TECHNOLOGY DEMONSTRATION PROJECT REPORT: TDP2

REMEDIATION OF BASFORD GASWORKS USING SOIL WASHING

CONTAMINATED LAND: APPLICATIONS IN REAL ENVIRONMENTS

WHAT IS CL:AIRE?

CL:AIRE was established as a public/private partnership in March 1999, to facilitate the field demonstration of remediation research and technology, including innovative methods for site characterisation and monitoring, on contaminated sites throughout the UK. The results of project demonstrations are published as research or project demonstration reports and disseminated throughout the contaminated land community.

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Contaminated Land: Applications in Real Environments (CL:AIRE)

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This is a CL:AIRE Technology Demonstration Project Report. Publication of this report fulfils CL:AIRE's objective of disseminating and reporting on remediation technology demonstrations. This report is a detailed case study of the application of soil washing technology based on specific site conditions at SecondSite Property Holdings Ltd's facility in Nottingham. It is not a definitive guide to the application of soil washing. CL:AIRE strongly recommends that individuals/organisations interested in using this technology retain the services of experienced environmental professionals.

EXECUTIVE SUMMARY

The former Basford Gas Works owned by SecondSite Property Holdings Ltd is located to the northwest of Nottingham City Centre. It operated from 1854 until 1972. The site was decommissioned and was remediated in 1997 using soil washing technology as one element of a larger integrated remediation programme of soil recovery and re-use.

The main contaminant at the site was coal tar, which occurred at depths ranging from 1.5 m to 9.5 m below ground surface within the made ground and the underlying natural ground beneath the site.

A risk based process was used to develop the remediation strategy for the site, utilising a source - pathway - receptor analysis. The site specific risk assessment process identified polynuclear aromatic hydrocarbons (PAHs), phenolics, ammonia and complex cyanides as the main drivers for remediation. Risk based remediation standards for a range of contaminants were agreed with the local authority and Environment Agency and these formed the target concentrations to be achieved by the soil washing plant. Other values were selected from published guidance and experience at similar sites.

The first stage of the waste minimisation process was to identify clean material on site; ensure that any significant contamination hotspots had not been missed; and provide detailed particle size information for the soil washing process. To achieve this, a further investigation of the site, primarily trial pitting was conducted on a 10 m x 10 m sampling grid.

From the trial pit data, and the geotechnical and chemical test results, a model was created detailing the spatial distribution of the different ground material types. This was used to create a "distribution of materials drawing" upon which the subsequent excavation was based.

Based on the model and drawing, material was selectively excavated and treated by appropriate methods using the following techniques:

Selective digging
Conventional dry screening
Crushing
Ash recovery
Tarmac recovery
Manual picking
Soil washing
Offsite removal

Based on the results of the field characterisation, the site was classified *in situ* into 10 categories of material types and a ground model was created detailing distribution of the different material types. Material was then selectively excavated and treated by the appropriate method.

A laboratory-scale treatability study was initially commissioned to assess whether soil washing was a viable treatment technology for the site. This included a pilot trial to select and scale the most appropriate unit processes for a full scale integrated plant and to allow the soil washing contractor to assess the technical and financial risks and thus arrive at unit costs for the process.

During remediation 277,748 tonnes of contaminated soil were excavated. Of that, approximately 161,650 tonnes of material were supplied to the soil washing plant. 152,042 tonnes passed the oversize screen and entered the plant and the remaining 9,608 tonnes were rejected. Approximately 36,698 tonnes were screened and crushed, 78,908 tonnes were consigned to offsite landfill, and 4,740 tonnes of tarmac and 6,744 tonnes of ash breeze were removed for offsite recycling. Approximately 81,402 tonnes of clean fill was imported to site and the site was restored to the original ground levels.

The material that entered the soil washing plant produced 125,761 tonnes of clean material (sand and gravel fractions) and 32,240 tonnes of contaminated filter cake. The average daily production was 370 tonnes of clean output. Of the material processed as clean, 99 % was successfully cleaned in the first pass to a level below the site limits. The plant operated under all weather conditions. During the winter period pipes were drained on cold nights to prevent freezing. The soil washing plant was relatively quiet particularly compared to other site operations such as concrete breaking.

The degree of contamination of the filter cake was typically three times the input contaminant concentration. The consistency of the cake varied from a soft clay to a slurry and required the blending in of more than 15,000 tonnes of excavated contaminated soil to stabilise it to a degree where it could be landfilled off-site.

The cost of soil washing 152,042 tonnes of material to produce 125,761 tonnes of clean and 32,240 tonnes of contaminated material was £21.11/tonne excluding screening of the feed and £20.43/tonne including screening the feed. The screening process was not included as part of the soil washing process and was costed as a separate item.

The on-site processing scheme saved over 14,500 lorry movements compared to the traditional dig and dump approach, a significant benefit to the local community over the lifetime of the project. The net environmental benefit consisted of the avoidance of 700,000 miles of transportation, a resultant saving of approximately 86,000 gallons of diesel fuel and the corresponding reduction in associated exhaust gas emissions.

The process used to remediate the site resulted in the recovery for re-use of approximately 76 % of the excavated material compared with only 11 % using traditional site characterisation and remedial methods, and represents a substantial saving in landfill space and primary aggregate production.

The application of soil washing resulted in a reduction in energy usage over traditional dig and dump. In this case, the difference is mostly due to the relative energy consumptions of the on-site processing plant compared to road haulage.

The results demonstrated that soil washing technology is capable of treating a wide range of granular made ground and natural soil types contaminated with gasworks processing wastes.

One of the main factors governing the economic viability of soil washing is the amount and moisture content of the contaminated fines fraction and their associated disposal cost. A method for treatment of the fines which would either render them suitable for re-use on the site or acceptable to the landfill operator would significantly improve the economic viability of soil washing.

Early involvement of the regulator is beneficial in identifying and addressing issues at an early stage. Reaching agreement on ground clean up specifications and the methodology to be employed is crucial. The team managing and progressing the remediation project should communicate information to the regulator at every stage. Delays due to poor communication can be expensive.

Significant contaminant losses can occur even before treatment through volatilisation during material handling activities such as excavation, sorting, stockpiling and moving. This should be taken into account during the planning of the trial or full scale cleanup, and every attempt should be made to minimise the handling and disturbance of contaminated material.

Occupational hygiene considerations for the full scale remedial operation are not trivial and should be considered carefully. Work involving hand digging at the site should be avoided if at all possible and should only be allowed if alternative means cannot be used.

This project only proved to be economic due to the relatively large quantities of material requiring treatment. Due to the high mobilisation costs associated with most *ex situ* treatment processes, it is unlikely that many projects will be cost effective where there are relatively small volumes of material requiring treatment. One possible solution is to establish 'semi-mobile' processing plant which can sit on a central hub site and process materials from other sites within an economic radius for transport before moving on to another location. Another is to erect a fixed treatment plant at the edge of an operating landfill. However, there are clearly regulatory issues which need to be addressed before this can happen.

The need for pilot studies remains one of the major barriers to the introduction of many remediation technologies to the UK market. Site owners are faced with the prospect of either adopting, with a high degree of confidence, the conventional disposal to landfill approach or having to invest in further site investigation and pilot studies to prove the viability of a proposed technology. Obviously, if this additional work subsequently shows that the technology is not suitable, the investment has been wasted. The scale of the pilot study is also important as larger scale tests provide more confidence.

These problems are exacerbated when more than one process technology is proposed, as integration becomes a key issue and the need for multiple licenses approved by the regulator impacts the economics. It is considered that truly integrated and sustainable approaches will only be encouraged under the proposed Remediation Permit.

The use of simple lab tests such as size/contaminant distribution can give a very useful first indication as to whether or not soil washing is potentially applicable. If these look promising then further lab tests to remove specific mineral/material types - e.g. sink/float tests can be conducted. Though as has been found in this study, it is not just the ability to separate the contaminants to specific fractions that determines applicability, the optimisation of dewatering and filtration of the fines is also a key cost driver.

There was no contractual agreement for properly controlling the physical quality of the filter cake. In some instances this led to difficulties in storage and transport of the cake and, in extreme cases, problems with the designated landfill site's ability to accept it. In future projects, it is therefore recommended that the physical properties of the cake be defined at the outset from laboratory and pilot scale trials.

Fines dewatering and subsequent filter cake disposal remain a concern and were perhaps the subject of more discussion during the project than any other single issue. It is predicted that disposal of filter cake will become more problematic as the European Landfill Directive is introduced as such materials are likely to fail the waste acceptance criteria (WAC). It is recommended that further research is conducted into stabilisation and/or treatment of filter cake.

Quality of product was generally very high, with 99 % of all batches achieving the specified remediation target. Experience on this project has shown that where soluble contamination (such as phenolics) is present in significant quantities, it may be prudent to include an additional 'rinse' step to remove entrained, contaminated water.

ACKNOWLEDGEMENTS

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CL:AIRE would also like to thank Graham Ball of Wealden Graphics who adapted and drafted a number of figures in this report.

Successful remediation projects are a team effort. In this instance the project team consisted of SecondSite Property Holdings Ltd (BG Property Holdings at the time of the project), Parkman Group Ltd, VHE Construction plc, Linatex Heijmans Joint Venture and Davis Langdon & Everest.

CONTENTS

List of Figures

List of Tables

List of Plates

ABBREVIATIONS

AA	Atomic Absorption
aOD	above Ordnance Datum
As	Arsenic
B	Boron
CBR	California Bearing Ratio
Cd	Cadmium
CDM	Construction Design and Management
CFC	Cross Flow Clarifier
Cl	Chlorine
CN	Cyanide
COSHH	Control Of Substances Hazardous to Health
Cr	Chromium
CRF	Contaminant Reduction Factor
Cu	Copper
DeSRT	Demonstration of Site Remediation Technology
DCM	Dichloromethane
DMS	Dense Medium Separator
DRO	Diesel Range Organics
EA	Environment Agency
EAL	Environmental Analysis Laboratories
E.L.Cyanide	Easily Liberatable Cyanide
FGL	Finished Ground Level
GC	Gas Chromatography
GC-FID	Gas Chromatography – Flame Ionization Detection
h	hour
ha	hectare
HPLC	High Performance Liquid Chromatography
ICE	Institution of Civil Engineers
ICP	Inductively Coupled Plasma
LA	Local Authority
LHJV	Linatex–Heijman Joint Venture
LOI	Loss On Ignition
LPG	Liquid Petroleum Gas
LPH	Lattice Property Holdings Ltd
m	metre
mg/kg	milligram per kilogram
MGP	Manufactured Gas Plants
mm	millimetre
MPL	Mobile Plant Licence
NAPL	Non-Aqueous Phase Liquid
NH_4	Ammonium
Ni	Nickel
PAH	Polynuclear Aromatic Hydrocarbon

Pb	Lead
PBT	Plate Bearing Tests
PPE	Personal Protective Equipment
rpm	Revolutions per minute
S	Sulphur
SO_4	Sulphate
TPH	Total Petroleum Hydrocarbon
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WAC	Waste Acceptance Criteria
WRF	Waste Reduction Factor
Zn	Zinc
µm	micrometre (micron)

1. INTRODUCTION

1.1 BACKGROUND

The former Basford Gas Works is approximately 2.5 miles to the northwest of Nottingham City Centre. The gas works were operational from 1854 to 1972. The site was decommissioned and used as a combined gas storage and transmission site, and district depot until it was remediated in 1997. The non-operational part of the site is currently awaiting development.

The site is owned by SecondSite Property Holdings Ltd (SecondSite) (formerly Lattice Property Holdings Ltd, formerly BG Property Holdings Ltd). SecondSite owns numerous gas works sites throughout the UK and is engaged in a major, voluntary programme of site assessment and remediation both to reduce potential statutory liabilities and to bring sites forward for disposal/development.

During the period 1995-1997, SecondSite conducted several investigations of the Basford site to determine the nature and extent of contamination, and to identify appropriate remedial techniques. A detailed review of the site characterisation data confirmed that the granular structure of the natural soil and made ground, and contaminant type and concentrations might make the site amenable to treatment by soil washing. The use of soil washing is consistent with SecondSite's desire to introduce technology-based remedial solutions.

A project was initiated with the aims of (i) confirming that soil washing could technically be applied to the site, (ii) determining whether soil washing could be commercially viable, and (iii) applying the technology at full scale (subject to a satisfactory outcomes of (i) and (ii). Although the technical aspects are described, this report also discusses these issues from the perspective of the planning, logistics and management of a project where the requirement to optimise utilisation of the technology had to be balanced against delivering a site remediated to the required standard.

The site was remediated on a voluntary basis and the final delivery of the site was a function of the most economical way of achieving the remediation objectives rather than the delivery by a target date dictated by site disposal. However, as the economics were, to a large extent, determined by the length of the project, the soil washing contract was based on production of fit for purpose material at an agreed delivery rate.

1.2 OBJECTIVES

Whilst the primary objective of the project was to remediate the contamination on the site to a standard acceptable to both the Environment Agency (EA) and the Local Authority (LA), the opportunity was taken to gather sufficient data related to the operation and efficiency of the soil washing plant, including economic considerations, in order to better understand its applicability to future projects.

Soil washing was only one element of a larger integrated remediation programme of soil recovery and re-use. The objective was to minimise off-site disposal by applying, sequentially, a number of techniques ranging from selective excavation (low cost, simple technology) to soil washing (higher cost, more sophisticated technology).

Risk based remediation standards for a range of contaminants were agreed with the LA and EA and these formed the target concentrations to be achieved by the soil washing plant. Earlier pilot studies identified the concentration ranges of materials amenable to treatment by soil washing and thus dictated the objectives and scope of this part of the remediation project.

1.3 SCOPE OF WORK

The scope of work that was carried out in the preparation of this report included:

- Review of soil washing report prepared internally by SecondSite
- Review of site investigation interpretative report prepared by Parkman
- Review of factual validation reports prepared by Parkman
- Discussions of the remediation programme with Dr Steve Wallace of SecondSite

This report focuses on the soil washing element of the remediation programme. The wider remediation works are discussed only to the extent that they place the soil washing in context.

1.4 REPORT ORGANISATION

A background to the development of soil washing is given in Chapter 2. Chapter 3 provides a general description of gas works sites followed by a detailed description of the Basford site. The strategy for remediating the site is discussed in Chapter 4. Chapters 5 and 6 describe the design of the treatment system and supporting issues. A description of the treatment process and an evaluation of its technical and economic performance are given in Chapters 7 to 10. This is followed by a discussion of environmental benefits in Chapter 11. Conclusions and lessons learned are provided in Chapters 12 and 13 respectively.

2. BACKGROUND TO THE DEVELOPMENT OF SOIL WASHING

2.1 INTRODUCTION

This chapter provides a general introduction to soil washing technology and its development.

2.2 WHAT IS SOIL WASHING?

Soil washing is a water-based, volume reduction process in which contaminants are extracted and concentrated into a small residual portion of the original excavated material volume.

It is an *ex situ* process that utilises traditional chemical and physical extraction and separation processes for removing organic and inorganic contaminants from soils. Soil washing does not destroy contaminants but, rather, separates the contaminants from the main mass of the treated material. Soil washing optimises the methods of particle separation to develop a large volume stream of "cleaned" material and a smaller volume waste stream which includes those particles which host the majority of the contaminants. The contaminant material concentrate is then disposed as a separate waste or is further treated to remove the contamination. Cost effectiveness is achieved by offsetting treatment and disposal costs against the cost of disposal of the total soil.

2.3 DEVELOPMENT OF SOIL WASHING

The equipment used in soil washing systems has been adapted from the mineral processing industry, specifically sand and gravel washing, coal washing, industrial mineral separation and hydrometallurgical extraction. Since the soil washing industry evolved from these older industries the equipment is readily available in many countries, particularly those with a traditional mining background.

Soil washing has become a well established technique to treat contaminated land. Fixed plant systems have been operating at full scale since the mid 1980s in the Netherlands and Germany (Pearl and Wood 1994). During the late 1980s and early 1990s, demonstrations of soil washing technology were carried out at Superfund Sites in the United States (USEPA 1996) and at contaminated sites in Canada under Environment Canada's Development and Demonstration of Site Remediation Technology (DeSRT) programme (Environment Canada 1993(a), 1993(b), 1994 and 1995). Since 1991, a research pilot scale soil washing plant has been operating in the UK at the former Warren Spring Laboratory in Stevenage and currently at UKAEA in Harwell. Some of the early work in the UK involved assessing the technology on soils contaminated with heavy metals, diesel and gasworks waste (Pearl et al 1994, Pearl et al 1996).

Soil washing systems can be set up on site as transportable units or fixed at a central processing facility. Soil washing has become most highly developed in Germany, The Netherlands and Belgium where fixed plants have been established at central treatment facilities alongside other treatment methods (e.g. biological, thermal) and landfilling.

2.4 SOIL WASHING TREATMENT PROCESS

The fundamental aim of a soil washing system is to separate the contaminants from most of the contaminated soil and this is achieved by one of the two following mechanisms:

- physically removing from the soil those particles which contain/host the contaminants using separation processes based on particle size separation, attrition scrubbing, gravimetric separation and magnetic properties; or

- transferring the contaminants into the wash solution for subsequent treatment such as sorption or precipitation.

Which of the two mechanisms predominates in any one soil washing system depends on the type of contamination, the type of soil involved and also on the contaminant/soil association. The final full scale configuration of the process equipment is designed through bench and pilot scale testing.

2.4.1 TYPES OF CONTAMINANT/SOIL ASSOCIATIONS

Contamination within a soil, or other bulk solid material, can occur in a variety of associations with the individual particles. Six types of association have been identified (Pearl and Wood 1994) and are summarised in Table 2.1:

Table 2.1: Types of contaminant/soil associations.

	Type of Association	Contaminant types
1	Adsorbed contamination	Heavy metals and organic compounds
2	Liquid or semi-liquid coating	Oils, tars and some other organic contaminants
3	Chemically precipitated coatings	Inorganic contaminants such as heavy metals and cyanide
4	Discrete particles	Free metal particles, some metallic compounds, tar balls and some waste materials (e.g. used catalyst fragments)
5	Part of individual grains	Heavy metals within vitrified slag matrices or associated with specific mineral phases such as magnetite
6	Internal contamination within pores	Absorbed contaminants (e.g. heavy metal or organic contamination); contaminants as a coating to the pore walls (e.g. heavy metals) or contaminants within and possibly occluding the pores (e.g. mineral oils)

Source: Pearl and Wood (1994)

2.4.2 GENERAL STAGES IN THE SOIL WASHING PROCESS

A typical soil washing system consists of a number of stages each requiring different equipment or combinations of equipment depending on the characterisation of the feed material. Pearl and Wood (1994) describe the following stages in the soil washing process:

(i) Pre-Treatment

Depending on the nature of the material, some degree of sorting and sizing may be required to remove material that may not be amenable to soil washing, and which may cause damage to the processing plant. Wood, plastic and metal are removed and oversized material that fails to pass a minimum screen size may be crushed.

(ii) Deagglomeration and Slurrying

Soil material is broken down and slurried using water sprays, log or sword washers and low intensity tumbling scrubbers. In some cases chemical reagents such as acids, alkalis, complexing agents, surfactants, and dispersants may be added to facilitate the transfer of contaminants totally or partially into the aqueous phase.

(iii) Suspension of Contaminants

Contaminants which occur as surface coatings on coarse grained particles such as gravel and sand are removed by high intensity attrition scrubbing, high pressure water sprays, centrifugal acceleration or vibration. Chemical reagents such as discussed in (ii) above may be added at this stage.

(iv) Sizing and Classification

Soil particles are sized into various fractions and classified using screens and hydrocyclones. Size fractions commonly consist of gravel and debris, sand, coarse silt, and fine silt and clay. The gravel and debris and sand fractions are typically "cleaned" and can be reused although further processing may be required to remove other materials that may be incorporated in the fraction. The fine silt and clay fraction contains elevated levels of contaminants due to its high adsorptive capacity and is the primary waste stream of the process.

(v) Segregation

Further processing of the size fractions may be required to remove other materials which may be contaminants or which may affect the properties of the cleaned fraction for re-use. Such processing may involve gravimetric, magnetic or surface chemical techniques.

(vi) Dewatering

Dewatering of coarse fractions involves settling or screening. The fine silt and clay fraction will normally require flocculation and settling or air flotation followed by filter pressing.

(vii) Process Water Treatment

Process water is re-used as much as possible in the process. If treatment is required, it may include sand filters to remove suspended fines and activated carbon, ion exchange or precipitation to remove dissolved phase contaminants. In some cases process water may be sewered. If chemical reagents have been added, then they need to be removed before the water can be re-used in the plant.

(viii) Disposal

Clean materials can be re-used on site whereas contaminated materials may be processed further or landfilled.

A simplified schematic diagram of the soil washing process is provided in Figure 2.1.

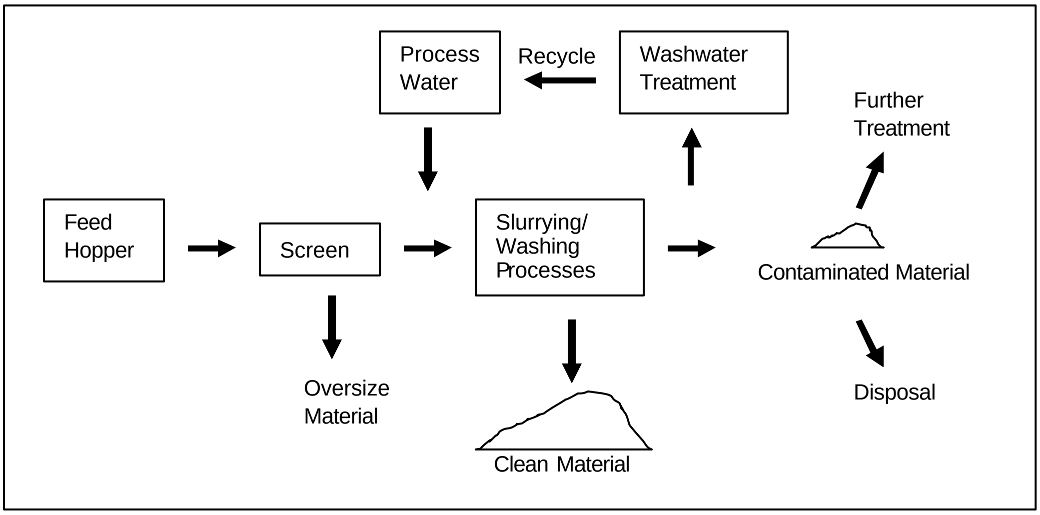

Figure 2.1: Schematic diagram of the stages in a typical soil washing process.

2.4.3 FACTORS AFFECTING PROCESS DESIGN

The stages described in the previous section will not necessarily be applied to the same degree in each soil washing application, and it depends very much on the nature of the soil material, the nature of the contaminant, and the physical/chemical interaction between the soil material and the contaminant.

Pearl and Wood (1994) list the following main factors which determine the applicability of soil washing as a remedial option:

- the target specification of the “cleaned” fraction
- the end use of the “cleaned” fraction and the ease with which they can be reused or disposed
- the costs to dispose of, or further treat, the concentrated contaminant fraction
- the degree of volume reduction
- the ability of the wash circuit to treat the range of contaminants and soil materials without major modification or capital investment
- the costs associated with the treatment of process water treatment to remove contaminants, suspended fines or chemical reagents
- the costs to manage secondary waste streams produced during processing, water treatment or vapour treatment

Soil that contains in excess of 30-35 % of particles in the silt and clay sized fraction (i.e. less than 0.063 mm) is generally unsuitable for soil washing (Pearl et al 1996).

3. SITE DESCRIPTION

3.1 SITE LOCATION

The former Basford Gas Works occupied 7.76 hectares of low lying ground in the northwest of Nottingham, bounded by the Robin Hood Railway line and the River Leen, Western Boulevard, the Nottingham Ring Road, the Radford Road, and a light Industrial Estate. A regional map showing the site location is provided in Figure 3.1.

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Figure 3.1: Site location map.

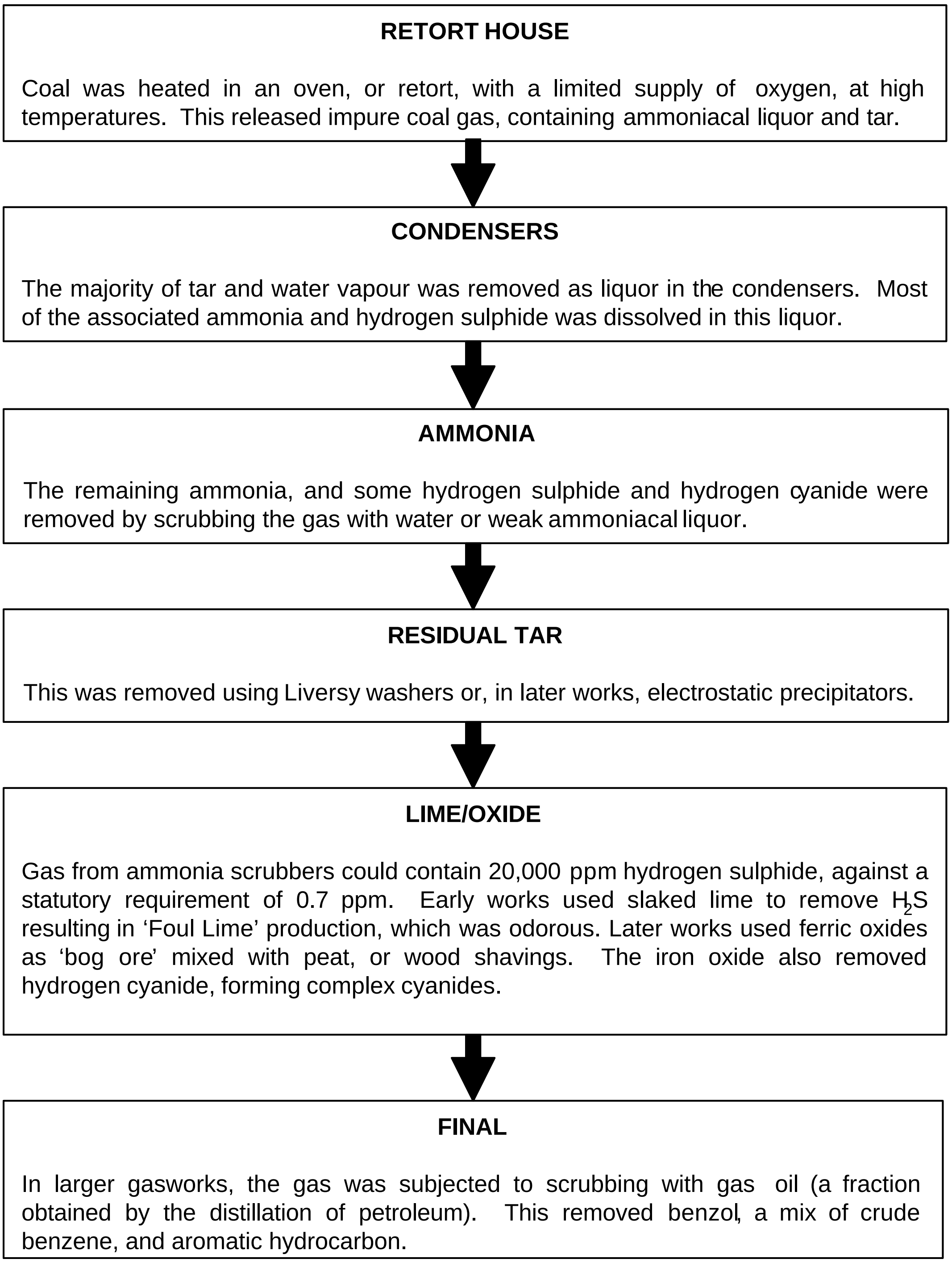
3.2 HISTORICAL BACKGROUND

This section describes the general development of gas production from coal and is taken largely from Smith et al (1998). It provides a historical context for the contamination at the Basford site.

3.2.1 GAS PRODUCTION PROCESSES

Gas for domestic and industrial use was manufactured from the early 1800s until the mid-1960s at approximately 3,000-10,000 gasworks sites located in cities, towns, and villages across the UK.

The manufacture of gas involved the heating of coal in the absence of air. Coal was heated in a retort, or oven, producing gas, which was purified under a succession of processes, and distributed to domestic and industrial users (see Figure 3.2). The manufacturing process generated a number of contaminating byproducts including: coke, coal tar, spent oxides and ammoniacal liquor. The yield and quality of these products varied according to the process conditions, design and coal composition. Coke was used for the manufacture of steel. Coal tar was distilled as a source of organic chemicals. Spent oxides containing sulphur were often recovered by exposure to air and sunlight due to their photochemical instability, and were sent as a feedstock for sulphuric acid manufacture. Ammonia was used for the manufacture of fertilisers.



RETORT HOUSE

Coal was heated in an oven, or retort, with a limited supply of oxygen, at high temperatures. This released impure coal gas, containing ammoniacal liquor and tar.

CONDENSERS

The majority of tar and water vapour was removed as liquor in the condensers. Most of the associated ammonia and hydrogen sulphide was dissolved in this liquor.

AMMONIA

The remaining ammonia, and some hydrogen sulphide and hydrogen cyanide were removed by scrubbing the gas with water or weak ammoniacal liquor.

RESIDUAL TAR

This was removed using Liversy washers or, in later works, electrostatic precipitators.

LIME/OXIDE

Gas from ammonia scrubbers could contain 20,000 ppm hydrogen sulphide, against a statutory requirement of 0.7 ppm. Early works used slaked lime to remove H_2S resulting in 'Foul Lime' production, which was odorous. Later works used ferric oxides as 'bog ore' mixed with peat, or wood shavings. The iron oxide also removed hydrogen cyanide, forming complex cyanides.

FINAL

In larger gasworks, the gas was subjected to scrubbing with gas oil (a fraction obtained by the distillation of petroleum). This removed benzol, a mix of crude benzene, and aromatic hydrocarbon.

Figure 3.2: Process diagram for the manufacture of coal gas. (Source: Smith et al 1990)

Advances in gas production technology resulted in better facilities management, new products and reduced impacts to the environment. In the late 1950s and early 1960s some gasworks began to convert to production of oil-gas, or synthetic town gas, due to the availability of a cheap oil distillate feedstock, which included liquefied petroleum gas (LPG), light distillates and naphtha, consisting primarily of methane, ethylene, acetylene and benzene. By the late 1960s coal gas manufacturing ceased as North Sea natural gas became available.

3.2.2 COMMON CONTAMINANTS AT GASWORKS SITES

Contaminants found at manufactured gas plant (MGP) sites are easily identifiable on an aesthetic basis due to their colour and odour. They can occur in several forms, depending on the characteristics of the contaminant and of the subsurface including:

- Free product
- Adsorbed to soil particles
- Vapour in soil
- Dissolved in groundwater

The main contaminating substance is coal tar, a condensate consisting of a complex, highly variable mixture of polynuclear aromatic hydrocarbons (PAHs) dominated by naphthalene, and volatile organic compounds (VOCs). Coal tar belongs to a class of contaminants known as non-aqueous phase liquids (NAPLs), so named because of their immiscibility with water. The composition of coal tar varies according to the source of coal, the manufacturing process, and the on-site depositional history. A summary of contaminants found at MGPs is provided in Table 3.1.

Table 3.1: Hazards posed by abandoned MGP sites

Hazard[1]	End use where hazard may exist	Contaminants[2]
Direct ingestion of contaminated soil by children, 'pica'	Domestic Gardens, recreation and amenity areas	arsenic, cadmium, lead **coal tars, phenols, sulphates** **free cyanide**
Uptake of contaminants by crop plants[3]	Domestic gardens, allotments and agricultural land	cadmium and lead
Phytotoxicity[3]	Any uses where plants are grown	copper, nickel, zinc, methane **sulphate**
Attack on building materials and services	Housing development, commercial and industrial buildings	**sulphate, sulphide, chloride, coal tars, phenols**, mineral oils
Fire and explosion	Any uses involving the construction of buildings and services	**sulphur, coal dust, oil, tar pitch**, rubber
Contact with contaminants	Mainly short term to site workers, investigation teams, etc.	**coal tars, phenols, oily and tarry substances**, asbestos
Contamination of water[3]	Any operation which may lead to run-off or leaching	**phenols, cyanide, sulphate soluble metals**

Notes

Source: Smith et al (1998)

1 – The hazards are not mutually exclusive

2 – BOLD indicates contaminants most likely to be found at MGP sites, others are site specific

3 – the soil pH will affect the importance of these hazards

Foul lime is a term used to describe a product from early gas purification, which can occur in very hard layers. 'Blue Billy' is a term used to describe ferrocyanide complexes which occur as a deep blue friable solid (See Table 3.2).

