robust capping system over the waste materials (which could constrain surface emissions), this result provides further evidence that gas production rates (and thus the gas pressures) within the former landfill are low.

It is therefore concluded that the ground gas risks posed by the infilled canal to nearby properties and their occupants are very low.

10. CONTROLLED WATERS RISK ASSESSMENT

10.1 Methodology

The assessment of risks to the relevant controlled water receptors has been performed using the Environment Agency's latest guidance on hydrogeological risk assessment, as described in the Remedial Targets Methodology (Environment Agency, 2006a).

The Remedial Targets Methodology is based on a phased approach to risk assessment. The methodology consists of up to four assessment levels which progressively follow the pathway from the contaminant source through to the receptor.

Remedial targets may be derived at each level incorporating more complex transport processes (including dilution and a range of attenuation processes including dispersion, retardation and degradation) at the higher assessment levels.

The analysis along each pathway takes account of the geometry of the pathway, but is essentially one-dimensional, with a simple description of the physical parameters affecting the contaminant migration along the pathway.

The pollution risks posed by the landfill leachate to identified controlled waters receptors have been assessed using both Level 2 and Level 3 Remedial Targets Methodology assessments.

At Level 2, the remedial target is set as the target concentration at the receptor (i.e., within the receiving groundwater). Hence, observed contaminant concentrations in monitoring boreholes positioned within the plume of contaminated groundwater are compared with the adopted target concentration to determine the need for further action (EA, 2006). Separate Level 2 assessments have been undertaken for the water quality datasets provided by both the in-waste and off-waste boreholes (i.e., two compliance points have been used for the Level 2 assessment; firstly, the shallow groundwater directly adjacent to the waste tip and secondly, shallow groundwater within the immediate vicinity of the waste (e.g., within 20 m of the waste limits)).

Target concentrations have been based on both published EQS values for freshwater and drinking water standards. Where relevant, updated EQS values associated with the recent Water Framework Directive (2010) have been adopted.

The potential pollution risks to local private groundwater abstractions (and by association local surface water drainage features) have been assessed using a Level 3 assessment. At Level 3 the assessment takes account of the potential attenuation (within the groundwater system) as contaminated groundwater moves towards the identified receptor. The Level 3 remedial target concentration for groundwater is derived by multiplying the target concentration at the receptor/compliance point by an attenuation factor (AF).

The attenuation factor is defined as the ratio of the contaminant concentration in groundwater (observed within the contaminant plume) to the calculated concentration at the compliance point. The later has been calculated using analytical solutions contained within the Environment Agency's Remedial Targets Worksheet (EA, 2006b); these calculations consider the effects of dispersion, retardation and degradation along the groundwater transport pathway.

10.2 Level 2 RTM assessment

10.2.1 In-waste water quality

The water quality data associated with ESI's in-waste boreholes are summarised in Table 10.1. Only those petroleum hydrocarbon fractions, VOCs and SVOCs which were measured above the limits of detection are shown on this table. For the calculation of average concentration values, any results which were recorded below the detection limit have been set at this limit.

Various target concentrations are also shown in Table 10.1; these relate to both drinking water quality (UK Drinking Water Standards and WHO drinking water quality recommendations) and environmental quality standards (EQS).

Comparison of the observed water quality results with the target concentrations provides an indication of the potential risks posed by the aqueous contaminant source. Note: given that the target concentrations typically relate to annual average water quality, it is considered appropriate to compare these values with the average observed water quality data. Exceedances of the target concentrations are highlighted in blue (dark blue where both drinking water and environmental quality standards are exceeded and light blue where only one of the standards is exceeded).

The information presented in Table 10.1 suggest that the waste materials are a source of significantly elevated ammonia and manganese plus moderately elevated chloride, phenol, lead, diesel range petroleum hydrocarbons, and selected PAHs. The presence of dissolved phase petroleum hydrocarbons is unsurprising given the observation of ‘slight sheens’ on the surface of water samples taken from four of the five in-waste boreholes.

It is noted that the soil leachability data (see Section 6.4) are broadly comparable with the results shown in Table 10.1; this offers further confirmation that the waste materials are the source of the observed aqueous contamination. The leachability data also indicate the potential for ongoing groundwater pollution.

Despite the limited data available, closer inspection of the groundwater quality results reveals some spatial variation in water quality along the Site. Hence, the groundwater/leachate associated with boreholes W2 and W4a (see Appendix P.2) appears less impacted (as demonstrated by lower ammonia, chloride and phenol concentrations). These results are consistent with the understanding that the waste materials deposited in the northern section of the canal were predominantly inert. As such, the section of infilled canal to the north of the junction between the A1122 and A47 is considered unlikely to pose any significant groundwater pollution risks.

Note: groundwater quality data provided by NCC (see Section 6.5.2) provides additional characterisation of the aqueous contaminant source. The NCC records show higher sulphate and metal concentrations compared with the ESI data. These results confirm that the waste materials are a source of aqueous contaminants.

