TECHNOLOGY DEMONSTRATION PROJECT REPORT: TDP1

REMEDIATION TRIAL USING LOW TEMPERATURE THERMAL DESORPTION TO TREAT HYDROCARBON CONTAMINATED SOIL

CONTAMINATED LAND: APPLICATIONS IN REAL ENVIRONMENTS

CL:AIRE

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

March 2004

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Remediation Trial using Low Temperature Thermal Desorption to Treat Hydrocarbon Contaminated Soil

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

TDP1 © CL:AIRE ISBN 0-9541673-4-1 (Printed Version)
ISBN 0-9541673-3-3 (CD ROM Version)

1. CL:AIRE, 5th Floor, 2 Queen Anne's Gate Buildings, Dartmouth Street, London SW1H 9BP
2. Solinst Canada Ltd., 35 Todd Road, Georgetown, Ontario, Canada L7G 4R8

Published by Contaminated Land: Applications in Real Environments (CL:AIRE), 5th Floor, 2 Queen Anne's Gate Buildings, Dartmouth Street, London SW1H 9BP.

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 Low Temperature Thermal Desorption (LTTD) on site specific conditions and is prepared from a variety of sources. It is not a definitive guide to the application of LTTD technology. CL:AIRE strongly recommends that individuals/organisations interested in using this technology retain the services of experienced environmental professionals.

EXECUTIVE SUMMARY

The chemical works is located on 130 hectares of reclaimed sand dunes and has been operational since the early 1960s. The tank farm area, which is the subject of this report, has been used as a storage area for a variety of hydrocarbons during their service life and was decommissioned in 1999.

The site is situated on levelled sand dunes overlain by slag imported from an adjacent steelworks. The surface geology comprises madeground, underlain by wind blown sand, and marine sands or estuarine alluvium, over glacial deposits. The wind blown sand, which is the main focus of the low temperature thermal desorption (LTTD) pilot trial, consists of a uniformly graded silt and fine to medium grained sand approximately 6 m in thickness. Groundwater is typically encountered in the sands at between 0.84 m bgl and 1.97 m bgl, and seasonal variations in the water table of approximately 0.60 m – 1.2 m have been observed. The direction of groundwater flow is generally towards the east, southeast at flow velocities estimated to be of the order of 20 m – 30 m per year.

Site investigations indicated high levels of hydrocarbon soil contamination within the sand horizon. Free phase petroleum hydrocarbon was measured in a number of monitoring wells ranging in thickness up to 400 mm over an estimated area of 15,000 m^2 to 20,000 m^2.

A site specific risk assessment was used to calculate specific remediation criteria and trigger levels. This model was used to calculate site specific remediation criteria or trigger levels. The main drivers for remedial action in the tank farm area, based on contaminant distribution, are benzene, toluene, ethylbenzene, diethylbenzene and styrene.

The granular character of the soil, together with the volatile nature of the aromatic hydrocarbon contaminants and the shallow depth of contamination, favoured an *ex situ*, on site treatment. A cost-benefit analysis was undertaken to assess various technologies. Low temperature thermal desorption was selected as the technology with the greatest potential benefit despite its highest potential cost.

The remediation design considered the following phases:

- Selection of material to be treated
- Excavation of contaminated material for the thermal desorption trial
- Monitoring of atmospheric air quality
- Identification of the extent of the contaminated area (for full scale remediation)
- Identification and removal of mobile hydrocarbons
- Calculation of the migration rate of mobile hydrocarbons into the excavation

The pilot trial was carried out at BAE Systems facility in Chorley, Lancashire with the full cooperation of the Environment Agency (the regulator) which was provided with data and apprised of decisions at each stage of the process.

Approximately 38 tonnes of contaminated soil with aromatic hydrocarbon concentrations no greater than 3 % were selected for the trial. An air monitoring programme was implemented to monitor the level of aromatic emissions to the atmosphere within the exclusion zone surrounding the excavation. All onsite workers directly involved with the excavation and sampling for the pilot trial were required to wear personal air quality monitoring devices.

Two trials were undertaken using the thermal soil remediation unit (SRU) owned and operated by BAE to determine the suitability of the remediation method for full scale remediation at the site.

The objectives of the trials were to assess:

- The treatability of the material
- The achievable material cleanup level
- The achievable material treatment rate
- Treatment costs

- The emissions to air
- Required health and safety controls, and
- The environmental impact

Samples of contaminated material used in the trials contained very low levels of arsenic, chromium, lead, copper, nickel and zinc. There was no detectable cadmium, mercury, selenium or boron. Volatile organic matter averaged 6.4 %, total sulphur content was less than 10 mg/kg and the calorific value of the material averaged 175 kJ/kg.

The contaminated material was separated into four different batches and diluted with clean sand in ratios of 1:7, 1:3, 1:1 and 1:0 respectively. This was done to assess the impact of the thermal contribution of the contaminants in order to determine the optimum treatment rate. Trial temperatures ranging between 200 ^{o}C to 300 ^{o}C were chosen to ensure complete desorption. Input and output samples were taken across the temperature range for each batch of material and analysed for individual and total aromatic hydrocarbons. An initial batch of clean sand was processed prior to the treatment of the contaminated soil to ensure that the plant reached the required operating temperature and steady state.

The first trial was terminated when excess heat caused the SRU to automatically shut down. A second trial was recommended to determine the achievable throughput rate without resulting in over temperature in the oxidizer, and to measure the atmospheric and human exposure levels during the trial.

The trial demonstrated that the SRU was capable of processing 1,150 tonnes of contaminated soil per week based on conditions at the site. Atmospheric and personal exposure levels were well within the Maximum Exposure Levels (MEL) and Occupational Exposure Standards (OES). Estimated costs of cleanup were made on the basis of the treatment of 25,000 tonnes, 50,000 tonnes and 100,000 tonnes of contaminated material, and included a 20 % contingency. Costs per tonne for the three material volumes were calculated to be approximately: £59, £50 and £45, respectively.

The sandy soil at the site had an inherent relatively low water content, and so gave little reduction of the efficiency of the thermal process. Based on experience from other sites, it is expected that moisture levels above 12 % would reduce the material throughput rate by approximately one tonne per hour for each additional 1 % of moisture content. It is expected that the full-scale remediation programme will require 83 weeks of continuous operation to treat the estimated 96,000 tonnes of material in the defined area.

The trial provided the following lessons:

- Technology field trials provide greater clarity for issues such as material handling and throughput, technology limitations, licensing, planning needs, health and safety, and full scale costs.

- Early involvement of the regulator is beneficial in order to identify and address any issues at an early stage. Reaching agreement on ground cleanup specifications and the methodology to be employed is crucial. The team managing the remediation project should communicate information to the regulator at every stage. Unnecessary 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 full scale remedial operation are not trivial and should be considered carefully. Hand digging at the site should be avoided if at all possible and should only be allowed if alternative means cannot be used.

- Analytical techniques for determining the concentration of aromatic compounds through (i) rapid field techniques and (ii) precise laboratory determination would be beneficial both for site characterisation and assessing remedial options.

ACKNOWLEDGEMENTS

CL:AIRE would like to acknowledge the support of the site owner who allowed the use of the site and trial information; Dr Gordon Bulloch and Mr Keith Lewthwaite of BAE Systems Property and Environmental Services who provided specific report information, all of whom also made themselves available to discuss and review various aspects of the project report.

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

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ABBREVIATIONS

aOD	above Ordnance Datum
bgs	below ground surface
BH	Borehole
BS	British Standard
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
COD	Chemical Oxygen Demand
COSHH	Control of Substances Hazardous to Health
DEB	Diethylbenzene
g/cc	gram per cubic centimetre
GC/MS	Gas Chromotography/Mass Spectrometry
HC	Hydrocarbon
HWID	Hazardous Waste Incineration Directive
ICRCL	Inter-Departmental Committee on the Redevelopment of Contaminated Land
IPC	Integrated Pollution Control
ISO	International Organization for Standardization
kJ/kg	kilojoules per kilogram
K_{ow}	Water partition coefficient
kVa	kilovolt amp
LEL	Lower Explosive Limit
LTTD	Low Temperature Thermal Desorption
m	metres
mg/kg	milligram per kilogram
mg/Nm^3	milligram per Normalised cubic metre
mm	millimetre
MEL	Maximum Exposure Limit
NAMAS	National Accreditation of Measurement and Sampling
ng/m^3	nanogram per cubic metre
OD	Outside Diameter
OES	Occupational Exposure Standards
OUST	Office of Underground Storage Tanks
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated biphenyl
PID	Photo-ionisation Detector
ppb	parts per billion
PPE	Personal Protective Equipment
ppm	parts per million
PVC	Polyvinyl Chloride
QA	Quality Assurance
QC	Quality Control
SRU	Soil Remediation Unit
STEL	Short-Term Exposure Limit

TEQ	Toxic Equivalent
TPH	Total Petroleum Hydrocarbon
TVA	Total Vapour Analyser
TWA	Time Weighted Average
UK	United Kingdom
USEPA	United States Environmental Protection Agency
v/v	volume per volume
V	Volt
VOC	Volatile Organic Compound
w/w	weight per weight
µg/l	microgram per litre

1. INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

This project report describes the successful pilot trial of low temperature thermal desorption (LTTD) technology as part of a process to assess the feasibility of full scale LTTD cleanup of contaminated soil at a chemical works.

Approximately 38 tonnes of soil contaminated with petroleum hydrocarbons was treated by the 'Thermal Soil Remediation Unit' (SRU), owned and operated by BAE Systems Property and Environmental Services (BAE).

The purpose of this report is to describe the site conditions, provide an objective assessment of the performance of the SRU technology under pilot trial conditions, and extrapolate costs to full scale cleanup of the site. Specific objectives are to:

- Describe the site characteristics including ground conditions and the nature and distribution of contaminants
- Describe the design and operation of the BAE SRU trial
- Assess the technical and economic performance of the SRU

1.2 BACKGROUND

The chemical works is located on 130 hectares of reclaimed sand dunes and has been in operation since the early 1960s.

The area of site that is the subject of this report is the Tank Farm Area (tank farm). This area, which has stored a variety of hydrocarbons during its service life was decommissioned in 1999 and is awaiting demolition and removal.

During the extended period of operation, product spillage and tank leakage occurred, leading to severe contamination of the subsurface soil and groundwater.

During the period 1993 to 1999, the site owner commissioned several environmental investigations of the whole chemical works site as part of its corporate due diligence programme. Phased ground investigations were carried out to investigate the extent of contamination and to obtain supporting geological and hydrogeological data on the area. Subsequent borehole sampling provided information on the nature and extent of contamination by hydrocarbons.

Following closure of the production plant in 1999 a more detailed investigation was undertaken to characterise contamination in the tank farm and to assess remedial options. This process led to the selection and evaluation of low temperature thermal desorption technology.

A pilot trial to assess LTTD was carried out at BAE Systems facility in Chorley, Lancashire with the full cooperation of the regulator, the Environment Agency, which was provided with data and apprised of decisions at each stage of the process.

2. BACKGROUND TO LOW TEMPERATURE THERMAL DESORPTION TECHNOLOGY

2.1 INTRODUCTION

This chapter provides a brief background to thermal desorption technology. Additional information can be found at the United States Environmental Protection Agency (USEPA) – Office of Underground Storage Tanks (OUST) (www.epa.gov/swerust1/pubs/tums.htm).

2.2 WHAT IS LOW TEMPERATURE THERMAL DESORPTION?

Low temperature thermal desorption (LTTD) is an *ex situ* remediation technology that uses heat to separate organic contaminants from soil. LTTD units are commercially available from a number of manufacturers and are typically designed to heat soils to temperatures ranging from 90 ^{o}C to 550 ^{o}C. Under these conditions, a wide range of organic contaminants will physically desorb from soil particles and volatilise. A moving air stream within the LTTD unit captures the contaminants and directs them to secondary treatment units. Secondary treatment can include: direct combustion, thermal or catalytic oxidation, condensation or adsorption onto activated carbon. Direct combustion and oxidisers destroy the organic constituents. Condensers and carbon adsorption units trap organic compounds for subsequent treatment or disposal.