Table 3.2: The contaminant matrix.

Contaminant Group	Specific Contaminants	Examples	Volatility	Solubility	Bio-degradability	Toxicity
DNAPL (Semi-VOCs)	2-3 ring PAHs	Naphthalene	Low	Low	Low - Moderate	Suspected carcinogens
	4-6 ring PAHs	Benzo (a) pyrene	Very Low	Low	Low - Very Low	
	Phenols[1]		Semi	High		
VOCs[2] (Volatile Organic Compounds)	Benzene, toluene ethylbenzene xylenes		High	Low	Moderate - High	Known carcinogens
Sulphates[3]	Free SO_4, Acid Compounds			High		Can be high esp. lead sulphate
Coal Residues[4]	Dust, granules, Lumps	Coke, coal dust.	N/A	Low		
Ammoniacal Liquors	Free Ammonia & Ammonia salts	Ammonium chloride, Ammonium thiocyanate		High		
Cyanides[5]	Easily liberatable	HCN & CN		High	High	High
		NaCN, KCN				
	Complex cyanides[6]	Ferrocyanide		Limited	Low; very stable	Less than easily liberatable
	Thiocyanate	Toluene diisocyanate				Less than easily liberatable
Metals	Heavy Metals	Copper, Zinc, Lead		Variable	Low	Generally high esp lead.
Mineral Fibres[7]	Asbestos	Blue, Brown and White Asbestos		Not applicable	None	High

Notes

Source: Smith et al (1998)

1 – Phenols can migrate through plastic pipes
2 – Soil disturbances can release VOCs trapped in soil
3 – Sulphates can attack concrete
4 – Low mobility unless on form of dust
5 – Little is known of cyanide geochemistry or fate and transport in groundwater
6 – Complex cyanides are stable under acidic conditions, typical of spent oxide residues
7 – Can be wind transported

NB. Entry left blank where no specific information is available for certain contaminant characteristics.

3.3 BACKGROUND TO THE BASFORD GASWORKS SITE

The Basford site was associated with the manufacture of gas from 1854. During its operational life, the gasworks provided considerable employment, lighting and energy to the Nottingham area as well as a range of valuable by-products for industry including coke, motor benzol, sulphuric acid and ammonium sulphate. In 1972, the manufacture of gas at Basford ceased and the site was largely cleared of above ground structures, although two gas holders, a modern Governor Compound, which takes gas from the national transmission system and reduces the pressure for local distribution, and a number of buildings remain along one boundary. A composite plan showing site structures as they appeared during the history of the site is provided in Figure 3.3.

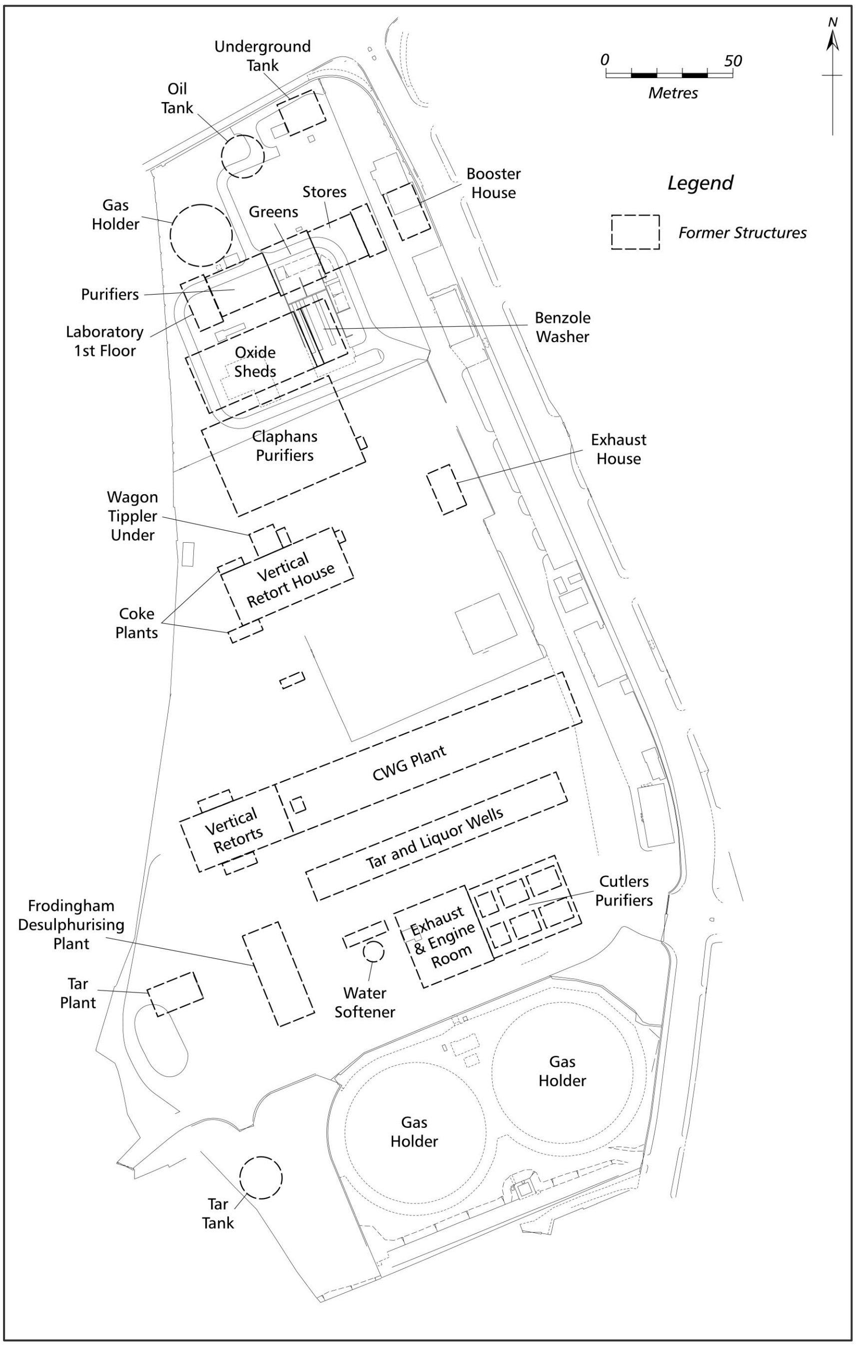


Figure 3.3: A composite plan showing historical site structures. Source: Parkman (2001)

3.3.1 SUMMARY OF ENVIRONMENTAL INVESTIGATIONS

The site has been intensively investigated. British Gas carried out investigations during the mid 1970s and in 1988. Two assessments of contamination were conducted by consultants in 1993. In 1995 and 1996 Acer Consultants produced environmental assessment and interpretive evaluation reports for the site. They also carried out detailed trial pit work, which was crucial to understanding the characteristics of the soil and the extent of contamination. Additional site work was carried out in Area D by Parkman in 1998. In 2001, Parkman produced a factual validation report for the entire site.

All data were critically reviewed before being used. Locations of selected boreholes are shown in Figure 3.4.

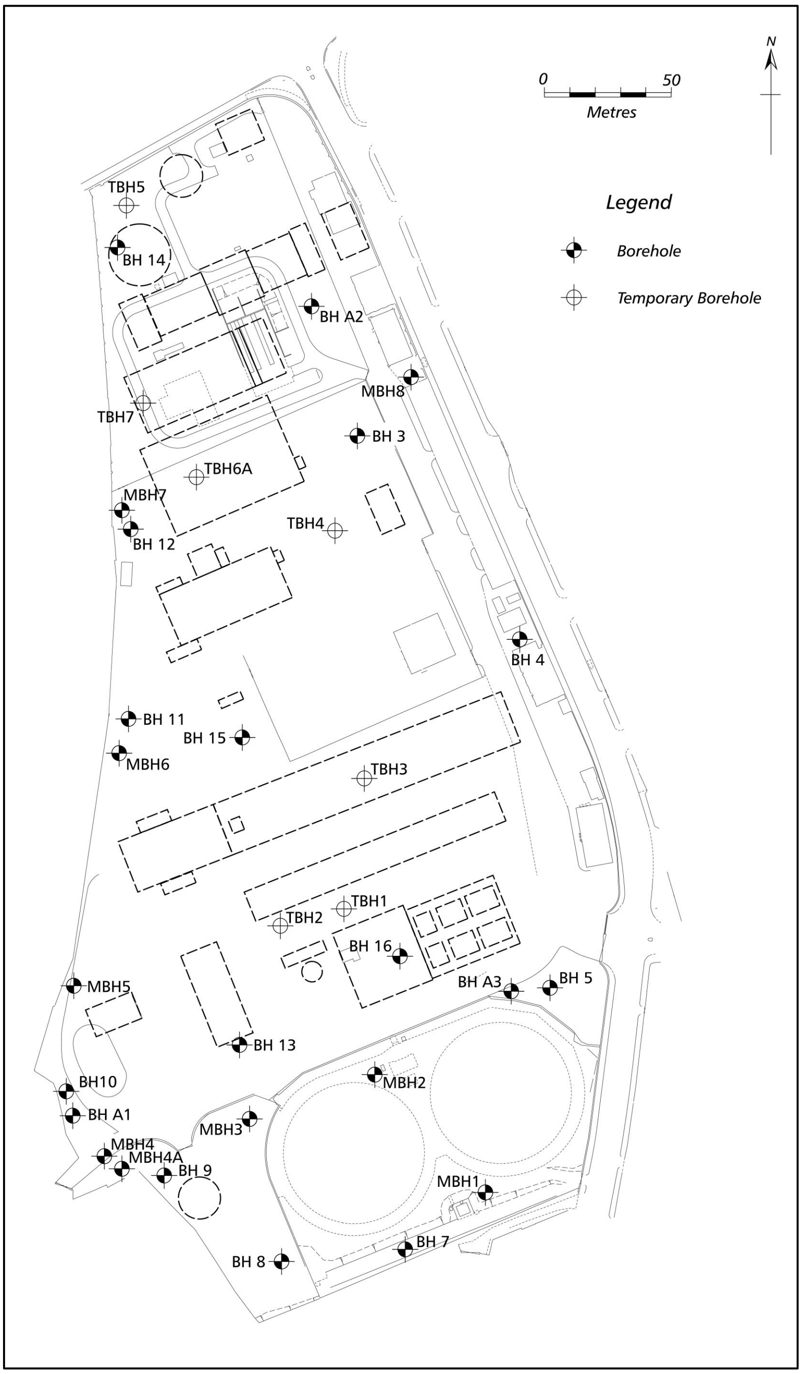


Figure 3.4: Locations of selected boreholes. Source: Parkman (2001)

Although the site conditions did not present a risk to the local community, these studies identified the need for remedial action in order to protect groundwater resources in the underlying Sherwood Sandstone aquifer.

3.3.2 TOPOGRAPHY AND DRAINAGE

The Basford site is on the floodplain of the River Leen astride the floodplain proper and the first river terrace. In its original, pre-remediation form the site varied in elevation from 38.5 m above Ordnance Datum (aOD) adjacent to the site entrance to 37.3 m aOD along the western boundary. In general, however, the site was flat with an average elevation of approximately 37.8 m aOD.

3.3.3 GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

3.3.3.1 Geology

The site, which lies on the river floodplain, was raised with fill materials to form a level area over the natural ground. The made ground, which varies from 1 m thick on the western edge of the site to 3.5 m at the eastern edge, consists both of clean fill materials imported from elsewhere within Nottinghamshire, or from the excavation of the holders/foundations, intercalated with by-products of the gas production processes such as ash, coke, clinker, spent oxide and slaked lime. Underlying natural materials in the western portion of the site comprise a layer of peat/organic silt over silty alluvial gravels, which in turn overlies sandstone of the Triassic Lenton Sandstone Formation within the Sherwood Sandstone Group. In the eastern portion of the site, fluvio-glacial sands and gravels of the First River Terrace underlie the made ground (see Appendix 3 for particle size distribution curves).

Two schematic cross-sections (ESE-WNW and NNE-SSW) of the site are given in Figure 3.6 along with a location map depicting where the cross-sections were taken (Figure 3.5).

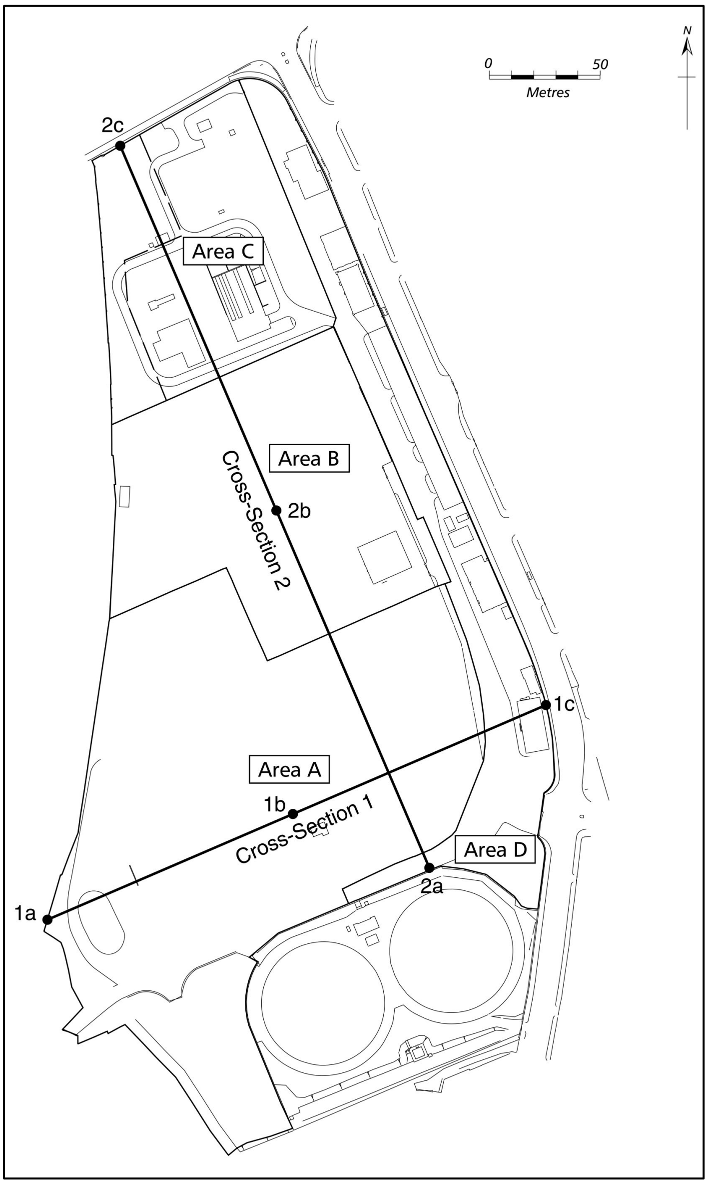
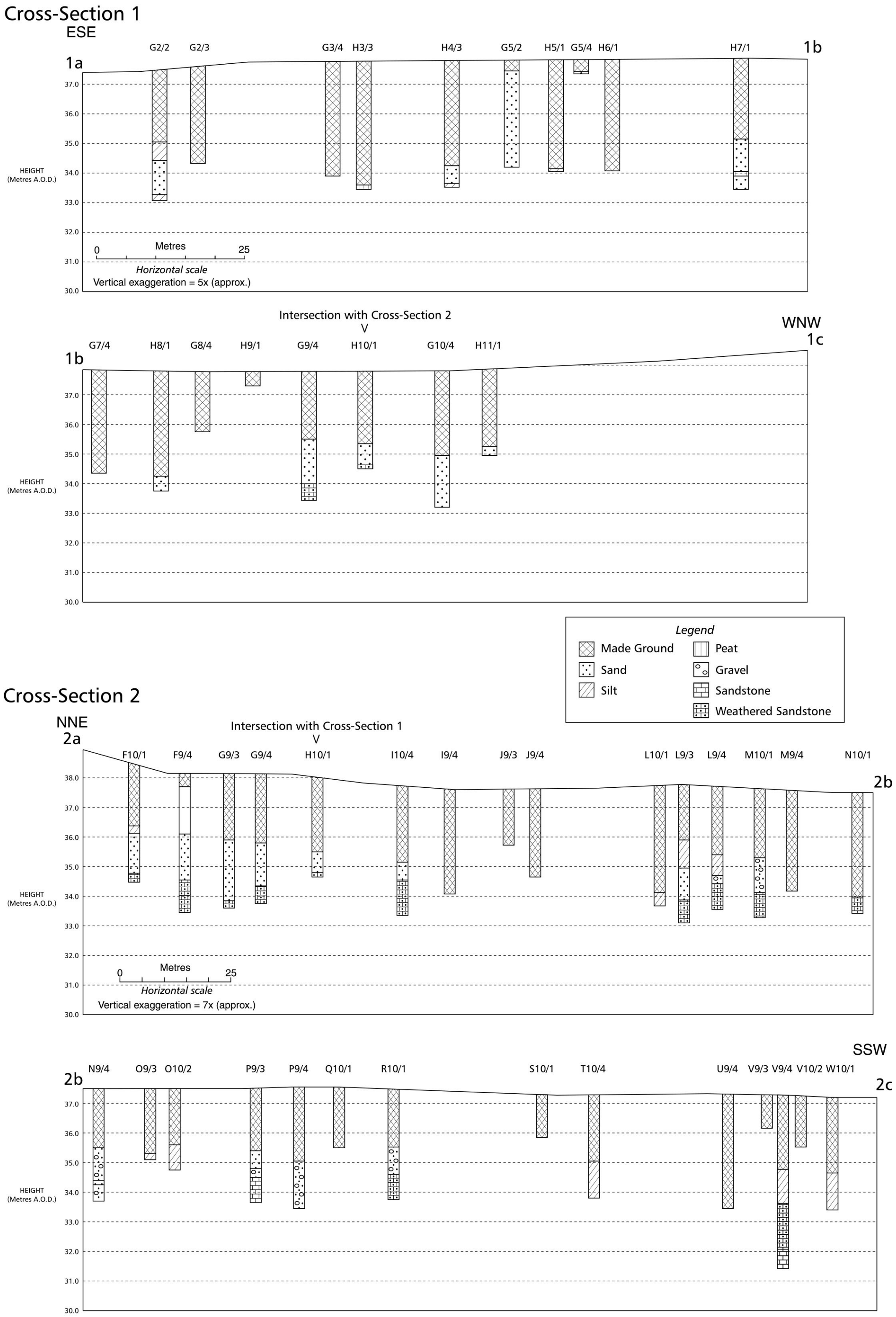


Figure 3.5: Location of cross-sections. Source: Parkman (2001)



Source: Parkman (2001)

Figure 3.6: Two schematic cross-sections (ESE-WNW and NNE-SSW) of the site.

3.3.3.2 Hydrogeology

The Sherwood Sandstone forms the main regional aquifer in the Nottingham area and is classified as a major aquifer. It dips eastwards and outcrops from its erosional edge 200 m west of the site to 3 km east of the site, where it becomes confined by the Mercia Mudstone. Groundwater within the aquifer flows predominantly southwards towards the River Trent, where it likely discharges. However, the influence of the River Leen causes a north-south trending flow divide beneath Nottingham, with groundwater west of the divide flowing to the River Leen (BGS, 1981). Regional groundwater quality, as evidenced from background water quality at the site, is relatively good. Concentrations of major ions do not exceed the maximum allowable concentrations, as defined by the European Community drinking water standards (EEC, 1989).

Appendices 1 and 2 show selected borehole logs and chemical analyses associated with the materials designated for soil washing. Although the site was fully characterised for risk assessment purposes, only the characterisation relevant to the soil washing has been included in this report.

3.3.4 NATURE AND EXTENT OF CONTAMINATION

The contamination at MGP sites results from the by-products of the gas-making process and includes tars and ammoniacal liquids, derived from removing sulphur and cyanide impurities from the gas (Munro, et al, 1995). The contamination is typically distributed heterogeneously throughout the soil, and resulted from product spills, leaking disposal facilities, and demolition work (Elektorowicz et al, 1995; ICRCL 1986).

Contaminants present at Basford are typical of former MGP sites in the UK and occur at depths ranging from 1.5 m to 9.5 m below finished ground level (FGL) and averaging 4.1 m within the made ground and the underlying natural ground beneath the site. Natural ground comprised: alluvial silts, peat, sands and gravels. The contamination was found to be distributed as a "patchwork" alternating with clean ground.

Site investigations identified approximately 200,000 tonnes of contaminated soil that required processing or treatment.

The site specific risk assessment process identified PAH, phenolics, ammonia and complex cyanides as the main drivers for remediation. In addition to these materials substantial remnant foundations and structures remained. Almost all of the developable area of the site had been built on at some period and many of the structures had been extremely large (7-8 storeys) with appropriate foundations. Substantial basements and underground retort furnace chambers remained. Mass concrete and masonry foundations ranging from two to three metres in thickness were not uncommon.

Although contamination was found to a greater or lesser extent across the whole site, “hot spots” were often associated with specific historic features. The lateral distribution of contamination is shown in Figure 3.7. Of particular note were Diesel Range Organics (DRO) in the central and eastern part of the retort house that required excavation to 6 m; ammonia, tarry sediments and contaminated waters associated with various tar and liquor tanks; and spent oxide and oily water associated with gasholder base 2 in Area C.

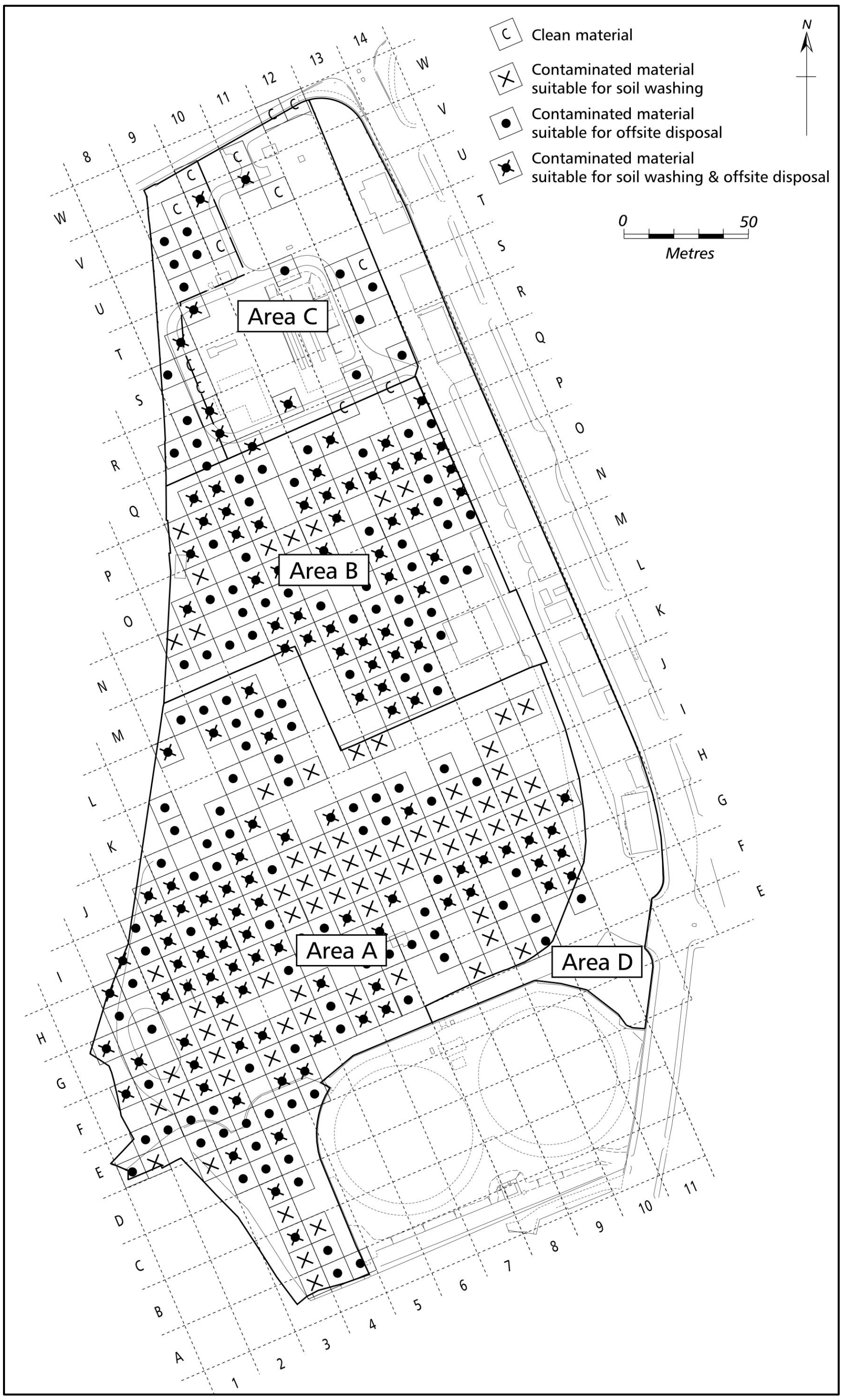


Figure 3.7: Lateral distribution of contamination across the site. Source: Parkman (2001)

4. REMEDIATION STRATEGY FOR THE SITE

4.1 PROCESS METHODOLOGY

A risk based process was used to develop the remediation strategy for the site. Utilising a Source - Pathway - Receptor analysis, the following principal risks were identified and categorised:

- The risk to individuals involved in the reclamation works, or involved in undertaking excavations above the water table, in its pre-remediated form was considered high. The risk to remediation workers could be significantly reduced by appropriate use of decontamination facilities and adherence to the Health and Safety at Work Act and the COSHH Regulations.

- In the pre-remediation condition of the site, the risk of direct contact with contaminated materials by members of the public or future users of the site was considered to be low, as the site was covered by hardstanding and surrounded by 1.8 m barbed wire topped fences or walls, with locked gates and floodlit during the hours of darkness. Development of the site and significant excavations (deeper than 0.5 m) would increase this risk.

- The risk of soluble contamination passing into the adjacent River Leen was considered to be low in the site's existing condition. Much of the site was covered with hardstanding limiting the infiltration of precipitation. The River is sheet piled at its closest point to the site and elsewhere has been canalised into an artificial and possibly lined bed. No previous pollution of the river from the site is recorded.

- The risk of direct contact by future developers of the site with contaminated ground or perched water was considered moderate as groundwater would only be encountered if excavations were dug deeper than 2.5 m. An exception was in the vicinity of certain containing structures where ponded contaminated water could be encountered at less than 1.0 m below ground level.

- The risk of contamination of the deep groundwater beneath the site from leachate generated by contaminated ground above and contamination by liquids arising from former buried tanks and structures was high, given the permeable nature of the overlying strata and the fact that the Sherwood Sandstone beneath the site is a major aquifer used for local supplies.

- The risk to existing services and future buildings was considered low, although sulphate resistant concrete to Class 4 would be required and water services should be within ductile iron pipes (as was the case with the existing services).

The specific risk of near surface sources potentially affecting the aquifer prompted SecondSite to identify the site as a priority for remediation.

4.2 RECLAMATION STRATEGY

To address the risks, the reclamation strategy aimed to remove all contaminated material within the top 1.5 m of the site and to remove contamination at greater depths where reasonably practicable. The reclamation involved (i) the excavation of contaminated material and *ex situ* processing/treatment by a variety of techniques (ii) the replacement with suitable processed fill and imported fills, and (iii) the offsite disposal of unacceptable material.

In accordance with SecondSite's desire to consider alternative treatment to landfilling, the site characterisation process identified the strong likelihood that process based *ex situ* treatment was technically feasible. The nature of the contaminants and the grain size distribution of the natural and made ground identified soil washing and bioremediation as possible alternatives. Further review based on previous experience suggested that bioremediation would be problematic for several reasons. First, the treatment area would have to be very large to treat the volume of contaminated soil and could restrict other phases of site development; second, the cost associated with the construction of a hard covered, bunded area to prevent leachate generation during treatment was considered too high; and third, the time required to treat the more recalcitrant PAH compounds was considered to be too long. Therefore, soil washing was reviewed in more detail and, considering the volume of material to be treated, the economics were potentially favourable enough to make it worth while proceeding to pilot study stage (see Chapter 5).

As it is rare for contamination at a site to be distributed homogeneously, the aim of the reclamation strategy was to separate as much as possible of the clean material from the contaminated, disposing of the minimum volume of material to landfill and reducing the requirement to import clean material to the site.

The objectives of the first stage of the waste minimisation process were to identify clean material on site, ensure that any significant contamination hotspots had not been missed, and provide detailed particle size information for the soil washing process. To achieve this, a further investigation of the site, primarily trial pitting, was undertaken to accurately characterise the materials both chemically and physically.

For the purpose of the investigation and to allow greater management of the remediation, the site was covered by a 10 m x 10 m sampling grid (see Figure 4.1), with the exception of areas affected by live utility services. One trial pit was positioned randomly within each square of the grid.

Soil samples were taken from each trial pit at approximately 0.75 m depth intervals and at every change of stratum or as otherwise directed by the resident environmental scientist. The samples were analysed for the SecondSite standard soil suite of contaminants. The laboratory used for this work, Environmental Analysis Laboratories, was selected from the SecondSite approved list. Sampling and analysis was in accordance with SecondSite's internal protocols. To ensure continuity and consistency of testing, the same laboratory was used for all samples collected in the course of the investigation. Additional testing for contaminants outside of the SecondSite specification was undertaken at the direction of the resident environmental scientist on the basis of visual and olfactory observation. Soil leaching tests, analysis of groundwater and geotechnical testing were also undertaken.

The frequency of testing in the initial investigation was at least 1 per 100 m^3 of material encountered. This complemented the earlier investigations, bringing the total number of exploratory holes on the 7.8 ha site to approximately 350 and the number of chemical test result suites to 2,500.

From the trial pit data, and the geotechnical and chemical test results, a model was created detailing the distribution of the different ground material types. This was used to create a "distribution of materials drawing" upon which the subsequent excavation was based. The ground material model was also used to calculate the bill of quantities both for the varying excavation depth bands and for the volumes processed at each tier of processing.

Based on the model and drawing, material was selectively excavated and treated by appropriate methods which are described below. The material was subsequently tested for potential re-use, based on both its physical and chemical characteristics. If the test results proved acceptable the material was passed for re-use within the works.

4.3 REMEDIATION PROCESSES

Soil was processed using the following techniques:

- Selective digging
- Conventional dry screening
- Crushing
- Ash recovery
- Tarmac recovery
- Manual picking
- Soil washing
- Offsite removal

Selective Digging

Material that had been identified as being chemically clean was selectively excavated and set aside for backfill.

Conventional dry screening

Conventional dry screening using vibrating screens was used for most material to remove oversize and large fragments of foreign matter e.g. wood, plastic etc. Screen size was typically 100 mm. The undersize fraction from this initial screening stage was picked for foreign matter and chemically tested. If suitable, it was then used as fill.

Crushing

The coarse fractions arising from the site screening operations and hard dig were mechanically crushed to less than 100 mm. Clean oversize and "dirty" oversize were crushed and stockpiled separately. The output stockpiles were tested for chemical suitability and if acceptable the material was used as fill, if not the material was passed to the soil washing plant. Much of the "dirty" oversize material proved acceptable when crushed, as the contamination was simply a surface staining, or associated with fines and once the clean inner core was 'liberated' the material tested as clean.

Ash Recovery

The ash and clinker fraction was dry screened to provide three fractions; an oversize fraction >40 mm, which was subjected to further processing, an intermediate fraction removed from the site (ground down and used as an additive in steel manufacture), and a fine fraction (also removed from site) which, dependent on its calorific value, was used either for block manufacture or as a low grade fuel.