Table 10.1 In-waste groundwater quality (aqueous contaminant source)

Parameter	Units	Max concen.	Average concen.	Target concentrations		
				UK DWS[1]	EQS (freshwater)[2]	WHO drinking water[3]
General Inorganics						
Sulphate as SO_4	µg/l	82000	39900	250000	400000	
Chloride	mg/l	840	348.9	250	250	
Ammon. Nitrogen as N	µg/l	160000	67600	500		
*Ammonia***	*mg/l*	3.74	1.7		*0.015*	
Total Phenols						
Tot Phenols (monohydric)	µg/l	24	17.4	0.5	300	
Heavy Metals / Metalloids						
Cadmium	µg/l	<LOD	<LOD	5	0.25*	
Chromium	µg/l	11	3	50	5 - 250	
Cobalt	µg/l	4	2.42			
Copper	µg/l	7.7	5.12	2000	1 to 25	
Lead	µg/l	45	13.78	10	7.2*	
Manganese	µg/l	1700	666	50		
Mercury	µg/l	<LOD	<LOD	1	0.05*	
Molybdenum	µg/l	7.2	3.9			70
Nickel	µg/l	6.7	3.16	20	20*	
Selenium	µg/l	<LOD	<LOD	10		10
Vanadium	µg/l	<LOD	<LOD		20 to 60	
Zinc	µg/l	39	12.2	5000	8 to 500	
Calcium	mg/l	340	198	250		
Magnesium	mg/l	60	40.9	50		
Petroleum Hydrocarbons						
TPH7 - Ali >C16 - C21	µg/l	17	11.4	10		
TPH7 - Ali >C21 - C35	µg/l	20	12	10		
TPH7 - Ali (C5 - C35)	µg/l	37	15.4	10		
TPH7 - Aro >C16 - C21	µg/l	28	13.6	10		
TPH7 - Aro >C21 - C35	µg/l	66	21.2	10		
TPH7 - Aro (C5 - C35)	µg/l	100	28	10		
SVOCs						
1,2-Dichlorobenzene	µg/l	5.9	1.22			1000
1,4-Dichlorobenzene	µg/l	3.8	0.8			300
Naphthalene	µg/l	0.53	0.18	0.1	2.4*	
2-Methylnaphthalene	µg/l	1.5	0.4		2.4*	
Acenaphthene	µg/l	0.91	0.28	0.1		
Fluorene	µg/l	0.32	0.07	0.1		
Phenanthrene	µg/l	0.52	0.11	0.1		
Anthracene	µg/l	0.1	0.03	0.1		
Fluoranthene	µg/l	0.33	0.07	0.1	0.1	
Pyrene	µg/l	0.24	0.06	0.1		

[1] DWS: UK drinking water standard (Water Supply (Water Quality) Regulations 2000)

[2] EQS: Environmental quality standard based on annual average concentrations (EA, 2003; EA, 2010)

[3] WHO: Guidelines for Drinking Water Quality, 1984

* Revised Daughter Directive EQS values

** Calculated values; see Appendix U

10.2.2 Off-waste water quality

The off-waste groundwater quality data alongside relevant target concentrations are summarised in Table 10.2. Any exceedances of the adopted target concentrations are highlighted as in Table 10.1.

Table 10.2 excludes those substances which were consistently measured below or marginally above the LOD (i.e., total petroleum hydrocarbons).

The results presented in Table 10.2 indicate that the majority of substances (based on either the maximum or average observed concentrations) do not pose a pollution risk to shallow groundwater. This includes the various petroleum hydrocarbon compounds (TPHs and PAHs) which were measured in the in-waste water samples. However, elevated concentrations of sulphate, chloride, ammonia, total phenol and manganese have been measured in the off-waste groundwater samples. Further discussion of the likely pollution risks posed by these substances is presented in the following paragraphs.

The average **sulphate concentration** (339,600 µg/l) is below the relevant EQS but exceeds the UK drinking water standard. This result is somewhat surprising given the in-waste results shown in Table 10.1. It is possible that the elevated off-waste sulphate concentrations reflect locally elevated sulphate levels in the adjacent waste materials. However, when considering adjacent borehole pairs (i.e., neighbouring in and off-waste monitoring boreholes), considerably higher sulphate and chloride concentrations were observed in certain off-waste locations (including boreholes A1 and A2; as compared with W2 and W4a). This may suggest that the off-waste groundwater quality is influenced by factors other than landfill leachate, such as the natural mineralogy of the local silts and clays.

The average **chloride concentrations** were also typically higher in the off-waste samples. This is once again surprising given the landfilled materials are an obvious source of dissolved chloride. However, given the nature of the Quaternary deposits (including saltmarsh deposits) it is feasible that the elevated chloride concentrations relate to the local mineralogy and possibly the presence of connate groundwater.

