London Borough of Hillingdon

New Years Green Landfill, Hillingdon

Updated Remediation Options Appraisal

May 2011

London Borough of Hillingdon

New Years Green Landfill, Hillingdon

Updated Remediation Options Appraisal

May 2012

Notice

This report was produced by Atkins Limited for the London Borough of Hillingdon for the specific purpose of assessing potentially viable remediation options for New Years Green Landfill.

This report may not be used by any person other than the London Borough of Hillingdon without the London Borough of Hillingdon's express permission. In any event, Atkins accepts no liability for any costs, liabilities or losses arising as a result of the use of or reliance upon the contents of this report by any person other than the London Borough of Hillingdon.

Atkins Limited

Document History

JOB NUMBER: 5109736			DOCUMENT REF: 5109736/GTG.20110055/R003rev0			
0	Draft	L Hay	D Matthews	D Matthews	N Ala	May 2012
Revision	Purpose Description	Originated	Checked	Reviewed	Authorised	Date

Plan Design Enable

ATKINS

Contents

List of Tables

List of Figures

Plan Design Enable

List of Appendices

Glossary of Terms

Term	Meaning / Definition
Atkins	Atkins Limited
bgl	below ground level
CDM	Construction (Design and Management) Regulations
CIRIA	Construction Industry Research and Information Association
CLR	Contaminated Land Report
CoC	contaminants of concern
CSM	conceptual site model
DQRA	detailed quantitative risk assessment
DWS	Drinking Water Standard
EPU	Environmental Protection Unit
GQRA	generic quantitative risk assessment
HSE	Health and Safety Executive
LBH	London Borough of Hillingdon
MNA	monitored natural attenuation
NHBC	National House Building Council
PAH	polycyclic aromatic hydrocarbon
PCL	potential contaminant linkage
PRB	permeable reactive barrier
PWS	Public Water Supply
ROA	Remedial Options Appraisal
SCL	significant contaminant linkage
SSSI	Site of Special Scientific Interest
TPH	total petroleum hydrocarbons

Executive Summary

Summary

Atkins Limited (Atkins) was commissioned by the London Borough of Hillingdon (LBH) to produce an updated Remediation Options Appraisal (ROA) for the New Years Green Landfill. The ROA has been updated to take account of the findings of the site investigation and detailed quantitative risk assessment (DQRA) undertaken by Atkins in 2012 (Ref. 1).

The appraisal identified four potentially viable remediation strategies that would be potentially effective in reducing and/or controlling the significant contaminant linkages (SCLs) identified at the site, with respect to controlled waters receptors:

1. leachate removal, treatment and re-circulation and Chalk groundwater abstraction, treatment and disposal or re-injection;
2. monitored natural attenuation (MNA) and phased increased abstraction at the Ickenham PWS;
3. leachate removal, treatment and re-circulation and MNA; and
4. additional treatment facilities at Ickenham public water supply (PWS) and MNA.

These four options were taken forward to cost benefit analysis.

The results of the cost benefit analysis identified MNA combined with phased increased abstraction at the Ickenham PWS (Option 2) as the most appropriate remedial option. The cost-effectiveness score for this option was much higher than that calculated for the other three options evaluated, indicating that it offers a cost-effective and reasonable approach to the on-going management and remediation of the site.

Recommendations

The results of the cost benefit analysis conclude that MNA combined with phased increased abstraction at the Ickenham PWS is the most cost effective remedial solution. This potential option was discussed during the stakeholder meeting on 03 May 2012. An outline of the recommendations is provided below:

- drilling and installation of three deep Chalk boreholes (potentially multi-level in order to target specific fracture horizons within the Chalk) located between the site and Ickenham PWS;
- geophysical logging of the wells in order to identify potential fracture horizons within the Chalk establish appropriate well installation specifications;
- groundwater sampling and monitoring of MNA parameters across the monitoring well network;
- step-pump test at Ickenham PWS to establish the maximum abstraction rate available where no impact is observed in the groundwater in Chalk wells installed to the south east of the site. It is understood that this will be undertaken and funded by Veolia Water); and
- evaluation of the declining waste source to input into an updated DQRA for Ickenham PWS. Updated modelling would also include transient hydraulic gradients and groundwater velocities measured during the step-pump test.

It has been proposed that monitoring and sampling of the Chalk wells is undertaken on a monthly basis for the first year, also more frequent and targeted to monitor impacts on the groundwater during the step-pump test. Quarterly monitoring has been considered appropriate thereafter, which may be reduced after an agreed time period, should natural attenuation be proven to be active.

1. Introduction

Atkins Limited (Atkins) was commissioned by the London Borough of Hillingdon (LBH) to produce an updated Remediation Options Appraisal (ROA) for the New Years Green Landfill (herein referred to as 'the site'). The ROA has been updated to take account of the findings of the site investigation and detailed quantitative risk assessment (DQRA) undertaken by Atkins in 2012 (Ref. 1).

1.1 Background

1.1.1 Site Description and History

The site is located in the River Pinn Valley within the London Borough of Hillingdon. There are four residential buildings (Middle Lodge, Lower Lodge, north bungalow and south bungalow) and a Civic Amenity Centre located within the boundary of the former landfill and three farms surrounding the landfill perimeter. Immediately adjacent to the eastern site boundary is the Bayhurst Wood Countryside Park, a designated Site of Special Scientific Interest (SSSI). Three rivers are situated in close proximity to the site; the River Colne located within 1 km to the west of the site, the New Years Green Bourne which runs along the eastern and southern site boundaries and discharges into ponds adjacent to the River Colne, and the River Pinn which is situated 760 m to the east of the site. A site location plan is presented as Figure 1.

It is understood that the site was originally used as a sand and gravel quarry until the 1960s after which it was largely infilled with domestic waste during the 1970s. The site is now covered with topsoil of varying thickness and used as agricultural land (the land was previously used for rough grazing, however, this has ceased since the site was determined as 'Contaminated Land', see Section 1.1.3). A culverted stream runs through the landfill from north to south, draining surface water to the north of the site and discharging to the New Years Green Bourne at the southern boundary of the site.

Information obtained from intrusive site investigations (Refs. 1 to 4) suggests that the site overlies sands and clays of the Reading Formation (designated a Secondary A Aquifer) to a maximum depth of 16 m below ground level (bgl). Upper Chalk underlies the Reading Formation, as is designated as a Principal Aquifer. Data from the intrusive investigations (Refs. 1 to 4) indicate that the London Clay, which overlies the Reading Formation across much of the surrounding area, is absent beneath the site.

There are three Public Water Supply (PWS) wells within 1 km of the site abstracting water from the Upper Chalk. As a result of decreasing groundwater quality identified at the Ickenham PWS, located approximately 1 km to the south east of the site, abstraction from this well ceased in 1996. A report undertaken by Symonds Travers Morgan (Ref. 2) in 1995 cited New Years Green Landfill as the most likely cause of the contamination observed at Ickenham.

While regional groundwater flow has historically been towards the south east, the recent monitoring data (undertaken in 2006 and 2012, Refs. 5 and 1) indicates that groundwater flow is towards the south west. The recent groundwater flow direction is considered to be influenced both by abstraction from a PWS well located to the west of the site and by the cessation of pumping at the nearby Ickenham PWS (located to the south east of the site).

1.1.2 Previous Reports

There have been several phases of investigation and assessment at the site; as listed below:

- Symonds Travers Morgan, November 1995. Investigation of Ammonia Pollution at Ickenham Public Supply Source, Hillingdon (Ref. 2);
- Aspinwall & Company, March 1999. Investigation of Water Pollution from New Years Green Landfill Site, Ickenham (Ref. 3);
- Enviros Consulting Ltd, May 2004. Critical Review of New Years Green Landfill (Ref. 4);
- Atkins Limited, December 2006. B.20(a) and B.20(b) Part IIA Detailed Inspection, New Years Green Landfill (Ref. 5);
- Atkins Limited, February 2011. Outline Remediation Options Appraisal, New Years Green Landfill, Hillingdon (Ref. 6); and
- Atkins Limited, May 2012. Detailed Quantitative Risk Assessment for Controlled Waters and Ground Gas (Ref. 1).

1.1.3 Determination of the Site

It is understood that the outcome of the site investigations and assessments undertaken prior to 2012 was that the Environment Agency advised the Council that the site was ‘Contaminated Land’ and a ‘Special Site’ under Part 2a of the Environmental Protection Act 1990. As a consequence in 2011 the landfill site was determined to be ‘Contaminated Land’ and a designated a ‘Special Site’ for Environment Agency control. It is understood the determination rests on the pollution of controlled waters and the significant risk of significant harm from landfill gas[1].

1.1.4 2011-2012 Schedule of Works

The Council’s Environmental Protection Unit (EPU) is currently working with the Environment Agency to draw up a suitable schedule to carry out remediation assessment actions at the site under Part 2a. As part of these works, the Council commissioned Atkins in 2011 to undertake a supplementary site investigation and produce a DQRA. The findings of these works are presented in Atkins’ DQRA report (Ref. 1) and summarised in Section 2 of this report. The results of the DQRA have been used to update the ROA for the site, as presented herein.

1.2 Objectives

The primary objective of this document is to reappraise potentially viable remediation options and their associated costs (as detailed within Aspinwall’s and Atkins’ ROAs (Ref. 3)) to assess the best practicable technique for remediation,

[1] The quantitative ground gas risk assessment undertaken within the Atkins DQRA report (Ref. 1), concluded that there are no significant risks to the identified receptors from ground gas at the site.

based on the findings of previous works and the recent site investigation and DQRA.

1.3 Scope of Works

In order to deliver the objective stated above, the following scope of works has been defined by LBH:

- identify potential remedial solutions which could break the significant contaminant linkages (SCLs), including consideration of:
  - the principle of the solution and the way in which it will break the SCL;
  - the requirements for further information before the solution can be fully costed and implemented;
  - the range of possible costs;
  - the possible timescale for implementing the solution; and
  - the potential risks and benefits associated with the action.
- assess the practicality, effectiveness and durability of each remedial treatment action option; and
- evaluate (including by cost-benefit analysis) which option amounts to the best practicable technique and provide the reasons for that assessment.

A stakeholder meeting was attended by LBH, Atkins, the Environment Agency and Veolia Water on 03 May 2012. This ROA includes potential management and remediation options discussed within the meeting.

1.4 Limitations

In producing this document a number of limitations have been identified that have limited the scope and detail of this updated ROA. These include:

- while site investigation has been undertaken within the landfill, due to the heterogeneity of the landfill waste material, it is recognised that full characterisation of the chemical composition of the waste material is unfeasible;
- details regarding the current landfill design are currently unknown and therefore assumptions have been made regarding the outline design requirements for potential options;
- in completing the assessment, Atkins has relied on information from third parties presented in previous reports which has not been independently verified; and
- the findings of the DQRA and this ROA are to be agreed with LBH and the Environment Agency, and potentially with other stakeholders (e.g. Veolia Water). Consultation with the Environment Agency and LBH will be undertaken prior to issuing the final version of this report. Costs presented herein are therefore based on both Atkins' and contractor's experience of investigating and remediating similar sites with similar contaminants of concern (CoC), and will be finalised when an appropriate way forward has been agreed by all parties.

2. Potential Pollutant Linkages and Contaminants of Concern

2.1 Summary of Atkins' 2012 Site Investigation

2.1.1 Scope of Works

The 2012 site investigation was undertaken between 23 January 2012 and 06 February 2012 and was designed to investigate:

- the spatial distribution, extent and concentration of CoCs in soil and groundwater (including the nature, thickness and extent of leachate);
- the nature, thickness and extent of all identified fill materials;
- the nature, thickness and extent of superficial deposits;
- the depth to bedrock across the site;
- the fracture network and hydraulic conductivity within the Chalk Aquifer;
- the location and continuity of surface water features at the site / the nature and impact of the river culvert below the landfill;
- the location and continuity of perched groundwater at the site;
- groundwater levels and flow direction in the Chalk Aquifer beneath the site; and
- the ground gas regime.