There are predominantly four different configurations of low temperature thermal desorption systems:
- Rotary kiln dryers
- Thermal screws
- Conveyance furnaces
- Heated pipes

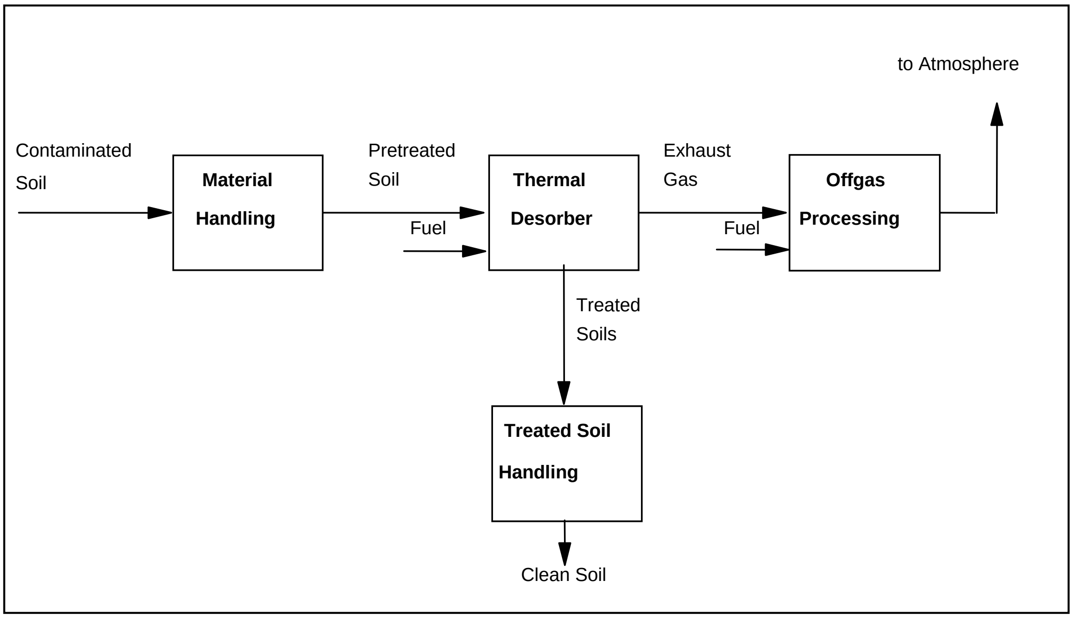
The systems differ in their mechanical design and process operating conditions, which includes such aspects as: how the contaminated soil is transported through the desorber, the process of soil heating, operating temperature of the desorber, residence time of the contaminated feedstock, and off-gas treatment.

A process flow diagram for a common LTTD design is provided in Figure 2.1.

LTTD units can be transportable or stationary facilities. With stationary units, contaminated soil is transported from site to the facility, whereas transportable units can be set up directly on site.

LTTD is suitable for the treatment of many organic compounds particularly petroleum products including: petrol, jet fuels, kerosene, diesel fuel, heating fuels, lubricating oils and can also treat polychlorinated biphenyls (PCBs) and explosives.

Depending on the nature of the soil, some pre-treatment may be necessary and commonly involves screening to remove large objects and clumps of soil. Oversize materials may be rejected, or crushed or shredded and returned to the feedstock. After treatment, soils are cooled and re-moistened to control dust.



Source: BAE Systems Property and Environmental Services

Figure 2.1: Process flow diagram for a common LTTD design

2.3 APPLICABILITY OF LOW TEMPERATURE THERMAL DESORPTION

Vapour pressure and/or boiling point of the contaminants, soil particle size and moisture content of the soil are often used as a first screen to assess the potential application of LTTD. Since the economics of the process is dependent on the amount of heat energy required to treat the soil, the characteristics of the soil and the contaminants present at the site need to be assessed in sufficient detail. Contaminant and soil characteristics that influence the application of LTTD are listed in Table 2.1 and discussed below.

Table 2.1 Key soil and contaminant characteristics that influence applicability of LTTD

Contaminant Characteristics	Soil Characteristics
Vapour Pressure	Particle Size Distribution
Boiling Point Range	Moisture Content
Contaminant Concentration	Plasticity
Thermal Alteration	Metal Concentration
Thermal Stability	Humus Content
Octanol/Water Partition Coefficient	
Aqueous Solubility	

Source: USEPA (1994)

2.3.1 CONTAMINANT CHARACTERISTICS

2.3.1.1 Vapour Pressure

Vapour pressure measures a compound's volatility and influences the rates of thermal desorption. The rate of desorption increases exponentially with increase in temperature. Therefore, modest increases in temperature can result in large increases in the rate of desorption.

2.3.1.2 Boiling Point Range

Boiling point ranges are also a measure of the volatility of a compound and are used to classify petroleum products. Boiling point is useful in assessing the applicability of LTTD. Whilst LTTD can be used to remove most petroleum based compounds, those compounds which have a higher boiling point and typically a higher molecular weight will require a longer residence time in the desorber at higher desorber operating temperatures. Heavier products tend to break down before volatilizing, or may form non-toxic, wax-like compounds that do not volatilise. The boiling point ranges for common petroleum products are shown in Table 2.2.

Table 2.2: Petroleum products boiling point ranges

Product	**Boiling Point Range (^{o}C)**
BTEX	80 to 144
Gasoline	40 to 225
Jet Fuel	100 to 250
Kerosene	180 to 300
Diesel Fuel	200 to 338
Heating Oil	> 275
EPA PAHs	218 to 536
PCB *Aroclor* 1254	335 (mean)
Lubricating Oils	Non volatile

Source: Adapted from EPA (1994) & BAE

Desorbers typically operate at temperatures up to 550 ^{o}C. However, some desorbers that are constructed of special alloys can operate at temperatures as high as 650 ^{o}C. Volatile products such as gasoline can be desorbed at lower operating ranges, while semi-volatile products such as kerosene and diesel fuel generally require temperatures in excess of 370 ^{o}C. Relatively non-volatile products such as heating oil, lubricating oils and PCBs require higher temperatures.

2.3.1.3 Contaminant Concentration

Contaminant concentration is a key parameter when reviewing the suitability of LTTD. The contaminant concentration will affect the process configuration, the soil treatment temperature and residence time. Organic compounds release thermal energy during treatment. High concentrations of such contaminants in soil will affect operating temperatures, and may cause overheating and damage to the desorber. Therefore, soils with high heating values may require dilution with cleaner soils to ensure that the system can be operated at lower and safer temperatures.

Elevated hydrocarbon concentrations in the off-gas may lead to several other considerations. Firstly, the levels may exceed the thermal capacity of the off-gas treatment system to effectively treat the off-gas and potentially result in the release of untreated vapours into the atmosphere. Secondly, high concentrations of vapours in the desorber can become an explosion hazard if they exceed the lower explosive limit (LEL). The LEL for most organics is generally 1 % - 5 % by volume. For safety reasons, the concentration of organic compounds in the exhaust gas of a thermal desorption device operating in an oxygen-rich environment should be limited to less than 25 % of the lower explosive limit. The maximum concentration of total petroleum hydrocarbons (TPH) in the material that can be treated without exceeding the LEL, ranges from 1 % - 3 %. Above 3 % the soil must be blended with material that has a lower organic content to ensure that the LEL is not exceeded.

Thermal screw systems operate in an inert atmosphere and so are not limited by the organic content. In an inert atmosphere, the concentration of oxygen is too low (less than 2 % by volume) to support combustion.

2.3.1.4 Thermal Alteration

The application of high temperatures to petroleum-based compounds can result in thermal alteration. This may take the form of cracking, where large molecular compounds are broken down to smaller compounds or polymerisation where large molecular compounds are created from smaller compounds. Thermal alteration can affect the physical, chemical and toxicological properties of compounds and this should be considered in any risk assessment. For example, thermal destruction of PCBs and other chlorinated compounds can lead to the formation of highly toxic dioxins. Therefore, it is important to carry out detailed chemical characterisation prior to thermal treatment to ensure that adequate protection of human health and the environment can be put in place.

2.3.1.5 Thermal Stability

Petroleum hydrocarbons are not expected to significantly decompose/combust in LTTD units, provided that the off-gas temperature is below the auto ignition temperature (i.e. the temperature at which a compound will spontaneously combust). Auto ignition temperature is, therefore, an indicator of the thermal stability of a compound, and the degree of thermal decomposition is related to the maximum temperature of exposure.

2.3.1.6 Octanol/Water Partition Coefficient K_{ow}

The octanol/water partition coefficient, $K_{ow,}$ represents the ratio of the solubility of a compound in octanol (a non-polar solvent) to its solubility in water (a polar solvent). K_{ow}, often expressed in log form, is generally used as a relative indicator of the tendency of an organic compound to adsorb to soil. Log K values are generally inversely related to aqueous solubility and directly proportional to molecular weight. Compounds with high log K values such as benzo(a)pyrene are more difficult to desorb than compounds with low values such as naphthalene.

2.3.1.7 Aqueous Solubility

Aqueous solubility is a measure of the extent to which a compound will dissolve in water. Solubility is generally inversely related to molecular weight: the higher the molecular weight, the lower the solubility. Compounds with higher molecular weight are also generally more difficult to desorb from soil than lower molecular weight compounds.

2.3.2 SOIL CHARACTERISTICS

2.3.2.1 Particle Size Distribution

Particle size determines the type of pre-treatment and influences the selection of the type of thermal desorber to be used. Large sized material in the treatment feed is typically crushed to <50 mm. Soils such as sands and gravels, are easier to treat as they require less pre-treatment and have a lower intrinsic moisture content. Finer grained materials containing clay sized particles have a higher intrinsic moisture content and can form lumps which require pre-treatment. Finer grained materials when dry can also cause the build up of particulates in the baghouse.

2.3.2.2 Moisture Content

The throughput or treatment rate of a thermal desorption system is inversely proportional to the moisture content of the feed stock. Moisture content determines the residence time and heat required to remove the contaminants from the soil. The higher the moisture content, the greater the heat energy required to drive the plant. For LTTD treatment, the optimal soil moisture range is from 10 % – 25 %. Soils with excessive moisture content may require dewatering prior to processing.

2.3.2.3 Soil Plasticity

Plastic soils are difficult to manage and treat with LTTD technology as the material often forms large clumps and can stick to equipment and slow down the feed rate. Plastic soils often have high clay and moisture contents. They require pre-treatment to break down the material size and require higher temperatures to remove moisture.

2.3.2.4 Humus Content

Humus material in soil can cause analytical interferences, yielding false positives for the presence of TPH or Benzene, Toluene, Ethylbenzene, Xylene (BTEX). Humus material can enhance adsorption of some organic compounds, making desorption more difficult. It can also add to the calorific loading of the plant. This needs to be factored into the operating settings of the plant to optimise energy usage.

2.3.2.5 Metal Concentration

LTTD does not treat metals (although certain metals such as mercury and lead can become volatile at high temperatures and portions of metals may partition to the gas phase). Therefore, it is important that any residual metals in the soil or in the discharged air stream meet appropriate disposal or release criteria.

2.3.3 SUMMARY

While this section describes a number of contaminant and soil characteristics which can be measured and assessed to determine whether LTTD is an appropriate remedial technique, practitioners will rely on a smaller number of key parameters which typically include:

- Contaminant volatility
- Contaminant concentration, and
- Soil type (based on particle size distribution)

3. SITE DESCRIPTION

3.1 SITE LOCATION

The chemical works is bounded by a river, estuary, coastal area, an industrial park development and residential estate.

The tank farm area from which contaminated soil was excavated to carry out the pilot trial is located in the south central portion of the chemical works and occupies an area of approximately 5 hectares (see Figure 3.1). It is rectangular in shape and consists of tanks and associated pipework set within a bunded area located directly on madeground.

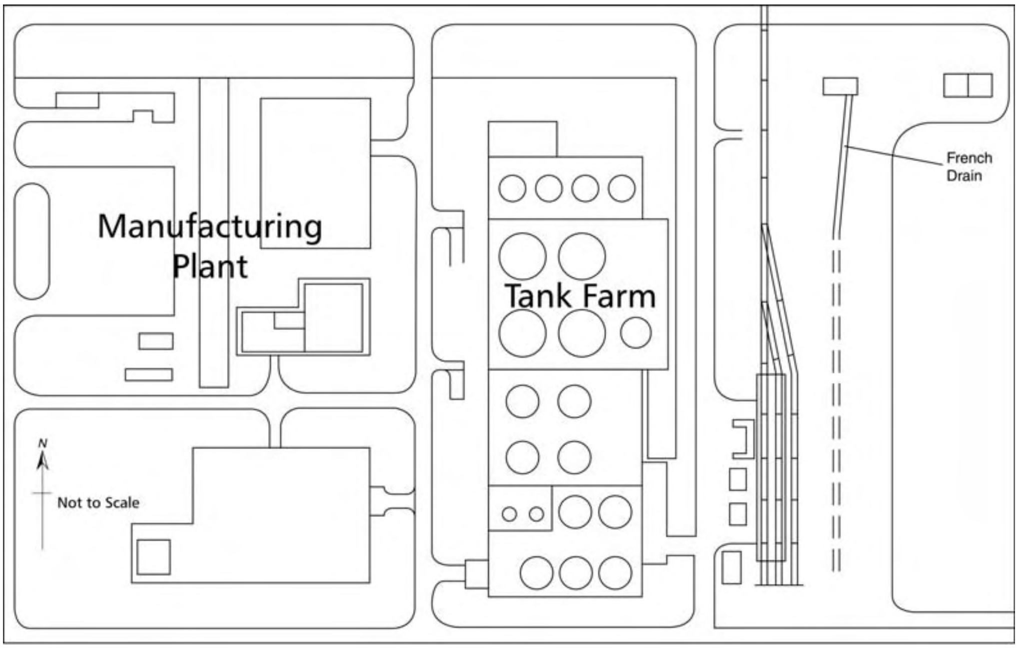


Figure 3.1: The tank farm area

3.2 TOPOGRAPHY AND DRAINAGE

The site topography is generally flat, lying at approximately 7 m - 10 m above Ordnance Datum (aOD), with a gentle slope towards the northeast.