In contrast to the sulphate and chloride results, measured **ammonia concentrations** were substantially lower in the off-waste boreholes (as compared with the in-waste results). Hence, the average observed ammonia concentration was approximately three times greater than the freshwater EQS for the off- waste samples, whereas the in waste result was 115 times greater than the EQS. This suggests that whilst pollution of the local groundwater may be occurring as a result of ammonia migration away from the landfilled wastes, the pollution impacts reduce rapidly with distance from the waste materials (this feature is discussed further in Section 10.3).

Note: given the spatial distribution in ammonia concentrations it is unclear why similar reductions in sulphate and chloride concentrations have not been observed between the in-waste and off-waste boreholes; this may offer further indirect evidence that the observed sulphate and chloride concentrations are partly the result of off-Site influences.

Phenol concentrations at the off-waste locations are closely comparable with the in-waste results (note: the statistics differ somewhat in Tables 10.1 and 10.2 due to the presence of a single elevated concentration associated with the off-waste samples). As such, there appears to be localised phenol pollution of the shallow groundwater surrounding the former canal.

Measured **manganese concentrations** are considerably in excess of the UK drinking water standard, however, given that this standard is largely specified on the grounds of taste and potential staining of laundry, the observed concentrations are not considered to pose a significant environmental or health risk.

Table 10.2 Off-waste groundwater quality

Parameter	Units	Max concen.	Average concen.	Target concentrations		
				UK DWS[1]	EQS (freshwater)[2]	WHO drinking water[3]
General Inorganics						
Total Cyanide	µg/l	<LOD	<LOD	50		
Free Cyanide	ug/l	<LOD	<LOD			
Thiocyanate as SCN	µg/l	<LOD	<LOD			
Sulphate as SO_4	µg/l	1300000	339600	250000	400000	
Sulphide	µg/l	<LOD	<LOD		0.25	
Chloride	mg/l	2200	567.6	250	250	
Ammon. Nitrogen as N	µg/l	11000	3640	500		
Ammonia**	mg/l	0.138	0.047		0.015	
Total Phenols						
Total Phenols (monohydric)	µg/l	130	28.7	0.5	300	
Heavy Metals / Metalloids						
Cadmium	µg/l	<LOD	<LOD	5	0.25*	
Chromium	µg/l	13	2.2	50	5 - 250	
Cobalt	µg/l	4.7	2.5			
Copper	µg/l	10	4.9	2000	1 to 25	
Lead	µg/l	7	5.2	10	7.2*	
Manganese	µg/l	3800	1155.7	50		
Mercury	µg/l	<LOD	<LOD	1	0.05*	
Molybdenum	µg/l	9.1	5.12			70
Nickel	µg/l	7.1	2.61	20	20*	
Selenium	µg/l	<LOD	<LOD	10		10
Vanadium	µg/l	16	7.41		20 to 60	
Zinc	µg/l	120	19.7	5000	8 to 500	
Calcium	mg/l	940	264.8	250		
Magnesium	mg/l	140	48.2	50		
SVOCs						
1,2-Dichlorobenzene	µg/l	<LOD	<LOD			1000
1,4-Dichlorobenzene	µg/l	<LOD	<LOD			300
Naphthalene	µg/l	<LOD	<LOD	0.1	2.4*	
2-Methylnaphthalene	µg/l	1.3	0.36		2.4*	
Acenaphthene	µg/l	<LOD	<LOD	0.1		
Diethyl phthalate	µg/l	<LOD	<LOD		1.3*	
Fluorene	µg/l	<LOD	<LOD	0.1		
Phenanthrene	µg/l	<LOD	<LOD	0.1		
Anthracene	µg/l	<LOD	<LOD	0.1		
Dibutyl phthalate	µg/l	0.17	0.08		1.3*	
Fluoranthene	µg/l	0.25	0.07	0.1	0.1	
Pyrene	µg/l	0.41	0.11	0.1		

[1] DWS: UK drinking water standard (Water Supply (Water Quality) Regulations 2000)

[2] EQS: Environmental quality standard based on annual average concentrations (EA, 2003; EA, 2010)

[3] WHO: Guidelines for Drinking Water Quality, 1984

* Revised Daughter Directive EQS values

** Calculated values; see dissociation calculations in Appendix U

In summary, there appears to be localised pollution of shallow groundwater associated with ammonia and phenol derived from the waste materials. Elevated sulphate, chloride and manganese are also evident in shallow groundwater although these may be influenced by factors unrelated to the infilled canal. Further consideration of the pollution risks posed by these substances to private water wells and surface water drainage structures located beyond the off-waste boreholes is given in the following Level 3 assessment.

10.3 Level 3 RTM assessment *(pollutant linkages: PL7 and PL8)*

A Level 3 assessment has been used to assess the likely contaminant distribution in groundwater beyond the immediate vicinity of the infilled canal. A nominal compliance point of 35 m from the waste edge has been selected; this corresponds to the position of the nearest private water well known to exist in close proximity of the former canal.

Based on the Level 2 assessment the modelled contaminants of concern comprise ammonium, chloride, phenol and manganese. The contaminant migration of TPH and PAH has also been assessed despite the absence of any appreciable concentrations observed beyond the waste extents (i.e. in the off-waste boreholes; see Table 10.2).