The site investigation also took into account the condition and extent of the existing monitoring borehole network.

The works comprised:

- five boreholes located within the boundary of the landfill drilled to the base of the waste (where identified) and installed as combined ground gas and leachate monitoring wells. Unsaturated soil samples were obtained from the Made Ground / landfill waste material;
- five boreholes located surrounding the landfill boundary installed as Chalk groundwater monitoring wells to supplement the existing Chalk groundwater monitoring network. Three of these wells were installed with dual installations within the Reading Beds Formation;
- geophysical logging of one Chalk well; and
- three leachate, groundwater, surface water and ground gas monitoring and sampling rounds; one round was undertaken in December 2011 prior to the supplementary site investigation works, with two subsequent rounds undertaken in February and March 2012.

The data collected from the boreholes was used to inform the hydrogeological conceptual site model (CSM) and provide further information with regard to the potential migration of landfill leachate into the Chalk groundwater and the hydraulic connectivity and vertical gradient between the Reading Beds and the Chalk groundwater.

A site layout plan is presented as Figure 2.

2.1.2 Physical Findings of the Investigation

Made Ground/Landfill Material

Using data from all previous site investigations, Figure 3 shows the thickness of the waste and Figure 4 the base of the waste. From these it can be seen that the base of the waste has two low areas; one in the north east of the site and a larger in the south of the site. These areas also correspond with the greatest thickness of Made Ground / landfill material.

From the logs it is noted that two types of material have been placed within the landfill:

- landfill waste material typically comprising sandy clay, gravelly clay, gravelly silt, clayey sand or silty sandy gravel with glass, ash, coal, plastic, concrete, cloth, paper, wood, slate, metal and brick fragments; and
- household waste typically comprising brown/black, dark/brown green mottled clay with plastic, organic matter, domestic refuse and brick fragments.

Based on the findings of the site investigation, it appears that the household waste has typically been placed within the low areas where the waste thickness is at its greatest and is overlain by the more inert landfill material.

Lambeth Group

The Reading Beds of the Lambeth Group are typically present beneath the Made Ground / landfill material in all locations except BH301 where the Lambeth Group was absent, however, it is noted that in this location the upper part of the Chalk was described as Putty Chalk.

The unit comprises interbedded layers or lenses of clayey sand, sandy clay, gravelly clay, sand and gravel.

Upper Chalk

The Upper Chalk was identified beneath the Reading Beds and generally recovered as structureless Chalk with flint fragments.

2.2 Summary of Atkins' 2012 GQRA

A generic quantitative risk assessment (GQRA), comparing the leachate and groundwater concentrations at the site against the UK drinking water standards (DWS) was undertaken to identify CoC that needed to taken forward for the DQRA.

Soil Leachate

The results of the GQRA indicated that concentrations of the following CoC in soil leachate from the landfill material may present a potential risk to the identified controlled waters receptors:

- ammonium (as NH_4);
- metals (lead and nickel);

- cyanide (total and easily liberatable)[2];
- polycyclic aromatic hydrocarbons (PAHs) (acenaphthene, anthracene, fluorene, fluoranethene, and pyrene); and
- aromatic total petroleum hydrocarbon (TPH) fractions (C12 – C16, C16 – 21 and C21- C35).

Exceedances were identified in BH301 (ammonium and lead), BH302 (lead), BH303 (ammonium, PAHs and TPHs) and BH304 (cyanide). All these boreholes except BH304 are within landfill material, with BH303 located within the area where household refuse was deposited.

Landfill Leachate / Perched Water within Landfill

The results of the GQRA indicated that concentrations of the following CoC in landfill leachate / perched water within the landfill may present a potential risk to the identified controlled waters receptors:

- chloride – exceeded in boreholes L9 and L13;
- sulphate – exceeded in boreholes L9 and BH304;
- ammonia (as NH_3) – exceeded in all boreholes sampled;
- metals (boron and nickel):
  - boron – exceeded in all boreholes except BH304; and
  - nickel – exceeded in borehole L13;
- cyanide (total and easily liberatable)[3] – exceeded in borehole BH304;
- PAHs (acenaphthylene, acenaphthene, anthracene, benzo(a)anthracene, crysene, fluorene, fluoranethene, naphthalene and phenanthrene pyrene) – exceeded in borehole L13;
- aliphatic TPH fractions (C10 – C12, C12 – C16, C16 – C21 and C21- C35 – exceeded in borehole L13; and
- aromatic TPH fractions (C10 – C12, C12 – C16, C16 – 21 and C21- C35) – exceeded in borehole L13.

The contaminants identified are similar to those identified from the soil leachate screening. Borehole L13 is located within the area of the landfill where household domestic waste was deposited.

Chalk Groundwater

The results of the GQRA indicated that concentrations of the following CoC in Chalk groundwater beneath the site may present a potential risk to the identified controlled waters receptors:

- sulphate – exceeded in boreholes BH106 and C5;
- chloride – exceeded in boreholes BH103 and BH107;

---

[2] Free cyanide was not reported at concentrations above the laboratory limit of detection.
[3] Free cyanide was not reported at concentrations above the laboratory limit of detection.

- ammonia (as NH_3) – exceeded in boreholes C2, C3, C5, C6, C7, BH103, BH104, BH106, BH205, BH202, and BH203; and
- metals (arsenic, boron and nickel);
  - arsenic – exceeded in borehole C6 (March 2012 only);
  - boron – exceeded in boreholes C2, BH103, BH104, BH106, and BH202; and
  - nickel – exceeded in borehole C3, BH103, BH104, BH205, BH202 and BH203.

All the boreholes where exceedances in the Chalk groundwater were observed are located in the southern part of the investigation area .

2.3 Summary of Atkins' 2012 DQRA

Contaminants of Concern

Indicator CoC assessed within the DQRA comprise:

- metals: boron and nickel;
- ammonium;
- chloride; and
- sulphate.

Landfill Leachate

Two scenarios were run to model the landfill leachate:

- Scenario 1 assumed there is a clayey layer present beneath the entire landfill; and
- Scenario 2 assumed that there is no specific clay layer beneath the landfill and that the literature parameters for Lambeth Group are applied to the entire thickness of the unsaturated zone.

The maximum reported leachate concentration from the 2011 and 2012 sampling rounds was conservatively assumed to be representative of leachate concentrations across the site.

The results of the modelling showed that there is the potential for ammonium to reach the receptor (Ickenham PWS) at concentrations greater than the UK DWS of (0.5 mg/l). The predicted concentrations at the base of the unsaturated zone and at the receptor (without dilution) are within the same order of magnitude and travel times were similar.

Comparison of diluted concentrations in groundwater below the site with reported concentrations from sampling rounds was undertaken to attempt to verify the model. Reported concentrations of ammonium (0.1 to 69 mg/l) are much higher than those modelled (0.78 mg/l for Scenario 1). This is considered to be due to the amount of dilution occurring in the groundwater. In the modelled scenario a constant hydraulic gradient was applied (taken from the regional hydrogeological map for the area). This is likely to be different from the hydraulic gradient at the site at present and during recent years when the groundwater flow direction changed from the south east to south west. It is also considered unlikely that during pumping the hydraulic gradient between Ickenham PWS and landfill will be consistent, instead it is likely that a shallower gradient will be present beneath the landfill which steepens towards the abstraction well. The sensitivity analysis indicates that at a lower hydraulic gradient of 0.0003 predicted diluted ammonium concentration within the groundwater below the site (8.11 mg/l) are similar to those observed.

It is therefore considered that the modelling undertaken is representative of conditions which could occur if the Ickenham PWS is pumped at rates similar to those prior to its closure in 1995, although there is the potential for concentrations at the receptor to be under estimated. The modelling indicates that ammonium would be the only contaminant of concern in the landfill leachate with the potential to impact on the Ickenham PWS. If pumping is not restored at Ickenham, it is not considered that ammonium will present a risk to the Chalk Aquifer as the plume within the groundwater is not migrating off site at concentrations greater than the UK DWS.

Groundwater

Two scenarios were run to model the groundwater plume beneath the site:

- Scenario 3 assumed the plume is present beneath the entire landfill; and
- Scenario 4 assumed that the plume is only present in the southern part of the site.

The maximum reported groundwater concentration from the 2011 and 2012 sampling rounds was conservatively assumed to be representative of concentrations within the groundwater plume beneath the site.

The results of the modelling showed that there is the potential for ammonium, boron, chloride and sulphate to reach the receptor (Ickenham PWS) at concentrations greater than the UK DWS of (0.5 mg/l). The predicted concentrations at the receptor (without dilution) and travel times are similar for both scenarios.

Time series plots for chloride, sulphate and ammoniacal nitrogen in landfill leachate and groundwater beneath the site were produced. These indicated that the concentration of chloride, sulphate and ammonium in the landfill leachate has been declining since monitoring was first undertaken in 1998. A decline in the groundwater concentrations beneath the site has also been observed in some boreholes, although to a lesser extent than observed in the leachate. It is therefore considered that the potential for the landfill material within the landfill to produce leachate is declining and the concentrations remaining within the landfill do not present a potential risk to the Ickenham PWS with the exception of ammonium. Concentrations are not declining as rapidly within the Chalk groundwater beneath the site, and this is considered to be due to the landfill leachate migrating through the Lambeth Group which continues to contribute to the groundwater.

It should be noted that the modelling was undertaken using the maximum groundwater concentrations from 2012. Sulphate concentrations in groundwater were only observed in two locations (boreholes C5 and BH106) with concentrations greater than the UK DWS, chloride concentrations in groundwater were also only observed above the UK DWS in two locations (BH103 and BH107) and boron concentration in groundwater were only observed above the UK DWS in four locations (boreholes BH202, BH103, BH106 and C2).

Given the concentrations of contaminants observed in the Chalk groundwater it is considered that ammonium is likely to be the only contaminant of concern which may impact the groundwater quality at the Ickenham PWS. If pumping is not restored at Ickenham it is not considered that ammonium will present a risk to the Chalk Aquifer as the plume within the groundwater is not migrating off site at concentrations greater than the UK DWS.

Surface Water

Surface waters were monitored in December 2011, February 2012 and March 2012 as part of the recent site monitoring undertaken by Atkins. Chemical analysis was undertaken on samples taken at seven locations, shown on Figure 2.

The results indicated that New Years Landfill is not currently impacting the water quality of the New Years Green Bourne for the following reasons:

- ammonia concentrations are higher in S1 (upstream of the landfill culvert) than at the culvert exit (S3) in December 2011 and March 2012. Concentrations in S3 for February 2012 are slightly higher than S1, but this is considered due to mixing with water from the New Years Green Bourne which had higher concentrations of ammonia;
- ammonia concentrations are higher in S6 and S7 upstream of the site in the New Years Green Bourne. It is therefore considered that these are potentially being impacted by another source of ammonia (potentially run off from surrounding farm land); and
- maximum concentrations of chloride and sulphate are highest in S4 south of New Years Green Lane. It is therefore considered that there is the potential the New Years Green Bourne at this location to be impacted from another source. Chloride concentrations at this location and downstream of the site in February 2011 had a greater concentration than those reported in the landfill leachate.

The New Years Green Bourne was therefore not considered further as a receptor for DQRA, but recommendations were made for additional sampling to confirm the above as the 2011/2012 monitoring was undertaken during a period of low / no rainfall.

Ground Gas

It is understood that a total of 23 ground gas monitoring rounds have been undertaken at up to 31 gas monitoring locations at the site with monitoring having been undertaken since March 1998.

There are a number of properties located along the southern boundary of the landfill: the north and south bungalows, Lower Lodge and the Civic Amenity Centre. Highway Farm (now the Dog's Home) and Dew's Farm cottages are located to the south of the landfill, Park Lodge Farm is located to the north west, Middle Lodge to the north and residential properties along The Furrows in South Harefield are located to the west of the landfill. These properties may be potentially at risk from landfill gas due to their proximity to the site.