Roadside drains direct site runoff to a site effluent treatment system prior to discharge to the sea or adjacent river. Large areas of the site are open ground allowing infiltration with little or no surface runoff.

3.3 SUMMARY OF ENVIRONMENTAL INVESTIGATION AND REPORTS

The chemical works was investigated in two phases between August 1993 and May 1995.

In 1993, Phase I investigation to investigate the potential contamination for the whole of the chemical works based on past and present usage. During this investigation a two stage sampling approach was adopted. Initially a soil vapour survey was conducted across the study area using shallow perforated casing and soil vapour diffuse monitor tubes packed with Tenax adsorbent. Soil vapour measurements were taken at approximately 250 locations. The second stage involved the drilling of 26 boreholes across the site with groundwater monitoring wells installed in 13 of the boreholes. Nine boreholes were drilled to depths of 4 m bgl in the tank farm area and three of the boreholes were completed with groundwater monitoring wells.

In 1994, a Phase II investigation of the tank farm area, adopting the same two stage sampling approach, was undertaken. A small soil-vapour survey was undertaken in the southern area of the tank farm followed by the drilling of 15 boreholes to depths of 4 m bgl, each completed with a groundwater monitoring well.

The location of boreholes and groundwater monitoring wells is shown in Figure 3.2.

In 1999, further investigation of the hydrocarbon processing plant (north of the study area) and tank farm was undertaken prior to decommissioning.

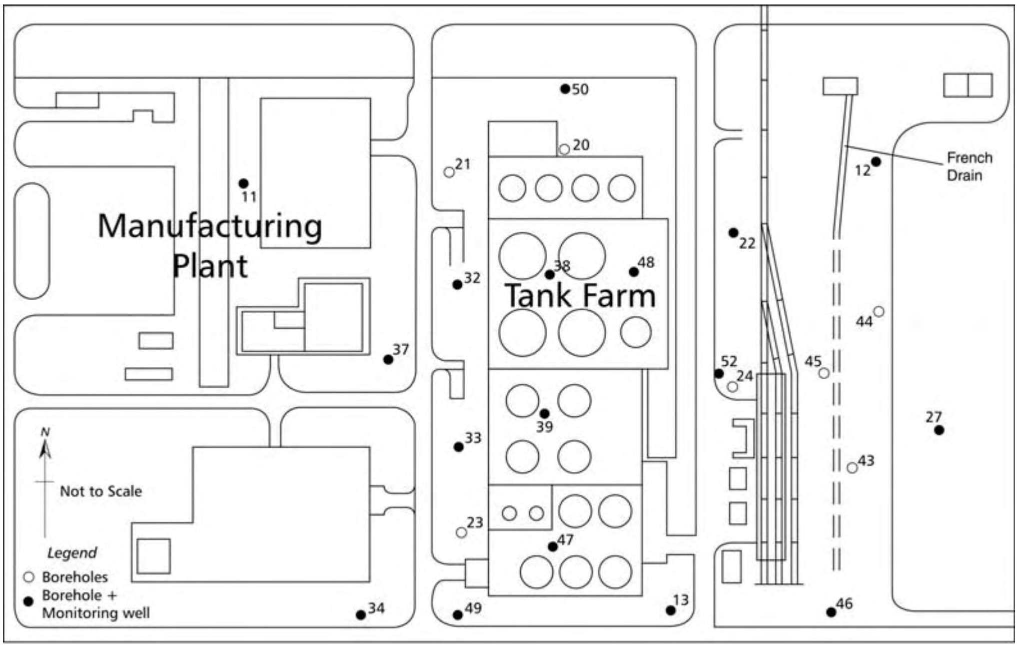


Figure 3.2: Location of borehole and groundwater monitoring wells

3.4 GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

3.4.1 GEOLOGICAL CONDITIONS

The chemical works is situated on levelled sand dunes overlain by slag imported from an adjacent steelworks. The geology comprises madeground, underlain by wind blown sand, marine sands or estuarine alluvium, over glacial deposits which are underlain by the Carboniferous Lower to Middle Coal Measures which occur beneath the site at a depth of approximately 40 m bgl.

In the tank farm area, the madeground (which occurs up to 3 m thick) consists of slag, gravel/sand with brick and concrete in the upper horizons. The wind blown sand consists of a uniformly graded coarse silt and fine to medium sand approximately 6 m in thickness and is the main focus of the LTTD pilot trial. The uniformity of this unit is illustrated by the very narrow range of variation in particle size distribution plotted from seventeen samples (see Figure 3.3). The sand unit is underlain by laminated clay up to 2.5 m in thickness which consists of a soft to firm, dark grey, silty clay with silt and sand lenses. An underlying marine sand deposit between 10 m and 15 m in thickness consists of a dense, fine to medium grey sand containing laminations of grey silty clay. Estuarine alluvial deposits which lie beneath the marine sand unit, range between 6 m and 16 m in thickness and consist of sandy/clayey silts, or peaty clay/silts, with peat layers. The alluvium overlies glacial deposits greater than 3 m in thickness consisting of boulder clay and comprising a silty clay matrix with angular rock fragments ranging in size from gravel to cobbles. The underlying Lower and Middle

Carboniferous Coal Measures comprise dark blue/grey, hard carbonaceous mudstones and shales, with thin coals, with an uneven upper surface. The thickness of this geological unit at the site has not been determined.

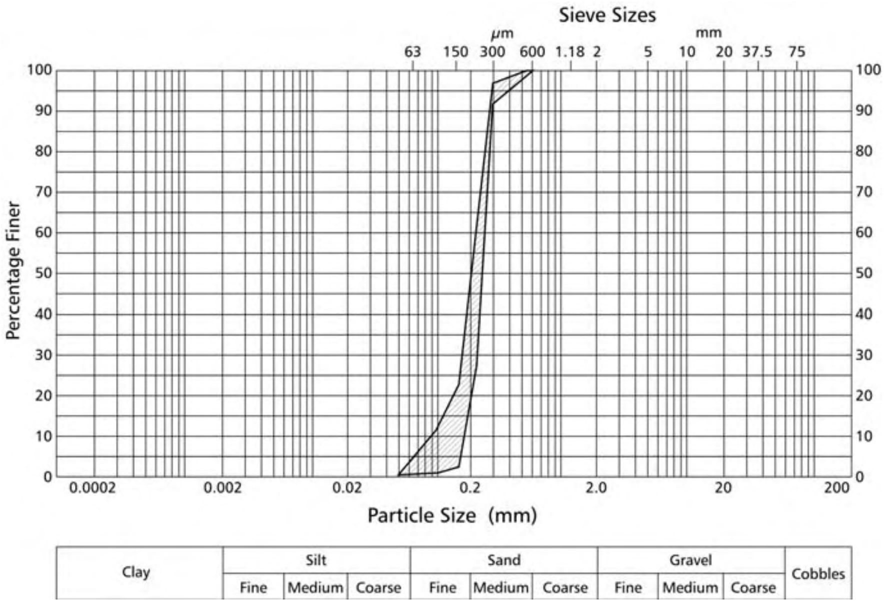


Figure 3.3: Particle size distribution curves of the wind blown sand

3.4.2 HYDROGEOLOGICAL CONDITIONS

Regionally across the site, the sequence of sands and alluvial deposits is classified as a minor aquifer of local importance with a high vulnerability to leaching. The Lower and Middle Carboniferous Coal Measures are classified as minor aquifers and form a multi-layered aquifer system.

Within the tank farm area, groundwater is typically encountered in the sands at depths between 0.84 m bgl (BH 11, 1995) and 1.97 m bgl (BH 13, 1995). Seasonal variations of approximately 0.60 m – 1.2 m occur in the water table, with highest levels occurring during the months of January and February and lowest levels during August and September. The seasonal variation in the water table in BH 13 is illustrated in Figure 3.4.

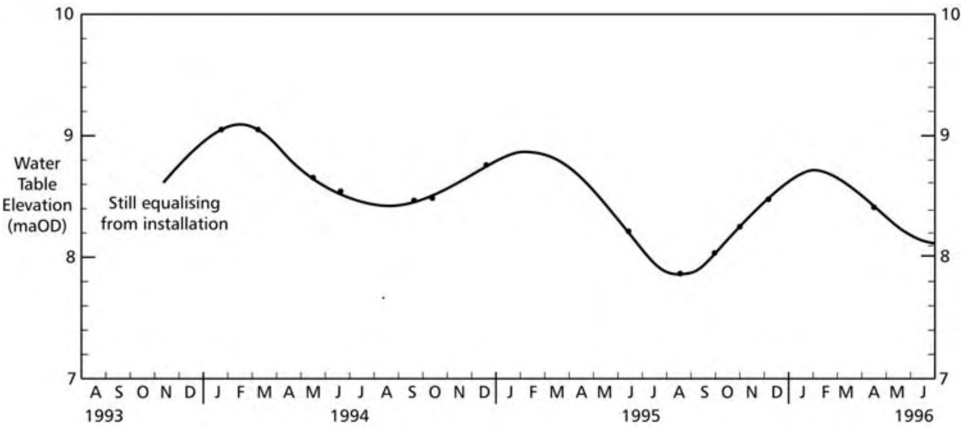


Figure 3.4: Seasonal variation of water table level in BH13

Hydrogeological data from ground investigations indicates that the madeground is highly permeable with occasional areas of perched water over impermeable concrete. An estimated 60 % of the annual rainfall infiltrates to the water table.

Based on particle size distribution, hydraulic conductivity of the sand is estimated to be of the order of 1-1.5 x10^{-4} m/s. The direction of groundwater flow is generally towards the east, southeast. During the late winter and spring, when groundwater levels are highest, shallow groundwater flow is intercepted by a french drain which is aligned north-south along the east side of the tank farm (see Figure 3.1). During late summer and autumn, when water levels are lowest, shallow groundwater flows beneath the drain. Hydraulic gradients for the area range from 0.004 – 0.005 in summer months to 0.007 – 0.012 during winter. Groundwater flow velocities are estimated to be of the order of 20 m - 30 m per year.

The low permeability laminated clay layer, which lies below the sand, acts as an aquitard, limiting vertical groundwater flow and contaminant transport into lower geological units. However, the continuity of this layer known to have a variable thickness of up to 2.5 m in the eastern half of the site, thinning to absent to the north and west, is not fully understood.

3.5 NATURE AND EXTENT OF CONTAMINATION

Soil and groundwater samples from the site were analysed for Volatile Organic Compounds (VOCs), total petroleum hydrocarbons, mercury, cadmium, iron, zinc and lead.

UK statutory remediation criteria for soil and groundwater did not exist for the organic contaminants identified at the time of the environmental investigations. Therefore, analytical results were compared against a number of guideline values from other jurisdictions including: Dutch C values, and values from New South Wales (Australia), and New Jersey (USA). These values were used only as an initial guide to assess the degree of contamination and potential environmental risks that existed on the site.

A simple site specific risk assessment was carried out using a contracted software package which utilises standard contaminant fate and transport models. This model was used to calculate site specific remediation criteria or trigger levels. The main drivers for remedial action in the tank farm area based on the contaminant distribution at the site are listed below and their trigger levels are provided in Table 3.1:

- benzene
- toluene
- ethylbenzene
- diethylbenzene
- styrene

Table 3.1: Trigger values for soil and groundwater

Contaminant	**Soil (mg/kg)**	**Water (µg/l)**
Benzene	10	100
Toluene	500	1000
Ethylbenzene	100	300
Diethylbenzene	N/A	300
Styrene	100	100

N/A: Not available

Source: Site Owner (1994)

3.5.1 SUMMARY OF SOIL CONTAMINATION

3.5.1.1 Soil Vapour

The 1993 Phase I soil vapour survey identified major contamination in the tank farm area and north beyond the area of interest. The soil-vapour results indicated a crescent shaped area of benzene contamination with a maximum lateral dimension of 150 m beneath the tank farm with maximum levels of contamination exceeding background levels by up to 500 times. Diethylbenzene contamination was located in four small zones, each roughly circular in shape and having diameters of 40 m – 50 m. Three of the zones are located around the tank farm area with two close to the ethylbenzene storage area at the northern end. The fourth zone was located south west of the benzene tank. The results also indicated three main areas of styrene contamination each roughly circular, 50 m – 60 m in diameter and over 500 times background levels. Two of these areas lay under the styrene tanks but did not extend beyond the inner fence line. The third area was immediately southwest of the benzene tank and outside of the study area.

The 1994 soil vapour survey confirmed the results of the 1993 results indicating high levels of contamination at the eastern boundary of the tank farm.

3.5.1.2 Soil

The results from the Phase I and Phase II site investigations indicated high levels of hydrocarbon soil contamination above site trigger values within the sand horizon in the tank farm area. Selected analytical results and sample locations are provided in Table 3.2.

Analytical results for metals in soil samples from this area identified several areas of elevated metals relative to Inter-Departmental Committee on the Redevelopment of Contaminated Land (ICRCL) threshold concentrations for soil under buildings or hardcover.