The theoretical impacts of these substances on the Terrington Beds (and by association the local network of surface drainage features) have been considered using the RTM worksheet (see Appendix V). The model inputs and results are discussed in the following sub sections.

i) RTM Level 3 input parameters

Contaminant input parameters are presented in Table 10.3. The various petroleum hydrocarbon fractions which were evident in the landfill leachate (although not in the shallow groundwater sampled from the off-waste boreholes) have been represented by the aromatic C16-C21 fraction (i.e., the most mobile of the observed hydrocarbon fractions). Naphthalene has been modelled as a representative PAH species due to its relative mobility in groundwater.

All source concentrations were taken to be the average observed chemical quality of the landfill leachate (i.e. the water quality results from the in-waste boreholes; see Table 10.1).

Additional model inputs which are required to characterise the contaminant source and pathway are presented Table 10.4.

Table 10.3 Contaminant parameters

Determinand	Parameter	Value	Units	Justification
Ammonium (NH4)	Target concentration	0.5	mg/l	UK DWS
	Kd (aquifer)	1.25	l/kg	Mid point for Kd sand values (Golders, 2000)
	Half life (decay)	∞	days	Pore space considered too fine to enable biological action (bacteria entry); Buss *et al*. (2003)
Chloride	Target concentration	250	mg/l	UK DWS
	Kd (aquifer)	0	l/kg	No retardation assumed
	Half life (decay)	∞	days	No decay assumed
Manganese	Target concentration	0.05	mg/l	UK DWS
	Kd (aquifer)	49	l/kg	Golders (2000): sand
	Half life (decay)	∞	days	

Determinand	Parameter	Value	Units	Justification
Phenol	Target concentration	0.0005	mg/l	UK DWS
	Koc (aquifer)	27	l/kg	Golders (2000)
	Foc (aquifer)	0.0011	/	Golders (2000): mean for lacustrine silt
	Half life (decay)	∞	days	No decay assumed
DRO (aromatic C16-C21)	Target concentration	10	ug/l	1989 UK drinking water standard for Oils/Hydrocarbons
	Koc (aquifer)	14,125	l/kg	LQM (2009)
	Foc (aquifer)	0.0011	/	Golders (2000): mean for lacustrine silt
	Half life (decay)	∞	days	No decay assumed. Note: this is a highly conservative assumption given that biological degradation may well act on petroleum hydrocarbon compounds along the contaminant pathway
Naphthalene	Target concentration	0.1	ug/l	UK drinking water standard for Total PAH
	Koc (aquifer)	1288	l/kg	Golder (2000)
	Foc (aquifer)	0.0011	/	Golders (2000): mean for lacustrine silt
	Half life	840	days	Golder (2000) 767 to 840 days. Maximum value used.

Table 10.4 Source and pathway parameters

Parameter	Value	Units	Justification
Hydraulic conductivity of aquifer	0.01	m/d	Geomean of published conductivities for silt: 0.0001 to 1.7 m/d (Golders, 2000)
Hydraulic gradient	0.005	Fraction	Groundwater gradients derived from the site investigation data are highly variable (possibly reflecting the absence of a continuous shallow groundwater system and/or the heterogeneity of the waste deposits/hydraulic characteristics). Gradients between adjacent pairings on in-waste and off-waste boreholes range from 0.03 to 0.001 (it is acknowledged that these gradients are unlikely to be representative of conditions within the wider Terrington Beds). An estimated gradient of 0.005 has therefore been assumed
Aquifer material bulk density	2.0	g/cm^3	Midpoint of 1.82 to 2.15 for silt (Golder, 2000)
Aquifer - effective porosity	0.25	%	Estimated based on silt porosity range of 0.34 to 0.61 (Golder, 2000)
Aquifer - saturated thickness	5	m	Estimated
Width of contaminant source in direction of groundwater flow	250	m	Nominal length of Canal section
Plume thickness at source	2	m	Estimated from site investigation data; typical saturated thickness of waste materials

Parameter	Value	Units	Justification
Distance to compliance point	35	m	Horizontal path length from edge of landfill to the nearest known water well (Birdbeck House, Outwell)

ii) Level 3 remedial target results

The RTM worksheets are presented in Appendix V. Salient observations taken from the model outputs shown in Appendix V include:

- No contaminant breakthrough is simulated at the compliance point (i.e., a private water well positioned 35 m from the edge of the waste) for ammonium, TPH, PAH and manganese after 1000 years from the time of contaminant release (i.e., from the time of waste deposition).
    - This is a function of the very low contaminant travel times within the subsurface (reflecting the low conductivity of the silts, the shallow groundwater gradient and the effects of retardation and dispersion along the groundwater pathway).
    - Note: regardless, of attenuation effects, it is estimated that contaminants would take around 140 years to travel a distance of 10 m (assuming homogeneous silt deposits).
    - The slow travel times are consistent with the observed absence of any appreciable petroleum hydrocarbon concentrations in those samples taken from the off-waste boreholes, plus the significant reduction in ammonium concentrations immediately beyond the waste deposits (i.e., an ammonium concentration of 160,000 ug/l was measured in the leachate sample taken from borehole W6, whereas only 260 ug/l was detected in the adjacent off-waste borehole (A18)).
    - The modelled results are also consistent with the very low ammonium concentration which was measured in the Birdbeck House well, despite the position of this well down hydraulic gradient of the waste material.
- Given that chloride and phenol are conservative contaminants (i.e., they exhibit little or no retardation along the groundwater pathway) which have been modelled with no degradation, the contaminant flow rates for these substances are equivalent to the calculated groundwater flow velocity (c. 0.07 m/d). As such, chloride and phenol would be expected to reach the compliance point after several hundred years.

In summary, the RTM calculations indicate that the rates of contaminant transport away from the waste mass are likely to be significantly constrained by the properties of the Terrington Bed (note: the RTM guidance (EA, 2006a) acknowledges that for low flow systems and for contaminants which are characterised by a high partitioning coefficient, the rates of contaminant movement can be slow). This situation is reflected in some, but not all, of the observed water quality results associated with the natural formation directly beyond the landfilled materials.

11. CONCLUSIONS AND RECOMMENDATIONS

11.1 Conclusions

The following conclusions are drawn from the site investigation works and subsequent risk assessments described in this report:

Conceptual site model

- The natural geological sequence comprises superficial tidal flat deposits (clay and silt with thin peaty layers) overlying the Ampthill Clay (comprising soft grey mudstone and pale grey calcareous mudstone of approximate 50 m thickness).
- Domestic type waste materials are present along the majority of the infilled canal; it is likely however that the infilled materials in the north of the Site (i.e., to the north of the Blacksmith Arms Public House) contain predominantly inert materials.
- The waste materials reside directly upon the natural silts and clays. The waste is overlain by a clayey cover layer which is of variable thickness and composition.
- The local lithologies are described by the Environment Agency as Non Aquifers or Non productive Strata. Regardless a number of private (unlicensed) groundwater abstractions exist within close proximity of the former canal. These are thought to abstract from locally occurring sandy horizons. No source protections zones have however been defined for the study area reflecting the low water resource potential of the region.
- Shallow groundwater was routinely encountered within 3 m of the ground surface during the recent site investigations; as such, saturated conditions were typically encountered within the lower half of the waste materials.
- The spatial variability in groundwater levels coupled with the low permeability of the natural lithologies suggest that rates of shallow groundwater movement are relatively limited in the vicinity of the former canal.
- The infilled canal is located adjacent to numerous surface water features (predominantly man made ditches and dykes). By definition, the superficial deposits are likely to be in reasonable hydraulic continuity with these drainage features. The degree of baseflow contribution (opposed to inflows derived from rainfall runoff) to these drainage features is however unclear. No licensed surface water abstractions are reported by the Environment Agency within 1 km of the Site.
- The chemical quality of both the near surface soils and the underlying waste materials is reasonable (considering former land use activities), with potential ‘solid phase’ contaminant sources limited to moderate PAH and TPH concentrations with further modest concentrations of selected VOCs and SVOCs.
- Aqueous phase contaminants within the waste materials include elevated concentrations of ammonia, chloride, phenol and various petroleum hydrocarbon compounds.
- Field data indicate that locally elevated methane and carbon dioxide concentrations occur within the infilled canal, however the vast majority of gas monitoring results indicate the absence of a significant methane source associated with the waste materials.
- Relevant receptors which may be impacted upon by any contaminated ground conditions include humans (i.e., members of the public using parts of the infilled canal for recreational purposes, and also occupants of nearby residential dwellings), residential and commercial buildings neighbouring the infilled canal, and to a lesser degree the shallow groundwater associated with the Terrington Beds and local surface water drainage features (predominantly man made dykes and ditches).

Human health risk assessment

- A conservative screening exercise has been undertaken using the latest CLEA methodology to identify any contaminants which may pose a significant risk to human health. On the basis of the available site investigation data, it may be concluded that neither the observed surficial and sub surface soil quality or the shallow groundwater quality pose any significant health risks to informal users of the Site or the residents of properties which extend over the infilled canal.

Soil gas risk assessment

- An assessment of the potential risks from observed ground gas concentrations has been undertaken. This assessment suggests 'low' or 'very low' gas risks are associated with the observed gas regime in and around the infilled canal.
- The absence of any significant ground gas risks is substantiated by a considerable volume of gas monitoring data (generated by both Norfolk County Council and ESI). This data shows that methane concentrations have diminished over the last 18 years, resulting in the absence of any appreciable methane gas source within the landfilled materials. Some moderate carbon dioxide concentrations remain within the waste mass however, all monitoring records show that there is limited potential for lateral gas migration away from the landfill. This is entirely consistent with the conceptual site model which suggests that the presence of natural silts and clays adjacent to the waste materials will inhibit lateral gas movements, as will the absence of any notable gas pressure within the waste materials.
- The results of a recent flux box investigation also indicate that surface gas emissions along the length of the infilled canal are negligible, despite the absence of any robust capping system.