In the ground gas risk assessment, the site was split into 6 areas. Flow rates and methane concentrations at monitoring locations in Areas 1 (Middle Lodge), 2 (Lower Lodge) and 5 (south bungalow) were consistently below 0.1 l/hr and 0.5 %, respectively, and therefore these areas were not considered further as the risk to receptors was considered to be low.

Area 3 (north bungalow) was not considered further within the assessment as the property is currently derelict with an earth bund at the property entrance preventing unauthorised access. Any future development at this property would require consideration of the ground gas regime.

Only Areas 4 (Civic Amenity Centre) and 6 (whole site, off-site receptors) were taken forward for further assessment. For Area 4, all scenarios indicated the level of risk is lower than that suggested as tolerable.

For Areas 6, if worst case conditions are considered, potential risks to human health are not tolerable compared to the defined threshold. However, 14 years of gas monitoring have been undertaken which indicate that worse case conditions are not representative of longer term conditions. The data were statistically assessed to derive gas flow rates which were considered to be more representative of the long term conditions for the site; under this scenario it was considered unlikely that there is a higher than tolerable risk presented to human health from ground gases present beneath the site in Area 6.

In summary, risks to the identified receptors from ground gas generated at the site we considered to be tolerable.

2.4 Significant Contaminant Linkages

Atkins' 2012 DQRA report has assessed previously identified potential contaminant linkages (PCLs). Where significant risks are considered to be presented to the identified receptors, these have been considered to represent significant contaminant linkages (SCLs), requiring remedial action. The SCLs considered within this ROA are presented in Table 2.1.

Table 2.1 - Significant Contaminant Linkages

SCL	Source	Pathway	Receptor
1	Waste materials	Leaching of contaminants and vertical migration	Groundwater in Principal and Secondary A Aquifers
2	Leachate	Vertical migration	Groundwater in Principal and Secondary A Aquifers
3	Waste materials	Leaching of contaminants and vertical and lateral migration	Ickenham PWS
4	Leachate	Vertical and lateral migration	Ickenham PWS
5	Waste materials	Leaching of contaminants and migration through the culvert or along culvert pathway	New Years Green Bourne*
6	Leachate	Migration through the culvert or along culvert pathway	New Years Green Bourne*
7	Waste materials	Leaching of contaminants and migration through the Secondary A Aquifer	New Years Green Bourne*

SCL	Source	Pathway	Receptor
8	Leachate	Migration through the Secondary A Aquifer	New Years Green Bourne*

* This pathway requires further assessment prior to remediation options appraisal

SCLs 5-8 require further assessment to confirm whether remediation is required. Pending the findings of this further assessment, it is currently considered unlikely that remediation will be required. However, for completness potential options for these SCLs have been considered within the assessment.

3. Potential Constraints to Remediation

The potential constraints to remediation identified from available information are summarised in Table 3.1, below.

Table 3.1 - Summary of Potential Constraints to Remediation

Waste types	A wide range of wastes are thought to have been disposed of at the site in its operational lifetime, and therefore items that may physically inhibit the use of various options are likely to be present. These may include timber, concrete, drums and other items that may impede the application of some methods.
Ground gas	Whilst the ROA is focussed on developing a remediation strategy with respect to controlled waters, the presence of ground gas beneath the site would need to be considered as part of the design and implementation of a remediation scheme, especially in relation to whether any remediation scheme might alter the ground gas regime and whether this would affect PCLs to other receptors.
Groundwater control	Potential remediation options will need to consider the effect options may have on the local hydrogeological conditions to ensure that this does not impact on migration of CoC and/or affect potential for flooding in surrounding areas (which may also lead to unwanted migration of impacts off site). Similarly, the design will also need to consider the potential influence on the nearby PWS abstractions.
Space and traffic	The site is approximately 80 ha. Consideration will need to be given to traffic management as some of the local roads appear to be narrow.
Site access	Access constraints may arise during the works. Site access will need to be considered for some remediation options, particularly if access is required to the residential properties and the Civic Amenity Centre.
Ground stability	Ground stability will need to be considered for some of the options, particularly if implementation requires heavy plant and machinery, or the construction of treatment areas/facilities.
Stakeholder views/public relations/ adjacent land users	Various options have potential to generate disruption (including vehicle movements, dusts and odours) and concern may be raised by local residents. Proactive risk communication measures would need to be put in place for the majority of considered remediation options.
Contaminant properties	The site is likely to have received a wide range of waste types during its operational history and as such the range of potential CoC in the waste is likely to be extensive. Whilst there is some information regarding CoC within waste material, it is recognised that due to the heterogeneity of the waste, full characterisation of the chemical composition of the waste material is unfeasible. While contaminant properties may not be so much of an issue where pathway based solutions are employed (e.g. cut off walls), detailed evaluation of the contaminants requiring treatment would need to be undertaken prior to employing some source-based solutions.

ATKINS

Licensing/ Permitting	Planning may be a requirement of any strategy proposed at the site. The removal of landfill tax exemption may impact on a number of remediation options that require some degree of excavation and subsequent disposal. Access agreements may be required where engineering of the landfill perimeter is required. Depending on the selected options and ultimate design, purchase of land in close proximity to the site may be required when considering some options.
Culverted watercourse and other underground services	The culverted water course and other underground services which may be present would need to be considered during the design and implementation of any remediation scheme. For some options, relocation of services is a likely requirement.
Buildings present on and near the site	There are a number of buildings located adjacent to the boundary of the former landfill area (four residential buildings and a Civic Amenity Centre). Access agreements may be required, particularly should remedial measures include works along the southern site boundary.

ATKINS

4. Remediation: Principles and Objectives

4.1 Updated ROA

4.1.1 Introduction

In order to appraise the potential remediation options for a site, it is important to understand the objective of the remediation scheme. Within this assessment, Atkins has assumed that the objective of any remediation solution for the site will be to address all identified SCLs that represent an unacceptable risk. Such unacceptable risks will either be reduced or controlled to a level agreed as satisfactory with the relevant statutory authorities and other key stakeholders.

The remediation strategy will also seek to achieve the objectives in a sustainable manner without compromising local environmental quality during its implementation and any remediation works on-site will be managed in such a manner that the potential for cross contamination is appropriately mitigated. The remediation strategy and validation criteria (yet to be determined) would need to be agreed with the Environment Agency and LBH as appropriate prior to the implementation of the remedial scheme on site.

Any remediation works would need to be designed to be undertaken in accordance with the pertinent Health and Safety legislation for working on contaminated sites (e.g. Environment Agency and National House Building Council (NHBC) R&D Publication 66, Health and Safety Executive (HSE) and Construction Industry Research and Information Association (CIRIA) guidance) and these aspects would be further strengthened by the Construction (Design and Management) Regulations (CDM) requirements of the project.

Any removal and disposal of excavated materials, soil arisings, groundwater and/or potentially contaminative materials from the site will require appropriate waste classification. Disposal would need to be undertaken in a controlled manner and with due regard to the statutory requirements in place at the time of the works.

4.1.2 Options Appraisal and Cost-benefit Analysis

Importantly, the final remediation objectives and strategy would be developed cognisant of the site's Part 2A determination, all pollutant linkages and with agreement from the regulatory authorities. This would include consideration of the regulators requirements, for example the views of the Environment Agency with respect to requirements to remediate groundwater beneath the site. Further, it is considered likely that the objectives will need to balance the environmental benefits against the operational and financial feasibility of the required works.

As stated within the Part 2A statutory guidance (Ref. 7), the broad aim of remediation should be: (a) to remove identified significant contaminant linkages, or permanently to disrupt them to ensure they are no longer significant and that risks are reduced to below an unacceptable level; and/or (b) to take reasonable measures to remedy harm or pollution that has been caused by a significant contaminant linkage.

The broad aim should be to manage or remediate the land in such a way that risks are minimised as far as is reasonably practicable. In deciding what is reasonable, various factors must be considered: (a) the practicability, effectiveness and durability of remediation; (b) the health and environmental impacts of the chosen remedial options; (c) the financial cost which is likely to be involved; and (d) the benefits of remediation with regard to the seriousness of the harm or pollution of controlled waters in question.

Where there is more than one potential approach to remediation that would be reasonable, the “best practicable technique” should be considered having regard to the factors above. Unless there are strong grounds to consider otherwise, the best practicable technique in such circumstances is likely to be the technique that achieves the required standard of remediation to the appropriate timescale, whilst imposing the least cost on the persons who will pay for the remediation. With this in mind, the ROA process shall have due regard to the “likely costs and benefits” of any proposed scheme ensuring a balance between economic and environmental considerations though cost-benefit analysis.

4.2 Remediation Options Appraisal Process

The remediation options appraisal presented herein has been undertaken in general accordance with the framework set out within Contaminated Land Report (CLR) 11 (Ref. 8). It recommends a phased approach for the ROA process which comprises:

- identification of a feasible remediation option for each SPL (which we have assumed to be the previously identified high risk SPLs (see below));
- carrying out a detailed evaluation of feasible remedial options to identify the most appropriate option for any particular linkage; and
- producing a remediation strategy that addresses all identified SPLs, where appropriate, by combining remedial options.

In addition, as agreed with LBH, Atkins has undertaken a cost-benefit analysis, in accordance with the Environment Agency document entitled “Cost-Benefit Analysis for Remediation of Land Contamination” (Ref. 9), which has been incorporated into the detailed evaluation.

Atkins has endeavoured to undertake a fair and impartial assessment of the potential remediation options for the study site and to this end has applied professional judgement based on our experience of working on similar projects. Available information on site conditions, including geology, hydrogeology, nature of the waste streams understood to be present at the site, the contaminant concentrations and the physio-chemical and toxicological properties of the identified CoCs, have also been used to aid the evaluation.

5. Appraisal of Potential Remediation Options

5.1 Identification of Potential Remediation Options

In identifying potential remediation options, Atkins has considered three approaches to remediation, namely:

- engineering solutions – e.g. excavation and off-site disposal of contaminated media or the use of containment, barrier or cover systems;
- process-based solutions – involving physical, biological and chemical processes; and
- management solutions – such as monitoring site conditions, or managing the potential impact to a receptor.

Previous ROAs undertaken for the site by Aspinwall in 1999 (Ref. 3) and Atkins in 2011 (Ref. 6) identified the following potential solutions that were considered to be feasible following the previous options appraisals:

Engineering solutions

- culvert remedial works;
- engineered capping;
- dense landscaping;
- landfill mining;
- solidification/stabilisation; and
- encapsulation.

Process based solutions

- leachate removal, treatment and re-circulation; and
- permeable reactive barriers (PRBs).

Management solutions

- do nothing;
- Chalk groundwater interception and disposal to sewer;
- Chalk groundwater interception, treatment and disposal to sewer;
- Chalk groundwater interception, treatment and discharge to watercourse;
- Chalk groundwater interception, treatment and re-injection;
- reduced abstraction[4] at Ickenham PWS; and
- additional treatment facilities at Ickenham.

[4] Reduced in relation to the full licensed abstraction volume. As a step-pump test would be required to establish an appropriate abstraction rate, this option has been termed "phased increased abstraction" herein.

The results of the 2012 DQRA (Ref. 1) suggest that monitoring natural attenuation (MNA) should also be considered as a potential remedial option, potentially in combination with other technologies.

Of the technologies listed above, those either taken forward for options appraisal, or not considered further are discussed below:

Culvert Remedial Works

The results of the DQRA are inconclusive with regards to the source of contamination identified within the New Years Green Bourne. It has previously been considered (Refs. 2, 3 and 4) that the source is leachate entering the culvert beneath the site and discharging into the stream. However, the 2012 DQRA (Ref. 1) does not necessarily support this conclusion.