Tarmac Recovery

Whilst tarmac recovery had not been specified within the initial strategy, the contractor opted to send this material to a contractor for crushing and blending with new asphalt.

Manual Picking

Coarse material arising from the screening, crushing and soils washing operations was picked for large fragments of wood and plastic, and steel reinforcement which was disposed of as U1/U2 material (see Table 4.1 for classification) or as scrap respectively. Material was further checked and additional picking undertaken where necessary at the stage where fill material was selected.

Soil Washing

Soil washing was the final processing stage. Details are provided in Chapter 7.

Offsite Removal

Despite the variety of treatment processes employed, some material still required removal from site because it was either not possible, or was uneconomic, to treat on site.

4.4 REMEDIATION STRATEGY

Reduction targets and site action values were agreed with the Environment Agency for the principal contaminants. Other values were selected from published guidance and experience at similar sites. Any material with concentrations exceeding these site action values was deemed to be contaminated.

For the remediation, the site was divided into four sub-areas, A to D, depending upon the anticipated material types, amounts of contamination and physical constraints on the excavation (see Figure 4.1). Utilising the results of the pre-remediation exploratory works, the locations and extent of contamination hotspots were identified. The contaminated material in Areas A, B and C was excavated and arisings were passed through the soil washing process, recovered for beneficial re-use or removed directly for off site disposal. Area D was not included in the planned remediation due to a lower degree of contamination, the presence of highly sensitive services, and the ongoing demolition of buildings forming the site boundary. Area D will be dealt with as part of any future development on the site.

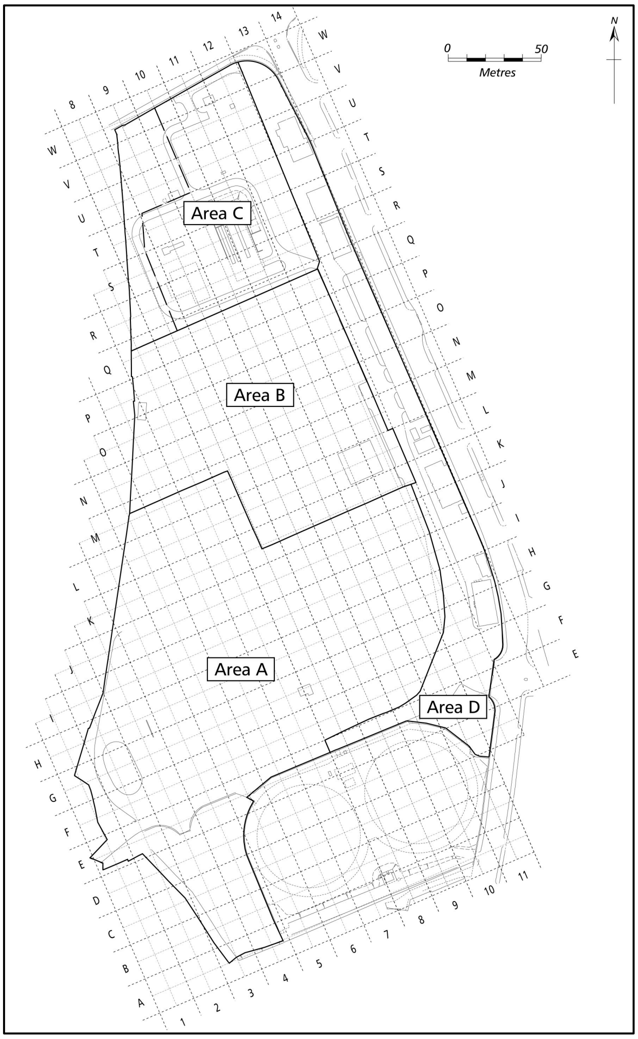


Figure 4.1: Site areas (A-D) and 10 m x 10 m grid. Source: Parkman (2001)

The remediation strategy for Area A involved excavation of identified contaminated areas, and the excavation of remaining clean material to a minimum depth of 1.5 m.

Area C is a secure compound containing various gas installations, operated by Transco, for the distribution of gas to Nottingham and surrounding areas. Whilst all efforts to remove contamination in this area were made it was recognised that because of safety restrictions and prohibitively high relocation costs, the presence of live gas equipment precluded the removal of all contamination.

The main contractor split the four sub-areas, A-D, into a series of excavation cells, which were generally worked in numerical sequence, though some cells were left open and unworked on occasions due to de-watering problems. The excavation cells were subdivided into 20 m x 20 m grid cells (e.g. L7, shown in Figure 4.1), which were further subdivided into four 10 m x 10 m grid squares (e.g. L7/1 to L7/4). The works are variously identified by overall site areas A, B, C and D and the grid cells (L7 etc.).

4.5 VALIDATION REGIME

This section details the testing required before, during and after the remediation of Basford Gas Works. Compliance with this validation regime was intended to provide assurances to regulatory authorities and future site users that a comprehensive risk-based remedial work programme had been carried out. The chemical analyses of different materials were compared to the site action values that had been agreed with the Environment Agency.

The regime detailed the minimum testing requirements for the project. Under special circumstances further testing was authorised by SecondSite as advised by Parkman supervisory staff.

4.5.1 MATERIAL CLASSIFICATION

From the pre-remediation exploratory works, the various types of on-site material were classified *in situ*. The remediation method involved, as the first stage, the selective excavation of the different material types and then separate further processing as appropriate. Materials were re-classified on the basis of visual and olfactory observation, or on the results of additional testing as directed by the resident environmental scientist or engineer. Ten material types were identified and are summarised in Table 4.1 below. The process streams are illustrated in Figure 4.2.

Table 4.1: Classification of materials on site.

Class	Material
Clean Gravel	Surface dressing
Clean Material	Chemically acceptable material
Clean Rubble	Chemically acceptable material containing a high proportion of brick and concrete rubble
Hard dig	Reinforced and un-reinforced concrete and brick masonry
Tarmac	Unacceptable material
U1*	Physically unacceptable material e.g. roots, vegetation, topsoil, steel, timber and plastic
U2	Chemically unacceptable material
U2 Rubble	Chemically unacceptable material containing a high proportion of brick and concrete rubble
U2A	Unacceptable ash and clinker material with a loss on ignition (LOI) > 20 %
U3	Chemically unacceptable material containing individual or a combination of viscous tar, asbestos and very high cyanide concentrations not suitable for soil washing

*Note. U1, U2 and U3 are standard engineering terms for describing construction materials.

Source: Parkman (2001)

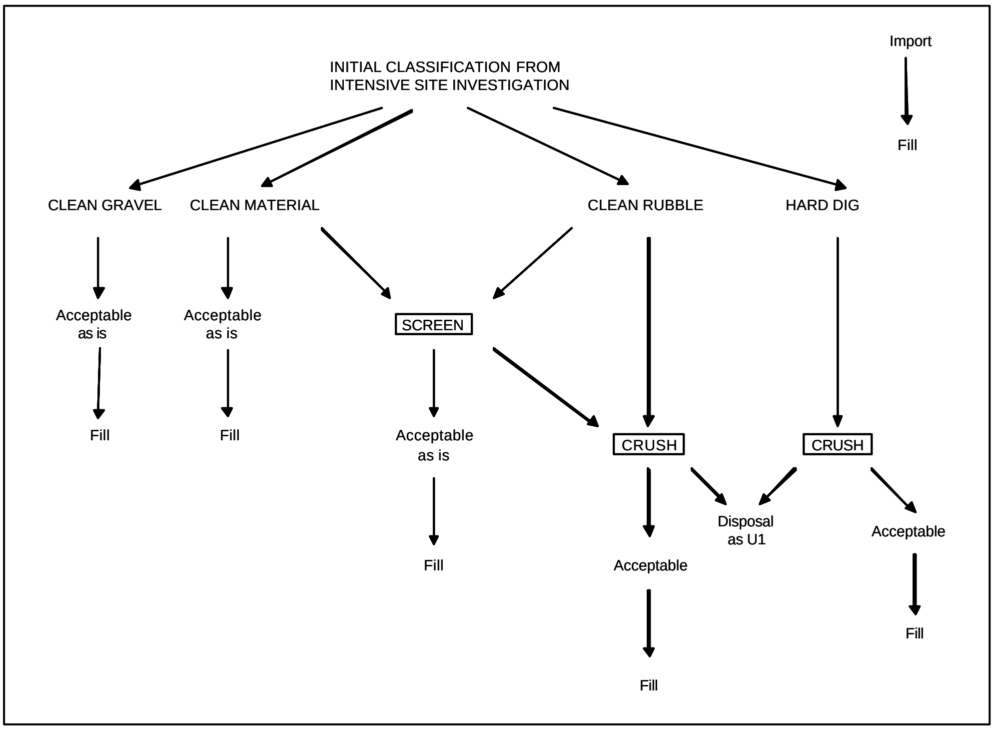


Figure 4.2(a): Process stream for clean material. Source: Parkman (2001)

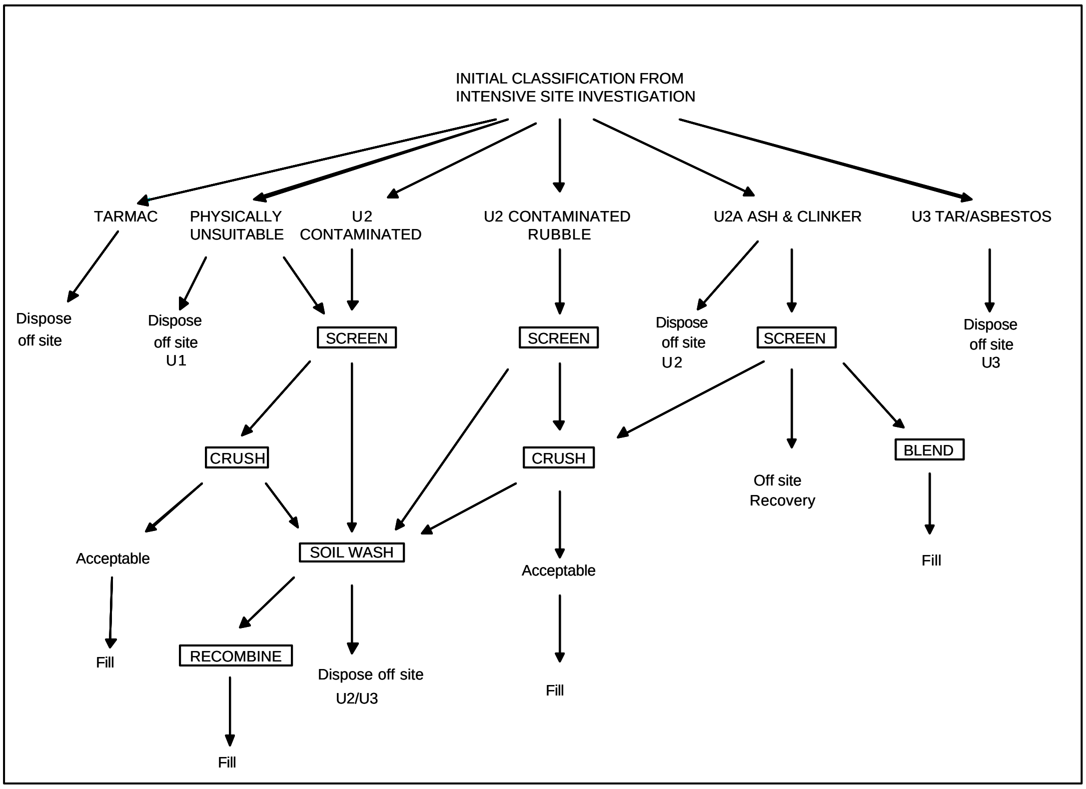


Figure 4.2(b): Process streams for material not classified as clean. Source: Parkman (2001)

On the basis of the site investigation data, clean material would be excavated separately from contaminated material. Clean material would generally be placed as fill to restore levels in areas where excavation had been completed. However, should local ground conditions be found not to be truly represented by investigation data then the material would be formed into 500 m^3 stockpiles and sampled. The material would then be re-classified depending upon the results of the chemical analyses. Clean material containing a high proportion of rubble would be screened, with the undersize fraction then being used directly as fill and the coarse material processed by crushing to render it physically acceptable.

Contaminated material (U2 and U2 rubble) suitable for soil washing would be processed by the following method: where contaminated material contained a high proportion of brick and concrete rubble, it would be screened, and the undersize material passed through the soil washing plant. The coarse fraction would be crushed. Should it fail the site action values, it would then be soil washed. The clean gravel (2 mm to 100 mm) and clean sand (63 µm to 2 mm) stream from the soil washing plant would be reused in the works after process testing. Initially the sand and gravel fractions were tested separately (for the first 6 weeks), but later in the project the recombined material would be tested as a whole. Testing involved the sub-sampling of daily sand and gravel stockpiles, which would be combined, mixed and then a sample from a quarter of the mix preserved and sent for analysis. Sub-samples were taken in two batches of five; one at midday when the stockpile was half formed, and the other as it was completed.

This method of sampling was originally designed to give a minimum testing rate of one sample per 500 tonnes of cleaned product (this equates to one sample per 285 m^3 assuming a density of 1.75 tonnes/m^3). However, the actual average frequency of testing was at least one test per 570 tonnes (325 m^3). Each stockpile would be stored until the results of analysis were available whereupon, if found to be acceptable the material would be used as fill. Should it fail it was returned for re-processing or disposed of off site. The soil washing process produced two low density organic waste streams and a filter cake in which the contaminants were concentrated. These streams were disposed of off site. Occasional testing was undertaken on this material with regard to its waste classification to satisfy the Duty of Care.

Ash and clinker material (U2A) with a characteristic loss on ignition greater than 20 % was to be used as fill, recovered or disposed of off site. U2A material that was chemically unacceptable measured against other site limits would be disposed of off site.

Hard obstructions (reinforced and un-reinforced concrete and brick masonry) together with rubble from the screening of clean material were crushed and then formed into 500 m^3 (approximately 875 tonnes) stockpiles. Each stockpile was then tested by the common method of taking 10 sub-samples not less than 2kg each, combining the sub-samples, mixing them and then taking the samples for analysis from one quarter of the mix. If the results were acceptable, then the material was used in the permanent works. If it failed, it was fed through the soil washing plant. The above procedure was also undertaken for contaminated hard material and the coarse fraction that did not pass the soil washing input screen, but such material was processed separately to avoid cross contamination. Crushed material containing foreign matter was removed by a combination of magnetic belts and manual picking.

U1 materials were chemically acceptable but physically unacceptable due to the presence of organic matter (vegetation, wood, peat). Such material was removed from site or processed by soil washing to remove the organic fraction. In the latter case, it was tested at the same frequency as U2/U2 rubble material.

4.5.2 FILL MATERIALS

Fill materials arose from several origins:

1. Clean “as dug”
2. Clean crushed rubble or hard dig
3. Clean soil washed material
4. Import

The testing and checking procedure for sources 1 to 3 is detailed previously.

As material was being disposed of off site, there was a requirement to use imported fill material to restore site levels. Before a new source of imported fill was accepted for use in the permanent works, the source was inspected, chemical analysis undertaken and the results checked. Sampling of imported material was undertaken at a minimum rate of one sample per 2,000 m^3 (approximately 3,500 tonnes) as summarised in Table 4.2.

Table 4.2: Frequency of testing of fill materials.

Type of test		Frequency of testing
Imported Fill	Classification Tests	1:2,000 m^3
	Chemical Testing	1:2,000 m^3
Processed Fill	Classification Tests	1:5,000 m^3
	Chemical Testing	1:500 m^3 or 1 per week of soil washing production, whichever is lowest
Validation of Fills	*Plate Bearing Tests (PBT)*	
	Finished Ground Level	1:10,000 m^2
	Between Excavated Formation & FGL	2:10,000 m^2
	California Bearing Ratio (CBR) tests	
	Finished Ground Level	1:10,000 m^2
	Between Excavated Formation and FGL at 0.5m intervals	1:10,000 m^2
	Skip Test	
	Finished Ground Level	1:7,500 m^2

Source: Parkman (2001)

4.5.3 TESTING OF BASE EXCAVATION

Excavation was considered to be completed upon reaching the target depth for that area/grid square given on the Distribution of Materials drawing (not part of this report). The area was visually inspected by the resident environmental scientist or engineer. If the visual and olfactory inspection indicated that the formation was acceptable, a validation sample was taken at a frequency of one sample per 400 m^2 of exposed formation. If the test result was satisfactory, then excavation ceased at that point and the formation was deemed acceptable and filling commenced.

5. DESIGN OF THE SOIL WASHING PROCESS

5.1 PILOT STUDY

Although an analysis of soil and contaminant types based on 'typical' site investigation data can suggest that a particular remediation process might be suitable, the type and amount of data collected is usually not sufficient to provide enough confidence to proceed immediately to full scale implementation. Every contaminated site has characteristics that make it unique, and only after detailed testing of the soil and contaminant types can a suitable soil washing plant be built containing the processing modules appropriate to the individual site.

In the case of soil washing, the need for pilot studies is particularly relevant as there is a wide range of unit processes which could be used. Part of the reason for the pilot study on the Basford site was to select and scale the most appropriate unit processes so that an integrated plant could be constructed. A further and very important reason for conducting the pilot study was to allow the soil washing contractor to assess the technical and financial risks and thus arrive at unit costs for the process. As the risk/reward structure of the contract was determined based on the data collected at this stage, it was considered important that the technology vendor had input to sample selection.

In order to test the hypothesis that soil washing could be undertaken on the materials from the Basford site and, importantly, produce materials suitable for reuse on the site, a laboratory-scale treatability study was commissioned. A volume of ten oil drums (about 2 m^3) of sample was collected from areas selected by the soil washing contractor, which exhibited the range of chemical and physical properties encountered during the site investigation. The oil drums were delivered to the soil washing contractor's laboratories where the 'as-received' material was visually inspected to provide a preliminary assessment of its suitability to treatment by standard soil washing process steps. Material that was considered to be totally unsuitable was discarded at this stage. Representative sub-samples from the material that remained were taken and then analysed to determine particle size distributions and chemical properties. After combining samples with similar properties, bench-scale soil washing tests were performed for each material type in order to define the optimum treatment conditions.

5.2 SITE ACTION LEVELS

The action levels for the site were developed in conjunction with the EA on the basis of risk assessment and cost benefit analysis and are provided in Table 5.1, which also defines the chemical limits of the three categories of material processing streams as agreed with the contractor.

5.3 SOIL WASH INPUTS

From the site investigations and historical information the site materials were classified *in situ* into 10 categories (shown previously in Table 4.1), based on physical and chemical characteristics obtained from test results and trial pit descriptions. Each material category was tailored to suit the likely processes that it was anticipated it would have to undergo. A more detailed description of the three categories of particular relevance to the soil washing project is given in Table 5.2.

Input samples were taken to check the degree of contamination of the excavated material before introduction to the plant.

Table 5.1: Soils washing chemical limits

Determinand	Site Action Levels	Soils Washing Limits		
		White[a]	Grey[b]	Black[c]
Total PAHs	500	0-1500	1500-3000	>3000
Total Phenols	25	0-50	50-75	>75
Arsenic	40	0-80	80-100	>100
Cadmium	15	0-30	30-40	>40
Chromium	1000	0-2000	2000-2500	>2500
Lead	2000	0-3000	3000-4000	>4000
Mercury	20	0-30	30-40	>40
Selenium	6	0-10	10-15	>15
Copper	130	0-200	200-300	>300
Nickel	70	0-100	100-200	>200
Zinc	300	0-500	500-750	>750
Easily Liberated Cyanide	100	0-200	200-300	>300
Complex Cyanide	250	0-500	500-1000	>1000
Sulphur	5000	ND	5000-6000	>6000
Water Soluble Sulphate	5000	ND	5000-6000	>6000
Water Soluble Chloride	2000	0-300	3000-4000	>4000
Boron	3	*	8	*
Exchangeable Ammonium	100	*	8	*
Asbestos	0.001 %	ND	ND	Black
Sulphide	250	*	8	*
BTEX	100	*	8	*
Total Petroleum Hydrocarbons	500	0-2000	2000-5000	>5000

Notes
All values in mg/kg unless otherwise indicated
ND = not determined
* = No test data before start of contract

[a] **White** - material which the soil washing contractor was contracted to process 100 % successfully (to a 95 percentile compliance limit) and was liable for the cost of re-processing should compliance not be attained. This category represented relatively lightly contaminated material falling above the site remediation action values.

[b] **Grey** - material which the soil washing contractor was contracted to process 75 % successfully (to a 95 percentile compliance limit) and was liable for the cost of any further processing to render the product chemically suitable for re-use. This category represented moderately to heavily contaminated material.

[c] **Black** - material which, for contractual purposes, was defined as not treatable by soil washing. However, it was agreed that attempts would be made to extend the grey/black boundary in order to maximise use of the soil washing plant and to define the true operational performance limits.

Source: Parkman (2001)

Table 5.2: Classification of feed stock for soil washing.

Classification	Description
Chemically Unacceptable - U2	Chemically contaminated material but generally physically acceptable for soil washing. Also includes contaminated waste arising from screening and crushing operations on the dirty streams which is disposed off-site as non special waste.
Chemically Unacceptable - U2 Rubble	Material both exceeds the site contamination limits and also contains significant rubble content.
Chemically Unacceptable - U2A "Ash and Clinker"	Material that is unacceptable due to a high loss on ignition and or/its arsenic content. Containing significant volumes of ash, coke, coal and clinker.

Source: Parkman (2001)

5.4 SOIL WASH OUTPUTS

Samples from the clean output, sands and gravels, were taken on a daily basis. Testing of the sand and gravel as separate fractions was undertaken for the first six weeks of the project. After this period, a combined sand and gravel sample was taken after blending.

Results from the chemical analysis were checked, upon receipt, against the action values given in Table 5.1. Stockpiles of sand and gravel that proved acceptable to the site action levels were approved for use as fill within the works. Stockpiles that proved unacceptable were, where deemed appropriate by the soil wash contractor, reprocessed. Those stockpiles which could not be re-washed were sent off-site.

Samples of the filter cake, coarse organics and fine organics were taken to check the contamination within each. Filter cake samples were usually sampled on a weekly basis. Elsewhere, the original data from the initial site investigation were used for off-site classification, though additional tests were taken where material visually differed from that anticipated.

Particle size distribution curves of the individual output materials are provided in Appendix 3.

6. TECHNOLOGY DEMONSTRATION SUPPORT ISSUES

6.1 REGULATORY APPROVAL AND GUIDELINES

The need to remediate the Basford site was agreed following negotiations with the Environment Agency and the Environmental Health Department of Nottingham City Council. The objectives of the remediation were agreed using a combination of risk based assessment and cost/benefit analysis. Where relevant, these were translated into contractual target values to be met by the soil washing contractor. Not all of the material on site was amenable to soil washing. The action values developed for the soil washing element of the project were used in the design of the system and were discussed in the previous chapter (Table 5.1).

6.2 PROJECT TEAM

The overall remediation project was managed by SecondSite (BG Property at the time of the work).

The works were fully supervised by VHE Construction Limited (VHE), the Main Contractor, and Parkman Ltd, the engineering/environmental consultant. VHE were responsible for the overall site management including earthworks, welfare facilities, security and off-site disposal of material to landfill.

Measurement and cost audit support was provided on a visiting basis by Davis Langdon and Everest.

Planning Supervisor services were carried out under Construction (Design and Management) Regulations (1994) by Pell Frischmann Projects Ltd.

The soil washing was subcontracted to an Anglo-Dutch joint venture between Linatex and Heijman. Linatex-Heijman Joint Venture (LHJV) was responsible for washing the soil and all the operations within the soil wash plant. VHE supplied the plant with soil and removed the output to stockpile.

Environmental Analysis Laboratories (EAL) was appointed to undertake the chemical analysis of all samples submitted from the site. EAL had already been involved in much of the analysis of samples from earlier investigations of the site and it was felt that consistency of testing would be desirable.

Contact details for the above are provided in Appendix 5.

The following sub-contractors were employed by VHE to carry out particular elements of the works in relation to the soil washing project.

Table 6.1: List of sub-contractors.

Sub-Contractor	Element of Work
Sullivans	Electrical Supply to Plant
Exploration Associates	Site Investigation and Geotechnical Testing
TES Bretby	Dust Monitoring

6.3 CONTRACT CONDITONS

The conditions of contract for the project were the Institution of Civil Engineers (ICE) Conditions of Contract, 6th Edition, with standard SecondSite amendments. The successful main contractor, VHE, tendered on the basis of plant and equipment hire rather than on the basis of rates and quantities of different materials types. This allowed the project team flexibility to employ whatever plant was necessary during the contract period and allocate it to whatever task was required each given week.

LHJV was contracted under a nominated sub-contractors route under ICE. Chemical limits, defined by LHJV, were used to define the contractual performance targets (white, grey and black) shown in Table 5.1.

Contract conditions required the sub-contractor to process fit-for-purpose material at an agreed average delivery rate of 500 tonnes per day.

6.4 HEALTH & SAFETY/SECURITY

The Basford remediation project was operated within the Construction (Design and Management) Regulations (1994). The Planning Supervisor for the project was Mr Paul Harrington of Pell Frischmann and the Principle Contractor was VHE Construction Limited. Method statements were developed and reviewed for each activity.

VHE's independent safety advisors, Willis Coroon and a team from Parkman inspected the site regularly.

No inspections of the site were made by the Health and Safety Executive.

Apart from the operators, site staff were excluded from the vicinity of the soil washing plant. In line with standard working practices, the site was segregated into 'dirty' and 'clean' areas with access only via a decontamination unit. 'Toolbox' talks and inductions were given for all site staff and visitors. Appropriate Personal Protective Equipment (PPE) was provided at all times and occupational health checks were undertaken on site on two occasions during the contract period.

Site security was provided at night and at weekends and a gateman was provided during working hours.

The site won VHE's Health and Safety Award for 1998.

6.5 SITE PREPARATION/ENABLING WORKS

A former Transco Depot building was converted to provide site offices.

The area beneath the soil wash slab footprint was excavated to stockpile and the void backfilled with clean surface gravels and imported demolition material arising from a local site.

A purpose built bunded slab was constructed for the soil washing plant.

6.6 WORKING PLAN

A working plan was developed to enable the site to operate efficiently. The overall objective was to manage the excavation in a manner that allowed the soil washing plant to operate as near continuously as possible (within the constraints of the planning permission) whilst ensuring that the excavation, validation testing and backfilling operations were properly controlled.

Based on the results of the field characterisation a ground model was created detailing spatial distribution of the different material types. Material was then selectively excavated and treated by the appropriate method.

6.7 SAMPLING PLAN

Material was consigned to the soil wash input stockpile based on the *in situ* test results (see Section 4.5.1 and Figure 4.2b). It proved to be beneficial from an overall site management perspective to adopt this approach in conjunction with a carefully controlled excavation, rather than to test material in the stockpiles immediately prior to treatment.

Oversized material was crushed to a size suitable for feeding to the soil washing plant. Since much of this material had the potential to be re-used on site without further treatment, it was tested in batches of 500 m^3, with only those batches above site action levels being fed to the plant.

The 'clean' output streams from the soil washing plant were tested on a daily basis at a rate of approximately 1 composite sample per 285 m^3. The volume of 285 m^3 was estimated from the number of loader shovels used to move the clean material from the output stream of the plant to a stockpile over the course of the day. This sampling regime was more comprehensive than would be used on future projects or than is typically applied to imported material (including that from secondary sources), and was selected due to the innovative nature of this project.

Contaminated coarse organic fractions from the soil washing plant were tested at a rate of one composite sample per 500 m^3 to provide data for off-site disposal. The fine organics and filter cake were tested at a rate approximating to one per week of production (approximately one composite sample per 500 tonnes). However, the testing rate for this material was varied as required to reflect any visual changes in quality.

For most of its operation, the soil washing plant was operated with a water deficit (i.e. water had to be added rather than discharged). Occasionally water was discharged from the plant and was mixed with a much larger volume of water from excavations. This mixed water was stored on-site before being tested and discharged to sewer. The majority of the contaminated water generated during treatment constituted the moisture in the filter cake.

6.8 LABORATORY ANALYTICAL METHODS

All samples were preserved and analysed in accordance with SecondSite's Environment Assessment Guidance 2.2. Samples were stored at 4 ^{o}C in the field and transported to the laboratory. A summary of the sampling procedures and the analytical methods employed are provided in Figure 6.1 and Table 6.2.

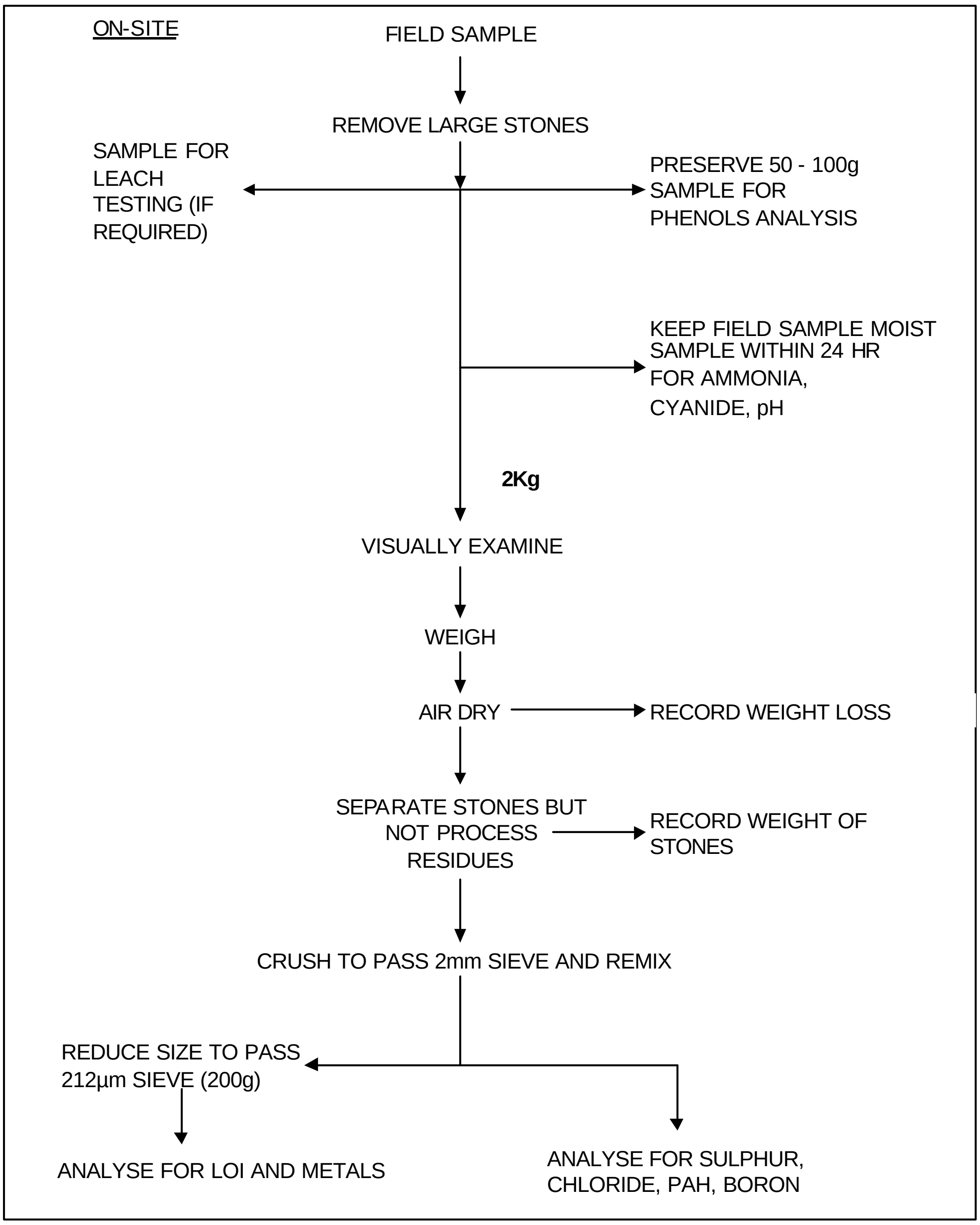


Figure 6.1: Sampling procedures.

Source: Parkman (2001)

Table 6.2: Determinands and analytical methods.