Controlled waters risk assessment

- The assessment of risks to controlled water receptors has been performed using the Environment Agency's Remedial Targets Methodology.
- A conservative screening assessment has been undertaken to identify any contaminants which may potentially cause pollution of controlled waters. The results of this exercise indicate that the majority of substances which were tested for do not pose a pollution risk. However, the landfill leachate present within the waste mass does represent a source of significantly elevated ammonia and manganese plus moderately elevated chloride, phenol, lead, diesel range petroleum hydrocarbons, and selected PAHs.
- Considering the observed groundwater quality directly beyond the waste extents there appears to be some pollution of shallow groundwater associated with ammonia and phenol derived from the waste materials (it is noted that the sensitivity of the shallow groundwater is low given that the Terrington Beds are classified as a non productive strata). Elevated sulphate, chloride and manganese are also evident in shallow groundwater although these may be influenced by factors unrelated to the infilled canal. No petroleum hydrocarbons were observed in groundwater samples taken from the off-waste boreholes.
- Spreadsheet calculations have been used to further consider the pollution risks posed by the contaminants of concern to private water wells and surface water drainage structures. These calculations indicate that the rates of contaminant transport away from the waste mass are likely to be significantly constrained by the properties of the Terrington Beds. As such, where homogeneous silt deposits are present between the infilled canal and any private water wells there is unlikely to be any breakthrough of contaminants at these wells. The localised presence of more permeable sandy horizons within the Terrington Beds may however enable more rapid contaminant transport.

- The pollution risks to any active water wells are therefore considered to be limited, especially where such wells are located a reasonable distance from the infilled canal (i.e., 50 m or more). Note: potable quality water has been proven at a private water well positioned some 30 to 40 m down hydraulic gradient of the waste materials (this is the closest known water well to the former canal).
- However, preferential transport of landfill leachate from the waste mass to other water wells (the number and location of private water wells in the vicinity of the infilled canal is unclear) cannot be discounted since by definition these wells will likely exploit local sandy horizons within the silt deposits.
- No significant pollution risks are considered to occur in relation to local surface water drains and ditches due to their relative distance from the infilled canal (see Figure 4.2) and the anticipated effects of dilution within these drainage features (note: it is expected that a high percentage of the flow in these drains will be derived from rainfall run off opposed to baseflow contributions from the Terrington Beds).

11.2 Recommendations

The following recommendations are made in the context of the conclusions outlined above:

- Based on the available site investigation data and associated interpretations it is not considered appropriate to determine the Site under the Part IIA regime.
- No additional site investigation or risk assessment activities are considered necessary.

12. REFERENCES

Boyes. J. and Russell R., 1977. The Canals of Eastern England.

British Geological Survey, 1995. Geological Map 1:50,000 Series, Sheet 159 (Wisbech), Solid and Drift Geology Edition.

British Standard Institute, 1999. Code of Practice for Site Investigations. BS 5930:1999.

British Standards Institute, 2001. Investigation of potentially contaminated sites – code of practice. ISO 10175:2001.

British Standards Institute, 2002a. Soil quality – Sampling. Part 1: Guidance on the design of sampling programmes. BSI ISO 10381-1:2002

British Standards Institute, 2002b. Soil quality – Sampling. Part 2: Guidance on sampling techniques. BSI ISO 10381-2:2002

CIEH and CLAIRE, 2008. Guidance on Comparing Soil Contamination Data with a Critical Concentration.

CIRIA, 2007. Assessing risks posed by hazardous ground gases to buildings. Research Publication C665.

CL:AIRE, 2010. Soil Generic Assessment Criteria for Human Health Risk Assessment (published in association with AGS and EIC).

DEFRA, 2006. Defra Circular 01/2006. Environmental Protection Act 1990: Part IIA. Contaminated Land.

DEFRA & Environment Agency, 2002. Soil guideline values for lead contamination. Department for Environment, Food and Rural Affairs.

Environment Agency, 2003. Hydrogeological Risk Assessment or Landfills: LFTGN01..

Environment Agency, 2004. Publication CLR 11. Model Procedures for the Management of Land Contamination.

Environment Agency, 2006. Remedial Targets Methodology: Hydrogeological Risk Assessment for Land Contamination.

Environment Agency, 2009a. CLEA Software version 1.06

Environment Agency, 2009b. Science Report SC050021/SR2: Human health toxicological assessment of contaminants in soil.

Environment Agency, 2009c. Science Report SC050021/SR3: Updated technical background to the CLEA model.

Environment Agency, 2009d. Science Report SC050021/SR4: CLEA Software (Version 1.05) Handbook.

Environment Agency, 2009e. Soil Guideline Vales for inorganic Arsenic. Science Report SC050021/Arsenic SGV.