Therefore, it is recommended that an updated CCTV survey is undertaken of the culvert during the winter months/a period of high leachate and/or rainwater levels, in order to establish the condition of the culvert. While the CCTV survey is being conducted (and therefore the covers of the inspection chambers will be removed) it is recommended that sampling of the water within the culvert is undertaken along its length.

As part of any ongoing monitoring regime for the site, it is recommended that further surface water sampling is undertaken, with the sampling network potentially extended further up-stream than the current sample locations in order to determine if there are alternative potential sources of contamination affecting the stream.

Previous assessments have identified that concentrations of contaminants in the stream are higher during dry months when flow rates are at their lowest. Therefore, it is recommended that flow measurements are taken during any sampling rounds.

Should the additional data confirm that the landfill leachate is the source of contamination within the stream, remedial works may be necessary. These may include:

- if the data indicates that contamination is entering the stream along the southern boundary of the site via surface run-off or ingress of leachate directly into the stream, lining the stream along the southern boundary may be required; or
- if the data indicates that contamination is entering the stream via the culvert, it is proposed that the culvert is lined to prevent leachate entering, or the existing culvert is replaced.

Remedial options taken forward within this appraisal also include leachate removal, treatment and re-circulation. This may also be an appropriate treatment technology to address SCLs associated with the New Years Green Bourne receptor if further monitoring indicated that leachate is impacting the stream.

As indicated above, further monitoring is required to confirm whether remediation of SCLs associated with New Years Green Bourne will be required. Pending the findings of the further monitoring, it is currently considered unlikely that remediation will be required, and therefore SCLs 5-8 have not been considered for further detailed evaluation at this stage.

Engineered Capping

This technology is considered to be prohibitively expensive and may increase potential risks to receptors associated with landfill gas. This technology has therefore not been considered further within this report.

Dense Landscaping

While this approach would seek to reduce infiltration, its effectiveness is likely to be limited and difficult to predict. It is therefore not considered to represent a robust remediation solution and has not been considered further within this report.

Landfill Mining

This technology is considered to be prohibitively expensive and unsustainable. This technology has therefore not been considered further within this report.

Solidification/Stabilisation

This technology is considered to be prohibitively expensive and has therefore not been considered further within this report.

Encapsulation

Considered to be financially and operationally prohibitive and has therefore not been considered further within this report.

Leachate Removal, Treatment and Re-circulation

Taken forward for detailed appraisal and cost benefit analysis.

Permeable Reactive Barriers

PRBs have not been considered further within this report due to the depth of the contaminant plume beneath the site (Chalk groundwater levels are generally >15-20 m bgl). Groundwater levels would further decrease should the Ickenham PWS be turned on due to draw-down. The technical difficulties and potentially prohibitive costs associated with installing PRBs at this depth means that this technology is not considered to be viable for this site and has therefore not been considered further within this report.

Do Nothing

This option is not considered to provide a durable remediation solution, and is considered unlikely to be acceptable to regulatory authorities and other stakeholders. This option has therefore not been considered further within this report.

Chalk Groundwater Remediation

Taken forward for detailed appraisal and cost benefit analysis.

Four potential options have been proposed, including: interception and disposal to sewer; interception, treatment and disposal to sewer; interception, treatment and discharge to watercourse; or interception, treatment and re-injection.

It is considered that, if Ickenham PWS was to be resume pumping, using a network of abstraction wells on the south eastern boundary of the site pumping at low rates it may be possible to achieve hydraulic containment of the contamination within the groundwater.

Should treatment be required, the disposal route of the water would need to be agreed with the Environment Agency.

Phased Increased Abstraction at Ickenham PWS

This option has not previously been considered further as it was not considered likely to be acceptable to regulatory authorities and other stakeholders.

However, this option was discussed with the Environment Agency and Veolia Water during the stakeholder meeting on 03 May 2012, and it was agreed that it should be considered further. This option has therefore been taken forward for detailed appraisal and cost benefit analysis.

Additional Treatment at Ickenham PWS

Taken forward for detailed appraisal and cost benefit analysis.

Monitored Natural Attenuation

Natural attenuation refers to the combination of physical, chemical and biological processes that act, without human intervention, to decrease contaminant concentrations, flux and toxicity, and thereby reduce the risks posed by contamination. These include:

- destructive mechanisms, such as biological degradation (biodegradation) similar to that in a compost heap, and chemical degradation;
- non-destructive mechanisms such as sorption, dispersion and volatilisation that act to reduce the concentration of a substance, but do not reduce its overall mass in the environment.

In the majority of cases, it is the destructive, or degradative, processes that dominate (quoted from Mobilising Nature's Armoury - MNA, Environment Agency, 2004).

Destructive natural attenuation via biological degradation occurs through the bacterial interaction between the groundwater geochemistry and the dissolved contaminant. Bacteria oxidise the dissolved contaminant, in the process consuming electron acceptors (for example dissolved oxygen) present in the groundwater. Different electron acceptors will preferentially react, such that electron acceptors with a high redox potential (e.g. dissolved oxygen) will react preferentially before electron acceptors with a lower redox potential (e.g. sulphate).

Measuring solute concentrations of the electron acceptors (i.e. dissolved oxygen, nitrate, ferric iron (Fe^{3+}) and sulphate, as well as the degradation products (carbon dioxide, nitrogen, ferrous iron (Fe^{2+}), hydrogen sulphide and methane) provides an indication whether destructive attenuation through biological degradation is occurring.

In order to monitor natural attenuation in the Chalk groundwater (and also potentially provide an "early warning system" for Ickenham PWS), it is considered likely that a series of Chalk boreholes would need to be installed along the pathway between the site and Ickenham PWS. Due to the fractured nature of the Chalk, in order to ensure any migrating contamination is intercepted, it is proposed that three wells are installed. Furthermore, it is proposed that MNA is undertaken within the landfill leachate to determine the characteristics of a declining source in the landfill. This data would then be used to update a DQRA for the Ickenham PWS.

MNA has been taken forward for detailed appraisal and cost benefit analysis.

5.2 Summary of Preliminary Appraisal of Feasible Remediation Options

Table 5.1 presents a preliminary assessment of the applicability of the appraised potential remedial options for the CoC (ammonium) and some or all SCLs identified for the site.

Table 5.1 - Applicability of Appraised Remedial Options for Key Landfill Management Aspects

Remedial Technology	Inorganics (i.e. ammonium)	Will Constraints Permit?
Leachate Removal, Treatment and Re-circulation	✓	✓

Chalk Groundwater Interception, Treatment and Disposal or Re-injection	✓	✓
Additional Treatment Facilities at Ickenham	✓	?
Phased Increased abstraction at Ickenham PWS	?	?
MNA	✓	✓

Notes: Soil matrix considerations are not included in the above table.
✓ Treatment technology applicable for contaminants
X Treatment technology not applicable for contaminants
? Feasibility uncertain

5.3 Qualitative Remediation Options Appraisal

The remediation technologies which are considered applicable for the identified CoCs, and identified constraints above have been taken forward to formal remediation options appraisal. Table 5.2 presents a qualitative assessment of each potential shortlisted option in terms of three preliminary assessment criteria:

- operational and technical constraints;
- environmental issues; and
- commercial viability.

The assessment has also considered which SCLs the various identified remediation technologies could potentially address.

Table 5.1 - Qualitative Remediation Options Appraisal

Remediation Technology	Preliminary Assessment Criteria			SCL Addressed	Evaluation
	Operational & Technical	Environmental	Commercial		
Processed-based Solutions					
Leachate removal, treatment and re-circulation (source/pathway based solution)	Feasibility studies would be required. Long-term monitoring of groundwater and maintenance would be required for the lifetime of the landfill (the results of the DQRA (Ref. 1) indicate that the leachate is a declining source with concentrations reducing over time). Plant would require planning permission. Recirculation would reduce volume of water requiring disposal to sewer. Permitting/licensing required for abstraction (and re-injection). Monitoring indicates that leachate is not present in large quantities across the whole site.	Sustainable technology utilising biological and physical treatment processes (sequencing batch reactor (and potentially wetland treatments)). Potential for impact on ecological habitats where treatment plant is situated. Potential concerns (predominantly perception based) from stakeholders, particularly adjacent land users and or local residents.Treated leachate likely to be of acceptable quality. Contamination that has already leached into the underlying Reading Beds and Chalk Aquifers would not be treated. Considered likely to provide a medium to long term improvement in groundwater (and potentially surface water) quality. Likely to result in long term betterment of Chalk Aquifer. Although not a statutory source under Part 2A, would not address contamination already present in Chalk in the short term.	The leachate treatment plant can be constructed with relative ease (i.e. technologies readily available). Spare treatment capacity can be designed for commercial water treatment application (i.e. treat imported leachates from external clients) without significant additional cost. Operational and monitoring costs (for leachate, groundwater and surface water) over the lifetime of system likely to be high. Potential opportunity to generate revenue for gas to grid scheme and treatment of third party leachate. Scheme dependent on planning and on suitable/available land on which to build the plant. Will require planning permission. On-going long-term operation and maintenance costs and monitoring requirements.	1, 2, 3 and 4	Technically feasible option, but does not treat contamination already present in the Reading Beds and Chalk groundwater.

Remediation Technology	Preliminary Assessment Criteria			SCL Addressed	Evaluation
	Operational & Technical	Environmental	Commercial		
Management Solutions					
Chalk groundwater abstraction and either: • discharge to sewer; • treatment and discharge to sewer; • treatment and discharge to water course; or • treatment and reinjection. (pathway based solution)	Long term maintenance and groundwater monitoring would be required. Only protects one PWS, however, may be an appropriate short term management option, in conjunction with other technologies. Feasibility studies would be required, including determining capacities of sewer/surface water course, and pump rates required to achieve hydraulic containment. Permitting/licensing required for abstraction (and re-injection).	Does not result in an improvement in soil, leachate or groundwater quality beneath the site if implemented in isolation. Would enable the Ickenham PWS to be operational again.	Planning permission may be required. May also require the purchase of land, or access to third party land for installation and maintenance (should any abstraction wells be located off-site). A relatively cost effective solution compared to an on-site leachate treatment system. However, only protects one identified receptor. May reduce the permitted abstraction volume at Ickenham PWS.	3 and 4	Technically feasible option, although discharge route would need to be agreed with Environment Agency. Only protects one identified receptor and does not treat the source.
Additional treatment facilities at Ickenham (receptor based solution)	May represent a management solution to enable the operation of the Ickenham PWS if the works can be undertaken to the satisfaction of the regulatory authorities and other stakeholders. Detailed hydrogeological modelling and feasibility study would be required. Long term maintenance and groundwater monitoring would be required.	Does not result in an improvement in soil, leachate or groundwater quality beneath the site if implemented in isolation. Would enable the Ickenham PWS to become operational again. Only protects one identified receptor.	Would require agreement from the water company and the Environment Agency. May not be an acceptable long term solution to the regulatory authorities and other stakeholders. Would provide a short term solution, if used in conjunction with other technologies.	3 and 4	Potentially feasible options to enable the Ickenham PWS to be operational again. Only protects one identified receptor and does not treat the source.
Phased increased abstraction at	May represent a management solution to enable the operation of	Does not result in an improvement in soil, leachate or groundwater	Would require agreement from the water company and the	3 and 4	Potentially feasible options to

Remediation Technology	Preliminary Assessment Criteria			SCL Addressed	Evaluation
	Operational & Technical	Environmental	Commercial		
Ickenham PWS (receptor based solution)	the Ickenham PWS if the works can be undertaken to the satisfaction of the regulatory authorities and other stakeholders. Detailed hydrogeological modelling and feasibility study would be required. Long term maintenance and groundwater monitoring would be required.	quality beneath the site if implemented in isolation. Would enable the Ickenham PWS to become operational again, subject to findings of feasibility study. Only protects one identified receptor.	Environment Agency. May not be acceptable long term solution to the regulatory authorities and other stakeholders, unless a long term reduced abstraction can be agreed. Would provide a short term solution, if used in conjunction with other technologies (e.g. MNA).		enable the Ickenham PWS to be operational again. Only protects one identified receptor and does not treat the source.
MNA	Long-term monitoring of leachate and groundwater would be required for the lifetime of the landfill (the results of the DQRA (Ref. 1) indicate that the leachate is a declining source with concentrations reducing over time).	Does not result in an improvement in soil, leachate or groundwater quality beneath the site if implemented in isolation.	Would provide a cost effective solution if used in conjunction with other technologies (i.e. to be implemented if natural attenuation is not observed). May not be acceptable long term solution to the regulatory authorities and other stakeholders. Would require agreement from the water company and the Environment Agency.	1, 2, 3 and 4	Technically feasible option although likely to be implemented in conjunction with another technology.