Determinand(s)	Analytical Methods
pH	Water/pH meter
Moisture content	Weight
Loss on Ignition (LOI)	Weight
PAH	DCM extraction then GC-FID
TPH	Heptane/acetone extraction then GC
Phenols	Methanol/water extraction then HPLC
Total metals	Aqua Regia digest then AA or ICP
Complex cyanide	Conversion to CN, distillation, then titration or ion chromatography
Elemental sulphur	DCM extraction then HPLC
Chloride & sulphate	Water extraction then ion chromatography
Exchangeable ammonia	potassium chloride extraction, distillation then titration

Source: Parkman (2001)

6.9 CHEMICAL VALIDATION SAMPLING AND TESTING

The results were analysed for the minimum, maximum, and mean values and the 95 % and 99 % confidence limits according to the methods outlined in USEPA (1988).

Samples for testing consisted of a sub-sample formed by taking 10 representative sub-samples, during formation of stockpiles, of not less than 2 kg each. These were then mixed, quartered and riffled before taking the sample for analysis.

The statistical analysis of the results assumed a worst case scenario that values less than the detection limit were equal to that limit. This caused some difficulties with individual contaminants (notably boron) where the limit of detection of 0.5 mg/kg is close to the action value of 3 mg/kg.

Figure 6.2 illustrates the different testing stages and frequencies.

6.10 QUALITY ASSESSMENT AND QUALITY CONTROL

SecondSite required that a quality control and assurance system be established and maintained in the laboratory by EAL who were responsible for all chemical testing of soil samples for the period of the works.

This allowed data comparison between surveys from different laboratories and to ensure that data is fit for purpose. In addition, the laboratory was required to have participated in an inter-laboratory exercise organised twice a year by Advantica, Loughborough to demonstrate satisfactory performance. EAL were tested in this way throughout the project and achieved satisfactory performance on each occasion. A homogenised contaminated soil was required to be used for quality control monitoring as a secondary reference material rather than standard mixtures of pure components.

Batches of analyses were also required to contain the following:

1. A reagent blank.
2. In-house reference materials (or certified reference materials).
3. One in every twenty samples duplicated (extraction and analysis)
4. An appropriate certified reference material (when available) analysed at regular intervals.

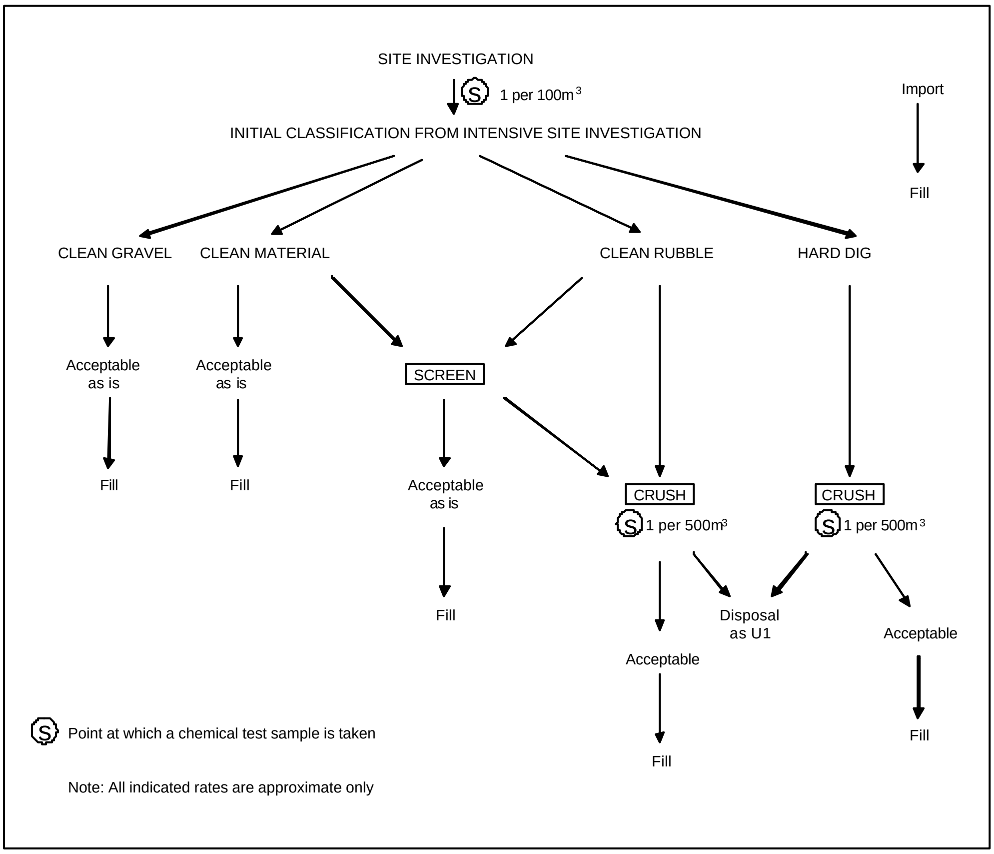
Quality control charts were maintained for each method and a traceable data recording system was used.

All chemical results received from EAL were checked independently by the field engineer as required by their BS 9001 accredited system. Although the frequency was not defined, occasional "blank" and duplicate samples were tested to verify the accuracy of the laboratory analyses.

Field samples were collected in appropriate containers supplied by the laboratory, with suitable preservatives added where necessary (e.g. methanol:water for phenols samples). All samples were delivered to the laboratory with chain of custody forms.

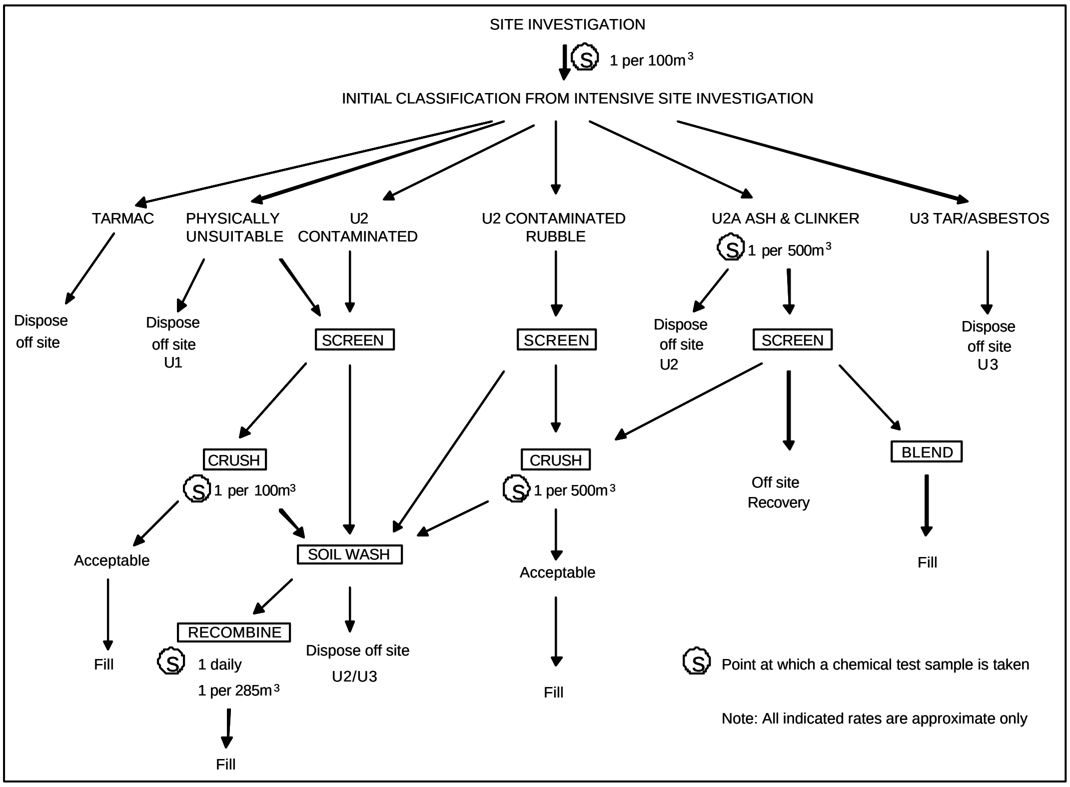
Each lorry taking contaminated material off-site to landfill was issued with the required consignment note which contained details of the weight, destination, haulier, vehicle registration, time and classification. Random checks were made by following lorries to their destinations to ensure that all Duty of Care obligations were being fulfilled.

In addition, the notes also contained details of the hazard code of the waste and the concentrations of the contaminants which made it Special Waste (when required). The notes will be stored for a period of five years by VHE.



Source: Parkman (2001)

Figure 6.2(a): Chemical testing stages and frequencies for clean material.



Source: Parkman (2001)

Figure 6.2(b): Chemical testing stages and frequencies for material not classified as clean.

7. SOIL WASHING OPERATION

7.1 INTRODUCTION

The soil washing plant was designed on the basis of the pilot study and detailed site investigation, and consisted of a train of integrated process operations (see Plate 7.1 and additional photographs in Appendix 4). The soil washing plant was mobilised and commissioned over a two week period.

Plate 7.1: Soil washing plant. Source: SecondSite

The main elements of the process are shown in Figure 7.1 and are described in more detail below:

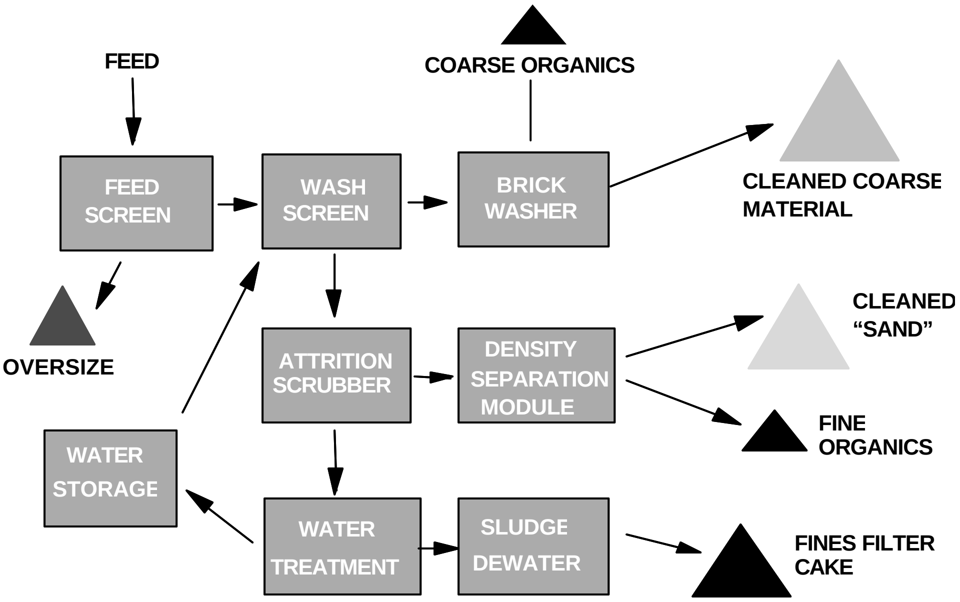


Figure 7.1: Elements of soil washing process steps. Source: Parkman (2001)

The following process stages were selected for the Basford site and are described below:

Stage 1 – Initial Feed and Screening
Stage 2 – Weighing Feed
Stage 3 – Washed Feed and Brick Washing
Stage 4 – Hydrocyclones and Attrition Scrubber
Stage 5 – Hydrocyclones and Dense Medium Separator
Stage 6 – Slurry Dewatering
Stage 7 – Process Water
Stage 8 – Sludge Dewatering

7.2 STAGE 1 - INITIAL FEED AND SCREENING

The raw feed is fed into the first static grizzly screen (150 mm) by loading shovel. Any oversize is directed to the crusher and tested for quality. Clean material is re-used and contaminated material is sent to the soil wash feed pile. The grizzly screen can be cleared by a manually operated hydraulic lift action. Material which passes the screen is fed through a hopper to be conveyed up to a second grizzly screen (100 mm). An overhead magnetic belt removes ferrous material to a collection skip. Material that passes the second grizzly screen falls into a hopper for forwarding to Stage 2.

7.3 STAGE 2 - WEIGHING FEED

Stage 2 consists of a conveyor for transporting the material from the hopper into the start of the washing process. As material is moved up the conveyor it is weighed to give an instantaneous feed rate and a total feed to date. A second magnetic belt removes any remaining ferrous metal.

7.4 STAGE 3 – WASHED FEED AND BRICK WASHER

From the conveyor, the material is wetted and discharged onto a 2 mm, near horizontal, vibrating wash screen where it is disaggregated using high pressure water from spray bars located on the wash screen deck. The oversize gravel (>2 mm) fraction exits the screen and falls into a brick washer whilst the <2 mm fraction passes through the screen with the water. The brick washer consists of a slightly inclined horizontal cylinder with internal baffles, which is rotated at between 10 and 30 revolutions per minute (rpm). As the gravel passes through the washer it is agitated and washed by a counter current of water which separates other materials such as clinker, wood and plastic from the gravel. At the end of the cylinder a fine screen allows the water to drain from the gravel before the gravel is discharged, typically as clean material, via a conveyor to the collection bay for reuse as fill material (after testing). Foreign materials (clinker, wood etc) which make up less than 1 % of the feed are removed from the counter current of water by discharging over a 2 mm vibrating screen and disposed. Water from the brick washer together with the water and < 2 mm material from the initial screen is collected at the base of the module and the resulting slurry is pumped into the next stage of the process.

7.5 STAGE 4 – HYDROCYCLONES AND ATTRITION SCRUBBER

The slurry from the preceding stage is split and injected tangentially into two hydrocyclones. The hydrocyclones separate the slurry into 63 µm – 2 mm 'sand' and a < 63 µm slurry which contains the contaminated fines fraction. The sand fraction from the two hydrocyclones passes into an attrition scrubber where a process of abrasion removes the surface contamination. The attrition scrubber consists of two vertical cylinders fixed with internal baffles. In each cylinder, kinetic energy is introduced by a propeller which causes mechanical abrasion of the particles and thus removes surface contamination. Sand and the finer particles generated from this process are collected in the base of the module, where water is added before being pumped to the next stage. The slurry from the attrition scrubbers is fed into two further hydrocyclones, where the < 63 µm fraction is separated from the 63 µm to 2 mm sand. The slurry from the top of the cyclones is pumped for dewatering (Stage 5, below).

7.6 STAGE 5 –DENSE MEDIUM SEPARATOR AND HYDROCYCLONES

The sand falls into a dense medium separator (DMS) where low density material (along with some fine sand) is separated from the coarse sand fraction. This large vertical cylinder is full of sand, maintained as a fluidised bed by the injection of water through the base of the cylinder. Clean sand is emptied from the base of the cylinder where it is dewatered by a vibrating 63 µm screen and then discharged via a conveyor into a collection bay. The water and low density material overflowing from the DMS is discharged over an inclined fixed screen which removes the low density material and recovers the majority of the fine sand particles. Low density materials are removed by conveyor to a bay where they are collected for disposal. The water and fine sand from the inclined screen are collected in a tank and passed through a hydrocyclone and reintroduced into the process.

7.7 STAGE 6 - SLURRY DEWATERING

The slurry from Stages 4 and 5 containing the 0 µm-63 µm size fraction is introduced along with flocculent into a Supraflow Thickener, a large circular high rate sedimentation tank for settling. The slurry passes through a floating bed of suspended solids which aids sedimentation. The settlement process results in a sludge, which can be produced at between 20 %– 40 % dry matter at the conical base of the tank, while the clear water flows over a V-notch weir at the top. The sludge is removed from the base by a raking mechanism that rotates at 0.3 rpm and is pumped to Stage 8. The water overflow is discharged to Stage 7.

7.8 STAGE 7 - PROCESS WATER

Most of the clarified water from the Supraflow Thickener is collected in two connected storage tanks, but a fraction is sent for further removal of solids. The water in the storage tanks is reused in the process and supplemented by additional mains water (maximum of 5 m^3/hr) to make up for water losses within the clean and waste products of the process.

The fraction of the settled water for further solids removal is sent to a Cross Flow Clarifier (CFC). The CFC consists of a rectangular tank containing a series of inclined plates. Water is introduced via a conditioning tank into the centre of the tank and as it flows outwards it passes between the inclined plates which accelerate the settlement of any solids in the water. The water from the CFC is used in applications where any solids could cause blockage or wear problems, such as at the high pressure spray nozzles in Stage 3. The sludge collected at the base of the CFC may be of variable quality, so it is reintroduced into the Supraflow Thickener (Stage 6) rather than being dewatered.

7.9 STAGE 8 - SLUDGE DEWATERING

Sludge consisting of settled fines from the base of the Supraflow Thickener is pumped to a sludge conditioning tank prior to further processing. From the conditioning tank, the sludge is pumped to the belt filter press via two stages where additives can be injected into the flow. The additives help the solid particles to adhere to each other and to repel water, and are added as necessary to ensure a low moisture cake from the press. The sludge is introduced to the top of the filter press and some water immediately drains off through the filter belt. The sludge then falls between the two filter belts where the spacing between the belts constricts the sludge in the "wedge zone". The belts are then pressed firmly together to remove the water and the resulting filter cake is collected by a conveyor for disposal as waste product. Each belt is back washed on each revolution and the collected water is pumped back to Stage 6, the Supraflow Thickener.

7.10 OUTPUT

The output of the Basford process consisted of five stockpiles, three waste and two clean, and these are discussed in Section 5.4 of this report.

The fine organics, coarse organics and filter cake fractions contained the bulk of the contaminant loading in a more concentrated form than the input and were disposed of off-site. The sand and gravel fractions still contained some contaminants, but at a far lower level than the input and at levels which were below the site action values. Following validation testing, these fractions were re-mixed to form a blend with suitable geotechnical properties and then re-used at appropriate locations across the site.

8. REMEDIATION SUMMARY AND TECHNOLOGY DEMONSTRATION CLOSE OUT

During remediation 277,748 tonnes of contaminated soil were excavated. Of that total 152,042 tonnes were processed by soil washing, 36,698 tonnes were screened and crushed, 78,908 tonnes were consigned to offsite landfill, and 4,740 tonnes of tarmac and 6,744 tonnes of ash breeze were removed for offsite recycling. The site was excavated to a minimum depth of 1.5 m below FGL and a maximum depth of 9.5 m, averaging 4.1 m for the entire excavation. Contamination was removed as far as was practicable. All concrete was removed to a minimum of 1.5 m below FGL.

Approximately 31,000 m^3 of contaminated groundwater was generated overall during the entire remediation process. Only a small fraction of this water was generated through the soil washing process. The water was tested, partially treated and disposed of to sewer or supplied to the soil washing plant as process water. 2,343 m^3 of water was tankered for disposal from structures on site.

A total of 81,402 tonnes of clean fill was imported to site and the site was restored to the original ground levels.

The soil washing plant was decommissioned over a four week period in early 1999.

9. PERFORMANCE ASSESSMENT

9.1 OVERVIEW

Approximately 161,650 tonnes of material were supplied to the soil washing plant of which 152,042 tonnes passed the oversize screen and entered the plant and 9,608 tonnes were rejected. The material that entered the plant produced 125,761 tonnes of clean material (sand and gravel fractions) and 32,240 tonnes of contaminated filter cake. The discrepancy between the input and the output tonnage is due to additional moisture in the output soil from the soil washing process.

The average daily production was 370 tonnes of clean output.

Analytical data from the validation testing of the washed output stockpiles are provided in Appendix 2.

9.2 SOIL WASH EFFICIENCY

The efficiency of the soil wash process at Basford was assessed on the basis of the overall mass of material treated and from material and contaminant mass balance calculations during the trial which allowed the calculation of: the waste reduction factor (WRF) and the contaminant reduction factor (CRF).

9.2.1 MASS BALANCE CALCULATIONS

The commercial constraints of operating such a large plant over a significant period of time meant that it was prohibitively expensive to collect research quality analytical data at high sampling densities for the full duration of the project. It was therefore decided to run selected trial batches where sampling and testing frequencies could be increased so that the efficiency of the plant could be more accurately assessed.

A rough mass balance exercise was undertaken, comparing materials and contaminants going into the plant to those coming out. A series of 8 trials involving detailed sampling and analysis were carried out to help fine tune the system and formed the basis of the mass balance calculations.

Each trial took place over one or two days under the normal working conditions of the soil wash plant. The mass of soil entering the plant was usually measured using a Loadmaster 5000 weighing device fitted to the loading shovel feeding the plant and cross checked against a weigh belt. The mass of the process outputs was measured using the loading shovel that emptied the output bins to stockpile. During the trial period, an intensive sampling regime was adopted (the exact frequency depended on the trial tonnage) in order to obtain a chemical profile of the input and output materials. The chemical testing suite differed from trial to trial. Some trials were targeted at one specific contaminant, whilst others examined the behaviour of a wider range of contaminants. The samples were staggered to allow for the residence times of the different materials (for example, it took approximately 40 minutes for sand to pass through the plant). Using the average chemical test results and the measured mass of the trial inputs and outputs a balance was calculated in order to deduce the fate of contaminants.

The materials mass balance is summarised in Figure 9.1. Most of the trial balances closed to within 10 %.

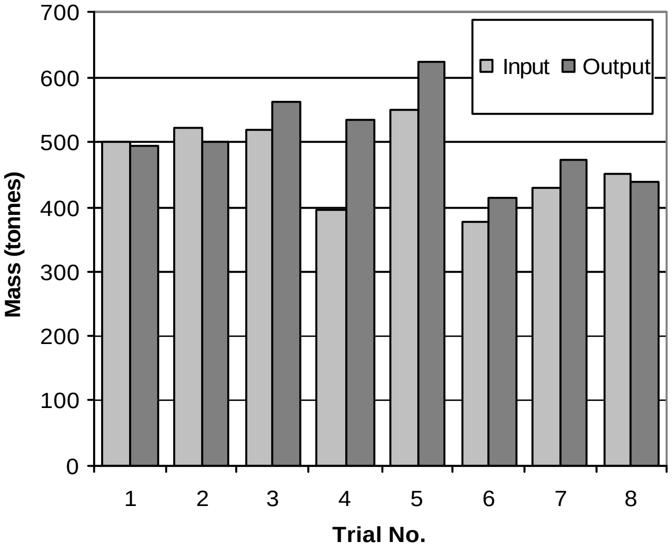
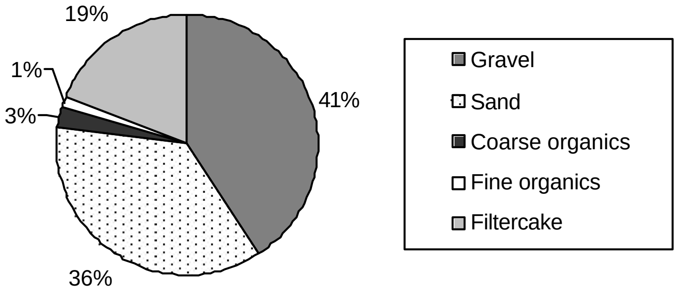


Figure 9.1: Materials mass balance for soil wash trials. Source: Parkman (2001)

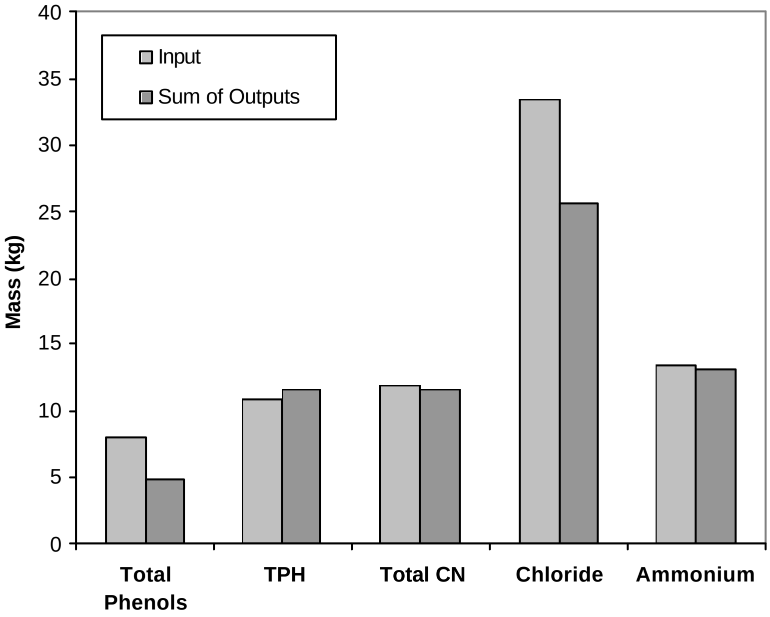
The percentage mass distribution of the product and waste fractions is given in Figure 9.2. It shows that the clean sand and gravel fraction in the mass balance trials made up approximately 77 % of the total input material with 23 % of the input going to waste predominantly as filter cake with minor amounts of fine and coarse organics.



Source: Parkman (2001)

Figure 9.2: Percentage mass distribution of the product and waste fractions.

The masses of contaminants in the input material were calculated using an average contaminant concentration multiplied by the total input mass. The masses of contaminants in each of the outputs were calculated in a similar fashion. The mass balance of selected contaminants is shown in Figure 9.3. The concentration distribution of selected contaminants in the various output streams is provided in Table 9.1. The concentration data have been normalised in Table 9.2 and displayed in Figure 9.4 using the contaminant concentrations from Table 9.1 and multiplying by the fraction of the various output streams taken from Figure 9.2.



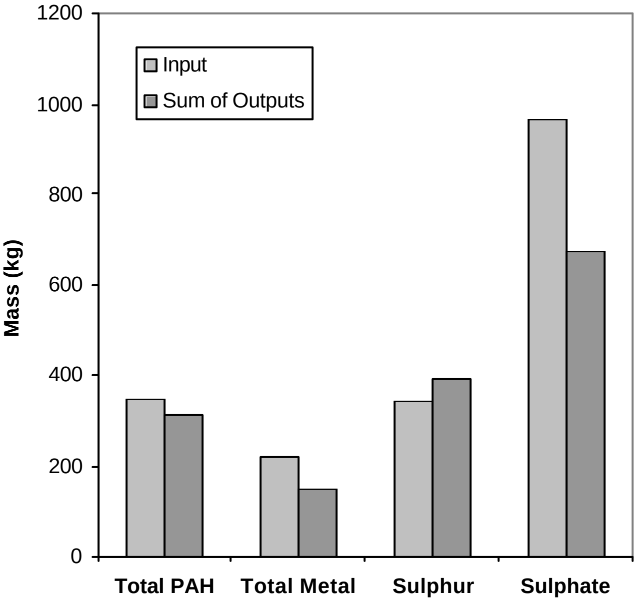


Figure 9.3: Mass balance of selected contaminants.

Source: Parkman (2001)

Table 9.1: Contaminant concentrations in output streams.

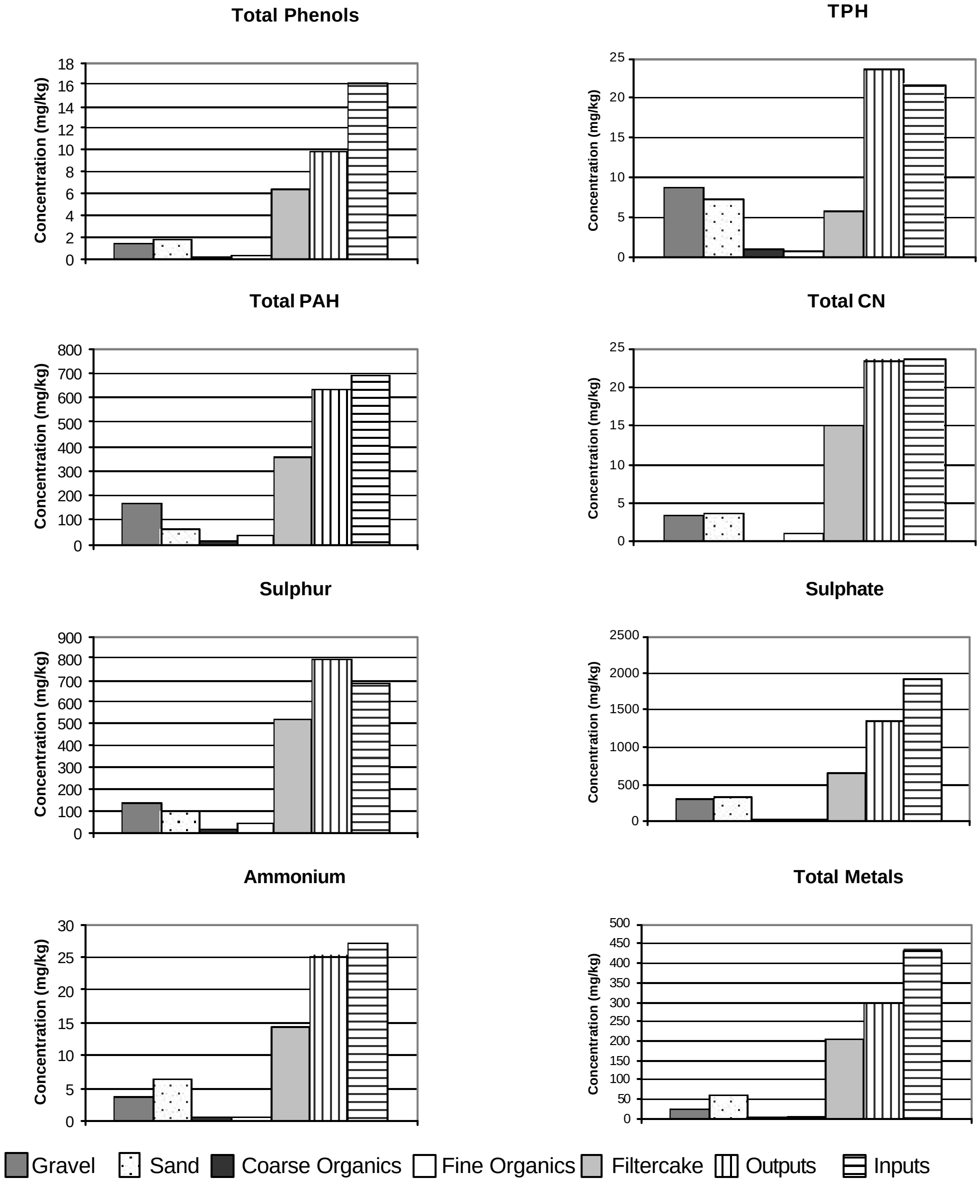
Contaminant	Gravel mg/kg	Sand mg/kg	Coarse Organics mg/kg	Fine Organics mg/kg	Filtercake mg/kg
Total Phenols	3.3	4.8	5.3	16.9	34
Total PAH	401	168.6	544	2503	1900
TPH	21.3	20	38.3	57.8	31.2
Total CN	8.4	10.1	6.03	76.3	80.36
Sulphur	328	248	490	2621	2760
Sulphate	734	941.8	1107	276.5	3476
Chloride	21.5	36.8	19	53.5	151.6
Ammonium	9.0	17.0	12.3	29.4	76.8
Total Metal	59.5	165.7	73.7	546	1079

Source: Parkman (2001)

Table 9.2: Contaminant concentrations for output streams (normalised values) and input material.