Table 3.2: Selected analyses of soils (all values ppm w/w)

Borehole No. and sample depth	**Benzene**	**Toluene**	**Ethylbenzene**	**DEB**	**Styrene**	**Total Purgeables**	**Total Hydrocarbon**
BH 20 (1.5m)	0.01	0.05	<0.005	22.14	34.02	155.4	NM
BH22 (0.15m)	0.399	7.543	**198.6**	25.97	**294.53**	535.17	NM
BH22 (0.9m)	0.044	0.566	27.59	17.81	48.38	112	NM
BH23 (1.5m)	3.203	1.45	78.12	13.96	60.92	192	NM
BH24 (0.5m)	<0.005	1.25	9.82	543.9	**150**	1031	NM
BH24 (1.25m)	1.2	63.1	**1423**	3133	**1741**	7473	NM
BH 32 (1.40m)	0.06	1.16	**121.40**	NM	**190.80**	553	61
BH33 (1.00m)	NM	NM	NM	NM	NM	NM	6753
BH33 (1.80m)	0.70	3.30	**2233**	NM	**2535**	6940	NM
BH38 (1.40m)	**41.70**	**508**	**12404**	NM	**19009.00**	37987	NM
BH39 (1.00m)	**161.80**	39.80	**839.70**	NM	**1230.80**	2655	789
BH47 (1.10m)	**11.42**	4.94	**745.70**	NM	6.60	868	223
BH49 (1.00m)	2.09	11.40	**2472.40**	NM	**3386.30**	8420	6231
BH50 (0.40m)	0.08	0.10	32	NM	38.70	268	80
BH50 (2.00m)	0.16	0.93	47.35	NM	43.44	313	91
BH52 (0.70m)	6.90	119.60	**8724**	NM	**21626.00**	39153	15712

Source: Site Owner (1994 & 1995)

Notes

1. Figures in bold and underlined exceed trigger values (see Table 3.1 for details of trigger values)
2. NM = Not measured
3. DEB = Diethylbenzene

3.5.2 SUMMARY OF GROUNDWATER CONTAMINATION

3.5.2.1 Free Phase Petroleum Hydrocarbon

Free phase petroleum hydrocarbon was measured in a number of monitoring wells in the tank farm area ranging in thickness up to 400 mm over an estimated area of 15,000 m^2 to 20,000 m^2 (see Figure 3.5). The major component composition of the free phase hydrocarbon as determined by laboratory testing is provided in Table 3.3.

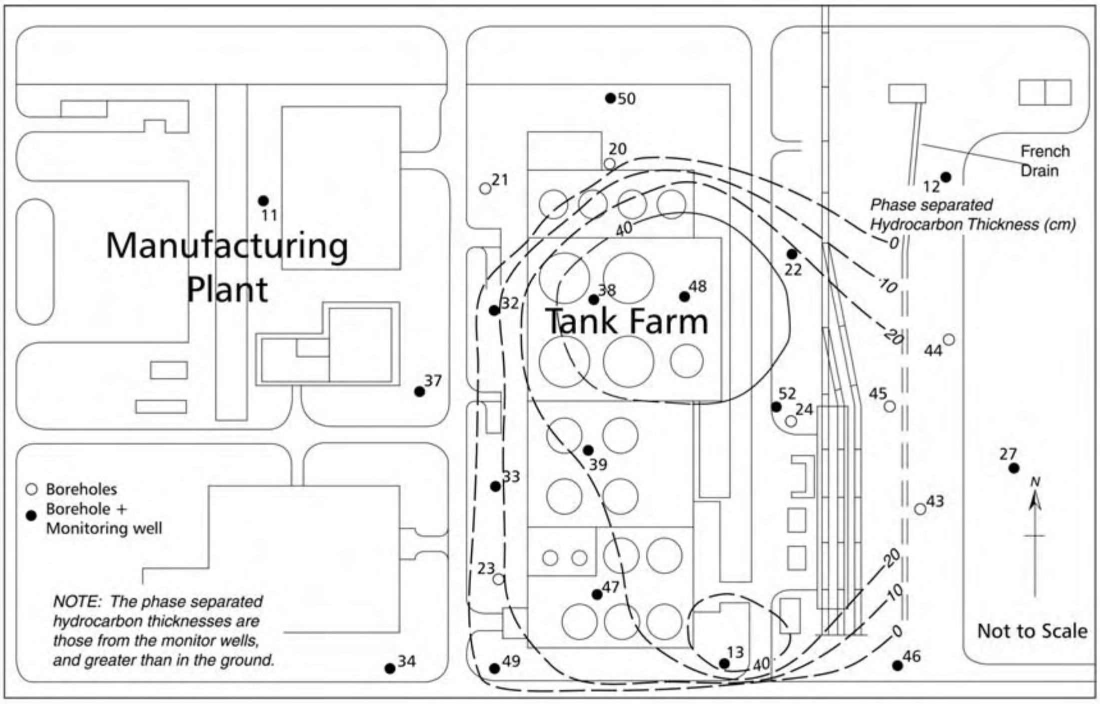


Figure 3.5: Free phase petroleum hydrocarbon measured across the site

Table 3.3: Composition of free phase hydrocarbon

Component	Value (% mass)
Ethylbenzene	40.3
Toluene	3.9
Diethylbenzene	4.3
Benzene	9.1
Styrene	39.2
Other Hydrocarbons	3.2

Source: BAE (1999)

The petroleum product is the result of a number of spills from different sources at different times. The thickness of free phase hydrocarbon measured in monitor wells at the site is typically two to six times greater than the in-ground thickness based on observations and theoretical calculations derived from bail tests. The volume of free product is estimated to be between 1000 m^3 - 1600 m^3 with up to 35 % - 45 % of the volume immobile or "residual" retained in the soil by capillary forces between the hydrocarbon liquid and the aquifer materials. Although the free phase hydrocarbon is less dense than water, with measured densities ranging from 0.891 g/cc to 0.925 g/cc, the seasonal fluctuation in the water table has generated a hydrocarbon "smear" zone where residual petroleum hydrocarbon becomes trapped above a lowering water table and below a rising water table. Furthermore, migration of free phase hydrocarbon eastward from the tank farm area in the direction of groundwater flow is captured by the french drain (see Figure 3.6). Free phase and dissolved phase hydrocarbon entering the french drain is directed to a sump and pumped to the treatment facility before being discharged.

3.5.2.2 Groundwater

Dissolved phase groundwater contamination was identified during the Phase I and Phase II investigations. Groundwater analyses from three selected boreholes BH 11, 12 and 13 from the tank farm area are provided in Table 3.4.

Table 3.4: Selected analyses of groundwater (all measurements in ppm v/v unless stated otherwise)

BH No	Date	Benzene	Toluene	Ethylbenzene	DEB	Styrene	Total Purgeables	Total Hydrocarbon (mg/l)
11[a]	1993	**2.77**[d]	**0.19**	**105**	**5.18**	0.079	116	NM
11	1994	<0.05	<0.05	<0.05	NM[e]	<0.05	NM	NM
12[b]	1993	**26.3**	**3.55**	**65.9**	**0.657**	**16.1**	113	168
12	1994	**70.2**	**8.80**	**113.50**	NM	**34.4**	230	NM
12	1994	**47.66**	**6.07**	**93.28**	NM	**22.19**	222	0.6
12	1994	**46.20**	**5.80**	**78.40**	NM	**21.10**	147	NM
13[c]	1993	**204**	**45.3**	**204**	**27**	**334**	826	140

Notes: Source Site Owner (1994 & 1995)
a Well located upgradient from the tank farm area
b Well located directly downgradient from the french drain
c Well contains free phase petroleum hydrocarbon upgradient of the french drain
d Figures in bold and underlined exceed trigger values (see Table 3.1 for details of trigger values)
e NM = Not measured
DEB = Diethylbenzene

3.6 CONCEPTUAL MODEL

A conceptual site model running east-west through the tank farm area is depicted in Figure 3.6. Contamination of the unsaturated zone above the water table occurs as a result of spills from the overfilling and leakage from tanks. The spilled petroleum hydrocarbon liquid will fill voids in the unsaturated zone to residual saturation and migrate vertically downward toward the water table under the influence of gravity, and laterally due to capillary forces. The lighter fractions of the residual contamination remaining above the water table will volatilise and form a contaminant vapour phase which can be detected by soil vapour surveys. The soluble portion of the residual phase will be dissolved over time by infiltrating rainwater.

On reaching the water table, the petroleum hydrocarbon liquid, which is less dense than water, will spread laterally across the top of the water table and provided there is sufficient height of free phase liquid, will depress the water table.

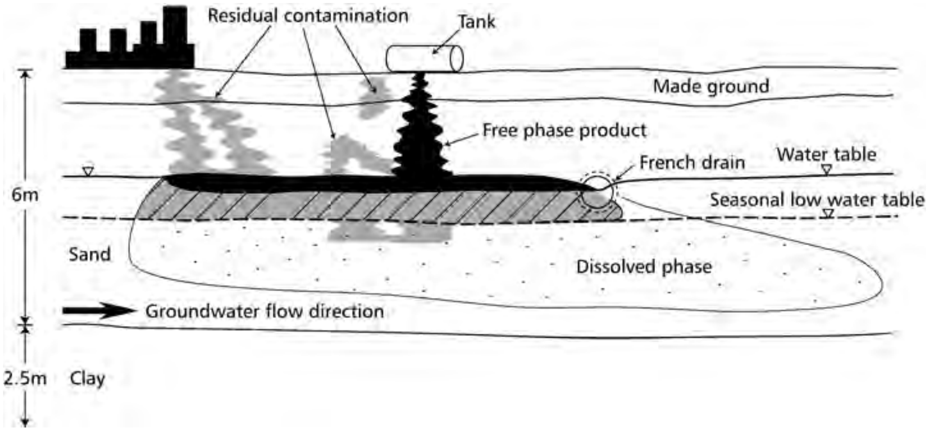


Figure 3.6: Conceptual site model

4. REMEDIATION PROCESS SELECTION AND DESIGN

4.1 INTRODUCTION

This section discusses the review and assessment of remedial options and the selection and design of the remediation process.

4.2 REMEDIATION OPTIONS

A number of options were considered for the remediation of the production plant and tank farm including:

1. Monitoring only
2. Containment by installation of a physical barrier and monitoring
3. Passive recovery by installing trenches/sumps to remove petroleum hydrocarbons
4. Active recovery by installing pumping or venting systems and monitoring
5. Excavation of contaminated soil and *ex situ* treatment

The granular character of the soil, together with the volatile nature of the aromatic contaminants and the shallow depth to the top of contamination, favoured *ex situ*, on site treatment. Special precautions to reduce air emissions and to protect workers were required during excavation of the free phase hydrocarbons.

A cost-benefit analysis was undertaken to assess the various technology options (see Figure 4.1). Isolation of the zone of contamination through the installation of a part cut off wall or a full wall and cap initially scored highest in the cost benefit assessment, but the benefit decreased over time due to expected degeneration of the materials at some point in the future. The remaining options fell within the upper half of the cost sector, with varying benefit. Low Temperature Thermal Desorption (LTTD) was selected as the technology with the greatest potential benefit although it also carried the highest potential cost.

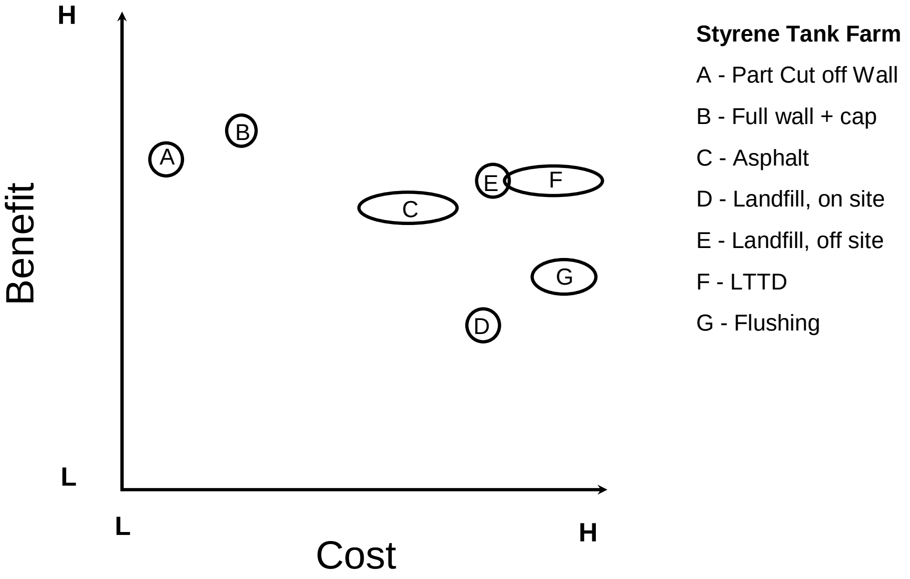


Figure 4.1: Cost-benefit analysis to assess various technologies

The main benefits of LTTD were:

- The site contaminants are easily volatilised and can be destroyed by appropriate off-gas treatment (eg thermal oxidiser)
- The treated soil could be placed back into the excavation

- Cleanup could be achieved at relatively low temperatures and cost effective energy requirements
- The structure of the soil would not be noticeably altered since it contained low clay and organic content
- The Soil Remediation Unit is transportable and the treatment could be carried out on site
- Stack emissions are continuously monitored on-line to ensure compliance.

It was accepted from the outset that off-gas emission quality from the LTTD operation would be heavily monitored and would have to meet strict criteria.