5.4 Combined Technologies

It is considered that no one solution will provide sufficient management of the identified SCLs and that the required remediation strategy would need to be a combination of remediation technologies.

Atkins has identified four potential remediation strategies which each provide a different management option for the site:

- leachate removal, treatment and re-circulation and Chalk groundwater abstraction, treatment and disposal or re-injection;
- MNA and phased increased abstraction at the Ickenham PWS;
- leachate removal, treatment and re-circulation and MNA; and
- additional treatment facilities at Ickenham PWS and MNA.

These four options have been considered further through cost-benefit analysis (Section 6).

6. Cost-benefit Analysis Methodology

6.1 Introduction and Methodology

The choice of remedial options has, in the past, largely been based on the capability of a particular remedial option to meet specified remedial objectives. Remedial costs have often strongly influenced choice of development solution (i.e. a high return has been needed from the option chosen in order to make remediation 'affordable'). However, in most cases explicit details of costs have usually remained confidential to the owner/developer, although these may have been discussed in general terms with the regulators. Therefore many 'cost-effective' solutions in the past have been inconsistent and have lacked the transparency needed to ensure that the most appropriate measures have been taken.

For these reasons, the Environment Agency developed a methodology (Ref. 9) that is intended to improve consistency and confidence between parties by giving explicit reasons as to why a particular decision has been taken. The method provides a framework by which the costs and benefits of two or more remedial options for a given site can be assessed, thereby enabling the relative merits of alternative remedial options to be compared.

Cost-benefit analysis in this form accords with the UK's risk-based approach to the management of contaminated sites, which requires remedial action to be taken where:

- the contamination poses unacceptable actual or potential risks to health or the environment; and
- there are appropriate and cost-effective means available to do so, taking into account actual or intended use the site.

The framework has been designed so that the user can utilise the most appropriate level of assessment for a particular site. The level of assessment builds in sophistication from 'Step I' to 'Step V' by leading the assessor from identification of the impacts to determination of their relative significance. The five steps are shown in Table 6.1.

There are various points throughout the assessment when, if it is realised that the preferred remedial option can be easily, clearly and defensibly identified in terms of costs and benefits, the assessment can stop. This was the case with New Years Green Landfill site, where the assessment was undertaken up to Step III.

Table 6.1 - Cost-benefit Analysis Stages

Step		Purpose	Level of sophistication	Steps performed for New Years Green
I	**Screening Stage**	To examine the characteristics of the contamination problem and associated solutions to determine what might be appropriate for a particular site, and hence further assessment requirements.	lowest	✓
II	**Qualitative Analysis**	The simplest of the three appraisals, it involves the observation of potential impacts without the need to estimate their significance.		✓

Step		Purpose	Level of sophistication	Steps performed for New Years Green
III	**Combined Cost-effectiveness Analysis and Multi-criteria Analysis**	Allows scores to be assigned to impacts according to their relative significance (defined by the user and related to the relative magnitude of impacts occurring on a site specific basis). The remedial option with the least significant impacts and the most significant benefits (compared to costs) can then be identified.	⇓	✓
IV	**Cost-benefit Analysis**	Used when an impact can be readily valued in monetary terms (e.g. fish kills at a fish farm). It is mainly limited to market-based effects, but some guidance is given on the valuation of other impacts should the assessor consider this to be appropriate.		×
V	**Sensitivity Analysis**	Where the influence of uncertainty and the robustness of the assumptions underlying the assessment are tested.	highest	×

The full methodology is presented in the Environment Agency document entitled "Cost-Benefit Analysis for Remediation of Land Contamination" (Ref. 9). It is a lengthy and complex document incorporating detailed direction on the identification and derivation of impacts, scores and weighting factors. Atkins has followed the defined methodology and the impacts, scores and weights used within the assessment, together with explanatory comments, are explicitly recorded using the pro forma tables that are included in the Environment Agency document. The cost-benefit analysis data are presented in Appendix A.

It should be noted that as Stage V (sensitivity analysis) has not been undertaken, all uncertainty scores within the tables have been assigned a zero value.

6.2 Results

The results of the cost-benefit analysis are presented in Table 6.2.

Table 6.2 – Summary of Cost-Benefit Analysis

Option	Total score	Cost (£)	Cost-effectiveness (score / cost)	Rank
1: Leachate treatment; Chalk treatment	18.2	11.4M	1.59	**3**
2: MNA; and phased increased abstraction at Ickenham PWS	54.0	390K	139	**1**
3: Leachate treatment; MNA	51.4	7.6M	6.76	**2**
4: Treatment at PWS; MNA	-1.6	10.0M	-0.16	**4**

As shown in Table 6.2, Option 2 (MNA combined with phased increased abstraction at the Ickenham PWS) is considered to be the most appropriate remedial option. The cost-effectiveness score for this option is much higher than that calculated for the other three options evaluated, indicating that it offers a cost-effective and reasonable approach to the on-going management and remediation of the site.

7. Conclusions and Recommendations

7.1 Conclusions

The purpose of this remediation options appraisal is to conduct a comparative evaluation of a number of technologies that were under consideration, including the options previously considered within Aspinwall's and Atkins' ROAs.

The appraisal identified four potentially viable remediation strategies that would be potentially effective in reducing and/or controlling the SCLs identified at the site, with respect to controlled waters receptors. This options were taken forward to cost benefit analysis.

The cost benefit analysis identified that MNA combined with phased increased abstraction at the Ickenham PWS is the most appropriate remedial option. The cost-effectiveness score for this option is much higher than that calculated for the other three options evaluated, indicating that it offers a cost-effective and reasonable approach to the on-going management and remediation of the site.

7.2 Recommendations

The results of the cost benefit analysis conclude that MNA combined with phased increased abstraction at the Ickenham PWS is the most cost effective remedial solution.

This potential option was discussed during the stakeholder meeting on 03 May 2012. An outline of the recommendations is provided below:

- drilling and installation of three deep Chalk boreholes (potentially multi-level in order to target specific fracture horizons within the Chalk) located between the site and Ickenham PWS;
- geophysical logging of the wells in order to identify potential fracture horizons within the Chalk establish appropriate well installation specifications;
- groundwater sampling and monitoring of MNA parameters across the monitoring well network;
- step-pump test at Ickenham PWS to establish the maximum abstraction rate available where no impact is observed in the groundwater in Chalk wells installed to the south east of the site. It is understood that this will be undertaken and funded by Veolia Water); and
- evaluation of the declining waste source to input into an updated DQRA for Ickenham PWS. Updated modelling would also include transient hydraulic gradients and groundwater velocities measured during the step-pump test.

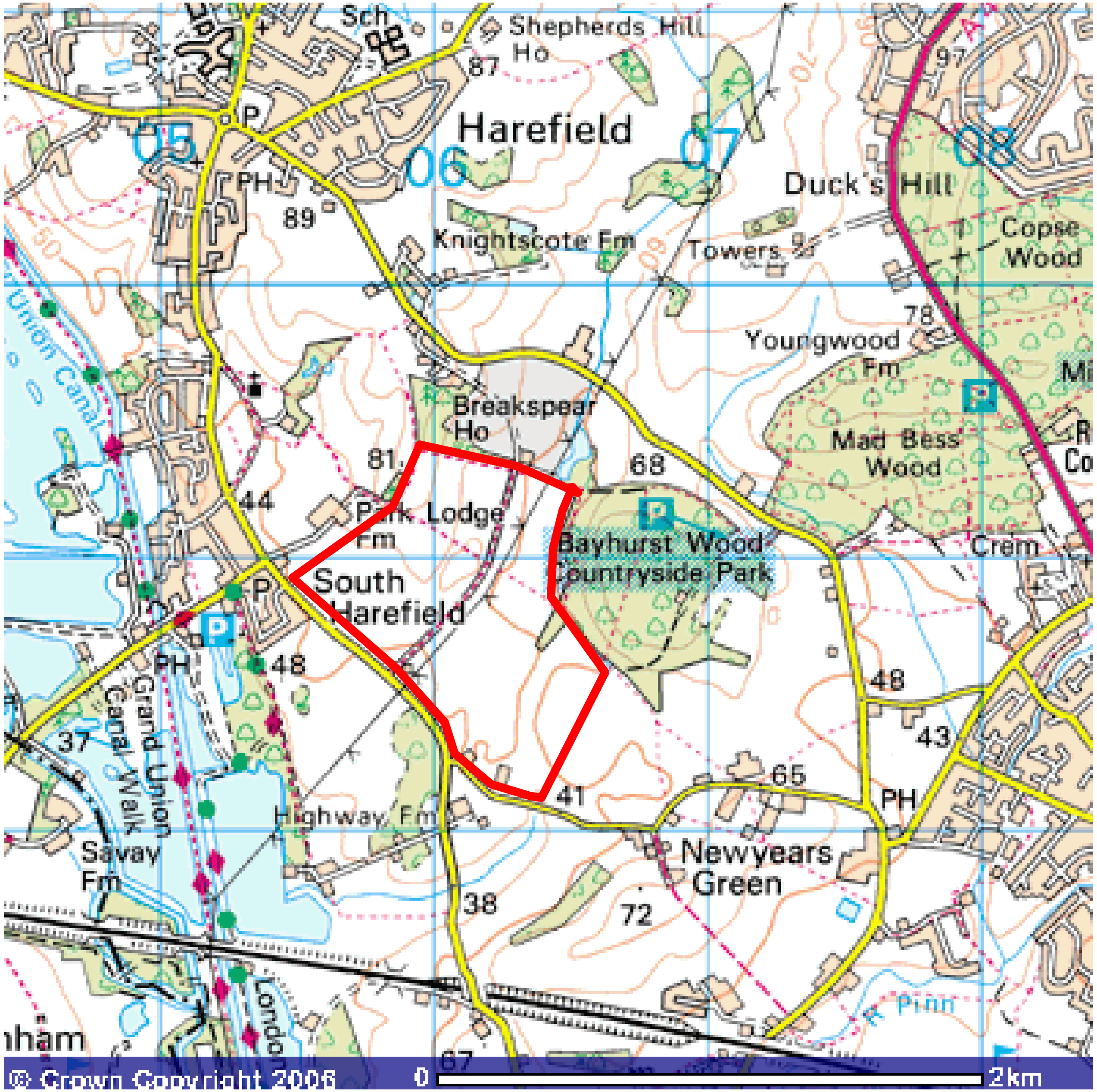
It is proposed that monitoring and sampling of the Chalk wells is undertaken on a monthly basis for the first year, also targeted to monitor impacts on the groundwater during the step-pump test. Quarterly monitoring is considered appropriate thereafter, which may be reduced after an agreed time period, should natural attenuation be proven to be active.