Contaminant	Gravel mg/kg	Sand mg/kg	Coarse Organics mg/kg	Fine Organics mg/kg	Filtercake mg/kg	Sum of Concentration in Outputs mg/kg	Input mg/kg
Total Phenols	1.4	1.8	0.14	0.23	6.39	9.87	16.15
Total PAH	164.1	61.2	14.3	34.5	357	631.2	687.02
TPH	8.7	7.3	1.00	0.80	5.86	23.6	21.75
Total CN	3.4	3.7	0.16	1.05	15.1	23.4	23.65
Sulphur	134.1	90.1	12.84	36.1	518. 7	791.8	680.83
Sulphate	300.1	342	29.04	38.1	653.2	1363	1925
Chloride	8.8	13.4	0.50	0.74	28.5	51.8	66.67
Ammonium	3.7	6.2	0.32	0.41	14.4	25.0	27.07
Total Metal	24.3	60.2	1.93	7.53	202.8	296.8	434.4

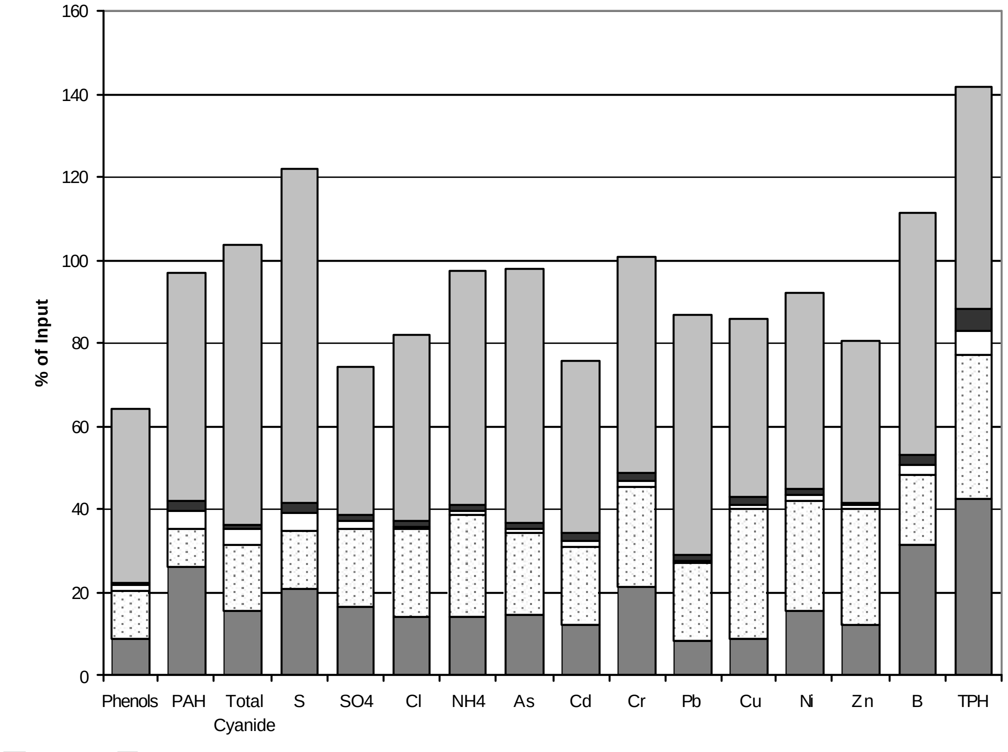
Source: Parkman (2001)



Source: Parkman (2001)

Figure 9.4: Mean concentrations of contaminants in wash input and outputs.

The distribution of contaminants as a function of the product and waste streams is shown in Figure 9.5.



Source: Parkman (2001)

Figure 9.5: Distribution of contamination as a function of the product and waste streams.

In general, the bulk of the contaminants were concentrated within the filter cake, as expected. The degree to which the dense medium separator (DMS) added to the efficiency and cost effectiveness of the process was not assessed. There were areas of the site where the DMS was definitely needed due to high proportions of material such as peat. However for the greater portion of processing the DMS did not make a significant difference except to enhance the visual appearance of the sand. The DMS was originally specified on the basis of the pilot study due to the very inhomogeneous feed material and allowing for worst case. Incorporation of the DMS into the original process was considered to be more cost effective than adding it after the circuit had already been set up.

In general, high input contaminant concentrations were washed more efficiently than low input concentrations. However, for phenol, TPH, sulphate, ammonium and easily liberated cyanide, the percentages were not as high as anticipated (less than 60 %). With these contaminants a significant percentage, over 40 % in some cases, was found in the sand and gravel output streams. As the outputs were stockpiled wet, this may be a reflection of the highly water soluble nature of these contaminants and consequently that they remained entrained within the process water. Unfortunately comparable test data is not available for the drained stock piles, although consideration of the data collected during normal operation of the plant suggests that concentrations were significantly reduced, as would be expected for a free draining granular material. However, these results could only be considered as indicative, as the sampling frequencies particularly of input and waste outputs were considerably less than for the clean outputs. They also varied throughout the project and may not necessarily be representative of feed and waste products as a whole. Furthermore, and more importantly from a commercial point of view, site action values were not exceeded for any analytes in any samples.

As the efficiency of the washing process is related to concentration of contaminant, inclusion of all of the data has the effect of reducing the apparent efficiency. Nevertheless, the data do show relatively good total mass balance given the sampling frequencies and the fact that the plant was being operated under normal commercial conditions. Differences between total input and output contaminant masses (e.g. phenol and chloride see Figure 9.3) is thought to be due to a combination of volatility, degradation and solution into the process water. In terms of distribution of contamination between the different product and waste fractions, the main fractionation occurred for the main target contaminant types (PAH, TPH and cyanide).

9.2.2 WASTE REDUCTION FACTOR

The waste reduction factor (WRF) is the amount by which the total mass of treated material is reduced to a clean fraction and can be described by:

$$\text{WRF} = \frac{\text{mass of clean fraction output}}{\text{mass of input material}}$$

The WRF is important in the overall economics of the process since the greater the mass of clean output, the greater the amount of material that can be re-used on the site and the lower the disposal costs for the contaminated waste stream.

WRFs for individual trials are listed in Table 9.3 and range from 0.7 to 0.9. The WRF for the entire soil washing operation calculated from the daily production records was 0.83 or 83 %.

Of the material submitted to the plant and processed as clean material, 99 % was successfully cleaned in the first pass to a level below the site limits. This was calculated on the basis of daily composite samples (see Section 4.5). Generally those samples that failed were marginal failures and in the majority of cases were associated with a high coarse organics content (coke fragments) within the gravel fraction.

9.2.3 CONTAMINANT REDUCTION FACTOR

The contaminant reduction factor (CRF) is the ratio of the contaminant concentration in the input and output streams and is described by:

$$\text{CRF} = \frac{\text{mean contaminant concentration in input stream}}{\text{mean contaminant concentration in clean output stream}}$$

CRFs were calculated for each main contaminant type during mass balance trials and varied substantially between each trial, with trials 3, 4, 6 and 7 showing greatest contaminant reduction. A CRF of 1 indicates that no reduction took place. Any value <1 indicates that the clean output stream contained higher contaminant concentrations than the input stream. A total of 50 CRFs were calculated and are listed in Table 9.3. Of the total, 8 CRF values were less than 1, and 2 values were equal to 1. Of the 40 values that exceeded 1, the minimum contaminant reduction was 1.1 for TPH in Trial 1 and the maximum reduction was 66 during Trial 7 also for TPH. Trial 7 performed the best, and Trial 8 performed the worst. It should be noted that the trials were carried out early in the project to help fine tune the process, and that the result of any one trial was not an indication of how the soil wash process operated overall.

Table 9.3: Waste reduction factors for each trial and contaminant reduction factors obtained for the main contaminants during each trial.

	Trial Number							
	1	2	3	4	5	6	7	8
WRF	0.8	0.7	0.7	0.9	0.7	0.8	0.7	N/A
CONTAMINANT								
Mineral Oil	-	-	-	-	-	2.7	1.2	-
PAH	2.4	2.9	0.9	-	1.2	3.2	2.0	0.4
Phenol	4.0	0.7	2.7	-	0.9	4.0	14.0	1.7
TPH	1.1	-	1.0	-	0.7	10.2	66.0	-
Sulphate	2.3	2.1	1.0	-	1.7	1.2		0.4
Ammonium	2.1	-	3.0	-	2.2	2.2	2.0	0.7
E.L. Cyanide	-	-	2.0	9.8	5.9	0.1		-
Complex Cyanide	-	-	14.0	4.7	2.0	2.6		-
Total Cyanide	2.6	-	15.3	-	-			1.7
Sulphur	2.3	-	6.0	-	-			-
Total Metals	3.9	-	4.0	-	1.4	1.7		-

Source: Parkman (2001)

9.3 RELIABILITY AND HOURS OF OPERATION

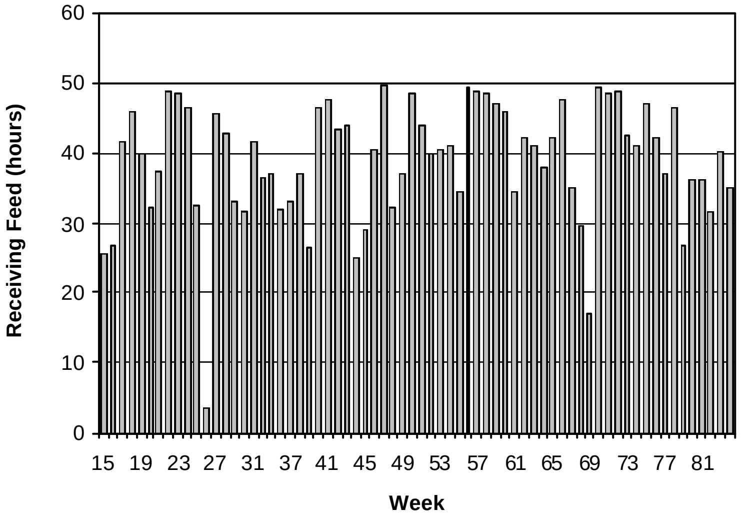
With this type of process, plant operation is optimised by running long and preferably continual shifts. The plant operated under all weather conditions. During the winter conditions pipes were drained on cold nights to prevent freezing. In all cases, adverse weather stopped the general excavation work before it stopped the plant except during occasional lightning storms when the plant was shut down to avoid work on high steel gantries.

The project planning permission restricted site operating hours from 07:30 to 18:00 hours in order to avoid potential noise impacts to the adjacent residential community. Noise levels were measured at various distances from the soil washing plant. There were a number of different contributors to noise at the site, depending on the time of day, including: other plant on site, local road traffic and general urban background noise.

The section of the plant which generated the highest noise levels proved to be the initial input dry screen to the plant. In the course of the works it became obvious that the soil washing plant was relatively quiet and did not greatly disturb local residents, particularly compared to other site operations such as concrete breaking, and did not have a greater impact than is typical of most construction/remediation projects. In future projects, the site working hours could be extended beyond the restricted limits for activities solely related to soil washing.

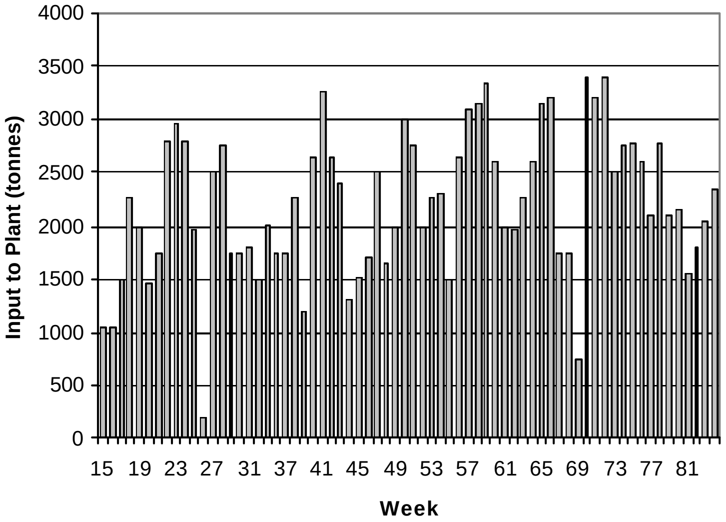
The requirements of the Waste Management Licence exemption also restricted the amount of material that could be processed in a single day to 500 tonnes. On peak production days this could be exceeded and on occasion, production rates had to be reduced to ensure it was not exceeded by an unreasonable amount. The wider application of Mobile Plant Licences to contaminated soil processing plants removes this obstacle.

Figures 9.6 and 9.7 show the operational hours and input masses to the soil washing plant during the project. In general, productivity was more variable than had been initially anticipated although this was to a large extent compensated for by fewer failures of batches of product. A number of factors contributed to plant down time including tearing of the conveyors by metal fragments, despite the presence of bulk magnetic separators, and blockages in transfer pipes, which tended to extend down time when the plant had to be stopped for other reasons.



Source: Parkman (2001)

Figure 9.6: Operational hours of the soil wash plant.



Source: Parkman (2001)

Figure 9.7: Input masses to the soil wash plant.

9.4 FILTER CAKE

The filter method was chosen to be the most cost effective for the job commensurate with the desired throughput.

The degree of contamination of the filter cake was typically three times the input concentration. At the beginning of the project, it was anticipated that the filter cake would contain less water and resemble a soft clay rather than a sludge or sewage slurry/cake.

In practice, the consistency of the cake varied from a soft clay with an angle of repose in a 1 m high heap of 40 º to a slurry with almost no angle of repose. Furthermore, even high quality cake was found to deteriorate either when worked or through vibration when travelling to tip, which was inevitable with road haulage. In practice, in excess of 15,000 tonnes of excavated contaminated soil were blended with the filter cake to stabilise it to a degree where it could be landfilled off-site. The high oil/tar content of the filter cake, which made it thixotropic, caused acute problems with the landfill site which was temporarily obliged to close, as heavy plant and machinery could not operate on it immediately. It would seem likely that with the banning of the co-disposal of wastes and the introduction of waste acceptance criteria (WAC), that the disposal of this material will become much more difficult unless its physical properties can be improved in future projects. Optimisation of the flocculation additives was a major issue and difficult since the feedstock was not homogeneous. This required constant adjustment to ensure optimal quality of the filter cake.

The limited number of analyses of the cake were not interpreted in detail. However, from site observations it was obvious that the viscosity of the cake was a function of several factors, including moisture content, liquid contaminant content (oils), the flocculent used, particle sizes within the cake and other contaminants, such as sulphate, which may adversely react with the flocculent.

10. ECONOMIC CONSIDERATIONS

The cost of soil washing 152,042 tonnes of material to produce 125,761 tonnes of cleaned and 32,240 tonnes of contaminated material was £21.11/tonne excluding screening of the feed and £20.43/tonne, including screening the feed. The screening process was not originally included as part of the soil washing process and was costed as a separate item.

The following assumptions were taken into account when arriving at this figure. These were:

i) The initial detailed ground investigation and feasibility studies were not included. These costs were omitted on the grounds that the detailed characterisation of the site was probably more important for the savings through selective digging and other process techniques. Also, to a degree, these were 'first time' costs associated with the unique nature of this technique within the UK.

ii) The loading shovels were built into the cost as these were items of plant that were dedicated to serving the soil washing plant. However, an allowance was made for the fact that they did do other items of work such as loading the off-site lorries.

iii) Down time and delays for whatever reason, including power failures, breakdowns (whether the soil washing contractors fault or not), were all included in the overall cost analysis. Such delays were judged to be likely to occur on future projects.

iv) The cost of disposing of the filter cake was factored in.

v) The cost of constructing the slab and setting up the soil wash plant was included.

vi) The water and power supplies to the plant were included.

vii) The cost of re-processing material that failed the first process pass were not included as they were reflected in the input figure.

viii) The cost of disposing of material that failed the first process pass was included.

It was felt that the original site investigation data did not provide sufficient confidence in the volumes of material capable of being treated for the project to proceed. Consequently a significantly more detailed site investigation was implemented. At face value, the cost of this second phase of investigation was prohibitively high assuming that the only benefit was to provide confidence in the soil washing volumes.

However, it must be remembered that during the course of a typical remediation project, many hundreds of soil samples will be tested in order to characterise excavated stockpiles into waste categories, or to prove that material is below the site action value and can be re-used. In this context, the approach adopted simply shifted the spend profile towards the start of the project. Obviously, there were extra costs associated with this approach (plant hire, staff etc.) however it is considered that the benefits that accrued from use of these data to better plan site activities during the remediation phase and the increased confidence in project budgets outweighed the costs.

11. ENVIRONMENTAL BENEFITS

11.1 REDUCED VEHICLE MOVEMENTS

Basford is at the centre of a mixed residential and industrial area. The entrance to the site has poor visibility in both directions and fronts onto a busy road. Nottingham City Council were extremely concerned that the large number of vehicle movements (in excess of 100 per day) associated with a dig and dump approach would contribute to accidents and inconvenience the local residents through the generation of dust, noise and fumes.

Figure 11.1 shows the difference in lorry movements between the two approaches. The on-site processing scheme saved over 14,500 lorry movements compared to the traditional dig and dump approach, a significant benefit to the local community over the lifetime of the project.

The reduction in lorry movements also brought wider environmental benefits. Figure 11.1 shows the actual road miles incurred during the project compared to those which would have been incurred using dig and dump. The on-site processing scheme saved over 14,500 lorry movements compared to the traditional dig and dump approach, a significant benefit to the local community over the lifetime of the project. In addition, the avoidance of nearly 700,000 miles of transportation gave a resultant saving of approximately 86,000 gallons of diesel fuel and a corresponding reduction in associated exhaust gas emissions.

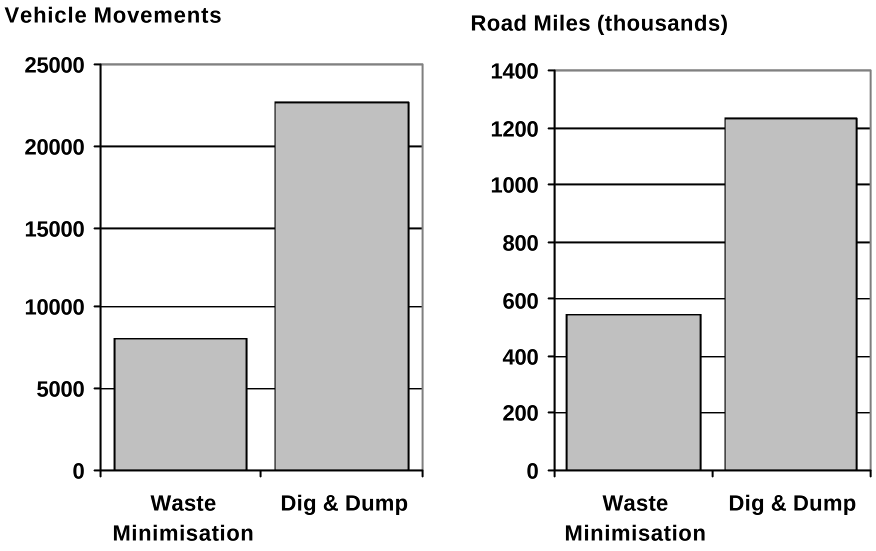


Figure 11.1. Comparison of vehicle movements and total road miles between soil washing and landfilling.

11.2 REDUCED DEMAND FOR LANDFILL AND PRIMARY AGGREGATES

The waste minimisation approach aimed to retain as much material as possible on site, thereby greatly reducing off-site disposal and corresponding import of clean fill. Figure 11.2 shows the materials balance for the Basford project in terms of the relative amounts of materials directly recovered, washed and disposed of to landfill.

It is estimated that using traditional site characterisation and remedial methods at this site, only 11 % of the total excavation volume would have been recovered with the remainder going to landfill. By contrast, with the application of the reclamation strategy described in

Chapter 4 of this report, SecondSite was able to recover for re-use approximately 76 % of the excavated material; 35 % by direct recovery and 41 % by soil washing. As over 200,000 tonnes of contaminated material was excavated over the duration of the project, this represents a substantial saving in landfill space and primary aggregate production.

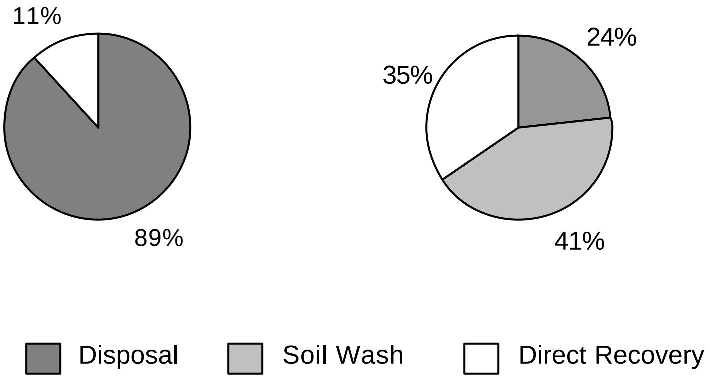


Figure 11.2: Materials balance for conventional and soil washing based remediation.

11.3 ENERGY USAGE

Whilst the primary aim of the project was to remediate the site by waste minimisation methods, it is important to consider the amount of energy consumed in this approach. Relative energy consumption calculations were based on the electrical power usage of the soil washing plant and the fuel use of the vehicles involved in feeding the plant and also in moving the untreatable material and the wash residues to landfill. The dig and dump comparison assumed removal of all contaminated material to landfill. Figure 11.3 shows that the application of soil washing resulted in a reduction in energy usage over traditional dig and dump.

Many recycling projects in different industry sectors have been shown to have a net negative environmental impact based on life cycle analysis due to high energy consumptions per unit recovered. In this case, the basis of the difference is mostly due to the relatively low energy consumptions of the on-site processing plant compared to road haulage. Haulage distances on this project were typical of many regeneration projects, showing that materials recovery can be energy efficient as well as attracting more obvious environmental benefits.

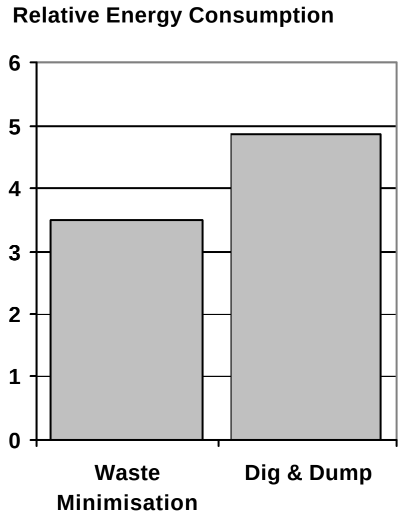


Figure 11.3: Comparison of energy consumption between soil washing and landfilling.

12. CONCLUSIONS

1. The results have demonstrated that soil washing technology is capable of treating a wide range of granular made ground and natural soil types contaminated with gasworks processing wastes.

2. This project has shown that one of the main factors governing the economic viability of soil washing is the amount and moisture content of the contaminated fines fraction and the associated disposal cost. In the extreme it is possible that a landfill operator would refuse to take such fines on the grounds of geotechnical properties alone (or at least charge a premium to take them). A method for treatment of the fines which would either render them suitable for re-use on the site or more acceptable to the landfill operator would significantly improve the economic viability of soil washing. Processes currently under consideration include solvent washing and chemical stabilisation. Pilot tests of the solvent washing process were encouraging and demonstrated that treatment targets could be attained, however, the overall economic viability is uncertain at this time.

3. Due to the high mobilisation costs associated with most *ex situ* treatment processes, it is unlikely that many will be cost effective on projects where there are relatively small volumes of material requiring treatment. One possible solution would be to establish 'semi-mobile' processing plant, which can set up at a central hub site to process materials from other sites within an economic transport radius before moving on to another location. Another would be to erect a fixed treatment plant at the edge of an operating landfill. However, there are clearly regulatory issues which need to be addressed before this can happen, perhaps the most significant of which is the interpretation of when the treated material ceases to be classified as a waste.

4. The need for pilot studies remains one of the major barriers to the introduction of many remediation technologies to the UK market. Site owners are faced with the prospect of either adopting, with a high degree of confidence, the conventional disposal to landfill approach or having to invest in further site investigation and pilot studies to prove the viability of a proposed technology. Obviously, if this additional work subsequently shows that the technology is not suitable, the investment has been wasted. Since, at present, there is little perceived difference between off-site disposal costs and on-site treatment costs in many cases, it is difficult to justify the financial risk in embarking on a project which might have to be aborted. The scale of the pilot study is also important, as larger scale tests provide more confidence. However, this also increases the financial risk and, in the case of Basford, one of the originally short listed technology vendors was rejected due to the excessively high cost and scale of the proposed pilot study. To a certain extent these are issues which have to be addressed by the technology vendors in structuring payment terms for pilot studies which, if successful would lead to full scale implementation.

5. The use of a novel remediation method on this site has been very well received by a wide range of interested parties from the local residents, who have seen a key site regenerated in a manner which has minimised traffic movements, to the Environment Agency and Environmental Health Department both of whom have been supportive of the approach adopted.

13. LESSONS LEARNED

13.1 INTRODUCTION

Whilst the overall project was successful both in economic and in technical terms, with any project, there are always areas where, with hindsight, improvements could have been made. Soil washing is a well established technology in some countries (e.g. Germany and the Netherlands), consequently confidence that the technology could be applied at this site was high. Much of the pilot study work was targeted at scaling the unit processes and establishing the contractual commitments of both parties.

The following comments on lessons learned are divided into regulatory, contractual and technical issues.

13.2 REGULATORY ISSUES

At the time that the project was commissioned, the current Mobile Plant Licensing (MPL) regime had not been introduced. The soil washing element of the project was conducted (in agreement with the EA) under an exemption from waste management licensing. All parties agreed that this was not ideal as it restricted productivity, but there was little alternative if a site waste management license was to be avoided with a concomitant risk to future development of the site. Clearly, any use of the same technology now would be subjected to the more appropriate mobile plant licensing regime. This change in itself would improve the economics of the process by allowing greater productivity. The interface between normal site works (excavation and stock piling etc) was found to be critical to the success of the project and concerns remain that these will be regulated under different systems. These problems are exacerbated when more than one process technology is proposed, as integration becomes a key issue and the need for multiple MPLs impacts the economics. It is considered that truly integrated and sustainable approaches will only be encouraged under the proposed Remediation Permit (Remediation Permit Working Group 2002).

Interpretation of the definition of waste as applied to contaminated land remediation remains a concern and will continue to be a barrier to *ex situ* remediation technologies until it is resolved.

The project was implemented with the benefit of planning permission and estimates of noise levels had to be provided in support of the planning application. This placed a further restriction on productivity (although secondary to the waste licensing issue). Noise monitoring during operation revealed that the plant was quieter than anticipated and, in retrospect, longer working hours would have been possible.

This project only proved to be economic due to the relatively large quantities of material requiring treatment. Many brownfield regeneration projects are significantly smaller than Basford, which makes many process-based remediation technologies not cost effective. It is recommended that a licensing regime for temporary location of fixed site treatment technologies be considered, whereby soil from a number of local sites could be treated before relocating the plant to another area.

13.3 CONTRACTUAL ISSUES

The soil washing sub-contract was established with three separate elements, namely mobilisation (and demobilisation), unit time charge and price per tonne of successfully treated material. For future projects, payment should be on only the basis of an initial mobilisation and corresponding demobilisation fee and then based on a price per tonne of clean produced soil. The removal of any time charge element would ensure that any losses due to down time from unreliability, or limited operating hours due to the requirements of the contractor's workforce would be borne by the nominated sub-contractor alone.

Additionally, though the soil washing contractor on this project was working to an end specification for 'clean' material in terms of both chemical and geotechnical properties, there was no contractual mechanism for properly controlling the physical quality of the filter cake. In some instances this led to difficulties in storage and transport of the cake and, in extreme cases, problems with the designated landfill site's ability to accept it. In future projects, it is therefore recommended that the physical properties of the cake be defined at the outset from laboratory and pilot scale trials.

13.4 TECHNICAL ISSUES

The use of simple lab tests such as size/contaminant distribution can give a very useful first indication as to whether or not soil washing is potentially applicable. If these look promising then further lab tests to remove specific mineral/material types can be conducted (e.g. sink/float tests). However, as has been found in this study, it is not just the ability to separate the contaminants to specific fractions that determines applicability, the optimisation of dewatering and filtration of the fines is also a key cost driver.

As discussed, the soil wash contractor made an offer based on an estimate of the ability of the plant to treat a range of contaminants and concentrations in a range of material types. Performance of the plant during the main phase of the contract demonstrated that it was capable of treating a wider range of materials than had been anticipated. Clearly, some of the difference was due to the contractor taking a conservative view of likely performance for contractual reasons. It is recommended that performance data be collated and assessed over a range of projects so that a better understanding of the potential for soil washing is obtained.

Quality of product was generally very high, with 99 % of all batches achieving the specified remediation target. Experience on this project has shown that where soluble contamination (such as phenolics) are present in significant quantities, it may be prudent to include an additional 'rinse' step to remove entrained, contaminated water.

Fines dewatering and subsequent filter cake disposal remain a concern and were perhaps the subject of more discussion during the project than any other single issue. It is predicted that disposal of filter cake will become more problematic as the European Landfill Directive is introduced, as such materials are likely to fail the waste acceptance criteria (WAC). It is recommended that further research is conducted into stabilisation and/or treatment of filter cake.

GLOSSARY OF TERMS

Activated carbon
A powdered or granular carbon which has been treated to remove hydrocarbons and to increase its powers of adsorption.

Adsorbed contamination
Contamination that is suspended on the surface of a solid liquid or gas particle.

Adsorptive capacity
A measure of how well a contaminant can be adsorbed onto the surface of a solid, liquid or gas particle.

Aliphatic hydrocarbons
Straight chained hydrocarbon without a benzene ring (C_6H_6).

Ammoniacal liquors
Waste liquid containing ammonia, phenol and tar, formed as a waste material from coal gas manufacture.

Ammonium sulphate
A white soluble crystalline salt $(NH_4)_2SO_4$, obtained as a by-product of coal-gas manufacture.

Aqua Regia digest
Method for dissolving rock and soil samples using a mixture of concentrated nitric and hydrochloric acids. The resultant solution can be analysed for metals by either Atomic Absorption or Inductively Coupled Plasma Emission Spectroscopy.

Aquifer
A subsurface permeable unit which is capable of transmitting significant quantities of groundwater.

Attrition scrubbing
A process within soil washing where the soil particles rub against each other, so removing the more adherent contaminant films from coarser particles.

Chromatography
The chemical method of separating compounds dissolved in one phase (usually mobile) through its equilibration with a second phase (usually stationary). The mechanism of separation may involve partition, adsorption, permeation or ion exchange.

Clinker
A fragment of incombustible material that is left after a wood, coal or charcoal fire.

Coal Carbonisation
The process whereby coal is heated in a retort in the absence of air and decomposes into coke and coal gas.

Coal Tar
A black viscous acidic liquid containing water and a vast range of hydrocarbon compounds with molecular weights varying from 10 to 4,000.

Coke
A greyish porous brittle solid containing about 80 % carbon. Often obtained as a residue in the manufacture of coal gas; also made specially in coke ovens, in which the coal is treated at lower temperatures than in gas manufacture.

Complex cyanides
Cyanide ion forming compounds with metal groups such as Cr, Mn, Fe. Many metal ions normally unstable in solution are stabilised when complexed with cyanide ions. Two common complexes are ferrocyanide $[Fe(CN)_6]^{4-}$ and ferricyanide $[Fe(CN)_6]^{3-}$.

Composite sample
A representative mixture of several different samples.

Contaminant
Any hazardous substance that does not occur naturally, or occurs at greater than natural background levels.

Cross Flow Clarifier (CFC)
This is a technology used to remove oils and solids from residual water. It takes advantage of the natural tendency of oils to float, and the decantation principle for suspended solids that are denser than water.

Dense medium separator
A section of plant used in soil washing where material is fed into a cyclone and separation of material occurs according to the density of the material.

Diesel Range Organics (DRO)
Organic Compounds which elute by gas chromatography between the beginning of n–C_{10} and the beginning of n-C_{25}

Ex situ
Having been removed from the original place of residence; as in the case with soil that has been excavated for treatment.

Fill materials
Materials that has been brought together from a number of sources such as brick rubble, concrete etc and used to raise the natural level of ground.

Filter press
An apparatus used for carrying out filtration. It consists of a series of frames, two sides of which are covered with filter cloth. The frames are clamped together and the liquid to be filtered is pumped into them so the solid residue forms a cake between the cloths while the filtrate is drained off.

Hydrocyclones
Used for separation and material classification operations and can be used as thickening devices prior to centrifuge or filtration.

Hydrosizers
A hydraulic screen which classifies and separates particle on the basis of settling velocities through a zone of suspended solids.

In situ
in place, without removal.

Made ground
Manmade soil that is laying on top of natural ground and often consist of natural soil mixed with clinker, ash, concrete and brick fragments etc.

Motor benzol
Formed as a by product when heating the coal to form gas.

Phenolics
Aromatic compound containing hydroxyl groups attached to a benzene ring.