The elliptical shape of the LTTD area on Figure 4.1 reflects uncertainties with the application of LTTD which the pilot trial would address. These included:

- Material handling
- Likely atmospheric emissions
- Worker PPE
- Treatment rate for full scale cleanup
- Costs for full scale cleanup
- Input to licensing, planning needs

In addition, the soil sampling and excavation carried out during the trial would provide further information on the site conditions and contaminant behaviour.

Trials were undertaken by BAE in Autumn 1999 at their facility in Chorley to assess the applicability of LTTD technology to full scale remediation. One key benefit of LTTD was that treatment would be relatively quick, allowing the treated material to be returned to site thereby reducing the need for imported fill.

4.3 REMEDIATION DESIGN

The following distinct phases were built into the remediation design:

- Selection of material to be treated during the thermal desorption trial
- Excavation of contaminated material for the thermal desorption trial
- Monitoring of atmospheric air quality
- Identification of the extent of the contaminated area (for full scale remediation)
- Identification and removal of mobile hydrocarbons
- Calculation of the migration rate of mobile hydrocarbons into the excavation

4.3.1 SELECTION OF MATERIAL

The contaminated soil was taken from the tank farm area, which remained operational during the trial period. Therefore it was necessary for the excavation, loading and transport activities to have minimal impact on ongoing operations. It was also essential that the contamination from the selected area would be representative of the entire area to be remediated. Borehole 48 (BH48) was immediately adjacent to the chosen area and contained >500 mm of free product. It was expected that the free product from the area around BH 48 would flow into the excavation providing the opportunity to assess the efficiency of recovering the free phase hydrocarbon from excavations efficiently and safely.

4.3.2 EXCAVATION OF CONTAMINATED MATERIAL

Approximately 38 tonnes of contaminated soil with aromatic hydrocarbon concentrations no greater than 3 % were selected for the LTTD trial. The soil was excavated from a trial pit measuring approximately 3 m square by 2 m in depth. The excavation allowed the opportunity to gain further information on the following:

- Ground contaminant concentrations at varying depths within a zone of fluctuating groundwater
- Levels of airborne aromatic concentrations during excavation
- Assessment of personal protective equipment (PPE) within the work areas
- Rate of migration of free phase hydrocarbon into the excavation

The excavation was carried out by hand by the site term civil contractor. Hand tools were used for excavation because the trial area was contained within an operating site which could not be isolated and there was a flammability risk associated with liquid aromatics. Machinery carried a higher degree of potential risk particularly since machine access was extremely difficult. The work was controlled under a series of method statements covering the following:

- Excavation stability and work practises
- Control of atmospheric emissions and PPE requirement
- Airborne atmospheric monitoring

An exclusion zone extending 8 m from each side of the excavation was created beyond which tank farm operations could continue without the need for PPE.

During the excavation, residual aromatic hydrocarbons were encountered in soil within 300 mm of the ground surface and free phase liquid aromatic hydrocarbons were encountered at a depth of 1.3 m. All liquids seeping into the excavation were removed using a porous probe placed at the edge of the trial pit and a diesel driven pump. The contaminated soil removed from the trial pit was stored in four metal skips situated in the exclusion zone. Plastic sheets and tarpaulins were used to cover the contaminated material in the skips and on the open excavation during times when no work was being undertaken, in an effort to minimise volatile losses to the atmosphere.

4.3.3 MONITORING OF ATMOSPHERIC AIR QUALITY

The control of air quality during the remediation of the tank farm area was a critical aspect of the work. An air monitoring programme was therefore implemented to monitor the level of emissions of aromatic hydrocarbons to the atmosphere at the following locations:

- Within the exclusion zone surrounding the excavation
- At the site boundary

Monitoring data from the exclusion zone allowed the prediction of levels of exposure to personnel carrying out the remediation work, and helped to define PPE requirements. The data from the site boundary allowed air quality at the perimeter of the site to be assessed relative to Annual Air Quality Standards.

4.3.3.1 Monitoring within the excavation and exclusion zone

Airborne contaminant measurements from within the excavation pit and its accompanying exclusion zone (8 m from each side of the pit) were made using a portable ‘Total Vapour Analyser’ (TVA), equipped with a flame ionisation detector. The TVA measures a total hydrocarbon value, but is not specific to individual aromatic compounds.

Total airborne hydrocarbon concentrations in the exclusion zone during the period when there were no liquid aromatics present in the pit ranged from 1 ppm to 4 ppm. When liquid aromatics were present concentrations ranged from 10 ppm to 100 ppm. The proportion of benzene in the total hydrocarbon value was not measured and would need to be determined to establish PPE requirement.

Total airborne hydrocarbon levels in the excavation ranged between 200 ppm and 2000 ppm, and benzene concentrations of up to 780 ppm were detected. Atmospheric concentrations immediately outside the exclusion zone were measured over a one and an eleven day period using Chromasorb 106 diffusion tubes. The concentrations of benzene were 0.07 ppm and 0.04 ppm respectively. These low levels show the rapid decline in airborne aromatic concentrations within 10 m of the free phase liquid hydrocarbon in the excavation.

All on-site workers directly involved with the excavation and sampling for the pilot trial were required to wear personal monitoring equipment.

4.3.3.2 Monitoring at Site Limits

Atmospheric monitoring was carried out at predetermined locations at the limits of the tank farm area. Chromosorb 106 diffusion samplers were placed at each location and analysed to determine the concentration of aromatics over ten and fourteen day periods. Upwind monitor stations were located more than 100 m from the work area, whereas downwind monitor stations were located as close as 25 m from the work area.

The following sets of atmospheric data were monitored and are discussed below:

- Background levels under normal site operations
- Levels during excavation work and despatching of material
- Levels with free phase hydrocarbons in the excavation

Background Levels

A mean benzene background value of 2.7 ppb was obtained at the site limits from the first series of analyses over a ten day period prior to the start of work. All results except two were below the benzene air quality limit for the site of 5 ppb. One location registered 6.2 ppb benzene possibly due to exhaust fumes from passing diesel powered vehicles involved in the demolition of an adjacent building. Another location registered 6.9 ppb and is unexplained and does not correlate with the low concentrations measured at locations either side of those registering high values.

During Excavation

A mean benzene value of 2.0 ppb was obtained while excavation work was being carried out. This value was less than the mean background level. Diesel powered vehicles were in operation in the vicinity which returned an elevated level of 5.7 ppb benzene. A benzene concentration of 1.7 ppb was also measured and was similar to levels measured in the remaining monitoring points. The excavation and general handling of contaminated material does not appear to have caused an increase in atmospheric levels of aromatics at the site limits.

In the Presence of Free Phase Hydrocarbons

Following the seepage of free phase hydrocarbons into the excavation, a mean benzene value of 1.5 ppb was obtained and coincided with the cessation of diesel vehicle movements in the area. No values exceeded the air quality limit of 5 ppb. The presence of exposed liquid aromatics in the excavation pit did not result in an increase in the level of aromatics at the site limits.

4.3.4 IDENTIFICATION OF THE EXTENT OF THE CONTAMINATED AREA

Contamination in the tank farm area was identified from previous investigations and was considered to be bounded by the french drain on the east side and access roads on the south and north sides. The degree of contamination was generally widespread and a nominal depth of 2 m across the entire area was used to determine the approximate upper limit of volume of material requiring remediation. It is expected that some of the ground within this volume may be uncontaminated.

The estimated upper limit volume of contaminated soil is 53,500 m^3 or 96,000 tonnes at a nominal density of 1.8. The analysis of the locations at the perimeter of the contaminated area is recorded in Table 4.1.

Table 4.1: Monitoring results around perimeter of site

Survey Location No.	Analysis at 1 metre depth (ppm)	Analysis at 2 metre depth (ppm)	Analysis at 3 metre depth (ppm)	Liquid HC depth (mm)
49	22*	11*	-	530
13	-	-	-	490
24	760	240	80	-
52	6*	12*	-	20
110	17300	27400	7310	-
111	322	7	-	-
116	26410	4320	31	-
115	31460	12300	-	-
114	12	<1	-	-
112	-	2670	-	-
33	3*	3*	6*	-
32	6*	2*	0.065*	-

* Value expressed as % LEL from soil vapour analyser
HC = Hydrocarbon

4.3.5 REMOVAL OF MOBILE HYDROCARBONS

The mass of liquid hydrocarbons residing within the tank farm area was estimated from the Phase II ground investigation to be 720 tonnes. Therefore it is estimated that four pits of 8,000 m^3 each would need to be opened to expose the liquid aromatics.

4.3.6 MIGRATION RATE OF MOBILE HYDROCARBONS TO THE EXCAVATION

Over a period of 90 days, 12 tonnes of aromatic petroleum hydrocarbons were recovered and tanked.

To gain information on the methodology and timescale for removal, an excavation 2 m north of BH 48 was carried out. The excavation measured 3 m by 3 m by 1.5 m in depth. An air operated pump installation was used to recover free phase and aqueous phase hydrocarbons, which were discharged to a nearby tank.

The thickness of free phase aromatic hydrocarbons in BH 48 remained constant at approximately 500 mm. The thickness of free phase aromatics in BH 38 decreased from approximately 540 mm to approximately 300 mm and increased in BH 39 from 60 mm to 400 mm (See Figure 3.2 for borehole locations).

This needs to be considered against a change in water table level and some inconsistency in the level measurements from the electronic dipping meter. Overall indications are that migration of the mobile hydrocarbons is slow and that even with many pits, the removal of liquid hydrocarbons from the tank farm area would take many months. The favoured option was to extensively excavate exposing large areas of liquid aromatics, however, this type of approach must be balanced against the risk of infringing Air Quality Limits.

The aqueous component of the liquid recovered into the tank during the aromatics recovery process, was sampled on a number of occasions, and the dissolved aromatic concentrations were significantly lower than the plant and IPC effluent limits. Sample results from the tank are provided in Table 4.2.

Table 4.2: Aqueous phase hydrocarbon concentrations from tank

Contaminant	17th October 1999 (ppm)	26th November 1999 (ppm)
Benzene	76	71
Toluene	12	12
Ethylbenzene	58	66
Diethylbenzene	4	5
Styrene	83	92

5. TECHNOLOGY DEMONSTRATION SUPPORT ISSUES

5.1 INTRODUCTION

This section discusses support issues associated with the initial site investigation work, and the LTTD field trial, and covers the following:

- Regulatory approval and compliance
- Contract agreement and health and safety
- Work plan
- Sampling plan
- Laboratory analytical methods, and
- Quality assurance/quality control

5.2 REGULATORY APPROVAL AND COMPLIANCE

The trial was carried out at the BAE Systems facility in Chorley, Lancashire, and was compatible with the then existing SRU plant authorisation. The SRU operated through an Integrated Pollution Control (IPC) authorisation to operate an incineration plant, issued under Section 6 of the Environmental Protection Act 1990. No additional regulatory controls were required.

The authorisation was varied in July 2001, subsequent to the trial. This was to include conditions relating to the requirements of the European Council Directive 94/67/EC on the incineration of hazardous waste. The main effect of this variation was an upgrade to the emissions monitoring requirements (see section 6.5 Emissions Control for more details).

5.3 CONTRACT AGREEMENT AND HEALTH AND SAFETY

All work at the BAE Systems facility was carried out in accordance with the SRU operating manual and the BAE Systems Health and Safety Management System.

This included operating the facility in accordance with the plant operating manual, operating instructions, plant risk assessment, environmental risk assessment and materials Control of Substances Hazardous to Health (COSHH) assessment.

5.4 WORK PLAN

The work involving the excavation of the contaminated material for the LTTD trial was undertaken by the site term contractor Andrew Scott, and was controlled using a series of method statements covering:

- Excavation stability and work practises
- Control of atmospheric emissions and Personal Protective Equipment (PPE) requirement
- Airborne atmospheric monitoring

All personnel working in the excavation were required to wear a 3M 4251 organic vapour mask while excavating down to 300 mm and positive pressure breathing apparatus and chemicals protection suits below this level. The level of PPE protection required to cope with the liquid aromatic hydrocarbons seeping into the pit, made it difficult to advance the excavation manually. Consequently, workers were limited to short work periods with frequent rest breaks. Personnel within the exclusion zone supporting the excavation activity were also required to wear 3M 4251 organic vapour masks.

Plant operators carrying out sampling and loading/unloading operations wore appropriate PPE including respirators with A2P3 canisters at all times.

5.5 SAMPLING PLAN

Drilling during the 1993 site investigation was performed using a Minuteman portable drill rig owned and operated by Ground Restoration Limited, and equipped with 100 mm outside diameter (OD) hollow stem flighted augers and a split spoon sampler.

During the 1994 investigation, the majority of the boreholes were located in easily accessible locations outside bunded areas and were drilled using a MX410 tracked drill rig equipped with 225 mm OD hollow stem augers. The Minuteman portable drill rig was used in the less accessible bunded area within the tank farm.

Soil samples were recovered at regular intervals during drilling of each borehole depending on soil and groundwater conditions. Soil samples were screened for hydrocarbon contamination using a GasSurveyor 4 portable direct photo-ionisation detector (PID) calibrated to methane.