ATKINS

8. References

1. Atkins Limited, May 2012. Detailed Quantitative Risk Assessment for Controlled Waters and Ground Gas
2. Symonds Travers Morgan, November 1995. Investigation of Ammonia Pollution at Ickenham Public Supply Source, Hillingdon
3. Aspinwall & Company, March 1999. Investigation of Water Pollution from New Years Green Landfill Site, Ickenham
4. Enviros Consulting Ltd, May 2004. Critical Review of New Years Green Landfill
5. Atkins Limited, December 2006. B.20(a) and B.20(b) Part IIA Detailed Inspection, New Years Green Landfill
6. Atkins Limited, February 2011. Outline Remediation Options Appraisal, New Years Green Landfill, Hillingdon
7. Environment Agency, 2004. Model Procedures for the Management of Contaminated Land, CLR 11
8. Defra, 2012. Environmental protection Act 1990: Part 2A, Contaminated Land Statutory Guidance.
9. Environment Agency, 1999. R&D Technical Report P316. Cost-Benefit Analysis for Remediation of Land Contamination

FIGURES



ATKINS

ATKINS CONSULTANTS Ltd.
WOODCOTE GROVE
ASHLEY ROAD
EPSOM
KT18 5BW
Tel: 01372 726140
Fax: 01372 740055

LEGEND

Approximate Site Boundary

CLIENT

London Borough of Hillingdon

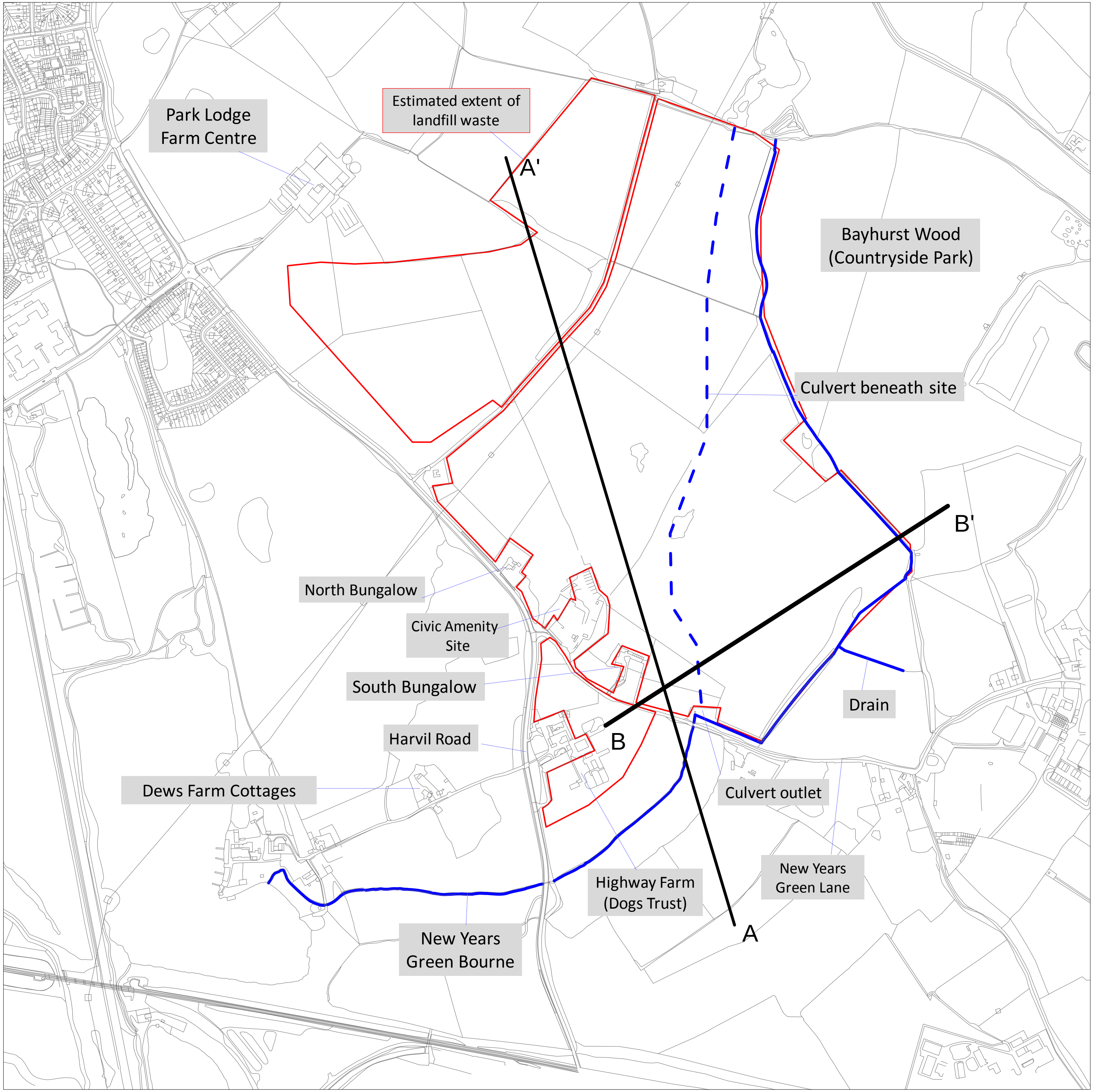
PROJECT

New Years Green Landfill
Updated Remediation Options Appraisal

TITLE

Site Location Plan

Figure 1



ATKINS
ATKINS CONSULTANTS Ltd.
WOODCOTE GROVE
ASHLEY ROAD
EPSOM
KT18 5BW
Tel: 01372 726140
Fax: 01372 740055

LEGEND

- Estimated areas of waste disposal
- Approximate location of stream
- Approximate location of culvert
- Cross section delineation

CLIENT

London Borough of Hillingdon

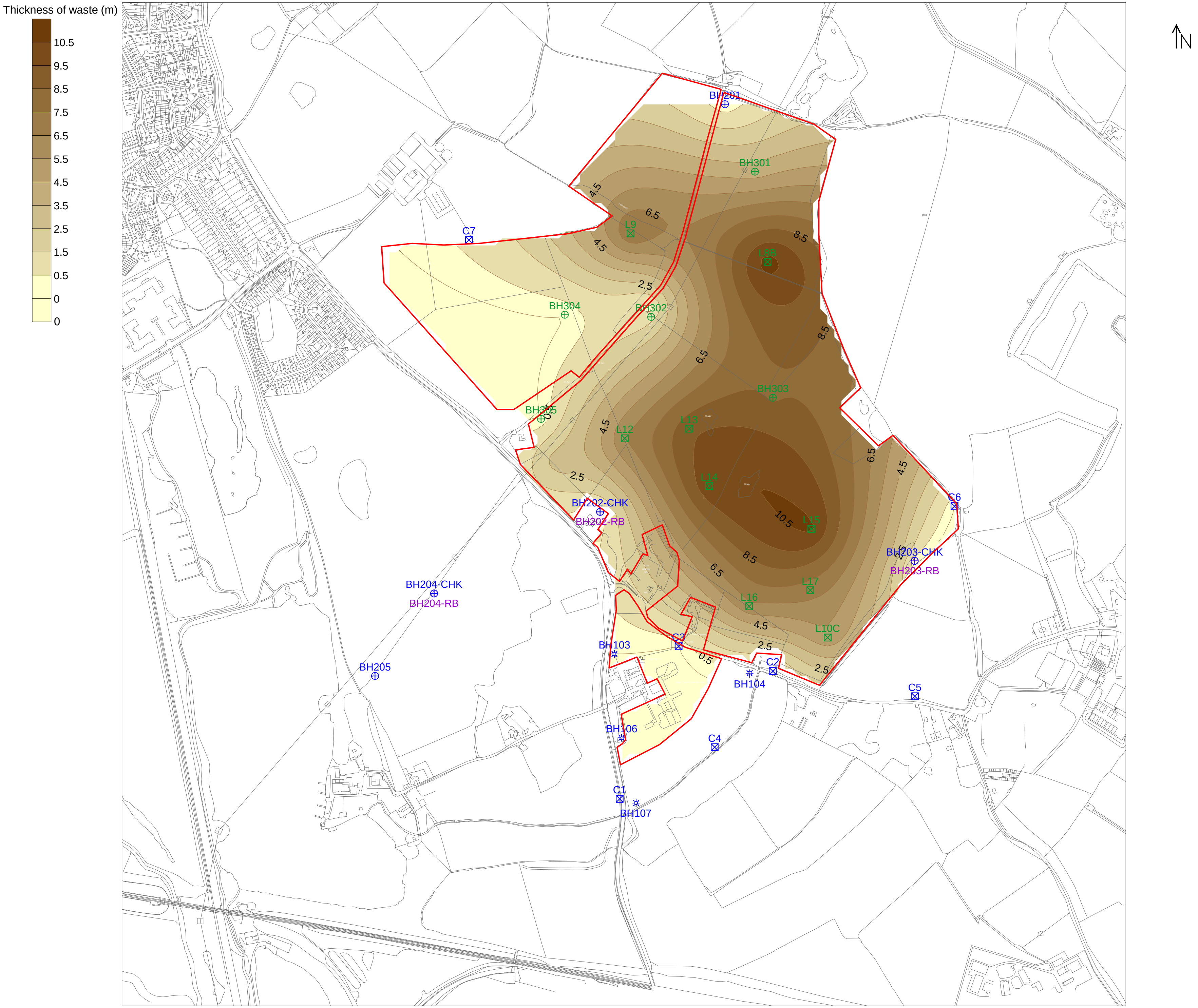
PROJECT

New Years Green Landfill Remediation Options Appraisal

TITLE

Site Layout Plan

Figure 2



ATKINS
ATKINS CONSULTANTS Ltd.
WOODCOTE GROVE
ASHLEY ROAD
EPSOM
KT18 5BW
Tel: 01372 726140
Fax: 01372 740055

LEGEND

- Chalk borehole - Aspinwall & Co. 1998
- Chalk borehole - Richard Jackson plc 2003
- Chalk borehole - Atkins Limited 2012
- Reading Beds borehole - Atkins Limited 2012
- Leachate borehole - Aspinwall & Co. 1998
- Leachate borehole - Atkins Limited 2012
- Estimated areas of waste disposal

CLIENT

London Borough of Hillingdon

PROJECT

New Years Green Landfill
Updated Remediation Options Appraisal

TITLE

Thickness of Waste in
New Years Green Landfill

Figure 3

ATKINS

ATKINS CONSULTANTS Ltd.
WOODCOTE GROVE
ASHLEY ROAD
EPSOM
KT18 5BW
Tel: 01372 726140
Fax: 01372 740055

LEGEND

- Chalk borehole - Aspinwall & Co. 1998
- Chalk borehole - Richard Jackson plc 2003
- Chalk borehole - Atkins Limited 2012
- Reading Beds borehole - Atkins Limited 2012
- Leachate borehole - Aspinwall & Co. 1998
- Leachate borehole - Atkins Limited 2012
- Estimated areas of waste disposal

CLIENT

London Borough of Hillingdon

PROJECT

New Years Green Landfill
Updated Remediation Options Appraisal

TITLE

Base of Waste in New Years Green Landfill (m AOD)

Figure 4

Appendix 1

New Years Green Landfill
Cost Benefit Analysis

This Cost Benefit Analysis has been undertaken by Atkins Limited for the London Borough of Hilligdon. The principal objective was to ascertain the most cost-effective remedial option for New Years Green Landfill site in Harefield. This was carried out in accordance with the Environment Agency methodology presented in Technical Report P316: Cost Benefit Analysis for the Remediation of Land Contamination". Details of the methodology as applied to the New Years Green Landfill site are provided in the Atkins report entitled "Updated Remedial Options Appraisal" May 2012 reference 5109736/GTG.20110055/R003rev0. This spreadsheet should be considered alongside that report.

WS Atkins, Woodcote Grove, Ashley Road, Epsom, Surrey KT18 5BW. Telephone 01372 726140.
Project contacts: Daniel Mathews, Lucy Hay

Spreadsheet modification

Any changes will affect cells in other spreadsheets. Text/numbers may not be changed (the cells are locked).