Polynuclear aromatic hydrocarbons (PAHs)
Hydrocarbon compound with multiple benzene rings. PAHs are typical components of asphalts, fuels, oils, and greases. They are also called Polycyclic Aromatic Hydrocarbons.

Remediation
The process of making a site fit-for-purpose through destruction, removal or containment of contaminants.

Retort
An oven used for the carbonisation of coal.

Sedimentation
The process of separating an insoluble solid from a liquid in which it is suspended by allowing it to fall to the bottom of the containing vessel, with or without agitation or centrifuging.

Site investigation
A study of an area of land including an intrusive study of the soil and groundwater.

Slaked lime
Calcium hydroxide $Ca(OH)_2$ formed by the heating of limestone. Lime was used as a purification agent prior to the introduction of ferric oxide in the 1890s. On becoming saturated with gas impurities, principally hydrocyanic and sulphuric acid the lime was said to become slaked.

Sorption
processes including adsorption and absorption, by which contaminants attached themselves to solid particles, thereby retarding their transport or movement.

Spent oxide
Ferric oxide used as purifying agent within coal gas production. On becoming saturated with Gas impurities, principally Hydrocyanic and Sulphuric Acid the Ferric oxide was said to be “spent”.

Sulphuric acid
A colourless oily liquid acid. It is extremely corrosive, and reacts violently with water, creating heat and can char organic matter. It is used extensively in many processes in the chemical industry.

Surfactant
A substance introduced into a liquid in order to affect (normally increase) its spreading and wetting properties. Detergent is a very common surfactant.

Thixotropic
Describes a material which undergoes a reduction in viscosity when shaken or otherwise mechanically disturbed and which readily recovers its original condition on standing.

Trial pitting
The excavation of holes in the ground using a mechanical excavator in order that a visual inspection can be made of the soil and samples can be taken for further inspection and laboratory analysis.

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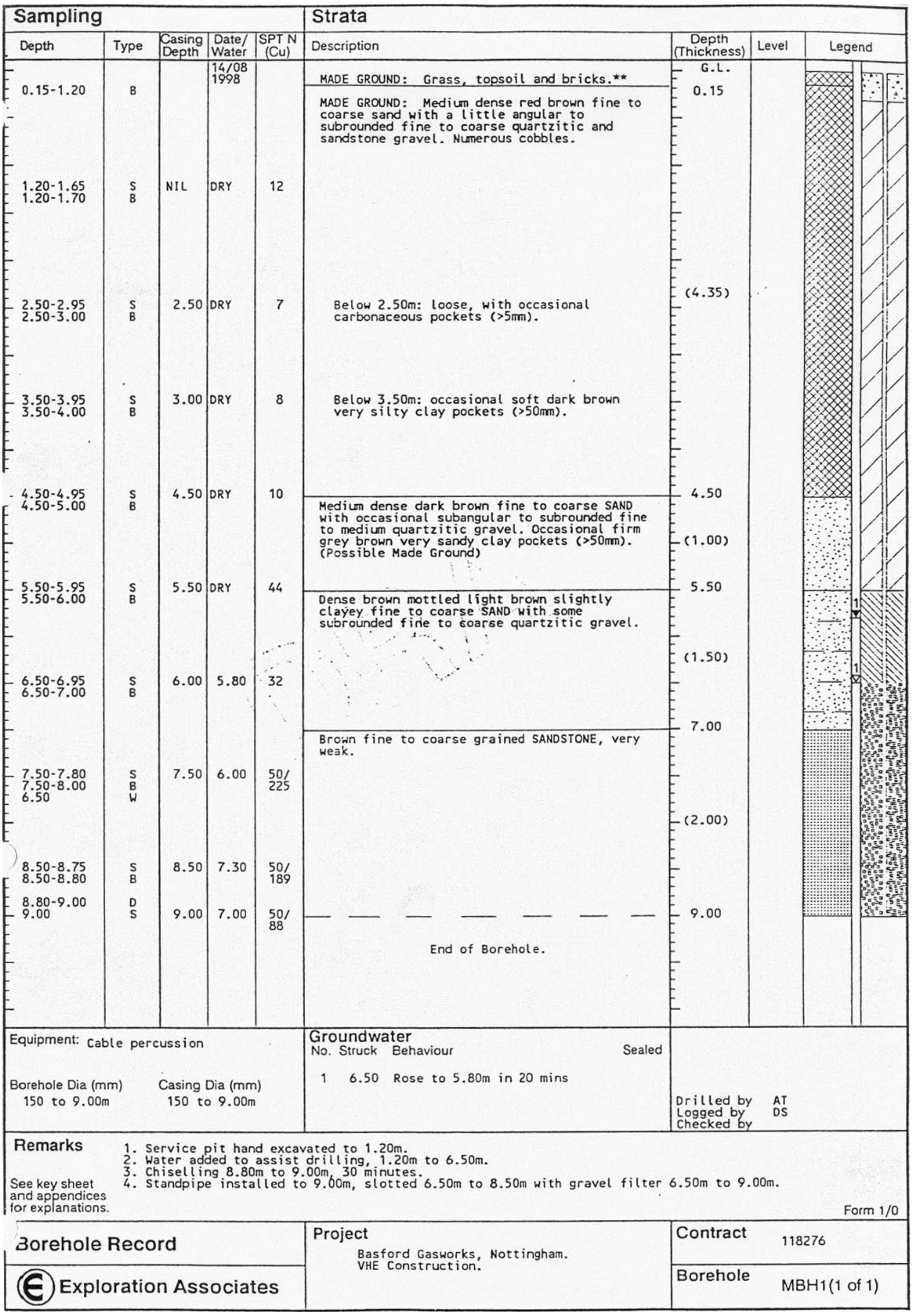
APPENDICES

Appendix 1: Representative Borehole Logs
Appendix 2: Detailed Soil Chemistry
Appendix 3: Particle Size Distribution Curves
Appendix 4: Plates
Appendix 5: Contact Details

APPENDIX 1
REPRESENTATIVE BOREHOLE LOGS



Sampling

Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)
			14/08 1998	
0.15-1.20	B			
1.20-1.65	S	NIL	DRY	12
1.20-1.70	B			
2.50-2.95	S	2.50	DRY	7
2.50-3.00	B			
3.50-3.95	S	3.00	DRY	8
3.50-4.00	B			
4.50-4.95	S	4.50	DRY	10
4.50-5.00	B			
5.50-5.95	S	5.50	DRY	44
5.50-6.00	B			
6.50-6.95	S	6.00	5.80	32
6.50-7.00	B			
7.50-7.80	S	7.50	6.00	50/ 225
7.50-8.00	B			
6.50	W			
8.50-8.75	S	8.50	7.30	50/ 189
8.50-8.80	B			
8.80-9.00	D			
9.00	S	9.00	7.00	50/ 88

Strata

Description	Depth (Thickness)	Level	Legend
	G.L.		
MADE GROUND: Grass, topsoil and bricks.**	0.15		
MADE GROUND: Medium dense red brown fine to coarse sand with a little angular to subrounded fine to coarse quartzitic and sandstone gravel. Numerous cobbles. Below 2.50m: loose, with occasional carbonaceous pockets (>5mm). Below 3.50m: occasional soft dark brown very silty clay pockets (>50mm).	(4.35) 4.50		
Medium dense dark brown fine to coarse SAND with occasional subangular to subrounded fine to medium quartzitic gravel. Occasional firm grey brown very sandy clay pockets (>50mm). (Possible Made Ground)	(1.00) 5.50		
Dense brown mottled light brown slightly clayey fine to coarse SAND with some subrounded fine to coarse quartzitic gravel.	(1.50) 7.00		
Brown fine to coarse grained SANDSTONE, very weak.	(2.00) 9.00		
End of Borehole.			

Equipment: Cable percussion

Borehole Dia (mm)
150 to 9.00m

Casing Dia (mm)
150 to 9.00m

Groundwater

No.	Struck	Behaviour	Sealed
1	6.50	Rose to 5.80m in 20 mins	

Drilled by AT
Logged by DS
Checked by

Remarks

1. Service pit hand excavated to 1.20m.
2. Water added to assist drilling, 1.20m to 6.50m.
3. Chiselling 8.80m to 9.00m, 30 minutes.
4. Standpipe installed to 9.00m, slotted 6.50m to 8.50m with gravel filter 6.50m to 9.00m.

See key sheet and appendices for explanations.

Form 1/0

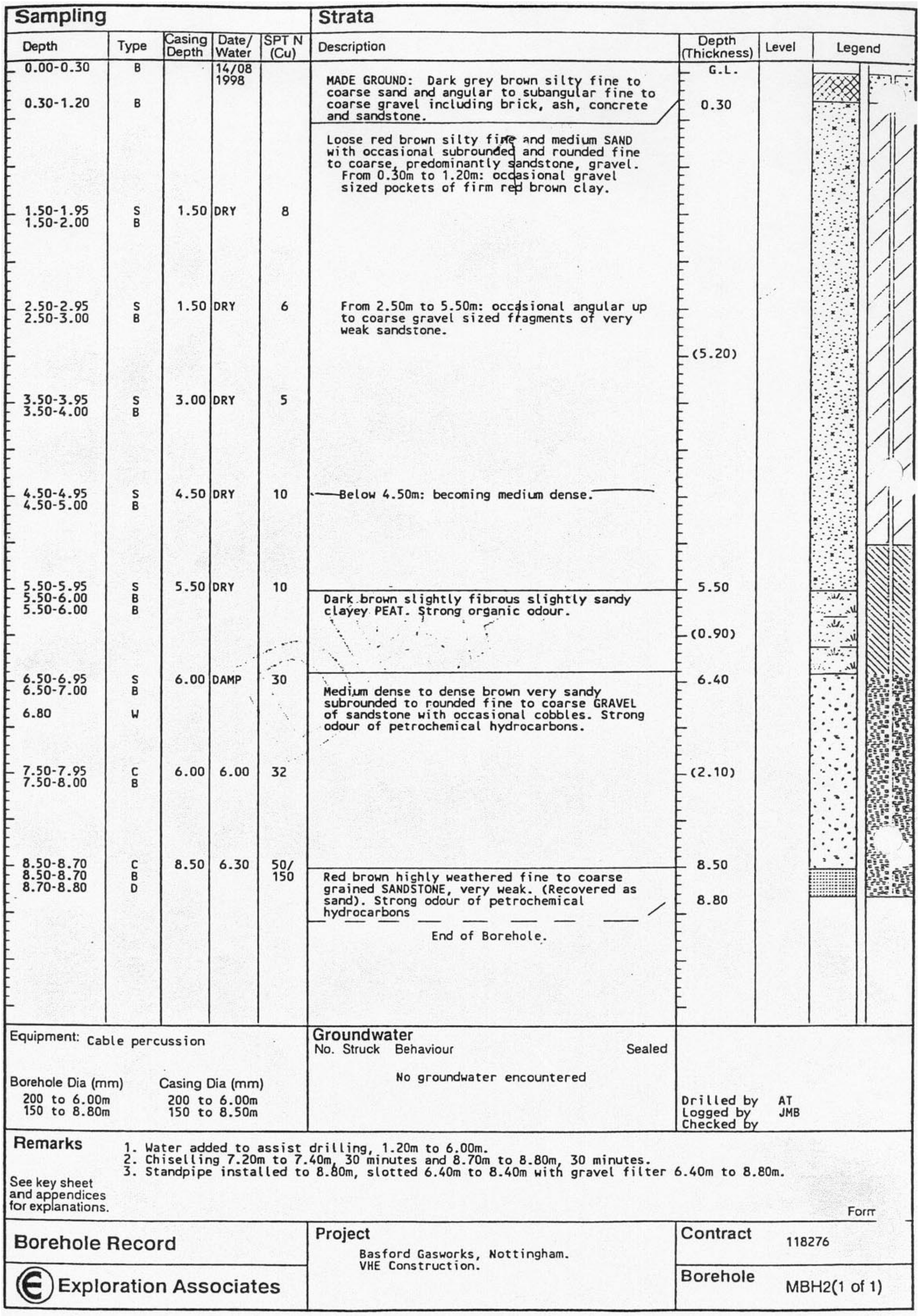
Borehole Record

Exploration Associates

Project
Basford Gasworks, Nottingham.
VHE Construction.

Contract 118276

Borehole MBH1(1 of 1)



Sampling | Strata

Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)	Description	Depth (Thickness)	Level	Legend
0.00-0.30	B		14/08 1998		MADE GROUND: Dark grey brown silty fine to coarse sand and angular to subangular fine to coarse gravel including brick, ash, concrete and sandstone.	G.L. 0.30		
0.30-1.20	B				Loose red brown silty fine and medium SAND with occasional subrounded and rounded fine to coarse, predominantly sandstone, gravel. From 0.30m to 1.20m: occasional gravel sized pockets of firm red brown clay.			
1.50-1.95 1.50-2.00	S B	1.50	DRY	8				
2.50-2.95 2.50-3.00	S B	1.50	DRY	6	From 2.50m to 5.50m: occasional angular up to coarse gravel sized fragments of very weak sandstone.	(5.20)		
3.50-3.95 3.50-4.00	S B	3.00	DRY	5				
4.50-4.95 4.50-5.00	S B	4.50	DRY	10	Below 4.50m: becoming medium dense.			
5.50-5.95 5.50-6.00 5.50-6.00	S B B	5.50	DRY	10	Dark brown slightly fibrous slightly sandy clayey PEAT. Strong organic odour.	5.50 (0.90)		
6.50-6.95 6.50-7.00	S B	6.00	DAMP	30	Medium dense to dense brown very sandy subrounded to rounded fine to coarse GRAVEL of sandstone with occasional cobbles. Strong odour of petrochemical hydrocarbons.	6.40		
6.80	W							
7.50-7.95 7.50-8.00	C B	6.00	6.00	32		(2.10)		
8.50-8.70 8.50-8.70 8.70-8.80	C B D	8.50	6.30	50/ 150	Red brown highly weathered fine to coarse grained SANDSTONE, very weak. (Recovered as sand). Strong odour of petrochemical hydrocarbons	8.50 8.80		
					End of Borehole.			

Equipment: Cable percussion

Borehole Dia (mm)
200 to 6.00m
150 to 8.80m

Casing Dia (mm)
200 to 6.00m
150 to 8.50m

Groundwater

No.	Struck	Behaviour	Sealed
		No groundwater encountered	

Drilled by AT
Logged by JMB
Checked by

Remarks

1. Water added to assist drilling, 1.20m to 6.00m.
2. Chiselling 7.20m to 7.40m, 30 minutes and 8.70m to 8.80m, 30 minutes.
3. Standpipe installed to 8.80m, slotted 6.40m to 8.40m with gravel filter 6.40m to 8.80m.

See key sheet and appendices for explanations.

Form

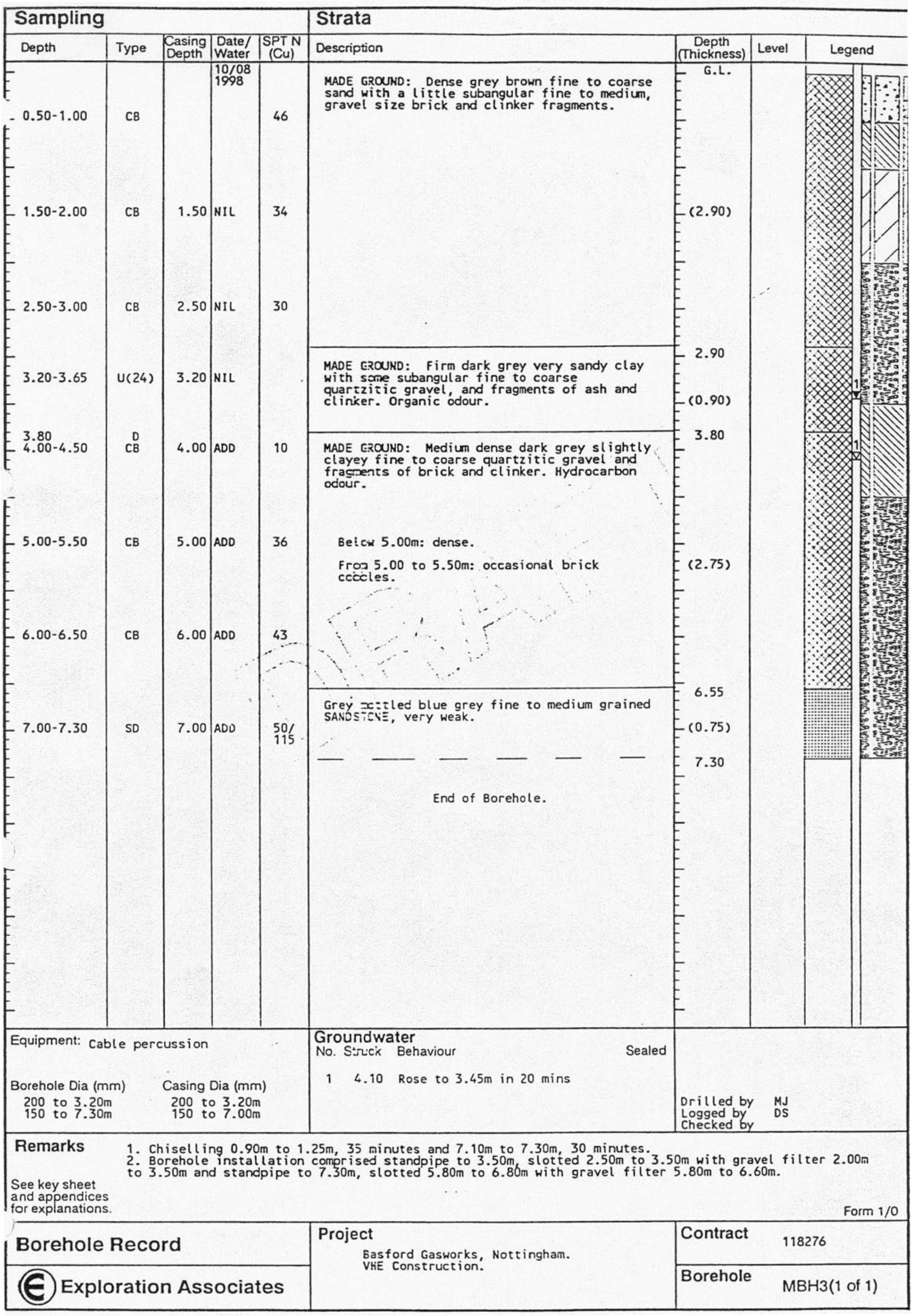
Borehole Record

Project
Basford Gasworks, Nottingham.
VHE Construction.

Contract 118276

Borehole MBH2(1 of 1)

Exploration Associates



Sampling

Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)
			10/08 1998	
0.50-1.00	CB			46
1.50-2.00	CB	1.50	NIL	34
2.50-3.00	CB	2.50	NIL	30
3.20-3.65	U(24)	3.20	NIL	
3.80	D			
4.00-4.50	CB	4.00	ADD	10
5.00-5.50	CB	5.00	ADD	36
6.00-6.50	CB	6.00	ADD	43
7.00-7.30	SD	7.00	ADD	50/ 115

Strata

Description	Depth (Thickness)	Level	Legend
	G.L.		
MADE GROUND: Dense grey brown fine to coarse sand with a little subangular fine to medium, gravel size brick and clinker fragments.	(2.90) 2.90		
MADE GROUND: Firm dark grey very sandy clay with some subangular fine to coarse quartzitic gravel, and fragments of ash and clinker. Organic odour.	(0.90) 3.80		
MADE GROUND: Medium dense dark grey slightly clayey fine to coarse quartzitic gravel and fragments of brick and clinker. Hydrocarbon odour. Below 5.00m: dense. From 5.00 to 5.50m: occasional brick cobbles.	(2.75) 6.55		
Grey mottled blue grey fine to medium grained SANDSTONE, very weak.	(0.75) 7.30		
End of Borehole.			

Equipment: Cable percussion

Borehole Dia (mm)	Casing Dia (mm)
200 to 3.20m	200 to 3.20m
150 to 7.30m	150 to 7.00m

Groundwater

No.	Struck	Behaviour	Sealed
1	4.10	Rose to 3.45m in 20 mins	

Drilled by MJ
Logged by DS
Checked by

Remarks

1. Chiselling 0.90m to 1.25m, 35 minutes and 7.10m to 7.30m, 30 minutes.
2. Borehole installation comprised standpipe to 3.50m, slotted 2.50m to 3.50m with gravel filter 2.00m to 3.50m and standpipe to 7.30m, slotted 5.80m to 6.80m with gravel filter 5.80m to 6.60m.

See key sheet and appendices for explanations.

Form 1/0

Borehole Record

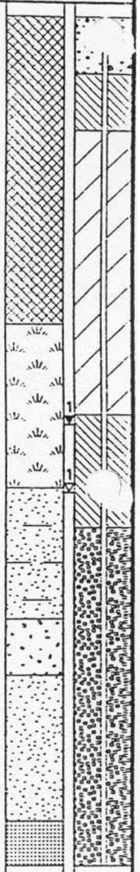
Exploration Associates

Project
Basford Gasworks, Nottingham.
VHE Construction.

Contract 118276

Borehole MBH3(1 of 1)

Sampling					Strata			
Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)	Description	Depth (Thickness)	Level	Legend
			07/08 1998		MADE GROUND: Dense grey brown silty fine to coarse sand with a little angular to subrounded fine to coarse quartzitic gravel and fragments of brick and clinker.	G.L.		
0.50-1.00	CB			39				
						(2.70)		
1.50-2.00	CB	1.50	NIL	39				
2.50-3.00	CB	2.50	ADD	26				
					Firm dark brown clayey PEAT with occasional rootlets.	2.70		
3.20-3.65	U(27)	3.20	NIL					
						(1.45)		
3.80	D							
						4.15		
4.30-4.80	CB	4.30	3.80	33	Dense peaty clayey fine to coarse SAND with some subrounded fine to medium quartzitic gravel.			
						(1.15)		
5.30-5.80	CB	5.30	ADD	27	Medium dense grey brown sandy subrounded fine to coarse quartzitic GRAVEL. Occasional cobbles. Hydrocarbon odour.	5.30 (0.50)		
					Dense red brown fine to coarse SAND with a little subangular to subrounded fine to medium quartzitic and sandstone gravel.	5.80		
6.30-6.80	CB	6.30	ADD	40				
						(1.30)		
					Red brown fine to coarse grained SANDSTONE, very weak.	7.10		
7.30-7.50	SD	7.30	3.90	50/ 105		(0.40) 7.50		
					End of Borehole.			



Equipment: Cable percussion

Borehole Dia (mm)
200 to 3.20m
150 to 7.50m

Casing Dia (mm)
200 to 3.20m
150 to 7.30m

Groundwater

No.	Struck	Behaviour	Sealed
1	4.20	Rose to 3.60m in 20 mins	

Drilled by MJ
Logged by DS
Checked by

Remarks

1. Chiselling 4.70m to 5.00m, 40 minutes and 7.30m to 7.50m, 30 minutes.
2. Borehole installation comprised standpipe to 7.50m, slotted 5.50m to 6.50m, with gravel filter 4.50m to 7.50m.

See key sheet and appendices for explanations.

Form

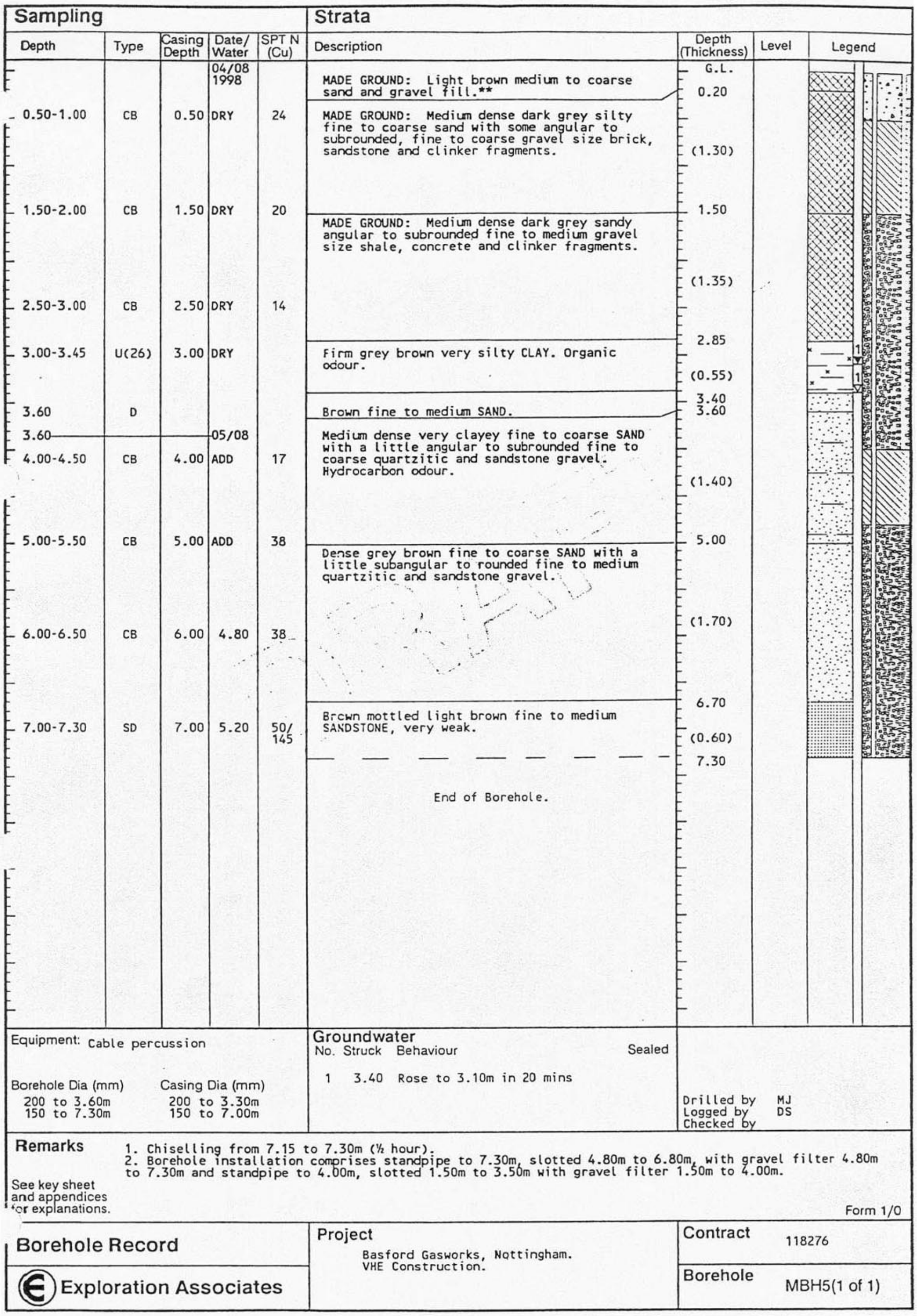
Borehole Record

Exploration Associates

Project
Basford Gasworks, Nottingham.
VHE Construction.

Contract 118276

Borehole MBH4(1 of 1)



Sampling

Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)
			04/08 1998	
0.50-1.00	CB	0.50	DRY	24
1.50-2.00	CB	1.50	DRY	20
2.50-3.00	CB	2.50	DRY	14
3.00-3.45	U(26)	3.00	DRY	
3.60	D			
3.60			05/08	
4.00-4.50	CB	4.00	ADD	17
5.00-5.50	CB	5.00	ADD	38
6.00-6.50	CB	6.00	4.80	38
7.00-7.30	SD	7.00	5.20	50/ 145

Strata

Description	Depth (Thickness)	Level	Legend
MADE GROUND: Light brown medium to coarse sand and gravel fill.**	G.L. 0.20		
MADE GROUND: Medium dense dark grey silty fine to coarse sand with some angular to subrounded, fine to coarse gravel size brick, sandstone and clinker fragments.	(1.30) 1.50		
MADE GROUND: Medium dense dark grey sandy angular to subrounded fine to medium gravel size shale, concrete and clinker fragments.	(1.35) 2.85		
Firm grey brown very silty CLAY. Organic odour.	(0.55) 3.40		
Brown fine to medium SAND.	3.60		
Medium dense very clayey fine to coarse SAND with a little angular to subrounded fine to coarse quartzitic and sandstone gravel. Hydrocarbon odour.	(1.40) 5.00		
Dense grey brown fine to coarse SAND with a little subangular to rounded fine to medium quartzitic and sandstone gravel.	(1.70) 6.70		
Brown mottled light brown fine to medium SANDSTONE, very weak.	(0.60) 7.30		
End of Borehole.			

Equipment: Cable percussion

Borehole Dia (mm)	Casing Dia (mm)
200 to 3.60m	200 to 3.30m
150 to 7.30m	150 to 7.00m

Groundwater

No.	Struck	Behaviour	Sealed
1	3.40	Rose to 3.10m in 20 mins	

Drilled by MJ
Logged by DS
Checked by

Remarks

1. Chiselling from 7.15 to 7.30m (½ hour).
2. Borehole installation comprises standpipe to 7.30m, slotted 4.80m to 6.80m, with gravel filter 4.80m to 7.30m and standpipe to 4.00m, slotted 1.50m to 3.50m with gravel filter 1.50m to 4.00m.

See key sheet and appendices for explanations.

Form 1/0

Borehole Record

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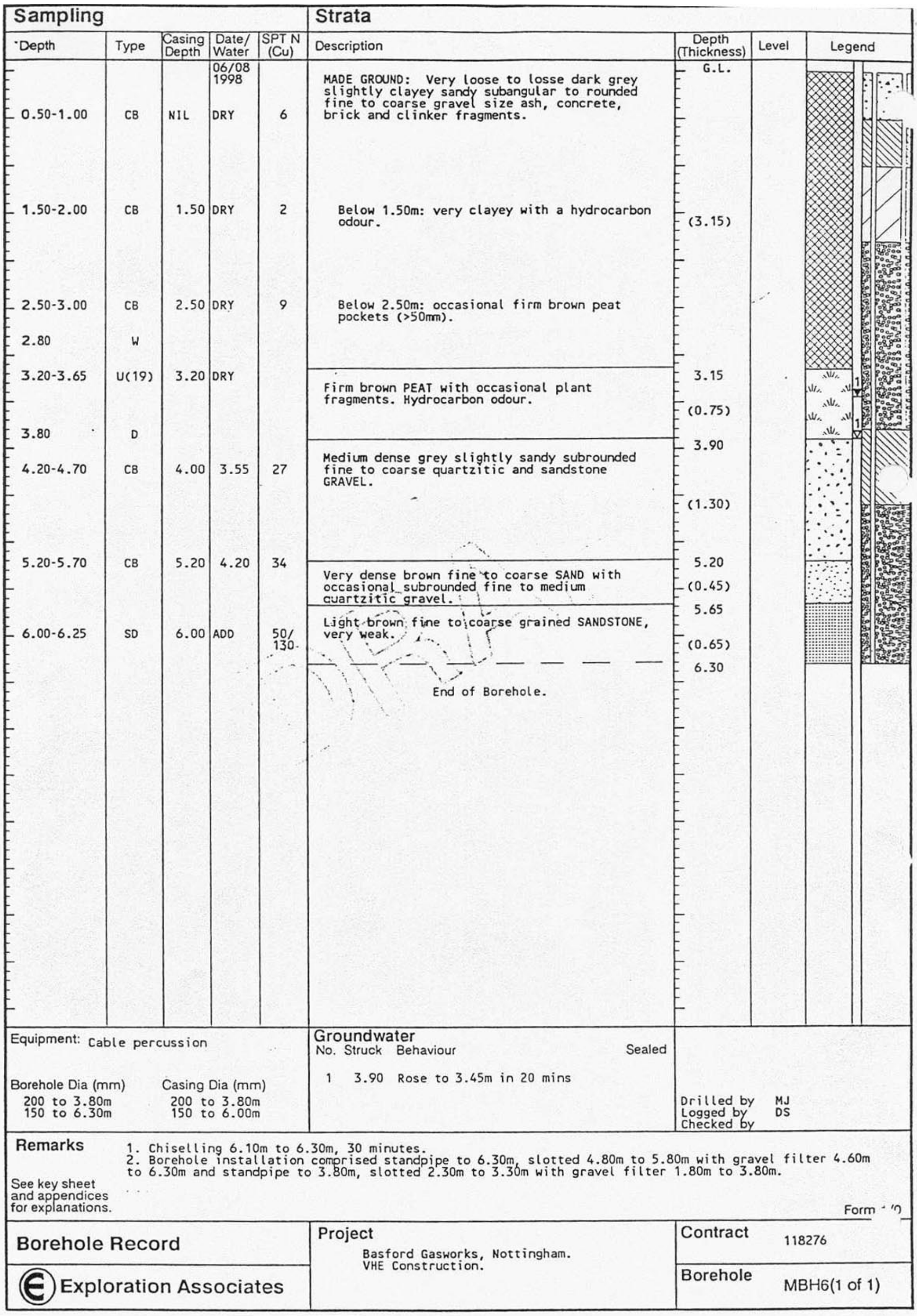
VHE Construction.