Environment Agency, 2009f. Soil Guideline Vales for inorganic Cadmium. Science Report SC050021/ Cadmium SGV.

Environment Agency, 2009g. Soil Guideline Vales for inorganic Mercury. Science Report SC050021/ Mercury SGV.

Environment Agency, 2009h. Soil Guideline Vales for inorganic Nickel. Science Report SC050021/ Nickel SGV.

Environment Agency, 2009i. Soil Guideline Vales for inorganic Selenium. Science Report SC050021/ Selenium SGV.

Environment Agency, 2009j. Soil Guideline Vales for inorganic Benzene. Science Report SC050021/ Benzene SGV.

Environment Agency, 2009k. Soil Guideline Vales for inorganic Toluene. Science Report SC050021/ Toluene SGV.

Environment Agency, 2009l. Soil Guideline Vales for inorganic Ethylbenzene. Science Report SC050021/ Ethylbenzene SGV.

Environment Agency, 2009m. Soil Guideline Vales for inorganic Xylene. Science Report SC050021/ Xylene SGV.

Environment Agency, 2009n. Soil Guideline Values for phenol in soil. Science Report SC050021 / Phenol SGV.

Environment Agency, 2010. H1 Environmental Risk Assessment; Annex D.

ESI, 2010. Assessment of greenhouse gas emissions from the infilled Wisbech Canal. Report reference: 60319R2.

KLWN, 2010. Desk Study Summary and Outline Scope

LQM, 2009. The LQM/CIEH Generic Assessment Criteria for Human Health Risk Assessment. 2nd Edition.

Norfolk Partnership Laboratory, 2009. Desk Study and site investigation including Quantitative Risk Assessment. Elm Low Road, Emneth, Norfolk. NPSE0012. November 2009.

Ordnance Survey, 2002. Ely and Wisbech (Landranger 143).

Smith, W. 2002. Local history: Outwell in a Nutshell.

FIGURES

APPENDICES

APPENDIX A

Sources of Information

Site:	Former Wisbech Canal

Information	Source	Comment
Envirocheck report for Outwell Road site *(site proposed for sale by Norfolk County Council)*	Supplied by King's Lynn and West Norfolk BC	Data report confirms: • Non aquifer in vicinity of Collett's Bridge • Absence of SPZs • No environmental designations in vicinity of Collett's Bridge • No GW abstractions within 1 km radius • Wastes placed in Wisbech canal 'included inert, industrial, commercial and household waste'
Envirocheck report for Elm Low Road site *(site proposed for sale by Norfolk County Council)*	Supplied by King's Lynn and West Norfolk BC	Data report confirms: • Non aquifer in vicinity of Wisbech • Absence of SPZs • No environmental designations in vicinity of Wisbech • Two agricultural GW abstractions within 1 km radius, both from 'fluvial sands and gravels' • Wastes placed in Wisbech canal 'included inert, industrial, commercial and household waste'
Desk study and site investigation of site on Elm Low Road, Emneth. *(report prepared by Norfolk Partnership Laboratory for NPS Property Consultants)*	Supplied by King's Lynn and West Norfolk BC	Provides summary of geological and hydrogeological setting, environmental designations plus site specific conditions
Plans showing 'Piping of Wisbech Canal' (1975 and 1979)	Fenland District Council	Drawings showing the proposed construction of sewerage/drainage structures in Wisbech along the route of the former canal
BGS borehole records	British Geological Survey (BGS)	Five records requested; comprise a larger number of boreholes and historical private water wells
• Historical land use maps for entire Site • Site photographs (contemporary and historical) • Previous SI documentation • Desk study report	Kings Lynn and West Norfolk DC	Various data, mapping, documents etc.
• Borehole logs and coordinates • Gas monitoring records (1992 to 2010) • Groundwater quality data • Water level records	Norfolk County Council	Various information associated with the long term gas monitoring activities undertaken by NCC along the Site
Various reference documents associated with the Wisbech Canal history	Wisbech Library	Much of this information was already collated by KLWN

Information	Source	Comment
• Historical land photographs • Schematic plans of the former canal structure • Details of the historical operation of the canal and subsequent landfilling activities	Local historian: William Smith	
Contemporary Site photographs	Taken during Site visit and subsequent investigation works	
Mapping: - Geological (Sheet 159: Wisbech) - Land use (Explorer 235, Wisbech and Peterborough North)	British Geological Survey Ordnance survey	
Additional data sets held by Environment Agency including: • Surface and groundwater abstraction licence details • Rainfall data • Geological summary information • Discharge consents • Sewage discharge quality data	Environment Agency, Anglian Central Groundwater Team	Various information as requested

APPENDIX B

Planning consent for canal infilling

APPENDIX C

Historical land use mapping

See accompanying CD-ROM

APPENDIX D

Historical photographs of the Wisbech Canal

APPENDIX E

BGS Borehole records

APPENDIX F

NCC borehole logs

See accompanying CD-ROM

APPENDIX G

NCC borehole coordinates

APPENDIX H

NCC soil gas measurements
(1992 to 2010)