KEY

Black	Denotes existed as part of original document
Blue	Denotes entered by external user
Red	Denotes the result of a formula within an existing worksheet
Green	Denotes a number linked to another worksheet
Plum	Denotes the result of a formula linked to another worksheet

Worksheet contents	
Worksheet	Contents
Introduction	Summary of project and key to enteries in worksheets.
Appraisal Table1	Checklist of Data Available
Appraisal Table2	Matrix for scoring Site Criteria
Appraisal Table3	Qualitative Appraisal
Appraisal Table4	Appraisal Routing to Step III and Step IV
Appraisal Table5	Human Health and Safety
Appraisal Table6	Environment
Appraisal Table7	Land Use
Appraisal Table8	Third Party or Stakeholder Concern
Appraisal Table9a	Applying Weights to Sub-Categories (During Remediation)
Appraisal Table9b	Applying Weights to Sub-Categories (After Remediation)
Appraisal Table10	Applying Weights to Impacts Occuring During and After Remediation
Appraisal Table11	Option Performance Scores and Weights
Appraisal Table12	Compare and Rank Options
Appraisal Table13	West Quay Road - Management and Operational Costs

Table 1: Checklist of Data Available

Data Required	Available?	Uncertainty	Details
Proposed end-use of site	✓		Fixed or variable (to remain as open farmland, used for grazing is possible)
Approaches Proposed (yes or no)			Clean-up
			Barriers
	✓		Natural Attenuation
	✓		Monitoring/surveillance only
			Other (please state):
	✓		Groundwater pump and treat
	✓		Reduced abstraction
	✓		Leachate pump and treat
	✓		Treatment at abstraction
Number of techniques proposed (details where available of types)	✓		Remedial Option 1: Combination of technologies: Leachate removal, treatment and re-circulation; and Chalk groundwater interception, treatment and discharge/re-injection
	✓		Remedial Option 2: Combination of technologies: Chalk groundwater monitored natural attenuation (MNA); and reduced abstraction at Ickenham PWS
	✓		Remedial Option 3: Combination of technologies: Leachate removal, treatment and re-circulation; and MNA
	✓		Remedial Option 4: Combination of technologies: Additional treatment facilities at Ickenham PWS; and MNA
Time available (length)	1-2 years		Time critical for Veolia Water, however, all options will take a relatively long time to complete before the PWS can be bought back on-line
Costs (and what this includes)	✓		Estimated - to be finalised on agreement with LBH
Size of site (area contaminated – all, some, pockets, etc.)	✓		~80 ha landfill site.
Does the remedial option meet the objectives (yes, no, maybe, uncertain)?	✓		Remedial Option 1: Yes - Addresses RPLs associated with regional groundwater quality (short to medium term) and Ickenham PWS (short to medium term)
	✓	✓	Remedial Option 2: Yes - Addresses RPLs associated with regional groundwater quality (long term) and Ickenham PWS (short to medium term)
	✓	✓	Remedial Option 3: Yes - Addresses RPLs associated with regional groundwater quality (short to medium term) and Ickenham PWS (medium to long term)
	✓	✓	Remedial Option 3: Yes - Does not address RPLs associated with regional groundwater quality, addresses RPLs associated with Ickenham PWS (short to medium term)
Other			
Do you have the results of the desk study?			Yes
Do you have the results of the site investigation?			Yes
Do you have the results of the risk assessment?			Yes

Table 2: Matrix for Scoring Site Criteria						
Criteria	**Ranks**					
	Description	✓	**Description**	✓	**Description**	✓
Current and Future Site Use	FIXED	✓	FIXED BUT		VARIABLE	
Approaches	ONE		TWO	✓	TWO PLUS	
Remedial Options	≤ 2		2		≥ 2	✓
Scale: Time	CRITICAL		MAY BE SIGNIFICANT?	✓	NOT SIGNIFICANT	
Scale: Costs	<£100K		<£500K		>£500K	✓
Will the Objectives be met?	YES; YES BUT		YES BUT; MAYBE; NO BUT	✓	MAYBE; NO BUT; NO	
Comments: There are two approaches (treatment at source and along the pathway or treatment at the receptor), and four options. Time is critical to allow Ickenham PWS to resume abstraction, however, all the remedial options will take a relatively long time.						

Table 3: Qualitative Appraisal										
Category	**Before remediation**	**During remediation**				**After remediation**				**Comments:**
Remedial Option:		1	2	3	4	1	2	3	4	
Human Health and Safety										
Significant risks to site users?	N	N	N	N	N	N	N	N	N	None of the remedial options are considered to present significant additional risks to site users (farmer/dog walkers etc)
Significant risks to public?	N	N	N	N	N	N	N	N	N	None of the remedial options are considered to present significant additional risks to public
Significant numbers of site users exposed?	N	N	N	N	N	N	N	N	N	Not considered to be significant.
Significant numbers of public exposed?	N	N	N	N	N	N	N	N	N	Not considered to be significant.
Environment										
Impacts on quality of surface water?	N	N?	N	N	N	N	N	N	N	DQRA indicates that the lanfill site is not the source of impacts on the New Years Green Bourne. Should Chalk groundwater treatment be undertaken (Option 1) with water discharged to surface water, during remediation there is the possibility that local surface water quaility may be impacted. However, the significance and likelylihood are both considered to be low as any treated water would be tested prior to discharge.
Impacts on quantity of surface water?	N	N?	N	N	N	N	N	N	N	Should Chalk groundwater treatment be undertaken (Option 1) with water discharged to surface water, during remediation the quantity of surface water would increase. However, under this remedial option, treated water may also be discharge to sewer, or re-injected, and all discharge
Impacts on quality of groundwater?	Y	Y	Y	Y	Y	N	Y?	N	Y?	Disturbance to the groundwater is expected as a result of all remedial options. As Options 2 and 4 do not treat the source, there is the possibility of long term impact on groundwater quality under Options 2 and 4.
Impacts on quantity of ground water?	Y	Y?	Y	N	N	N	Y?	N	N	Under Option 1, Chalk groundwater would be lost to the system unless re-injected, under Option 2, the Ickenham PWS would abstract at a lower rate meaning a reduction in useable groundwater.
Use of surface water or groundwater for industry, agriculture, or drinking water?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Ickenham PWS remains an important groundwater resource before, during and after remediation.
Chemical or physical properties of soil and groundwater likely to be changed?	Y					Y	Y	Y	Y	Post remediation, it is assumed that groundwater quality would have been improved.
Impacts on local air quality?	N	N	N	N	N	N	N	N	N	Not considered to be significant.
Plant and animal numbers impacted?	N	N	N	N	N	N	N	N	N	Not considered to be significant.
Designated sites impacted?	N	N	N	N	N	N	N	N	N	Not considered to be significant.
Land Use										
Site land value reduced?	Y	Y	Y	Y	Y	N?	Y?	N?	Y?	Site currently determined as 'Contaminated Land' and designated as a Special Site. Options 2 and 4 do not treat the source, and there may therefore be ongoing impacts on the land value, particularly in the short to medium term.
Surrounding land value reduced?	N	N	N	N	N	N	N	N	N	Not considered to be significant.
Site land use restricted?	Y	Y	Y	Y	Y	N	Y?	N	Y?	Site currently determined as 'Contaminated Land' and designated as a Special Site. Options 2 and 4 do not treat the source, and there may therefore be ongoing impacts on the land use (grazing of the land currently not possible following determination).
Surrounding land use restricted?	N	N	N	N	N	N	N	N	N	Not considered to be significant.
Third Party or Stakeholder Concern										
Significant level of public interest?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Remediation of the site would potentially allow Ickenham PWS (a strategic PWS) to operate again.
Lack of available information?	N	N	N	N	N	N	N	N	N	SI and DQRA to support ROA assessment.
Costs at net present value						***£11.4M***	***£390K***	***£7.6M***	***~£10M?***	***30 year monitoring period***

Table 4: Appraisal Routing to Step III and Step IV			
	Valuation recommended	**Scoring recommended**	**Impacts identified (from qualitative appraisal)**
Human health and safety			
Environment: water resources		✓	✓
Environment: water quality	✓	✓	✓
Environment: soil			
Environment: air quality			
Environment: habitat and ecology			
Land Use: land values		✓	✓
Land Use: land use		✓	✓
Third party of stakeholder concern	✓	✓	✓
	Cost-benefit analysis (Step IV/Appendix I)	Cost-effectiveness analysis (Step III)	
Comments:			

Table 5: Human Health and Safety					
IMPACT					
Criteria	**Option**	**Score**		**Uncertainty (±)**	
		During	**After**	**During**	**After**
Risks to site users	1: Leachate treatment; Chalk treatment	0	0	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	0	0	0	0
	3: Leachate treatment; MNA	0	0	0	0
	4: Treatment at PWS; MNA	0	0	0	0
Comments:	*Not considered to be significant and therefore not scored*				
Risks to public	1: Leachate treatment; Chalk treatment	0	0	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	0	0	0	0
	3: Leachate treatment; MNA	0	0	0	0
	4: Treatment at PWS; MNA	0	0	0	0
Comments:	*Not considered to be significant and therefore not scored*				
TOTAL	1: Leachate treatment; Chalk treatment	0	0	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	0	0	0	0
	3: Leachate treatment; MNA	0	0	0	0
	4: Treatment at PWS; MNA	0	0	0	0
Comments:	*Not considered to be significant and therefore not scored*				

Table 6: Environment					
IMPACT					
Criteria	**Option**	**Score**		**Uncertainty (±)**	
		During	**After**	**During**	**After**
Surface water quality	1: Leachate treatment; Chalk treatment	0	0	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	0	0	0	0
	3: Leachate treatment; MNA	0	0	0	0
	4: Treatment at PWS; MNA	0	0	0	0
Comments: Not considered to be significant and therefore not scored					
Surface water quantity	1: Leachate treatment; Chalk treatment	0	0	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	0	0	0	0
	3: Leachate treatment; MNA	0	0	0	0
	4: Treatment at PWS; MNA	0	0	0	0
Comments: Not considered to be significant and therefore not scored					
Groundwater quality	1: Leachate treatment; Chalk treatment	-100	100	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	-80	90	0	0
	3: Leachate treatment; MNA	-50	90	0	0
	4: Treatment at PWS; MNA	-50	90	0	0
Comments: Additional disturbance that may be caused by longer remediation programmes justifies the lowest 'during' scores being given to Options 1 and 2. Improved quality is expected for Options 1 and 3 due to the treatment of the source. Option 1 is assumed to acheive a 100% improvement; Option 2 is assumed to acheive 80% improvement of the groundwater, but 100% of the water abstracted from the PWS therefore an overall 90% improvement has been assigned; Option 3 to acheive 90% improvement (as does not treat the contamination already in the Reading Beds and Chalk groundwater), and Option 4 is assumed to acheive 80% improvement of the groundwater, but 100% of the water abstracted from the PWS therefore an overall 90% improvement has been assigned.					
Groundwater quantity	1: Leachate treatment; Chalk treatment	-100	100	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	-80	50	0	0
	3: Leachate treatment; MNA	-50	100	0	0
	4: Treatment at PWS; MNA	0	100	0	0
Comments: *During remediation: Groundwater would be abstracted under Option 1 (and possibly lost from the system), therefore the highest score has been assigned to this Option; groundwater abstraction would be reduced at Ickenham PWS under Option 2, however increased via a series of step-pump tests and therefore a score of -80 has been assigned to this Option; contaminated groundwater already in the Reading Beds and Chalk would not be treated under Option 3 and therefore it is assumned that a proportion of groundwater would not be suitable for PWS; under Option 4, the PWS would be able to begin operation straight away and therefore a score of 0 has been assigned to this option.* *Post remediation: Following remediation it is assumed abstraction from Ickenham PWS could be undertaken at its full capacity under Options 1, 3 and 4. Under Option 2, step-pumping tests would be undertaken during remediation, with the final end-point potentially being at reduced abstraction (currently unknown, but assumed to be 50%). Therefore all Optoins have been assigned the maximum score of 100, except Option 2, which has been scored at 50%.*					
Air	1: Leachate treatment; Chalk treatment	0	0	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	0	0	0	0
	3: Leachate treatment; MNA	0	0	0	0
	4: Treatment at PWS; MNA	0	0	0	0
Comments: Not considered to be significant and therefore not scored					
Habitat and ecology	1: Leachate treatment; Chalk treatment	0	0	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	0	0	0	0
	3: Leachate treatment; MNA	0	0	0	0
	4: Treatment at PWS; MNA	0	0	0	0
Comments: Not considered to be significant and therefore not scored					
TOTALS	1: Leachate treatment; Chalk treatment	-200	200	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	-160	140	0	0
	3: Leachate treatment; MNA	-100	190	0	0
	4: Treatment at PWS; MNA	-50	190	0	0
Comments:					