Contract 118276

Borehole MBH5(1 of 1)



Sampling

Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)
			06/08 1998	
0.50-1.00	CB	NIL	DRY	6
1.50-2.00	CB	1.50	DRY	2
2.50-3.00	CB	2.50	DRY	9
2.80	W			
3.20-3.65	U(19)	3.20	DRY	
3.80	D			
4.20-4.70	CB	4.00	3.55	27
5.20-5.70	CB	5.20	4.20	34
6.00-6.25	SD	6.00	ADD	50/ 130

Strata

Description	Depth (Thickness)	Level	Legend
	G.L.		
MADE GROUND: Very loose to losse dark grey slightly clayey sandy subangular to rounded fine to coarse gravel size ash, concrete, brick and clinker fragments. Below 1.50m: very clayey with a hydrocarbon odour. Below 2.50m: occasional firm brown peat pockets (>50mm).	(3.15)		
	3.15		
Firm brown PEAT with occasional plant fragments. Hydrocarbon odour.	(0.75)		
	3.90		
Medium dense grey slightly sandy subrounded fine to coarse quartzitic and sandstone GRAVEL.	(1.30)		
	5.20		
Very dense brown fine to coarse SAND with occasional subrounded fine to medium quartzitic gravel.	(0.45)		
	5.65		
Light brown fine to coarse grained SANDSTONE, very weak.	(0.65)		
	6.30		
End of Borehole.			

Equipment: Cable percussion

Borehole Dia (mm)	Casing Dia (mm)
200 to 3.80m	200 to 3.80m
150 to 6.30m	150 to 6.00m

Groundwater

No.	Struck	Behaviour	Sealed
1	3.90	Rose to 3.45m in 20 mins	

Drilled by MJ
Logged by DS
Checked by

Remarks

1. Chiselling 6.10m to 6.30m, 30 minutes.
2. Borehole installation comprised standpipe to 6.30m, slotted 4.80m to 5.80m with gravel filter 4.60m to 6.30m and standpipe to 3.80m, slotted 2.30m to 3.30m with gravel filter 1.80m to 3.80m.

See key sheet and appendices for explanations.

Form

Borehole Record

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VHE Construction.

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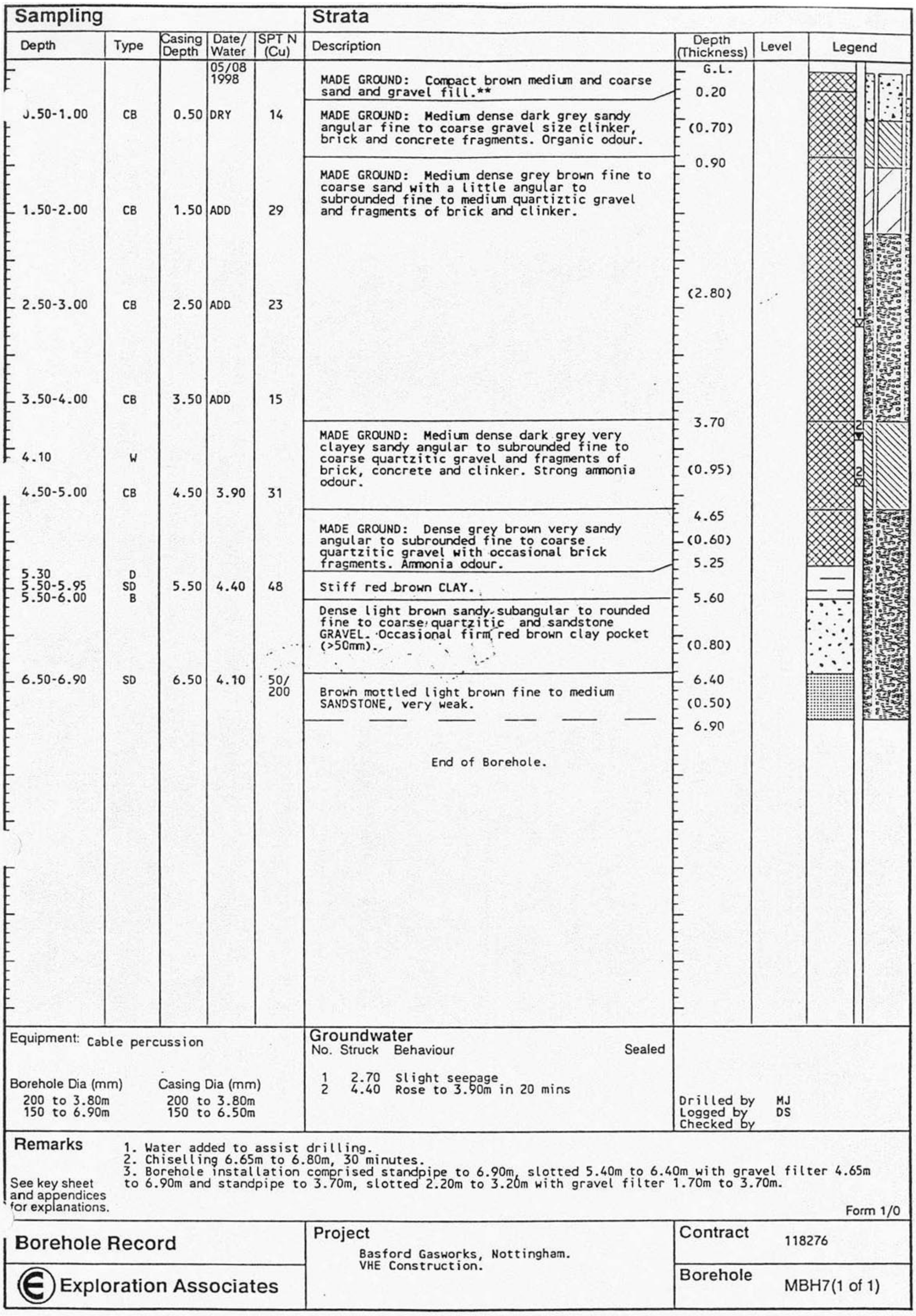
Borehole MBH6(1 of 1)



Sampling

Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)
			05/08 1998	
J.50-1.00	CB	0.50	DRY	14
1.50-2.00	CB	1.50	ADD	29
2.50-3.00	CB	2.50	ADD	23
3.50-4.00	CB	3.50	ADD	15
4.10	W			
4.50-5.00	CB	4.50	3.90	31
5.30	D			
5.50-5.95	SD	5.50	4.40	48
5.50-6.00	B			
6.50-6.90	SD	6.50	4.10	50/ 200

Strata

Description	Depth (Thickness)	Level	Legend
	G.L.		
MADE GROUND: Compact brown medium and coarse sand and gravel fill.**	0.20		
MADE GROUND: Medium dense dark grey sandy angular fine to coarse gravel size clinker, brick and concrete fragments. Organic odour.	(0.70) 0.90		
MADE GROUND: Medium dense grey brown fine to coarse sand with a little angular to subrounded fine to medium quartiztic gravel and fragments of brick and clinker.	(2.80) 3.70		
MADE GROUND: Medium dense dark grey very clayey sandy angular to subrounded fine to coarse quartzitic gravel and fragments of brick, concrete and clinker. Strong ammonia odour.	(0.95) 4.65		
MADE GROUND: Dense grey brown very sandy angular to subrounded fine to coarse quartzitic gravel with occasional brick fragments. Ammonia odour.	(0.60) 5.25		
Stiff red brown CLAY.	5.60		
Dense light brown sandy subangular to rounded fine to coarse quartzitic and sandstone GRAVEL. Occasional firm red brown clay pocket (>50mm).	(0.80) 6.40		
Brown mottled light brown fine to medium SANDSTONE, very weak.	(0.50) 6.90		

End of Borehole.

Equipment: Cable percussion

Borehole Dia (mm)	Casing Dia (mm)
200 to 3.80m	200 to 3.80m
150 to 6.90m	150 to 6.50m

Groundwater

No.	Struck	Behaviour	Sealed
1	2.70	Slight seepage	
2	4.40	Rose to 3.90m in 20 mins	

Drilled by MJ
Logged by DS
Checked by

Remarks

1. Water added to assist drilling.
2. Chiselling 6.65m to 6.80m, 30 minutes.
3. Borehole installation comprised standpipe to 6.90m, slotted 5.40m to 6.40m with gravel filter 4.65m to 6.90m and standpipe to 3.70m, slotted 2.20m to 3.20m with gravel filter 1.70m to 3.70m.

See key sheet and appendices for explanations.

Form 1/0

Borehole Record

Exploration Associates

Project
Basford Gasworks, Nottingham.
VHE Construction.

Contract 118276

Borehole MBH7(1 of 1)

Sampling					Strata			
Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)	Description	Depth (Thickness)	Level	Legend
			07/08 1998		MADE GROUND: Concrete.	G.L. 0.20		▨
0.20-1.20	B				MADE GROUND: Dark grey sandy angular to subrounded fine to coarse quartzitic gravel and brick and clinker fragments.	(1.00) 1.20		▨
1.20-1.70	B				Grey brown fine to coarse SAND with some angular to subrounded fine to coarse quartzitic and sandstone gravel.	(0.50) 1.70		⁘
1.50	C			50/ 0				
					End of Borehole.			

DRAFT

Equipment: Cable percussion

Borehole Dia (mm) 150 to 1.70m

Casing Dia (mm) 150 to 1.70m

Groundwater

No. Struck	Behaviour	Sealed
	No groundwater encountered	

Drilled by AT
Logged by DS
Checked by

Remarks

1. Chiselled at 1.70m for 1 hour, no progress. Location moved to MBH8A.
2. Borehole backfilled with arisings.

See key sheet and appendices for explanations.

Forr '0

Borehole Record

Exploration Associates

Project
Basford Gasworks, Nottingham.
VHE Construction.

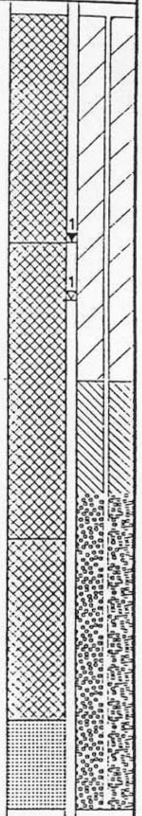
Contract 118276

Borehole MBH8(1 of 1)

Sampling / Strata

Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)	Description	Depth (Thickness)	Level
			17/08 1998		**MADE GROUND:** Medium dense dark brown fine to coarse sand with a little angular to subrounded fine to coarse quartzitic gravel and fragments of ash, concrete and brick.	G.L.	
0.50-0.95 0.50-1.00	S B	NIL	DRY	13			
						(2.00)	
1.50-1.95 1.50-2.00	S B	1.50	DRY	17			
					MADE GROUND: Dense dark brown fine to coarse sand with some angular to subrounded fine to coarse quartzitic gravel and fragments of brick, ash and shale.	2.00	
2.50-2.95	C	2.50	DRY	34			
2.50			18/08				
2.50-3.00 3.00	B W						
						(2.60)	
3.50-3.95 3.50-4.00	C B	3.00	2.00	29			
4.50-4.95 4.50-5.00	C B	4.50	3.10	43			
					MADE GROUND: Dense sandy angular fine to coarse gravel size fragments of brick, concrete and clinker. Numerous cobbles. Ammonia odour.	4.60	
5.10-5.40	B						
5.50-5.95 5.50-6.00	C B	5.50	2.50	42		(1.60)	
					Grey brown medium to coarse grained SANDSTONE, very weak. Ammonia odour.	6.20	
6.50 6.50-6.80	S B	6.00	2.10	49		(0.80)	
6.80-7.00 7.00	D C	7.00	3.50	50/ 117		7.00	
					End of Borehole.		

Legend



Equipment: Cable percussion

Borehole Dia (mm)	Casing Dia (mm)
200 to 7.00m	200 to 7.00m

Groundwater

No.	Struck	Behaviour	Sealed
1	2.50	Rose to 2.00m in 20 mins	

Drilled by AT
Logged by DS
Checked by

Remarks

1. Water added to assist drilling, 0.00m to 3.00m.
2. Chiselling 2.10m to 2.30m, 30 minutes; 5.10m to 5.40m, 1 hour and 6.70m to 7.00m, 1 hour.
3. Standpipe installed to 7.00m, slotted 4.20m to 6.50m with gravel filter 4.20m to 7.00m.

See key sheet
and appendices
for explanations.

Form 1/0

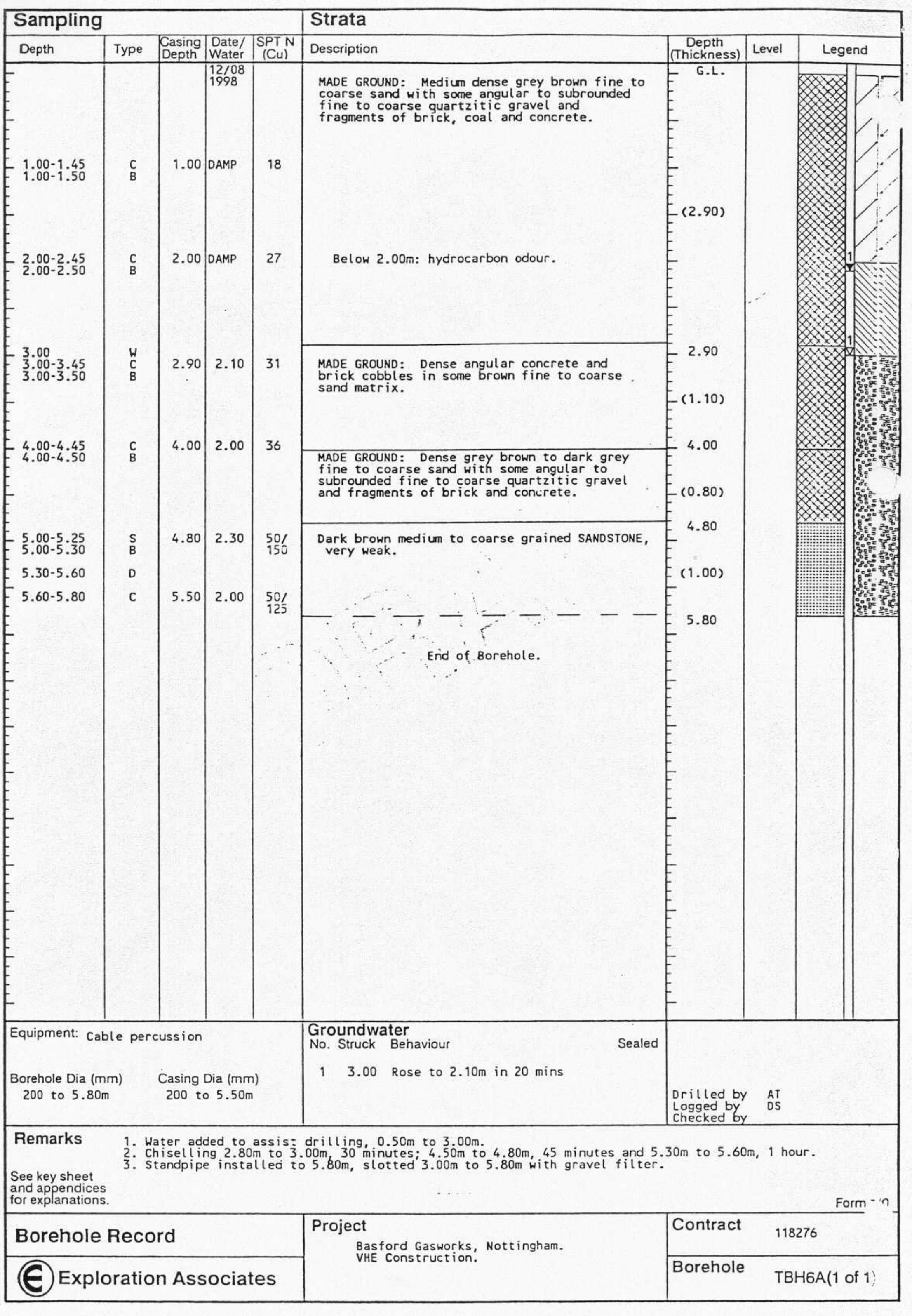
Borehole Record

Exploration Associates

Project
Basford Gasworks, Nottingham.
VHE Construction.

Contract 118276

Borehole TBH2(1 of 1)



Sampling					Strata			
Depth	Type	Casing Depth	Date/ Water	SPT N (Cu)	Description	Depth (Thickness)	Level	Legend
			12/08 1998		MADE GROUND: Medium dense grey brown fine to coarse sand with some angular to subrounded fine to coarse quartzitic gravel and fragments of brick, coal and concrete.	G.L.		
1.00-1.45 1.00-1.50	C B	1.00	DAMP	18				
						(2.90)		
2.00-2.45 2.00-2.50	C B	2.00	DAMP	27	Below 2.00m: hydrocarbon odour.			
						2.90		
3.00 3.00-3.45 3.00-3.50	W C B	2.90	2.10	31	MADE GROUND: Dense angular concrete and brick cobbles in some brown fine to coarse sand matrix.			
						(1.10)		
4.00-4.45 4.00-4.50	C B	4.00	2.00	36		4.00		
					MADE GROUND: Dense grey brown to dark grey fine to coarse sand with some angular to subrounded fine to coarse quartzitic gravel and fragments of brick and concrete.	(0.80)		
						4.80		
5.00-5.25 5.00-5.30	S B	4.80	2.30	50/ 150	Dark brown medium to coarse grained SANDSTONE, very weak.			
5.30-5.60	D					(1.00)		
5.60-5.80	C	5.50	2.00	50/ 125				
						5.80		
					End of Borehole.			

Equipment: Cable percussion

Borehole Dia (mm) 200 to 5.80m

Casing Dia (mm) 200 to 5.50m

Groundwater

No.	Struck	Behaviour	Sealed
1	3.00	Rose to 2.10m in 20 mins	

Drilled by AT
Logged by DS
Checked by

Remarks

1. Water added to assist drilling, 0.50m to 3.00m.
2. Chiselling 2.80m to 3.00m, 30 minutes; 4.50m to 4.80m, 45 minutes and 5.30m to 5.60m, 1 hour.
3. Standpipe installed to 5.80m, slotted 3.00m to 5.80m with gravel filter.

See key sheet and appendices for explanations.

Form

Borehole Record

Exploration Associates

Project
Basford Gasworks, Nottingham.
VHE Construction.

Contract 118276

Borehole TBH6A(1 of 1)

APPENDIX 2
DETAILED SOIL CHEMISTRY

INPUT

SOILS	**TP/BH Sampled Our Ref**	**Count**	**Min**	**Mean**	**Max**	**STD 1 Degree**	**Variance**	**Upper Conf Limit**	**Cleanup Standard**
pH Value		106	5.6	7.49	9.4	0.59	0.34	7.83	10
Loss on Ignition	**(%)**	106	0.1	2.01	7.72	1.68	3.05	3	20
% Moisture	**(%)**	106	3.47	14.98	30.5	4.82	23	17.84	10
% Stones	**(%)**	106	0	19.37	78	17.07	288.41	–	–
Phenol	**(mg/kg)**	106	0.1	0.64	16	1.94	3.75	1.79	10
Cresols	**(mg/kg)**	106	0.1	2.49	55.9	7.2	51.81	6.76	10
Xylenols & Ethylphenols	**(mg/kg)**	106	0.1	2.84	62.3	7.76	60.27	7.44	10
Napthols	**(mg/kg)**	106	0.07	0.19	4.23	0.45	0.2	0.46	10
Trimethylphenol	**(mg/kg)**	106	0.1	0.16	1.4	0.21	0.04	0.29	10
Total Phenols	**(mg/kg)**	106	0.5	6.2	134.2	16.93	286.57	8.93	25
Naphthalene	**(mg/kg)**	106	0.5	4.22	93.9	12.95	166.09	11.88	10
Acenaphthylene	**(mg/kg)**	106	0.5	3.41	37.1	5.76	32.86	6.83	10
Acenaphthene	**(mg/kg)**	106	0.5	3.12	24.6	4.72	22.06	5.92	10
Fluorene	**(mg/kg)**	106	0.5	8.17	81.8	12.12	145.83	15.36	10
Phenanthrene	**(mg/kg)**	106	0.5	20.25	197.3	42.05	1753	45.23	10
Anthracene	**(mg/kg)**	106	0.5	7.86	71.2	11.42	129.2	14.66	10
Fluoranthene	**(mg/kg)**	106	0.5	22.91	182.2	36.16	1294	44.43	10
Pyrene	**(mg/kg)**	106	0.5	20.67	176.7	34.83	1200	41.37	10
Benzo (a) Anthracene	**(mg/kg)**	106	0.5	7.68	96.2	17.5	303.42	18.05	10
Chrysene	**(mg/kg)**	106	0.5	9.3	76	13.24	174.21	17.15	10
Benzo (b) Fluoranthene &	**–**	106	0.5	1.4	2.3	1.27	1.62	–	–
Benzo (k) Fluoranthene	**(mg/kg)**	106	0.5	12.81	123.3	22.13	484.2	25.99	10
Benzo (a) Pyrene	**(mg/kg)**	106	0.5	7.34	79.8	13.7	185.55	15.47	10
Indeno (1,2,3-cd) Pyrene &	**–**	–	–	–	–	–	–	–	–
Dibenzo (a.h.) Anthracene	**(mg/kg)**	106	0.5	3.72	55.5	9.24	84.51	9.25	10
Benzo (g.h.i.)Perylene	**(mg/kg)**	106	0.5	3.81	57.2	9.31	85.93	9.32	10
TOTAL PNAH CONTENT	**(mg/kg)**	106	0.5	132.61	1267	231.07	52864	169.86	500
Total Cyanide	**(mg/kg)**	106	1	28.63	435.9	69.9	4839.77	69.99	250
Easily liberated Cyanide	**(mg/kg)**	106	1	2.68	27.5	5.06	25.39	5.66	100
Complex Cyanide	**(mg/kg)**	106	1	48.15	795	129.02	16495.81	124.37	250
Elemental Sulphur	**(mg/kg)**	106	10	483.55	3683	619.76	380931.39	852.87	5000
Water sol. Sulphate	**(mg/kg)**	106	215.4	1271	7249	1082	1172275	1446	5000
Water sol. Chloride	**(mg/kg)**	106	10	59.95	424	73.51	5346.58	102.86	2000
Ammonium	**(mg/kg)**	106	1	30.24	746.7	82.51	6738.3	79.03	100
Arsenic	**(mg/kg)**	106	1.1	14.25	71.18	13.75	196.45	22.43	40
Cadmium	**(mg/kg)**	106	0.5	0.88	3.1	0.54	0.3	1.21	15
Chromium	**(mg/kg)**	106	1.98	7.9	27	4.05	16.64	10.31	1000
Lead	**(mg/kg)**	106	3	110.82	3357.69	350.71	121729.5	317.65	2000
Mercury	**(mg/kg)**	106	0.2	0.51	4.7	0.67	0.5	0.91	20
Selenium	**(mg/kg)**	106	0.5	0.56	1.9	0.18	0.03	0.67	6
Copper	**(mg/kg)**	106	3	22.32	127	14.98	343.67	31.28	130
Nickel	**(mg/kg)**	106	2	10.42	28	5.02	25.78	13.42	70
Zinc	**(mg/kg)**	106	10	60.79	254	54.32	2948.78	93.07	300
Water sol. Boron	**(mg/kg)**	106	0.5	0.79	3.5	0.63	0.39	1.16	3
Total Petroleum Hydrocarbons	**(mg/kg)**	106	0.5	666.87	7164.02	1318.49	1738423.78	1422.21	500
Asbestos	**(%)**	56	0.01	0.01	0.02	0	0	0.01	10
Benzene	**(mg/kg)**	–	–	–	–	–	–	–	–
Toluene	**(mg/kg)**	5	0.05	0.09	0.17	0.06	0	–	–
Ethylbenzene	**(mg/kg)**	6	0.05	0.16	0.43	0.18	0.03	–	–
Xylene	**(mg/kg)**	4	0.05	0.59	1.87	0.87	0.76	–	–
Mineral Oil	**(%)**	6	0.05	3.81	12.37	5.85	34.22	–	–

SAND

SOILS	TP/BH Sampled Our Ref	Count	Min	Mean	Max	STD 1 Degree	Variance	Upper Conf Limit	Cleanup Standard
pH Value		78	6.6	7.7	9	0.4	0.17	7.76	10
Loss on Ignition	**(%)**	78	0.17	1.1	8.83	1.4	1.97	1.39	20
% Moisture	**(%)**	79	5.4	16.9	37.4	6.6	43.19	18.15	10
% Stones	**(%)**	79	0	0.4	32	3.6	12.96	1.09	10
Phenol	**(mg/kg)**	79	0.1	0.2	0.9	0.2	0.03	0.2	10
Cresols	**(mg/kg)**	79	0.1	0.6	10.5	1.2	1.56	0.86	10
Xylenols & Ethylphenols	**(mg/kg)**	79	0.1	0.7	4.8	0.9	0.89	0.85	10
Napthols	**(mg/kg)**	79	0.1	0.1	2.8	0.3	0.1	0.21	10
Trimethylphenol	**(mg/kg)**	79	0.1	0.1	0.9	0.1	0	0.1	10
Total Phenols	**(mg/kg)**	79	0.5	1.6	18.4	2.4	5.76	2.08	25
Naphthalene	**(mg/kg)**	79	0.5	0.6	4.1	0.5	0.3	0.73	10
Acenaphthylene	**(mg/kg)**	79	0.5	0.8	6.8	0.9	0.8	1	10
Acenaphthene	**(mg/kg)**	79	0.5	0.9	8.9	1.1	1.24	1.13	10
Fluorene	**(mg/kg)**	79	0.5	1.3	8.7	1.7	2.91	1.6	10
Phenanthrene	**(mg/kg)**	79	0.5	3	45.1	8.4	69.82	4.52	10
Anthracene	**(mg/kg)**	79	0.5	2.8	17.7	3.6	12.99	3.51	10
Fluoranthene	**(mg/kg)**	79	0.5	5.9	54.7	10.4	108.66	7.88	10
Pyrene	**(mg/kg)**	79	0.5	5.5	54.6	9.8	95.16	7.32	10
Benzo (a) Anthracene	**(mg/kg)**	79	0.5	3.3	92	10.7	114.14	5.27	10
Chrysene	**(mg/kg)**	79	0.5	2.97	17.9	4.3	18.24	3.77	10
Benzo (b) Fluoranthene &	–	–	–	–	–	–	–	–	–
Benzo (k) Fluoranthene	**(mg/kg)**	78	0.5	3.1	32.9	5.8	33.2	4.18	10
Benzo (a) Pyrene	**(mg/kg)**	79	0.5	1.98	19.2	3.3	10.63	2.6	10
Indeno (1,2,3-cd) Pyrene &	–	–	–	–	–	–	–	–	–
Dibenzo (a.h.) Anthracene	**(mg/kg)**	78	0.5	1.2	31.7	3.6	13.03	1.89	10
Benzo (g.h.i.)Perylene	**(mg/kg)**	79	0.5	0.9	10.6	1.3	1.69	1.13	10
TOTAL PNAH CONTENT	**(mg/kg)**	79	0.5	30.2	318.5	54.6	2978.74	40.39	500
Total Cyanide	**(mg/kg)**	78	1	6.2	58.95	10.2	104.27	8.1	250
Easily liberated Cyanide	**(mg/kg)**	82	1	1.2	8.8	0.9	0.8	1.3	100
Complex Cyanide	**(mg/kg)**	82	1	7	56.44	10.7	114.8	8.95	250
Elemental Sulphur	**(mg/kg)**	78	10	137	442	104.7	10960.8	156.7	5000
Water sol. Sulphate	**(mg/kg)**	78	158	1001.1	6970	1041.8	1085409	1197.49	5000
Water sol. Chloride	**(mg/kg)**	78	10	92	3460	387.5	150164.82	165	2000
Ammonium	**(mg/kg)**	78	1.69	16	49.64	11.4	130	18.18	100
Arsenic	**(mg/kg)**	78	0.5	7.1	34.8	7	48.51	8.43	40
Cadmium	**(mg/kg)**	78	0.5	0.6	1.7	0.2	0.06	0.69	15
Chromium	**(mg/kg)**	78	1	5.2	12	2.4	5.69	5.61	1000
Lead	**(mg/kg)**	78	6	89.3	2891	333.9	111492.13	152.26	2000
Mercury	**(mg/kg)**	78	0.2	0.3	3.1	0	0	0.4	20
Selenium	**(mg/kg)**	78	0.5	0.5	0.5	0	0	0.5	6
Copper	**(mg/kg)**	78	2	17.5	82	18.4	337.42	20.93	130
Nickel	**(mg/kg)**	78	3	7.7	32	5	22.97	8.61	70
Zinc	**(mg/kg)**	78	11	48.1	176	37.98	1442.41	55.27	300
Water sol. Boron	**(mg/kg)**	78	0.5	0.6	1.7	0.22	0.05	0.61	3
Total Petroleum Hydrocarbons	**(mg/kg)**	78	0.5	13.5	121.7	21.7	468.97	17.58	500
Asbestos	**(%)**	20	0.005	0.005	0.005	0	0	0.005	10
Benzene	**(mg/kg)**	–	–	–	–	–	–	–	–
Toluene	**(mg/kg)**	–	–	–	–	–	–	–	–
Ethylbenzene	**(mg/kg)**	–	–	–	–	–	–	–	–
Xylene	**(mg/kg)**	–	–	–	–	–	–	–	–