See accompanying CD-ROM

APPENDIX I

KLWN soil sampling and laboratory analyses

See accompanying CD-ROM

APPENDIX J

ESI site investigation photographs (2010)

Appendix J.1: site walkover (10^{th} June 2010)

View along line of former Wisbech Canal: Outwell

Vegetable cultivation on top of infilled canal: Collett's Bridge

Route of former canal passed to rear of commercial premises in Wisbech

Appendix J.2: intrusive site investigations (July 2010)

Hand dug inspection pit at borehole location A2

Drilling at borehole location A5

Borehole cores from location W2: waste materials

Borehole cores from location W5: waste materials

Garden area post grab sampling

Large drainage ditch located south of the former canal

APPENDIX K

ESI borehole logs

See accompanying CD-ROM

APPENDIX L

ESI borehole location descriptions

APPENDIX M

Site diary
(ESI site investigation, July 2010)

APPENDIX N

Grab sample details
(ESI site investigation, 2010)

APPENDIX O

Laboratory analyses
(ESI site investigation, 2010)

See accompanying CD-ROM

APPENDIX P

Summary of laboratory analyses

Appendix P.1: Summary of ESI soil quality analyses

Appendix P.2: Summary of ESI soil leachability quality analyses

Appendix P.3: Summary of ESI groundwater quality analyses

Appendix P.4: Summary of NCC groundwater quality analyses

See accompanying CD-ROM

APPENDIX Q

Laboratory analyses

(NCC groundwater sampling, 2010)

APPENDIX R

ESI soil gas measurements (2010)

APPENDIX S

Statistical Calculator output

See accompanying CD-ROM

APPENDIX T

Modified BaP assessment criteria

Modified BaP assessment criteria

The risk screening described in Section 8 indicates that potential human health risks may be posed by the exposure of selected residents to BaP concentrations in shallow soils. In order to further delimit the likely risks posed by observed BaP soil concentrations, various sensitivity analyses have been performed on the assessment criteria value (the critical concentration). Hence, a range of modified assessment criteria have been generated using the CLEAv1.06 software (see accompanying CD).

The modified assessment criteria are shown in Table 1 alongside a description of the parameterisation used to derive the assessment criteria.

Note: in the case of exposure risks from BaP, the CLEA software is relatively insensitive to variations in soil type, building type and parameterisation associated with the consumption of home grown produce.

The results presented in Table 1 indicate that receptor age class, exposure frequency and BaP toxicity are the most sensitive model parameters.

Table 1 BaP sensitivity runs

Modified exposure scenario		Modified parameter	Default model input	Modified model input	Justification	Modified assessment criteria: mg/kg	Comment
1	Critical receptor assumed to be an adult of working age	Modelled age class (years) *(plus all default exposure parameterisation associated with age class 17)*	0 - 6	16 - 65		6.4	Reject the Null Hypothesis on the balance of probability (i.e., potentially significant health risks remain)
2	BaP health criteria values increased by factor of 10	ID_{oral} (ug/kg/bw d^{-1})	0.02	0.2		10	
		ID_{inhal} (ug/kg/bw d^{-1})	0.00007	0.0007			
3	Exposure frequencies (EF) halved *(remaining parameterisation based on standard residential land use with a child receptor)*	Exposure frequencies associated with ingestion, inhalation and dermal exposures (days/year)	365	180		1.8	
4	Outdoor occupancy time halved *(remaining parameterisation based on standard residential land use with a child receptor)*	Occupancy outdoors (hours/day)	1.0	0.5		1.0	
5	Soil to skin adherence factor halved *(remaining parameterisation based on standard residential land use with a child receptor)*	Soil to skin adherence factor, outdoors	1.0	0.5		1.13	

Modified exposure scenario		Modified parameter	Default model input	Modified model input	Justification	Modified assessment criteria: mg/kg	Comment
6	Soil and dust ingestion rate halved *(remaining parameterisation based on standard residential land use with a child receptor)*	Combined soil and dust ingestion rate (grams/day)	0.1	0.05		1.22	Reject the Null Hypothesis on the balance of probability (i.e., potentially significant health risks remain)
7	Maximum exposed skin fraction halved *(remaining parameterisation based on standard residential land use with a child receptor)*	Maximum exposed skin fraction, outdoors	c. 0.27	0.15		1.15	
8	Combination of modified scenarios 3 to 7	As per items 3 to 7 above	various	various		3.0	
9	Adult receptor and halved default exposure frequencies	As per items 1 and 3	various	various		13.1	Borderline statistical outcome
10	Adult receptor, halved default exposure frequencies and modified BaP toxicology	As per items 1, 2 and 3	various	various		131	No evidence to reject the Null Hypothesis: no evidence of significant health risks

[1] the upper and lower bounds of evidence are calculated when the Chebychev Theorem is used. The actual level of evidence is a value within this range

APPENDIX U

Ammonia dissociation calculations

APPENDIX V

RTM worksheets