Table 7: Land Use					
IMPACT					
Criteria	**Option**	**Score**		**Uncertainty (±)**	
		During	**After**	**During**	**After**
Site use	1: Leachate treatment; Chalk treatment	-70	100	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	-100	70	0	0
	3: Leachate treatment; MNA	-80	90	0	0
	4: Treatment at PWS; MNA	-90	80	0	0
Comments: The site has been determined as 'Contaminated Land', which has affected the potential for the land to be grazed by cattle. It is uncertain at what point the determination may be removed, however, for the purposes of this CBA the assumtion has been made that this would be once the landfill no longer impacts the underlying groundwater. The time period is assumed to be shortest of Option 1, then Option 3, then Option 4, then Option2. Conversely the 'after' score are based on the greatest level of remediation should reduce future impacts/constraints on users.					
Surrounding land use	1: Leachate treatment; Chalk treatment	0	0	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	0	0	0	0
	3: Leachate treatment; MNA	0	0	0	0
	4: Treatment at PWS; MNA	0	0	0	0
Comments: Not considered to be significant and therefore not scored					
TOTALS	1: Leachate treatment; Chalk treatment	-70	100	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	-100	70	0	0
	3: Leachate treatment; MNA	-80	90	0	0
	4: Treatment at PWS; MNA	-90	80	0	0
Comments:					

Table 8: Third Party or Stakeholder Concern					
IMPACT					
Criteria	**Option**	**Score**		**Uncertainty (±)**	
		During	**After**	**During**	**After**
Third party or stakeholder confidence	1: Leachate treatment; Chalk treatment	-80	60	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	-40	100	0	0
	3: Leachate treatment; MNA	-60	80	0	0
	4: Treatment at PWS; MNA	-100	40	0	0
Comments: Following a stakeholder meeting, Option 2 is considered by the stakeholders to be the most favourable option, followed by Option 3, 1 and finally 4.					
Third party or stakeholder acceptability	1: Leachate treatment; Chalk treatment	-80	60	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	-40	100	0	0
	3: Leachate treatment; MNA	-60	80	0	0
	4: Treatment at PWS; MNA	-100	40	0	0
Comments: Following a stakeholder meeting, Option 2 is considered by the stakeholders to be the most favourable option, followed by Option 3, 1 and finally 4.					
TOTALS	1: Leachate treatment; Chalk treatment	-160	120	0	0
	2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	-80	200	0	0
	3: Leachate treatment; MNA	-120	160	0	0
	4: Treatment at PWS; MNA	-200	80	0	0
Comments:					

Table 9: Applying Weights to Sub-Categories				
IMPACT				
Criteria	**Option**	**Score**	**Weight**	**Revised Score**
During remediation				
Human health and safety: Site users	1	0		0
	2	0		0
	3	0		0
	4	0		0
Public	1	0		0
	2	0		0
	3	0		0
	4	0		0
TOTAL	1	0		0
	2	0		0
	3	0		0
	4	0		0
Environment: Surface water quality	1	0		0
	2	0		0
	3	0		0
	4	0		0
Surface water quantity	1	0		0
	2	0		0
	3	0		0
	4	0		0
Groundwater quality	1	-100	1	-100
	2	-80		-80
	3	-50		-50
	4	-50		-50
Groundwater quantity	1	-100	0.8	-80
	2	-80		-64
	3	-50		-40
	4	0		0
Air	1	0		0
	2	0		0
	3	0		0
	4	0		0
Habitat and Ecology	1	0		0
	2	0		0
	3	0		0
	4	0		0
TOTAL	1	-200		-180
	2	-160		-144
	3	-100		-90
	4	-50		-50
Land Use: Site use	1	-70	1	-70
	2	-100		-100
	3	-80		-80
	4	-90		-90
Surrounding Land Use	1	0		0
	2	0		0
	3	0		0
	4	0		0
TOTAL	1	-70		-70
	2	-100		-100
	3	-80		-80
	4	-90		-90
Third party or stakeholder concern: Confidence	1	-80	0.8	-64
	2	-40		-32
	3	-60		-48
	4	-100		-80
Acceptability	1	-80	1	-80
	2	-40		-40
	3	-60		-60
	4	-100		-100
TOTAL	1	-160		-144
	2	-80		-72
	3	-120		-108
	4	-200		-180

Table 9: Applying Weights to Sub-Categories				
IMPACT				
Criteria	**Option**	**Score**	**Weight**	**Revised Score**
After remediation				
Human health and safety: Site users	1	0		0
	2	0		0
	3	0		0
	4	0		0
Public	1	0		0
	2	0		0
	3	0		0
	4	0		0
TOTAL	1	0		0
	2	0		0
	3	0		0
	4	0		0
Environment: Surface water quality	1	0		0
	2	0		0
	3	0		0
	4	0		0
Surface water quantity	1	0		0
	2	0		0
	3	0		0
	4	0		0
Groundwater quality	1	100	1	100
	2	90		90
	3	90		90
	4	90		90
Groundwater quantity	1	100	0.8	80
	2	50		40
	3	100		80
	4	100		80
Air	1	0		0
	2	0		0
	3	0		0
	4	0		0
Habitat and Ecology	1	0		0
	2	0		0
	3	0		0
	4	0		0
TOTAL	1	200		180
	2	140		130
	3	190		170
	4	190		170
Land Use: Site use	1	100	1	100
	2	70		70
	3	90		90
	4	80		80
Surrounding Land Use	1	0		0
	2	0		0
	3	0		0
	4	0		0
TOTAL	1	100		100
	2	70		70
	3	90		90
	4	80		80
Third party or stakeholder concern: Confidence	1	60	0.8	48
	2	100		80
	3	80		64
	4	40		32
Acceptability	1	60	1	60
	2	100		100
	3	80		80
	4	40		40
TOTAL	1	120		108
	2	200		180
	3	160		144
	4	80		72

Table 10: Applying Weights to Impacts Occurring *During* and *After* Remediation				
	Option 1	**Option 2**	**Option 3**	**Option 4**
DURING REMEDIATION: Human Health & Safety				
Score applied (from Step III)	0	0	0	0
Weight	0	0	0	0
Revised score	0	0	0	0
AFTER REMEDIATION: Human Health & Safety				
Score applied (from Step III)	0	0	0	0
Weight	0	0	0	0
Revised score	0	0	0	0
DURING REMEDIATION: Environment				
Score applied (from Step III)	-180	-144	-90	-50
Weight	0.8	0.8	0.8	0.8
Revised score	-144	-115.2	-72	-40
AFTER REMEDIATION: Environment				
Score applied (from Step III)	180	130	170	170
Weight	1	1	1	1
Revised score	180	130	170	170
DURING REMEDIATION: Land Use				
Score applied (from Step III)	-70	-100	-80	-80
Weight	0.8	0.8	0.8	0.8
Revised score	-56	-80	-64	-64
AFTER REMEDIATION: Land Use				
Score applied (from Step III)	100	70	90	90
Weight	1	1	1	1
Revised score	100	70	90	90
DURING REMEDIATION: Third Party or Stockholder Concern				
Score applied (from Step III)	-144	-72	-108	-180
Weight	0.8	0.8	0.8	0.8
Revised score	-115.2	-57.6	-86.4	-144
AFTER REMEDIATION: Third Party or Stockholder Concern				
Score applied (from Step III)	108	180	144	72
Weight	1	1	1	1
Revised score	108	180	144	72
Comments: Aim of remediation is to bring Ickenham PWS back on-line, and general betterment of the groundwater; all impacts are therefore assumed to be more important post-remediation that during remediation.				

Table 11: Option Performance Scores and Weights				
OPTION : 1				
	Human Health and Safety	**Environment**	**Land Use**	**Third Party or Stakeholder Concern**
During remediation (D)	0	-144	-56	-115.2
After remediation (A)	0	180	100	108
Total impact category score (A+D)	0	36	44	-7.2
Normalise to 100	÷2	÷6	÷2	÷2
Normalised Impact Category Score (NICS)	0	6.0	22	-3.6
Weight	0	1	0.7	0.9
SCORE (NICS x weights)	0	6.0	15.4	-3.24
Comments *The most important sub-category is considered to be the environment (betterment of the groundwater quality and increase in groundwater quantity that can be abstracted from Ickenham PWS). Stakeholder views were considered to be the next most important factor, with returning the site use to grazing as the least important.*				

Table 11: Option Performance Scores and Weights				
OPTION : 2				
	Human Health and Safety	**Environment**	**Land Use**	**Third Party or Stakeholder Concern**
During remediation (D)	0	-115.2	-80	-57.6
After remediation (A)	0	130	70	180
Total impact category score (A+D)	0	14.8	-10	122.4
Normalise to 100	÷2	÷6	÷2	÷2
Normalised Impact Category Score (NICS)	0	2.466666667	-5	61.2
Weight	0	1	0.7	0.9
SCORE (NICS x weights)	0	2.466666667	-3.5	55.08
Comments *The most important sub-category is considered to be the environment (betterment of the groundwater quality and increase in groundwater quantity that can be abstracted from Ickenham PWS). Stakeholder views were considered to be the next most important factor, with returning the site use to grazing as the least important.*				

Table 11: Option Performance Scores and Weights				
OPTION : 3				
	Human Health and Safety	**Environment**	**Land Use**	**Third Party or Stakeholder Concern**
During remediation (D)	0	-72	-64	-86.4
After remediation (A)	0	170	90	144
Total impact category score (A+D)	0	98	26	57.6
Normalise to 100	÷2	÷6	÷2	÷2
Normalised Impact Category Score (NICS)	0	16.33333333	13	28.8
Weight	0	1	0.7	0.9
SCORE (NICS x weights)	0	16.33333333	9.1	25.92

Comments *The most important sub-category is considered to be the environment (betterment of the groundwater quality and increase in groundwater quantity that can be abstracted from Ickenham PWS). Stakeholder views were considered to be the next most important factor, with returning the site use to grazing as the least important.*

Table 11: Option Performance Scores and Weights				
OPTION : 4				
	Human Health and Safety	**Environment**	**Land Use**	**Third Party or Stakeholder Concern**
During remediation (D)	0	-40	-64	-144
After remediation (A)	0	170	90	72
Total impact category score (A+D)	0	130	26	-72
Normalise to 100	÷2	÷6	÷2	÷2
Normalised Impact Category Score (NICS)	0	21.7	13	-36
Weight	0	1	0.7	0.9
SCORE (NICS x weights)	0	21.7	9.1	-32.4

Comments *The most important sub-category is considered to be the environment (betterment of the groundwater quality and increase in groundwater quantity that can be abstracted from Ickenham PWS). Stakeholder views were considered to be the next most important factor, with returning the site use to grazing as the least important.*

Table 12: Compare and Rank Options				
Option	**Total score***	**Cost (£)**	**Cost-effectiveness (score / cost)**	**Rank**
1: Leachate treatment; Chalk treatment	18.2	11.4M	1.59	**3**
2: Chalk groundwater MNA; and reduced abstraction at Ickenham PWS	54.0	390K	139	**1**
3: Leachate treatment; MNA	51.4	7.6M	6.76	**2**
4: Treatment at PWS; MNA	-1.6	10.0M	-0.16	**4**
Comments:				