On completion, boreholes were equipped with 38 mm internal diameter monitoring well casing, installed to a depth of at least 1.0 m below the measured groundwater depth. The wells consisted of 1 m length sections of threaded PVC pipe. Well screens were constructed of PVC with a slot size of 0.5mm and fitted with geofabric filter sock of 150 micron mesh. Monitoring wells were installed through the hollow stem auger or immediately after removal of the augers. The annulus between the monitor well and borehole was backfilled using natural sand or BS 16/30 filter sand having a grain size of 0.5 mm to 1 mm. A bentonite seal was placed from 0.5 m to 0.25 m below ground surface (bgs) and completed to ground surface with a concrete seal capped with a manhole cover.

Monitoring wells were developed by purging a minimum five casing volumes of water from each borehole. The water was allowed to recover before groundwater samples were collected using a Teflon® bailer.

5.6 LABORATORY ANALYTICAL METHODS

5.6.1 SOIL-VAPOUR

Soil-vapour probes containing Tenax diffusion tubes were placed in the soil at a depth of 0.3 m and left to absorb soil-vapour for 24 hours. The tubes were then retrieved and submitted to the site owners own laboratory for analysis. Analysis was carried out using a thermal desorption/gas chromatography technique in accordance with NAMAS Method No. 211/EP2.

5.6.2 SOIL

Soil samples for metals analysis were initially digested in cold concentrated aqua regia and then heated. Mercury analysis was carried out by cold vapour atomic absorption using ISO Method No. 5666/1. The remaining metals were analysed by atomic absorption.

Volatile organic compounds (VOCs) were analysed using purge and trap techniques. A known amount of material was diluted with distilled water and purged with nitrogen, whilst being heated. The liberated VOCs were trapped in thermal desorption tubes and analysed using a thermal desorption/GC technique in accordance with NAMAS Method No. 211/EP2.

Total petroleum hydrocarbons (TPH) in soils were analysed using infra-red spectroscopy. A known amount of sample was mixed with an equivalent amount of anhydrous sodium sulphate and extracted with 200 ml of Freon® effected by ultrasonication. After reduction to 10 ml, analysis was by infra-red spectroscopy at three wavelengths.

5.6.3 GROUNDWATER

Chemical oxygen demand (COD**)** analysis was carried out using a standard Dr. Lange test kit. A sulphuric acid/potassium dichromate solution was added using silver sulphate as an oxidation catalyst. Chloride was masked with mercury sulphate. Chromium (III) was measured photometrically and related to COD.

Total suspended solids were analysed using method 33.041 from the "Official Methods of Analysis" by Association of Official Analytical Chemists.

Electrical conductivity and pH analyses were carried out in accordance with "Methods for the Examination of Waters and Associated Materials" issues by the Standard Committee of Analysts (Department of the Environment and National Water Council).

VOCs in groundwater were analysed using purge and trap techniques as described for soil above.

TPH in groundwater was measured by infra-red spectroscopy at three wavelengths following acidification to pH <2, Freon® extraction and a volume reduction to 10 ml.

5.7 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

QA/QC for pre - trial site characterisation and during the trial is discussed below.

5.7.1 FIELD QA/QC

During the site investigation, all drilling and sampling equipment was pressure washed. No drilling fluids or water were used during the drilling process.

Each soil vapour, soil or groundwater sample was collected in the appropriate laboratory supplied container, labelled and immediately transferred to an on site cool box. At the end of each work day, all samples were transferred to an on site laboratory fridge and were then subsequently transported to a laboratory testing facility.

5.7.2 LABORATORY QA/QC

During the thermal desorption trial, all samples were analysed at BAE Systems laboratories at Chorley.

Soil samples were analysed for benzene, toluene ethylbenzene, styrene and diethylbenzenes using documented in-house standard procedures. A known amount of sample was rapidly transferred to an extraction bottle containing drying agent and extracted using dichloromethane containing a deuterated (d^8) styrene standard. The extraction bottle was sealed and agitated overnight. A blank was run with every sample batch using the same procedure but without soil. The extraction was analysed using a GC/MS system calibrated with 9 standards of varying concentration of the contaminant compounds listed above, together with the d^8 styrene internal standard (diethylbenzenes were calibrated on one isomer and all isomer areas summed for calculation). A mid-range standard was then analysed as a QC standard sample and this analysis was repeated every ten samples to confirm system performance.

6. DESCRIPTION OF THE BAE LTTD SOIL REMEDIATION UNIT

6.1 INTRODUCTION

This section discusses the BAE Systems LTTD SRU under the following headings:

- The Plant
- Operation of the Plant
- Online Monitoring
- Emissions Control
- Capabilities of Soil Remediation Unit

6.2 THE PLANT

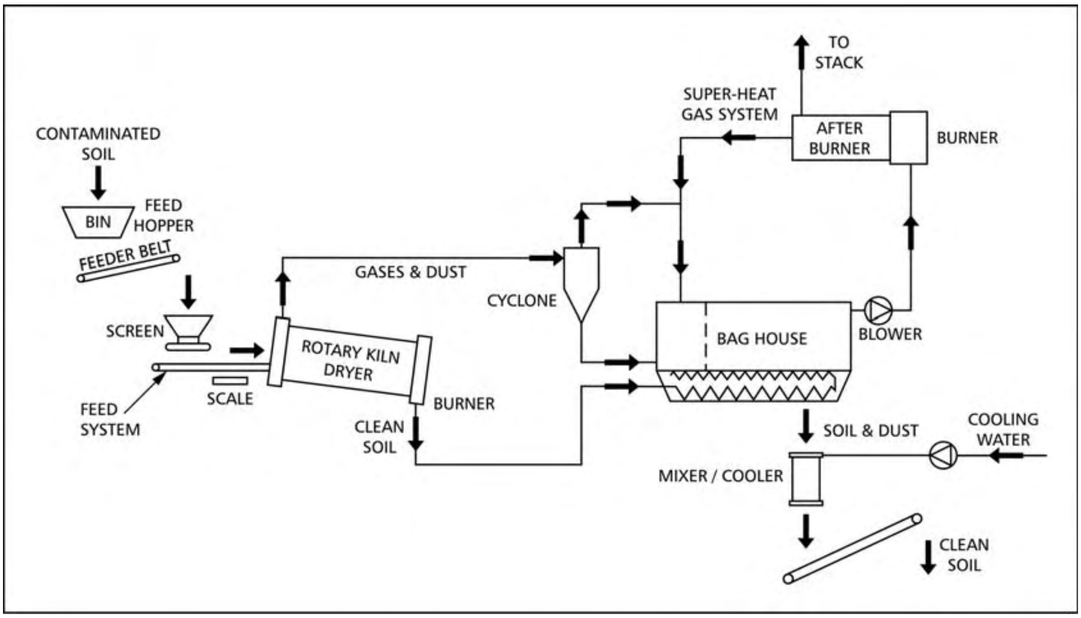
The SRU was manufactured by Gencor Beverley of Thermotech Systems, Orlando, Florida in 1993.

The system is transportable, but has mainly operated from a semi-permanent facility in Chorley, Lancashire. The unit has been designed principally to treat soils contaminated with light and middle distillate hydrocarbons such as solvents, gasoline, kerosene, diesel fuel and light fuel oils. The system can also treat explosives and PCBs.

The footprint of the plant is 35 m x 26 m and is set on hardstanding. An area with a free radius of 10 m around the plant provides access for plant erection, disassembly and maintenance. The emissions stack is 15 m in height and has a separate concrete foundation to support its weight. To comply with UK legislation, the stack is located at least 75 m from any building that is over 7.5 m tall.

Stock pile bays that hold up to 1000 m^3 of treated and untreated material are located adjacent to the plant. There is also an area of approximately 500 m^2 close to the plant for material preparation which typically could involve crushing, screening, shredding and mixing.

The plant is licensed for use in the UK under IPC legislation. Plant emissions and treatment parameters are based on those described in the EC Hazardous Wastes Incineration Directive (94/67/EC; Anon, 1994a) (HWID). The plant has a treatment capacity of 22.5 tonnes per hour. It can be fuelled by natural gas, liquid propane gas or domestic fuel oil. Electricity can be supplied by a site generator if mains supply is not available and operates on three phase neutral 420 V electricity supply rated at 350 kVA capacity. The plant is equipped with a 50 mm water feed which is capable of delivering 60 litres/minute. A process flow diagram of the SRU is provided in Figure 6.1 and Plate 6.1 shows the SRU in operation.



Source: BAE Systems Property and Environmental Services

Figure 6.1: Process flow diagram of SRU

Source: BAE Systems Property and Environmental Services

Plate 6.1: SRU in operation at BAE Chorley site

6.3 OPERATION OF THE PLANT

Soil is placed into a feed hopper, which discharges onto a feeder belt. The feeder belt passes soil onto a vibrating screen which rejects oversized material (+50 mm) and sends it back for crushing or shredding depending on the material type. A magnet is positioned above the feeder belt to remove any ferrous metal. Screened material is passed onto a weighing conveyor to measure feed rate and weight.

The weighing conveyor carries the contaminated soil into the rotary kiln desorber. The rotary kiln is cylindrical in shape and is inclined slightly from the horizontal. A burner is located at the lower end, furthest from the feed input. The desorber is directly fired by natural gas. As the drum rotates, soil is conveyed through the drum. Lifters raise the soil, carrying it to near the upper surface of the drum before allowing it to fall. This process heats the soil rapidly to the appropriate predetermined temperature necessary to volatilise and desorb the contaminants from the soil. Desorbed vapours and soil flow in opposite directions to increase desorption efficiency. The treated soil leaves the desorber through a chute at the burner end and passes to a mixer/cooler via a screw auger in the base of the baghouse.

Exhaust gases (including the desorbed vapours) from the desorber are directed to a cyclone where larger particulates are removed to reduce particulate loading to the baghouse.

The exhaust gas stream is then passed through a series of *Gore-tex*® bag filters, in the baghouse, to remove particulates. Dust particulates collected from the baghouse and cyclone are mixed with clean soil using an enclosed auger and dampened with water to reduce the temperature of the soil to approximately 40 ^{o}C before being discharged from the plant by conveyor. The Wet Dust Collector is used to catch any dust particles that are caught up in the steam that leaves the output conveyor. The dust forms water droplets which are removed by a mist eliminator. The dust free steam is blown back on to the clean soil in the output bay.

All the exhaust gases from the baghouse are directed via a blower unit into the after-burner for treatment. The after-burner is a thermal oxidiser which burns the collected gases for a minimum of two seconds at a minimum temperature of 850 ^{o}C in an environment containing a minimum of 6 % excess oxygen. The oxidiser is directly fired by natural gas. At low operating temperatures a hot gas bleed (superheat) system attached to the oxidiser and the baghouse is used to avoid contaminant condensation occurring in the baghouse. All exhaust gases from the oxidiser are discharged to the atmosphere through a 15 m high stack. The stack is fitted with emission monitoring equipment for continuous sampling for specific substances as detailed in section 6.4.

6.4 ONLINE MONITORING

The SRU is equipped with continuous online and data logging equipment to monitor the operational performance of the plant. During the trial, the following parameters were measured and recorded for reporting to the Environment Agency:

- sulphur dioxide
- nitrogen oxides
- particulates
- carbon monoxide
- oxygen
- soil temperature
- oxidiser temperature
- weight of soil treated

The level of flammable gases within the baghouse is continuously measured using a combustible gas detector. In the event that explosive conditions are reached in the baghouse due to a build up of concentrations and temperatures of exhaust gases, an automatic shut down procedure of the plant is triggered.

Note: Since the trial, the SRU emissions monitoring equipment has been upgraded to comply with the Hazardous Waste Incineration Directive (HWID)94/67/EC, and now also continuously monitors:

- *hydrogen chloride*
- *hydrogen fluoride*
- *volatile organic compounds*

6.5 EMISSIONS CONTROL

As a requirement of the SRU's plant authorisation, a number of emissions are also measured on a quarterly or annual basis. In addition, the Environment Agency carries out spot checks independently on an annual basis. The measured emission parameters and the consent and frequency are detailed in Table 6.1.