SAND AND GRAVEL

SOILS	TP/BH Sampled Our Ref	Count	Min	Mean	Max	STD 1 Degree	Variance	Upper Conf Limit	Cleanup Standard
pH Value		208	6.7	7.93	10.3	0.55	0.31	8	10
Loss on Ignition	**(%)**	208	0.05	0.85	16.63	1.69	2.85	1.04	20
% Moisture	**(%)**	208	3.25	11.75	50.73	5.81	33.8	12.42	10
% Stones	**(%)**	208	0	31.98	77	17.16	294.59	33.94	10
Phenol	**(mg/kg)**	207	0.1	0.23	3.6	0.38	0.14	0.28	10
Cresols	**(mg/kg)**	208	0.1	0.98	12.1	1.67	2.8	1.17	10
Xylenols & Ethylphenols	**(mg/kg)**	207	0.1	1.35	12.2	1.92	3.7	1.57	10
Napthols	**(mg/kg)**	206	0.1	0.13	1.9	0.14	0.02	0.14	10
Trimethylphenol	**(mg/kg)**	205	0.1	0.18	3.3	0.32	0.1	0.22	10
Total Phenols	**(mg/kg)**	204	0.5	2.76	25.3	3.85	14.82	3.21	25
Naphthalene	**(mg/kg)**	208	0.5	0.81	12.8	1.4	1.95	0.97	10
Acenaphthylene	**(mg/kg)**	208	0.5	0.91	7.4	1.11	1.23	1.03	10
Acenaphthene	**(mg/kg)**	208	0.5	0.93	11.4	1.3	1.69	1.08	10
Fluorene	**(mg/kg)**	208	0.5	1.28	17.1	1.7	2.89	1.48	10
Phenanthrene	**(mg/kg)**	207	0.5	3.26	58.6	6.37	40.58	3.99	10
Anthracene	**(mg/kg)**	207	0.5	2.62	23.9	3.61	13.04	3.03	10
Fluoranthene	**(mg/kg)**	207	0.5	4.98	59.7	6.36	40.41	5.71	10
Pyrene	**(mg/kg)**	208	0.5	4.85	47.1	6.09	37.07	5.54	10
Benzo (a) Anthracene	**(mg/kg)**	207	0.5	2.49	74.9	6.15	37.84	3.2	10
Chrysene	**(mg/kg)**	207	0.5	2.49	15	3	8.97	2.84	10
Benzo (b) Fluoranthene &	–	–	–	–	–	–	–		–
Benzo (k) Fluoranthene	**(mg/kg)**	208	0.5	2.53	33.2	3.21	10.3	2.89	10
Benzo (a) Pyrene	**(mg/kg)**	208	0.5	1.62	21	1.94	3.75	1.85	10
Indeno (1,2,3-cd) Pyrene &	–	–	–	–	–	–	–		–
Dibenzo (a.h.) Anthracene	**(mg/kg)**	208	0.5	1.34	13.13	1.89	3.58	1.56	10
Benzo (g.h.i.)Perylene	**(mg/kg)**	208	0.5	1.01	9.9	1.12	1.25	1.14	10
TOTAL PNAH CONTENT	**(mg/kg)**	206	0.5	28.27	327.2	33.79	1141.53	32.16	500
Total Cyanide	**(mg/kg)**	208	1	3.95	55.2	5.17	26.76	4.54	250
Easily liberated Cyanide	**(mg/kg)**	206	1	1	1.02	0	1.42	1	100
Complex Cyanide	**(mg/kg)**	208	0.5	3.84	54.2	5.08	25.79	4.42	250
Elemental Sulphur	**(mg/kg)**	205	10	116.62	2223	190.66	36352.16	138.62	5000
Water sol. Sulphate	**(mg/kg)**	208	100	1008.41	4454	881.96	777848.17	1109.45	5000
Water sol. Chloride	**(mg/kg)**	205	10	46.43	2384	166.32	27662.6	65.63	2000
Ammonium	**(mg/kg)**	207	0.3	11.79	67.1	10.08	101.66	12.95	100
Arsenic	**(mg/kg)**	208	0.5	6.63	41.7	6.65	44.18	7.4	40
Cadmium	**(mg/kg)**	205	0.5	0.61	1.9	0.23	0.05	0.64	15
Chromium	**(mg/kg)**	208	1	4.27	26	3.12	9.75	4.63	1000
Lead	**(mg/kg)**	208	3	28.79	659	52.06	2710.31	34.76	2000
Mercury	**(mg/kg)**	203	0.2	0.36	4.5	0.61	0.37	0.43	20
Selenium	**(mg/kg)**	207	0.2	0.5	1.1	0.05	0	0.51	6
Copper	**(mg/kg)**	208	1	9.97	57	9.8	96.02	11.09	130
Nickel	**(mg/kg)**	208	1	5.31	27	3.53	12.48	5.72	70
Zinc	**(mg/kg)**	208	4	36.73	282	44.33	1965.57	41.81	300
Water sol. Boron	**(mg/kg)**	204	0.5	0.57	2.3	0.26	0.07	0.6	3
Total Petroleum Hydrocarbons	**(mg/kg)**	201	0.5	15.48	199.5	20.8	432.5	17.9	500
Asbestos	**(%)**	–	–	–	–	–	–	–	10
Mineral Oil	**(%)**	31	0.0002	0.02	0.37	0.07	0	0.04	10
Benzene	**(mg/kg)**	2	0.05	0.05	0.05	–	–	–	–
Toluene	**(mg/kg)**	2	0.05	0.1	0.15	–	–	–	–
Ethylbenzene	**(mg/kg)**	2	0.05	0.05	0.05	–	–	–	–
Xylene	**(mg/kg)**	2	0.2	0.25	0.29	–	–	–	–

GRAVEL

SOILS	TP/BH Sampled Our Ref	Count	Min	Mean	Max	STD 1 Degree	Variance	Upper Conf Limit	Cleanup Standard
pH Value		74	5.4	7.98	10.4	0.67	0.45	8.11	10
Loss on Ignition	**(%)**	74	0.03	2.99	11.29	2.48	6.15	3.47	20
% Moisture	**(%)**	75	2.44	8.97	21.05	4.69	21.95	9.87	10
% Stones	**(%)**	75	0	52.71	92	26.05	678.63	–	10
Phenol	**(mg/kg)**	74	0.1	0.18	0.9	0.2	0.04	0.22	10
Cresols	**(mg/kg)**	75	0.1	0.8	10.4	1.58	2.5	1.1	10
Xylenols & Ethylphenols	**(mg/kg)**	75	0.1	0.8	7.1	1.37	1.87	1.07	10
Napthols	**(mg/kg)**	75	0.1	0.13	0.8	0.11	0.01	0.15	10
Trimethylphenol	**(mg/kg)**	75	0.1	0.12	0.6	0.07	0	0.13	10
Total Phenols	**(mg/kg)**	75	0.5	1.93	18.7	3.16	9.96	2.53	25
Naphthalene	**(mg/kg)**	75	0.5	1.75	15.1	2.74	7.51	2.27	10
Acenaphthylene	**(mg/kg)**	75	0.5	1.93	14.2	2.87	8.24	2.48	10
Acenaphthene	**(mg/kg)**	75	0.5	2.78	26.72	4.37	19.12	3.62	10
Fluorene	**(mg/kg)**	75	0.5	6.79	60.7	10.52	110.64	8.82	10
Phenanthrene	**(mg/kg)**	75	0.5	30.54	144.5	35.14	1234.79	37.3	10
Anthracene	**(mg/kg)**	75	0.5	10.67	57.3	10.92	119.23	12.77	10
Fluoranthene	**(mg/kg)**	75	0.5	35.74	131.9	31.4	986.13	41.78	10
Pyrene	**(mg/kg)**	75	0.5	31.04	118.1	29.08	845.49	36.63	10
Benzo (a) Anthracene	**(mg/kg)**	75	0.5	23.3	248.36	39.5	1560.2	30.9	10
Chrysene	**(mg/kg)**	75	0.5	15.79	249.05	30.25	915.02	21.61	10
Benzo (b) Fluoranthene &	–	–	–	–	–	–	–	–	–
Benzo (k) Fluoranthene	**(mg/kg)**	74	0.5	18.1	100.7	17.49	306.03	21.49	10
Benzo (a) Pyrene	**(mg/kg)**	75	0.5	9.1	47.2	9.13	83.28	10.85	10
Indeno (1,2,3-cd) Pyrene &	–	–	–	–	–	–	–	–	–
Dibenzo (a.h.) Anthracene	**(mg/kg)**	74	0.5	5.13	49.2	8.33	69.32	6.74	10
Benzo (g.h.i.)Perylene	**(mg/kg)**	75	0.5	4.03	37.3	6.26	39.13	5.23	10
TOTAL PNAH CONTENT	**(mg/kg)**	75	0.5	194.88	929.7	191.78	36777.89	231.76	500
Total Cyanide	**(mg/kg)**	74	1	3.76	27.7	4.71	22.17	4.68	250
Easily liberated Cyanide	**(mg/kg)**	78	1	1.08	5	0.47	0.22	1.17	100
Complex Cyanide	**(mg/kg)**	78	1	5.37	89	11.02	121.51	7.45	250
Elemental Sulphur	**(mg/kg)**	74	10	374.03	2335.88	427.23	182524.54	456.77	5000
Water sol. Sulphate	**(mg/kg)**	74	100	1308.46	18483.12	2284.94	5220957.38	1750.98	5000
Water sol. Chloride	**(mg/kg)**	74	10	85.45	3346	387.03	149792.08	160.41	2000
Ammonium	**(mg/kg)**	74	1	11.46	116.9	16.95	287.3	14.75	100
Arsenic	**(mg/kg)**	74	0.8	9.56	41.62	8.34	69.55	11.18	40
Cadmium	**(mg/kg)**	74	0.5	0.86	2.92	0.46	0.21	0.94	15
Chromium	**(mg/kg)**	74	1.1	7.71	33	5.09	25.88	8.69	1000
Lead	**(mg/kg)**	74	3	73.45	1299	211.71	44821.27	114.45	2000
Mercury	**(mg/kg)**	74	0.2	0.56	16	1.88	3.52	0.92	20
Selenium	**(mg/kg)**	74	0.5	0.52	0.95	0.08	0.01	0.53	6
Copper	**(mg/kg)**	74	1.4	20.92	382.25	44.18	1952.31	29.48	130
Nickel	**(mg/kg)**	74	1	8.33	25	5.21	27.14	9.34	70
Zinc	**(mg/kg)**	74	3.3	29.85	124.74	21.54	463.96	34.02	300
Water sol. Boron	**(mg/kg)**	74	0.5	1.04	4	0.6	0.36	1.16	3
Total Petroleum Hydrocarbons	**(mg/kg)**	61	0.5	36.76	301.5	64.45	4153.38	50.54	500
Asbestos	**(%)**	16	0.005	0.005	0.005	–	–	0.005	10

COARSE ORGANICS

SOILS	TP/BH Sampled Our Ref	Count	Min	Mean	Max	STD 1 Degree	Variance	Upper Confidence Limit	Cleanup Standard
pH Value		12	5.7	6.42	8.8	0.86	0.74	6.87	10
Loss on Ignition	**(%)**	12	1.97	15.92	50.42	17	289.08	24.74	20
% Moisture	**(%)**	12	8.27	24.89	91.66	25.03	626.58	37.87	10
% Stones	**(%)**	12	0	27.86	79	35.13	1234.27	–	10
Phenol	**(mg/kg)**	12	0.1	0.4	1	0.34	0.12	0.58	10
Cresols	**(mg/kg)**	12	0.1	2	6.1	1.92	3.7	3	10
Xylenols & Ethylphenols	**(mg/kg)**	12	0.1	2.75	17	4.5	20.27	5.08	10
Napthols	**(mg/kg)**	12	0.1	0.1	0.3	0.06	0	0.13	10
Trimethylphenol	**(mg/kg)**	12	0.1	0.13	0.55	0.14	0.02	0.2	10
Total Phenols	**(mg/kg)**	12	0.5	5.24	23.1	6.13	37.58	8.42	25
Naphthalene	**(mg/kg)**	12	0.5	4.16	32.2	9.13	83.42	8.9	10
Acenaphthylene	**(mg/kg)**	12	0.77	3.65	9.5	3.22	10.34	5.32	10
Acenaphthene	**(mg/kg)**	12	0.5	4.74	24.5	6.6	43.62	8.16	10
Fluorene	**(mg/kg)**	12	1.13	11.52	27.9	8.33	69.35	15.83	10
Phenanthrene	**(mg/kg)**	12	0.5	65.49	238.1	64.57	4169.75	98.96	10
Anthracene	**(mg/kg)**	12	1.5	14.95	34.3	11.2	125.48	20.75	10
Fluoranthene	**(mg/kg)**	12	3.42	77.55	210.3	55.28	3056.24	106.21	10
Pyrene	**(mg/kg)**	12	3.17	63.96	206.5	54.3	2948.37	92.11	10
Benzo (a) Anthracene	**(mg/kg)**	12	0.5	52.88	298.8	79.42	6307.36	94.05	10
Chrysene	**(mg/kg)**	12	2.39	27.28	80.5	23.22	538.96	39.31	10
Benzo (b) Fluoranthene &	–								–
Benzo (k) Fluoranthene	**(mg/kg)**	12	2.12	43.9	118.83	35.49	1259.87	62.3	10
Benzo (a) Pyrene	**(mg/kg)**	12	1.07	23.12	50.96	15.02	225.62	30.9	10
Indeno (1,2,3-cd) Pyrene &	–	–	–	–	–	–	–	–	–
Dibenzo (a.h.) Anthracene	**(mg/kg)**	12	0.5	16.37	75.7	21.27	460.9	27.5	10
Benzo (g.h.i.)Perylene	**(mg/kg)**	12	0.5	12.33	48.06	13.69	187.29	19.43	10
TOTAL PNAH CONTENT	**(mg/kg)**	12	17.93	421.39	1114.3	308.01	94868.66	581.07	500
Total Cyanide	**(mg/kg)**	12	1.3	17.51	60	20.46	418.73	28.12	250
Easily liberated Cyanide	**(mg/kg)**	12	1	1.55	9.3	2.38	5.65	2.78	100
Complex Cyanide	**(mg/kg)**	12	1.3	16.47	54.47	18.64	347.3	26.13	250
Elemental Sulphur	**(mg/kg)**	12	228.36	636.56	1998	474.76	225401.21	882.69	5000
Water sol. Sulphate	**(mg/kg)**	12	594.22	1362.26	3362	953.29	908758.88	1856.47	5000
Water sol. Chloride	**(mg/kg)**	12	10	70.77	444	119.46	14271.3	132.7	2000
Ammonium	**(mg/kg)**	12	3.7	9.22	19.74	4.8	23.06	11.71	100
Arsenic	**(mg/kg)**	12	3.17	14.63	43.8	13.5	182.34	21.63	40
Cadmium	**(mg/kg)**	12	0.5	0.77	1.6	0.35	0.12	0.95	15
Chromium	**(mg/kg)**	12	2.73	6.12	11	2.44	5.94	7.39	1000
Lead	**(mg/kg)**	12	9.24	58.23	194	52.65	2772.02	85.53	2000
Mercury	**(mg/kg)**	12	0.2	0.57	3.4	0.96	0.92	1.06	20
Selenium	**(mg/kg)**	12	0.5	0.55	1	0.18	0.03	0.64	6
Copper	**(mg/kg)**	12	5.67	30.54	134	34.56	1194.17	48.46	130
Nickel	**(mg/kg)**	12	3.52	8.43	15	4.02	16.2	10.52	70
Zinc	**(mg/kg)**	12	13.86	40.83	99	23.34	544.83	52.93	300
Water sol. Boron	**(mg/kg)**	12	0.5	1.46	2.9	0.67	0.44	1.81	3
Total Petroleum Hydrocarbons	**(mg/kg)**	11	4.7	145.8	537.68	208.81	43603.54	259.91	500

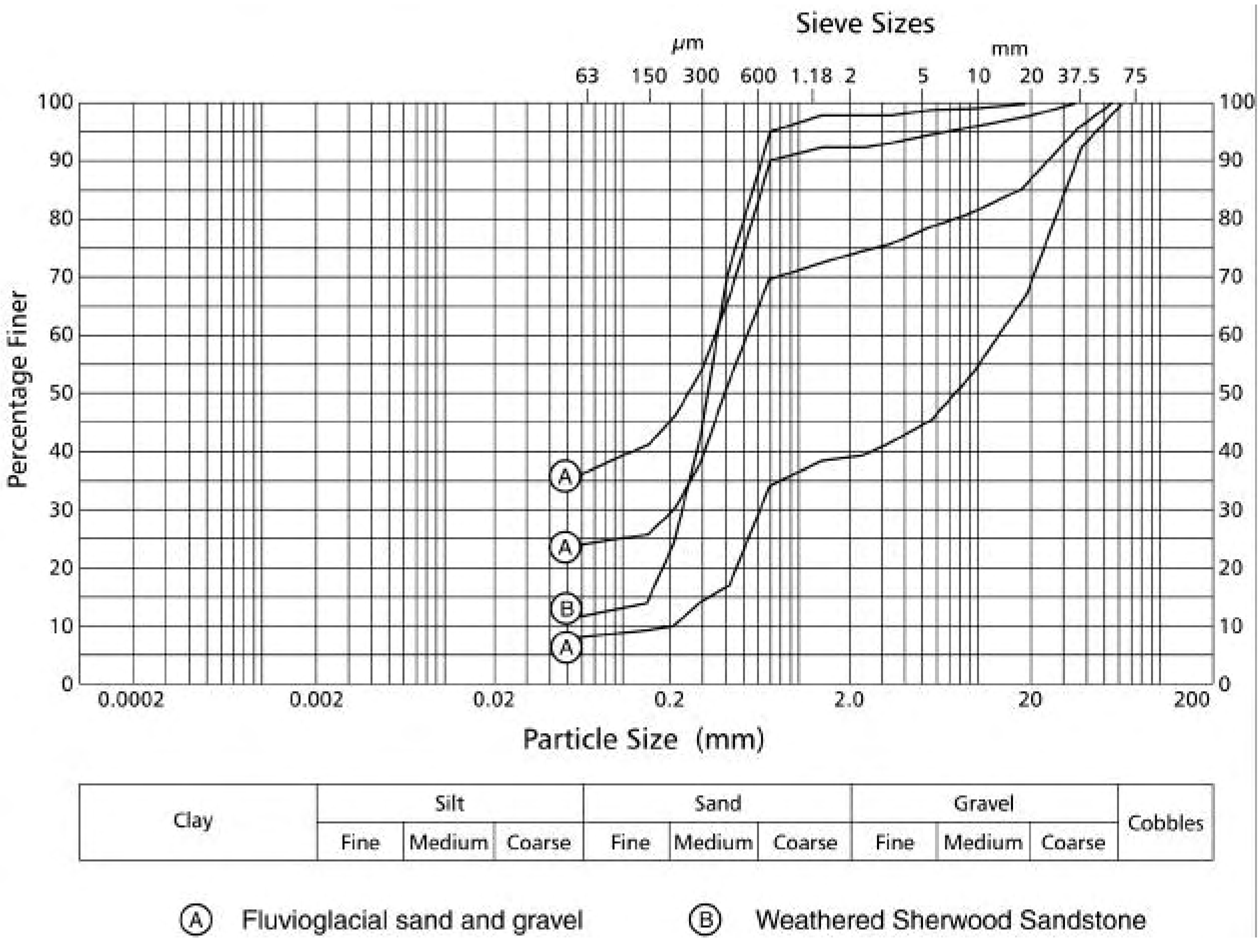
FINE ORGANICS

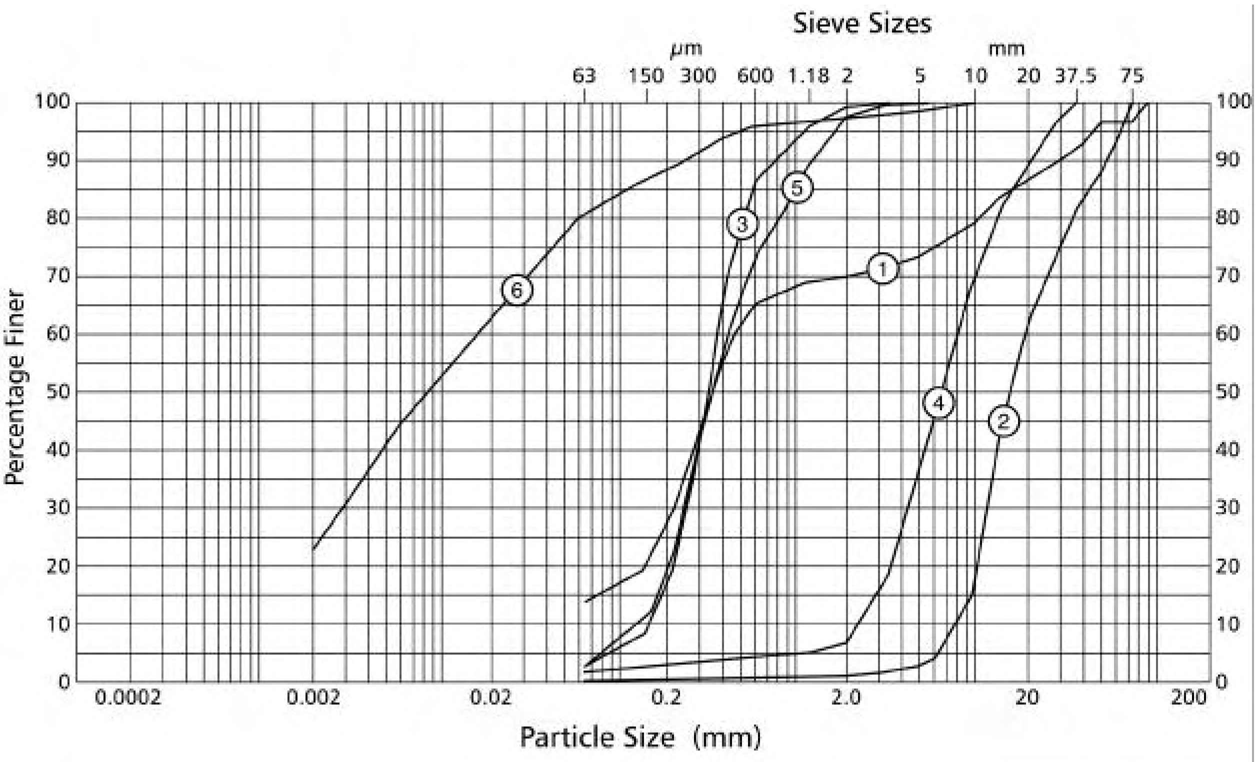
SOILS	TP/BH Sampled Our Ref	Count	Min	Mean	Max	STD 1 Degree	Variance	Upper Confidence Limit	Cleanup Standard
pH Value		7	7.2	6.83	9	0.76	0.58	7.38	10
Loss on Ignition	**(%)**	7	14.38	18.33	27.86	4.35	18.95	21.53	20
% Moisture	**(%)**	7	42.32	49.69	74.92	12.41	153.99	58.8	10
% Stones	**(%)**	7	–	–	–	–	–	–	10
Phenol	**(mg/kg)**	7	0.1	0.78	2.6	1.15	1.33	1.63	10
Cresols	**(mg/kg)**	7	0.44	2.72	6.6	2.88	8.32	4.84	10
Xylenols & Ethylphenols	**(mg/kg)**	7	0.71	3.53	9.1	3.13	9.79	5.83	10
Napthols	**(mg/kg)**	7	0.1	0.12	0.3	0.07	0.01	0.17	10
Trimethylphenol	**(mg/kg)**	7	0.1	0.17	0.5	0.15	0.02	0.29	10
Total Phenols	**(mg/kg)**	7	1.28	7.19	18.4	6.98	48.73	12.32	25
Naphthalene	**(mg/kg)**	7	0.5	34.99	164.1	68.74	4725.04	85.47	10
Acenaphthylene	**(mg/kg)**	7	0.5	21.77	105.5	38.71	1498.41	50.2	10
Acenaphthene	**(mg/kg)**	7	0.5	14.35	70.7	26.8	718.01	34.03	10
Fluorene	**(mg/kg)**	7	0.69	43.69	184.2	67.34	4534.79	93.15	10
Phenanthrene	**(mg/kg)**	7	0.6	73.64	291.3	96.75	9360.21	144.7	10
Anthracene	**(mg/kg)**	7	3.54	80.61	443.8	158.18	25021.68	196.79	10
Fluoranthene	**(mg/kg)**	7	24.3	123.1	333.4	117.73	13861.17	209.57	10
Pyrene	**(mg/kg)**	7	24.1	100.37	281	110.67	12248.44	181.65	10
Benzo (a) Anthracene	**(mg/kg)**	7	5.2	60.77	171.3	60.67	3680.35	105.33	10
Chrysene	**(mg/kg)**	7	19.5	77.44	291.6	97.19	9446.84	148.82	10
Benzo (b) Fluoranthene &	–	–	–	–	–	–	–	–	–
Benzo (k) Fluoranthene	**(mg/kg)**	7	18.1	112.63	434.7	147.32	21701.76	220.82	10
Benzo (a) Pyrene	**(mg/kg)**	7	8.9	74.61	305.7	105.63	11157.72	152.19	10
Indeno (1,2,3-cd) Pyrene &	–	–	–	–	–	–	–	–	–
Dibenzo (a.h.) Anthracene	**(mg/kg)**	7	0.5	48.2	190.1	69.4	4816.88	99.18	10
Benzo (g.h.i.)Perylene	**(mg/kg)**	7	0.5	32.38	143.2	51.15	2616.74	69.95	10
TOTAL PNAH CONTENT	**(mg/kg)**	7	124.9	897.98	3029.3	1067.66	1139887.49	1682.12	500
Total Cyanide	**(mg/kg)**	7	2.13	31.87	82.4	33.09	1094.96	56.18	250
Easily liberated Cyanide	**(mg/kg)**	7	1	1.49	2.7	0.76	0.58	2.05	100
Complex Cyanide	**(mg/kg)**	7	2.13	24.32	68	25.21	635.42	42.84	250
Elemental Sulphur	**(mg/kg)**	7	629	1337.54	3057	819.46	671515.47	1939.39	5000
Water sol. Sulphate	**(mg/kg)**	7	691.4	1835.55	3328	1063.39	1130794.37	2616.56	5000
Water sol. Chloride	**(mg/kg)**	7	43	68.65	112	29.78	887	90.52	2000
Ammonium	**(mg/kg)**	7	10.2	19.03	38.43	10.78	116.14	26.95	100
Arsenic	**(mg/kg)**	7	19.81	27.96	41.3	7.6	57.7	33.54	40
Cadmium	**(mg/kg)**	7	0.8	1.03	1.9	0.36	0.13	1.29	15
Chromium	**(mg/kg)**	7	9	10.38	16	2.67	7.13	12.34	1000
Lead	**(mg/kg)**	7	101	146.72	292	71.67	5136.06	199.36	2000
Mercury	**(mg/kg)**	7	0.26	2.4	11.2	3.89	15.15	5.26	20
Selenium	**(mg/kg)**	7	0.5	0.75	1.3	0.29	0.09	0.97	6
Copper	**(mg/kg)**	7	36	44.23	57	7.45	55.46	49.7	130
Nickel	**(mg/kg)**	7	13	14.42	21	3.06	9.37	16.66	70
Zinc	**(mg/kg)**	7	76.73	106.59	237	54.73	2995.47	146.79	300
Water sol. Boron	**(mg/kg)**	7	0.99	1.76	3.4	1.02	1.04	2.51	3
Total Petroleum Hydrocarbons	**(mg/kg)**	7	6.8	422.54	1135.03	481.58	231919	776.24	500

FILTER CAKE

SOILS	TP/BH Sampled Our Ref	Count	Min	Mean	Max	STD 1 Degree	Variance	Upper Confidence Limit	Cleanup Standard
pH Value		52	2.2	7.5	9.1	0.73	0.53	7.65	10
Loss on Ignition	**(%)**	57	0	11.9	40.8	6.4	41.01	13.32	20
% Moisture	**(%)**	57	15.4	99.3	191.5	32.65	1066.11	106.49	10
% Stones	**(%)**	57	0	0.1	12	1.25	1.57		
Phenol	**(mg/kg)**	51	0.1	1.6	15.9	3.07	9.42	2.35	10
Cresols	**(mg/kg)**	52	0.1	10	104.4	16.59	275.38	13.85	10
Xylenols & Ethylphenols	**(mg/kg)**	52	0.1	15	99	19.21	369.03	19.49	10
Napthols	**(mg/kg)**	51	0.1	0.9	7.9	1.36	1.84	1.22	10
Trimethylphenol	**(mg/kg)**	51	0.1	0.9	16	2.16	4.66	1.38	10
Total Phenols	**(mg/kg)**	52	0.5	28.2	185.2	37.03	1371.3	36.83	25
Naphthalene	**(mg/kg)**	52	0.5	69.5	1471	185.15	34280.1	112.56	10
Acenaphthylene	**(mg/kg)**	52	0.5	32.1	309.9	45.81	2098.35	42.76	10
Acenaphthene	**(mg/kg)**	52	0.5	38.8	587.8	70.87	5023.34	55.24	10
Fluorene	**(mg/kg)**	52	0.5	70.6	382	68.83	4736.98	86.58	10
Phenanthrene	**(mg/kg)**	52	0.5	123	1146.7	149.46	22339.81	157.75	10
Anthracene	**(mg/kg)**	52	0.5	39.1	302.7	50.64	2564.11	50.84	10
Fluoranthene	**(mg/kg)**	52	0.5	119.6	573.3	93.05	8658.07	141.23	10
Pyrene	**(mg/kg)**	52	0.5	110.6	498.7	90.19	8133.65	131.54	10
Benzo (a) Anthracene	**(mg/kg)**	52	0.5	60.8	494.2	93.12	8671.66	82.46	10
Chrysene	**(mg/kg)**	52	0.5	53	485.2	76.07	5786.73	70.71	10
Benzo (b) Fluoranthene &	**–**	–	–	–	–	–	–	–	–
Benzo (k) Fluoranthene	**(mg/kg)**	52	0.5	57.9	279.3	47.35	2242.05	68.87	10
Benzo (a) Pyrene	**(mg/kg)**	52	0.5	33.2	153.8	27.44	752.91	39.54	10
Indeno (1,2,3-cd) Pyrene &	**–**	–	–	–	–	–	–	–	–
Dibenzo (a.h.) Anthracene	**(mg/kg)**	52	0.5	20	128.1	24.05	578.41	25.58	10
Benzo (g.h.i.)Perylene	**(mg/kg)**	52	0.5	18.1	220	27.77	771.39	24.51	10
TOTAL PNAH CONTENT	**(mg/kg)**	52	0.5	1133	27773.9	2990.29	8941845.3	1827.73	500
Total Cyanide	**(mg/kg)**	52	1	66.1	343.9	68.03	4628.47	81.94	250
Easily liberated Cyanide	**(mg/kg)**	52	1	6	50	7.82	61.1	7.81	100
Complex Cyanide	**(mg/kg)**	52	1	60.8	339.6	64.44	4152.35	75.81	250
Elemental Sulphur	**(mg/kg)**	57	10	2311.4	12000	2195.74	4821277.9	2797.81	5000
Water sol. Sulphate	**(mg/kg)**	52	189	3734.3	9291	2093.14	4381228.2		5000
Water sol. Chloride	**(mg/kg)**	52	28	155.3	457	65.46	4285.12	170.54	2000
Ammonium	**(mg/kg)**	57	1.7	114.8	746.7	133.28	17762.7	144.27	100
Arsenic	**(mg/kg)**	52	3.5	63.7	1150.5	122.72	15059.3	92.22	40
Cadmium	**(mg/kg)**	52	0.5	4.8	207.8	22.03	485.23	9.93	15
Chromium	**(mg/kg)**	52	5	33	560	57.47	3302.53	46.4	1000
Lead	**(mg/kg)**	52	3	340.8	1171	179.42	32192.57	382.48	2000
Mercury	**(mg/kg)**	52	0.2	2.3	39.7	4.31	18.54	3.25	20
Selenium	**(mg/kg)**	52	0.3	1.4	3.9	0.6	0.36	1.57	6
Copper	**(mg/kg)**	52	5	77.1	237	36.39	1323.99	85.59	130
Nickel	**(mg/kg)**	52	5	33.9	192	19.24	370.07	38.38	70
Zinc	**(mg/kg)**	52	10	170.2	680	99.74	9949.02	193.34	300
Water sol. Boron	**(mg/kg)**	52	0.5	1.8	4.8	0.73	0.53	1.93	3
Total Petroleum Hydrocarbons	**(mg/kg)**	53	0.5	1251.4	41622.6	4642.27	21550675	2319.34	500
Asbestos	**(%)**	–	0.1	–	0.1	–	–	–	10

APPENDIX 3
PARTICLE SIZE DISTRIBUTION CURVES


Sieve Sizes
μm
mm
63
150
300
600
1.18
2
5
10
20
37.5
75
Percentage Finer
100
90
80
70
60
50
40
30
20
10
0
0.0002
0.002
0.02
0.2
2.0
20
200
Particle Size (mm)
A
A
B
A
Clay
Silt
Fine
Medium
Coarse
Sand
Fine
Medium
Coarse
Gravel
Fine
Medium
Coarse
Cobbles
Ⓐ Fluvioglacial sand and gravel
Ⓑ Weathered Sherwood Sandstone



Clay	Silt			Sand			Gravel			Cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	

① Input
② Gravel
③ Sand
④ Coarse organics
⑤ Fine organics
⑥ Filtercake

APPENDIX 4
PLATES

Plate 1: Pre-screening of excavated material for feed to soil washing plant.

Plate 2: Clean coarse output from soil washing plant containing natural and made ground.

Plate 3: Clean sand output from soil washing plant.

Plate 4: Contaminated stream from the dense medium separator, mostly consisting of contaminated peat and root fragments.

Plate 5: Contaminated filter cake from belt filter press.

Plate 6: Water treatment system.

APPENDIX 5
CONTACT DETAILS

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