Table 6.1: SRU emissions monitoring – consent and frequency

Parameter	**Consent (mg/*N*m^3)^a**	**Consent (mg/*N*m^3)^b**	**Monitoring Frequency^b**
Volatile organic compounds	20	10	Continuous and quarterly
Carbon monoxide	50 (c) 100 (d) 150 (e)	50	Continuous and quarterly
Particulates	20	10	Continuous and quarterly
Hydrogen chloride	10	10	Continuous and quarterly
Hydrogen fluoride	2	1	Quarterly
Sulphur dioxide	50	50	Continuous and quarterly
Oxides of nitrogen (as NO_2)	190	190	Continuous and quarterly
Heavy metals	1 (c)	N/A	Quarterly
Polychlorinated dibenzo-*p*-dioxins(f)	$1x10^{-6}$	N/A	Annually
Polychlorinated dibenzo-furans (f)	$1x10^{-6}$	N/A	Annually
Dioxins and furans (TEQ)	N/A	0.1 (ng/m^3)	Quarterly
Total cadmium and thallium	N/A	0.05	Quarterly
Mercury	N/A	0.05	Quarterly
Total group III metals	N/A	0.5	Quarterly

Source: BAE Systems Property and Environmental Services

Notes:
a.Consent at time of trial
b.Consent and frequency as per HWID as of July 2001
c.Daily average value
d.Hourly average value
e.At least 95 % of all measurements determined as 10-minute average values taken in any 24-hour period
f.Determined as toxic equivalents – specified consent refers to overall toxic equivalents of both species

6.6 CAPABILITIES OF SOIL REMEDIATION UNIT (SRU)

The SRU is currently set up to treat the following soil and contaminated material without pre-treatment:

Soil Type
Less than 25 % fines content (material passing 75 µm sieve)
Less than 5 % material greater than 50 mm diameter
Less than 25 % moisture content
Less than 0.5 % combustible solids, eg wood, coal, roots, plant material
Less than 0.1 % coal dust

Inorganic Contamination
Less than 0.001 % asbestos (dry weight) in any 5 m^3
Less than 5 mg/kg mercury (dry weight) in any 5 m^3
Less than 200 mg/kg elemental sulphur (dry weight) in any 5 m^3

Organic Contamination
Less than 30,000 mg/kg (dry weight) total hydrocarbon
Less than 5,000 mg/kg (dry weight) organo-nitrogen compounds
Less than 250 mg/kg (dry weight) organo-sulphur compounds
Less than 1000 mg/kg (dry weight) halogenated organic compounds
Less than 500 mg/kg (dry weight) hydrocarbons greater than C_{20}
Less than 500 mg/kg (dry weight) organic compound boiling above 350 ^{o}C

Where any of these parameters are exceeded, pre-treatment of the materials would normally be required.

7. LOW TEMPERATURE THERMAL DESORPTION TRIAL AND PERFORMANCE EVALUTION

7.1 INTRODUCTION

Two trials were undertaken using the BAE SRU to determine the suitability of the remediation method for full scale remediation at the site.

7.2 OBJECTIVES OF TRIAL

The objectives of the trial were to assess:

- The treatability of the material
- The achievable material cleanup level
- The achievable material treatment rate
- Treatment costs
- The emissions quality
- Required health and safety controls, and
- The environmental impact

7.3 PRINCIPAL CONTAMINANTS

The principal contaminants for treatment were identified from the site investigation as:

- Ethylbenzene
- Toluene
- Diethylbenzene
- Benzene
- Styrene

7.4 MATERIAL PREPARATION

7.4.1 CHEMICAL ANALYSIS OF SOIL

Approximately 38 tonnes of contaminated material were delivered to BAE's Chorley facility on 16th September 1999 in sheeted lorries. The material was tipped into the receipt area before being sampled and transferred to a covered storage area.

Twelve random samples were taken and analysed in the on-site laboratory for aromatic hydrocarbon content. Selected samples were also submitted for analysis of metal content, volatile matter (a surrogate for moisture content), total sulphur and calorific value. The analytical results for aromatic hydrocarbons are provided in Table 7.1.

Table 7.1: Aromatic hydrocarbon analyses of contaminated soil at delivery

Lab Ref.	Sample Ref.	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Styrene (mg/kg)	Other Aromatics (mg/kg)	Total Aromatics (mg/kg)
1858	RS/D/1	750	510	6370	7600	1930	17160
1859	RS/D/2	580	370	5100	6020	1500	13570
1860	RS/D/3	560	410	5130	6150	1930	14180
1861	RS/D/4	1020	770	7860	10300	2130	22080
1862	RS/D/5	910	640	7340	9270	2100	20260
1863	RS/D/6	1320	610	7180	7530	2640	19280
1864	RS/D/7	840	550	6590	7990	2050	18020
1865	RS/D/8	570	400	5240	6170	1840	14220
1866	RS/D/9	3080	1680	15600	19300	3610	43270
1867	RS/D/10	1240	870	9020	11800	2050	24980
1868	RS/D/11	2070	1290	13200	16500	3340	36400
1869	RS/D/12	560	450	5940	7660	1850	16460
mean		**1125**	**713**	**7881**	**9691**	**2248**	**21657**

Source: BAE Systems

Soil samples analysed for metal contamination indicated very low levels of arsenic, chromium, lead, copper, nickel and zinc and below detection values for cadmium, mercury, selenium and boron.

The volatile matter was measured in four samples, with results ranging between 6.2 % and 6.6 % with a mean value of 6.4 %. Total sulphur content was less than 10 mg/kg in all four samples tested. The calorific value in four samples ranged between 101 kJ/kg to 324 kJ/kg with a mean value of 175 kJ/kg.

7.4.2 SOIL DILUTION AND HOMOGENISATION

The achievable treatment rate using the SRU is affected by the energy contribution of the contaminant itself. In order to assess the optimum treatment rate, four batches of soil were prepared. The original contaminated soil was diluted with clean sand in ratios of 1:7, 1:3, 1:1 and 1:0 using a loading shovel. The final batch contained only contaminated soil without any dilution with clean sand. Dilution ratios, approximate concentrations of total aromatic hydrocarbons and approximate quantities of each batch of soil are provided in Table 7.2. The process of mixing and dilution homogenised the material, reducing the variations in contamination and moisture levels and resulted in more efficient running of the SRU.

Table 7.2: Soil batch dilution

Batch No.	Dilution Ratio (Contaminated /Clean)	Approx. Aromatics Concentration	Quantity (tonnes)
1	1:7	0.25%	24
2	1:3	0.50%	24
3	1:1	1.00%	18
4	1:0	2.00%	20

The handling and mixing of the soil can result in losses of aromatic hydrocarbons to the atmosphere. The potential for volatile loss during soil batch dilution is shown in Table 7.3, which compares the initial aromatic hydrocarbon concentration, taken as the average concentration from Table 7.1, against expected concentrations from dilution and actual average concentrations from input soil batches after dilution but before treatment. The actual average input concentration for each batch was derived by taking the average of 6 grab samples collected from the conveyer carrying contaminated soil into the SRU at roughly equal time segments during the course of the trial. The results indicate that losses from Batches 3 and 4 were minimal, and that losses from Batches 1 and 2 were significant. These apparent losses are the result of a combination of the increased material handling during mixing and the high level of dilution particularly in Batches 1 and 2. The volatile losses caused by the mixing are compounded by the difficulty of taking a representative sample due to the high level of clean material added. Furthermore, any SRU treatment of bulk quantities at full scale would not necessarily involve this much material handling/mixing and therefore the potential for volatile losses would be reduced.

Table 7.3: Potential volatile losses

Batch No.	Delivered soil contaminant conc. (mg/kg)	Dilution ratio (contam. /clean)	Calculated expected aromatics conc. (mg/kg)	Actual average aromatics content (post mixing) mg/kg (from average input sample analysis)	Apparent volatile loss %
1	21657	1:7	2707	643	76
2		1:3	5414	3990	26
3		1:1	10829	10127	6
4		1:0	21657	21682	0

Source: BAE Systems

7.5 SRU Trial 1

7.5.1. PROGRAMME

Trial 1 commenced on September 29th, 1999. Each of the four batches of soil was processed through a range of temperatures. The particular aromatic hydrocarbons of interest all had boiling points below 200 ^{o}C. Trial temperatures ranging between 200 ^{o}C to 300 ^{o}C were chosen to ensure complete desorption. Input and output samples were taken across the temperature range for each batch of material and analysed for individual and total aromatic hydrocarbons. An initial batch of clean sand was processed prior to the treatment of the contaminated soil to allow the plant to reach the required operating temperature and steady state.

7.5.2 RESULTS

The maximum design capacity of the SRU is 22 tonnes per hour based on 1 % to 3 % hydrocarbon contamination (dependent on the particular hydrocarbon) and less than 12 % moisture content.

During Trial 1, Batches 1, 2 and 3 achieved throughput rates of between 21 and 20 tonnes per hour, which was close to the plant capacity for the lower levels of contamination. However Batch 4, which contained undiluted (approximately 2 % hydrocarbon contamination) material, achieved a reduced treatment rate of 19 tonnes per hour. The optimum operating temperature of the thermal oxidizer is between 850 ^{o}C and 900 ^{o}C. The fuel contribution from "hot-spots" of material in Batch 4 raised the oxidizer operating temperature to in excess of 950 ^{o}C causing the after-burner to enter the controlled shutdown mode, thereby reducing the treatment rate.

It was decided not to proceed any further with Trial 1 until the analytical results of the feed material were available for study. A second trial would be required to determine the achievable throughput rate.

A summary of the analytical results for Batches 1 to 4 in Trial 1 are provided below in Tables 7.4 to 7.7.

Table 7.4: Results of Batch 1 (Contaminated Soil:Sand=1:7)

Sample Ref.		**Total Aromatics**			**Residual Polystyrene ***		
	Temp (^oC)	**Before (mg/kg)**	**After (mg/kg)**	**Reduction (%)**	**Before (mg/kg)**	**After (mg/kg)**	**Reduction (%)**
1	200	410	4	99.02			
2	200	1410	4	99.72	640	<200	68.75
3	250	800	5	99.38			
4	250	390	2	99.49	210	<200	4.76
5	300	550	0	100.00			
6	300	300	0	100.00	440	<200	54.55

Throughput rate of 21 tonnes per hour
* expressed as weight loss after CH_3Cl extraction based on original weight

Table 7.5: Results of Batch 2 (Contaminated Soil:Sand=1:3)

Sample Ref.		**Total Aromatics**			**Residual Polystyrene ***		
	Temp (^oC)	**Before (mg/kg)**	**After (mg/kg)**	**Reduction (%)**	**Before (mg/kg)**	**After (mg/kg)**	**Reduction (%)**
7	300	1520	0	100.00			
8	300	3670	3	99.92	880	200	77.27
9	250	5260	10	99.81			
10	250	2220	8	99.64	680	<200	70.59
11	200		18				
12	200	7280	16	99.78	1280	560	56.25

Sample reference 11 not analysed
Throughput rate of 21 tonnes per hour
* expressed as weight loss after CH_3Cl extraction based on original weight

Table 7.6: Results of Batch 3 (Contaminated Soil:Sand=1:1)

Sample Ref.		**Total Aromatics**			**Residual Polystyrene ***		
	Temp (^oC)	**Before (mg/kg)**	**After (mg/kg)**	**Reduction (%)**	**Before (mg/kg)**	**After (mg/kg)**	**Reduction (%)**
13	200	10240	14	99.86			
14	200	13100	13	99.90	1670	960	42.51
15	250	8400	10	99.88			
16	250	12840	11	99.91	1560	680	56.41
17	300	11070	0	100.00			
18	300	5110	0	100.00	1120	320	71.43

Throughput rate of 20 tonnes per hour
* expressed as weight loss after CH_3Cl extraction based on original weight

Table 7.7: Results of Batch 4 (Contaminated Soil:Sand=1:0)

Sample Ref.	Total Aromatics				Residual Polystyrene *		
	Temp (°C)	Before (mg/kg)	After (mg/kg)	Reduction (%)	Before (mg/kg)	After (mg/kg)	Reduction (%)
19	300	11490	7	99.94			
20	300	16320	9	99.94	2440	680	72.13
21	250	26860	21	99.92			
22	250	28510	16	99.94	2800	1120	60.00
23	280	25230	27	99.89	2810	1640	41.64
24	280		17				

* expressed as weight loss after CH_3Cl extraction based on original weight
Throughput rate of 19 tonnes per hour

A detailed summary of the analytical results are included at Appendix 2. A comparison of SRU achieved levels (for Batches 3 and 4) with the Site Trigger Levels are shown in Table 7.8.

Table 7.8: SRU achieved levels for Batches 3 and 4

Sample Ref.	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Styrene (mg/kg)	Total Aromatics (mg/kg)
Site Trigger Levels	**10**	**500**	**100**	**100**	**70***
13	<1	<1	3.4	8.5	14
14	<1	<1	3.0	8.5	13
15	<1	<1	2.2	6.7	10
16	<1	<1	2.1	7.7	11
17	<1	<1	<1	<1	<1
18	<1	<1	<1	<1	<1
19	<1	<1	3.7	1.7	7
20	<1	<1	3.4	3.1	9
21	<1	<1	5.0	13.7	21
22	<1	<1	4.1	9.4	16
23	1.2	<1	8.2	13.4	27
24	<1	<1	4.1	10.5	17

* Note: No Site Trigger Level was developed for Total Aromatic Hydrocarbons. The number quoted is for the current Dutch Trigger Level which is under review.

The SRU achieved greater than 99 % reduction in each run. The greatest reductions correlate well with higher operating temperatures. However, as the average cleanup achieved for each temperature was below the Site Trigger Levels in all cases, any temperature within the 200 °C to 300 °C range would appear to be sufficient to desorb the contamination, with the lower temperatures being the most fuel efficient.

During the trial, the thermal oxidiser burner gas flow valve progressively closed as the material contamination level increased. The valve was initially set at around 50 % open for the first batch (Batch 1) of the material, and gradually reduced to almost full closure for Batch 4 (2 % contamination), indicating that the oxidiser was obtaining most of its thermal energy from the contaminants themselves and running with the minimum amount of natural gas fuel.

The elevated operating temperatures of the LTTD process led to the formation of a polystyrene residual in the treated soil. In general, reduction in the residual polystyrene content of the soil material increased with an increase in temperature.

Results of stack emissions are summarised in Table 7.9.

Table 7.9: Stack emissions

Substance	Actual Level (mg/Nm^3)	Authorisation Limit (mg/Nm^3)
Nitrogen Oxides (as NO_2)	83	190
Sulphur Dioxide (SO_2)	0	50
Carbon Monoxide (CO)	5	50
Particulate	5	20

7.6 SRU TRIAL 2

A second trial was recommended to determine the achievable throughput rate without generating excess temperature in the oxidiser and to measure the atmospheric and human exposure during the trial**.**

7.6.1 PROGRAMME

The second trial was carried out on the 13th October 1999. During this time the remaining material from Batch 1 (2 % contamination) was processed through a temperature range of 250 °C to 350 °C at a throughput rate of 16 tonnes per hour. Input and output samples were taken across the temperature range and analysed for individual and total aromatic hydrocarbons. Atmospheric and personal air sampling was also carried out. Cleaned material was run through the plant prior to the trial, to allow the plant to reach required operating temperatures and steady state. A summary of the trial parameters and analytical results is provided in Table 7.10. It should be noted that the input or “before” levels of total aromatic hydrocarbons are significantly below the original levels of approximately 2 % for Batch 1 in Trial 1. This is largely due to volatile losses arising from additional material handling and the 14 day waiting time period between the two trials.

Table 7.10: Summary of the trial parameters and analytical results

Sample Ref.		Total Aromatics			Residual Polystyrene *		
	Temp °C	Before mg/kg	After mg/kg	Reduction %	Before mg/kg	After mg/kg	Reduction %
25	275	7900	11	99.86	2280	1630	28.51
26	300	7220	91	98.74	2540	1890	25.59
27	350	6620	6	99.91	2520	900	64.29
28	350	9590	6	99.94	2450	740	69.80

*expressed as weight loss after CH_3Cl extraction based on original weight
Throughput rate of 16 tonnes per hour

7.6.2 ATMOSPHERIC AND PERSONAL EXPOSURE

Atmospheric and personal exposure levels were measured for individual aromatic hydrocarbons at a number of locations across the working area. The results obtained were not statistically valid due to the reporting of some results as "greater than", see Table 7.11 for details. However, where results were fully quantified they were well within the EH40 Maximum Exposure Levels (MEL) and Occupational Exposure Standards (OES).

Table 7.11: Atmospheric and personal exposure levels

Tube Ref.	SRU Ref.	Benzene (mg/m^3)	Toluene (mg/m^3)	Ethyl Benzene (mg/m^3)	Styrene (mg/m^3)	Total HC's (mg/m^3)	Location Details
CM-285	S1	0.8	0.7	>3.1	>2.2	>9.2	25m NE
CM-321	S2	0.2	0.2	>1.2	0.7	>3.1	35m NE
CM115	S3	0.1	0.1	0.5	0.3	>1.3	45m NE
CM302	P1	1.1	0.9	>4.0	<3.0	>12.3	Sampling operative
CM304	P2	>1.5	>1.6	>5.4	<2.7	>128.7	Loading Shovel driver
MEL (8hr TWA)		5[*]	191	441	430	NA	
(15 min STEL)		NA	574	552		NA	

Note: * The 8 hr TWA at the time of the trial. This was changed to 3 ppm which is valid until June 2003. The current 8hr TWA is 1 ppm set in March 2003. TWA = time weighted average; STEL = short-term exposure limit

The main objective of Trial 2 was to ascertain the achievable throughput rate. The actual rate achieved, without excess temperature in the oxidiser and with minimum natural gas usage was 16 tonnes per hour. The average oxidiser temperature was 925 °C.

Cleanup was achieved across the temperature range with results comparable to Trial 1. See Appendix 2 for full results.

Very good results across the material temperature range were achieved during Trial 2, with a slightly improved reduction of volatile contaminants when higher temperatures were used.

The fuel contribution from the contaminated material minimised natural gas consumption in the oxidiser.

Reduction in residual polystyrene levels increased with temperature, as in Trial 1.

The continuously monitored stack emissions were again all below the SRU authorisation limits. The actual emissions are summarised in Table 7.12.

Table 7.12: Stack emissions

Substance	Actual Level (mg/*N*m^3)	Authorisation Limit (mg/*N*m^3)
Nitrogen Oxides (as NO_2)	92	190
Sulphur Dioxide (SO_2)	0	50
Carbon Monoxide (CO)	4	50
Particulates	5	20

7.7 SUMMARY OF PERFORMANCE

1. From the results of the two trials, it can be concluded that material contaminated with levels of aromatic hydrocarbons up to 2 % were successfully treated using SRU with a throughput rate of 16 tonnes per hour.

2. The SRU process demonstrated that the material cleaned to below the Site Trigger Levels and the Dutch intervention levels with stack emissions being maintained at below the authorisation limits.

3. Atmospheric and personal exposure levels were kept within acceptable limits (subject to confirmatory monitoring on site).

4. If similar material is to be treated it is expected, based on experience from other sites, that moisture levels in excess of 12 % will reduce the material throughput rate by approximately one tonne per hour for each additional 1% of moisture content.

5. Contamination levels in excess of 2 % will reduce the material throughput rate by approximately one tonne per hour for each additional 0.25 % of contaminant concentration.

8. ECONOMIC CONSIDERATIONS

The economic evaluation of the LTTD process is derived from the SRU trial and is crucial to assessing full scale cleanup costs.

For the purposes of this project, costs for full scale remediation have been divided into variable and fixed costs. In addition, estimates have been made on the full scale costs to treat three different volumes of contaminated material: 25,000, 50,000 and 100,000 tonnes. The provision of tenting to minimise release of volatile contaminants to the atmosphere has been included, and a 20 % contingency has been applied to all costs.

The SRU is capable of processing 1150 tonnes of contaminated soil/week based on the following operational parameters:

- Feed rate of 16 tonne/hour@ 2 % aromatic concentration
- Operation of 15 hours/day
- Two shift operations over 6 days/week
- Equipment reliability of 80 %

Based on the above, approximately 86 weeks would be required to process 100,000 tonnes of material.

Table 8.1: Estimated costs for full scale cleanup at the site using the SRU

BUDGETARY COSTS	**TOTAL TONNAGE**		
	25,000	**50,000**	**100,000**
Fixed Costs			
Fixed cost for tenting/extraction/air treatment	162,000	162,000	162,000
Mobilisation and demobilisation	119,000	119,000	119,000
Project team (2 persons 1 year)	120,000	120,000	120,000
Variable Costs			
Excavation/blending/backfilling @ £5.04 per tonne	126,000	252,000	504,000
Hire of tenting etc. @ £0.64 per tonne	16,000	32,000	64,000
Thermal treatment of contaminated material @ £24.24 per tonne	606,000	1,212,000	2,424,000
Electricity using a 500 KVA diesel generator @ £1.16 per tonne	29,000	58,000	116,000
Natural gas @ £2.15 per tonne	53,750	107,500	215,000
Contingency @ 20%	246,350	412,500	744,800
Total	£1,478,100	£2,475,000	£4,468,800
Cost per tonne	£59.12	£49.50	£44.69

The above costs assume electricity generation from a diesel generator. Additional cost savings could be realised if electricity was supplied from a sub station.

Planning decisions can impact the total cleanup cost. At the site, local planning required that stock piles for the SRU be limited to 1000 m^3. Savings would be made on the unit cost of contaminated material movement if stock pile size were not restricted. Local planners also required additional personal protection if the work extended beyond 6 months.

9. CONCLUSIONS

1. Cost-benefit analysis on a range of remedial options carried out at the site showed that based on site investigation work, LTTD technology was worth assessing on a pilot trial basis.
2. LTTD technology successfully treated more than 85 tonnes of contaminated sand during a field trial at the BAE site. The results showed that sand containing an optimum contamination level of 2 % can be satisfactorily treated to below Site Trigger Levels at a feedrate of 16 tonne/hour with stack emissions being maintained at below authorisation limits.
3. Desorption temperatures of 300 ^{o}C to 350 ^{o}C should be maintained within the SRU to ensure that residual aromatic levels in treated sand are kept within the specification limits.
4. The site comprised sandy soil with an inherent relatively low water content, which did little to reduce the efficiency of the thermal process. Based on experience from other sites, it is expected that moisture levels in excess of 12 % would reduce the material throughput rate by approximately one tonne per hour for each additional 1 % of moisture content.
5. The safety of personnel carrying out the remediation is a major consideration, and occupational hygiene considerations for the full scale remedial operation are not trivial. During the trial, atmospheric and personal exposure levels were kept within acceptable limits. Airborne aromatic concentrations were found to diminish significantly at a distance of ten metres from the contamination source. During excavation work, atmospheric aromatic concentrations at the site limits were significantly lower than the Annual Air Quality Standards. The minimum PPE required when working within close proximity of the contaminated material is a 3M 4251 organic vapour mask with a A2P3 filter.
6. The ground contamination was shallow. Contamination observed in the area of the excavation used to obtain contaminated sand for the trial extended from immediately beneath the surface to the water table, a depth of 1.5 m to 2 m.
7. Free phase aromatics remaining in the ground beyond the excavation will drain into the excavation. This process is expected to be slow. Additional pits covering extensive areas will be required to recover the aromatics in the summer time window appropriate for this operation (i.e. low water table).
8. The air operated pumping system and tank used to store and separate the aqueous phase hydrocarbons recovered from the pit proved to be satisfactory.
9. The 96,000 tonnes estimated for remediation is a best estimate using current information, there is a contingency allowance for contamination extending beyond the defined boundaries. The remediation programme will require 83 weeks continuous operation to treat the estimated volume of material in the defined area.
10. The remediation of the area in a one stage process allowing reuse of the soil will carry significant cost benefits.

10. LESSONS LEARNED

1. Technology field trials provide greater clarity for associated issues such as material handling and throughput, technology limitations, licensing, planning needs, health and safety, and full scale costs.

2. Early involvement of the regulator is beneficial to identify and address issues at an early stage. Reaching agreement on ground cleanup specifications and the methodology to be employed is crucial. A team to manage and progress the remediation project should communicate information to the regulator at every stage. Unnecessary delays due to poor communication can be expensive.

3. 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 planning the trial or full scale cleanup, and every attempt should be made to minimise the handling and disturbance of contaminated material.

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

5. Analytical techniques for determining the concentration of aromatic compounds through (i) rapid field techniques and (ii) precise laboratory determination would be beneficial both for site characterisation and assessing remedial options.

GLOSSARY OF TERMS

Activated Carbon
Fine granular form of carbon which has been treated to remove hydrocarbons and to increase its powers of adsorption.

Adsorption
The binding of molecules or particles to a surface.

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 Adsorption or Inductively Coupled Plasma Emission Spectroscopy.

Baghouse
Area of LTTD unit which houses a number of bag filters which remove particulates from the process.

Desorption
Separation of a compound from a solid surface/matrix.

Hydraulic Conductivity
The measure of how easily a medium can transmit a specified fluid. In groundwater terms it relates to an aquifer’s ability to transmit water and is often expressed in terms of metres/second.

Potentiometric Surface
A hypothetical surface defined by the level to which water in a confined aquifer rises in observation boreholes.

Slag
A by-product of iron and steelmaking largely composed of limestone. It is solidified and used in soil mix, road surfaces and cement.

Styrene
A colourless aromatic liquid which can alter when heated to form polystyrene and is also used in the manufacture of synthetic rubber.

Thermal Oxidation
A relatively high temperature process (approximately 750 ^{o}C-1100 °C) which purifies contaminated exhaust air through thermal combustion of the organic contaminants to carbon dioxide and water.

Volatile
Easily converted to the vapour phase.

REFERENCES

BAE Environmental Services. November 1999. Report on Thermal Remediation Trial of Aromatic Hydrocarbon Contaminated Sand. Report Number 2609-1

BAE Systems Environmental Services. 2000. Environmental impact assessment for proposed remediation of styrene tank farm.

Celtic Technologies Ltd. December 2000. Desk Study Report No. R575/00/1413

Confidential Report. May 1993. Soil and Groundwater Study, Preliminary Site Assessment, Desk Study.

Confidential Report. February 1994. Soil and Groundwater Study Phase One Site Assessment Results.

Confidential Report. May 1995. Soil and Groundwater Study Phase 2, Site Assessment and Remedial Options.

Confidential Report. August 1995. Phase 2 Soil and Groundwater Study, Interim Monitoring Report.

Confidential Report. December 1995. Phase 2 Soil and Groundwater Study, Interim Monitoring Report.

European Council Directive. 16 December 1994. Hazardous Waste Incinerator Directive 94/67/EC.

Ground Restoration Limited. September 1993. “Environmental Site Investigation Report.

Ground Restoration Limited. November 1994. Environmental Site Investigation Report.

Ground Restoration Limited. October 1999. Environmental Site Investigation (Tank Farm).

Her Majesty’s Stationery Office. 1998. Environmental Protection Act 1990.

United States Environment Protection Agency - Office of Underground Storage Tanks (OUST). 1994. How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers. (EPA 510-B-94-003 and EPA 510-B-95-007).

APPENDICES

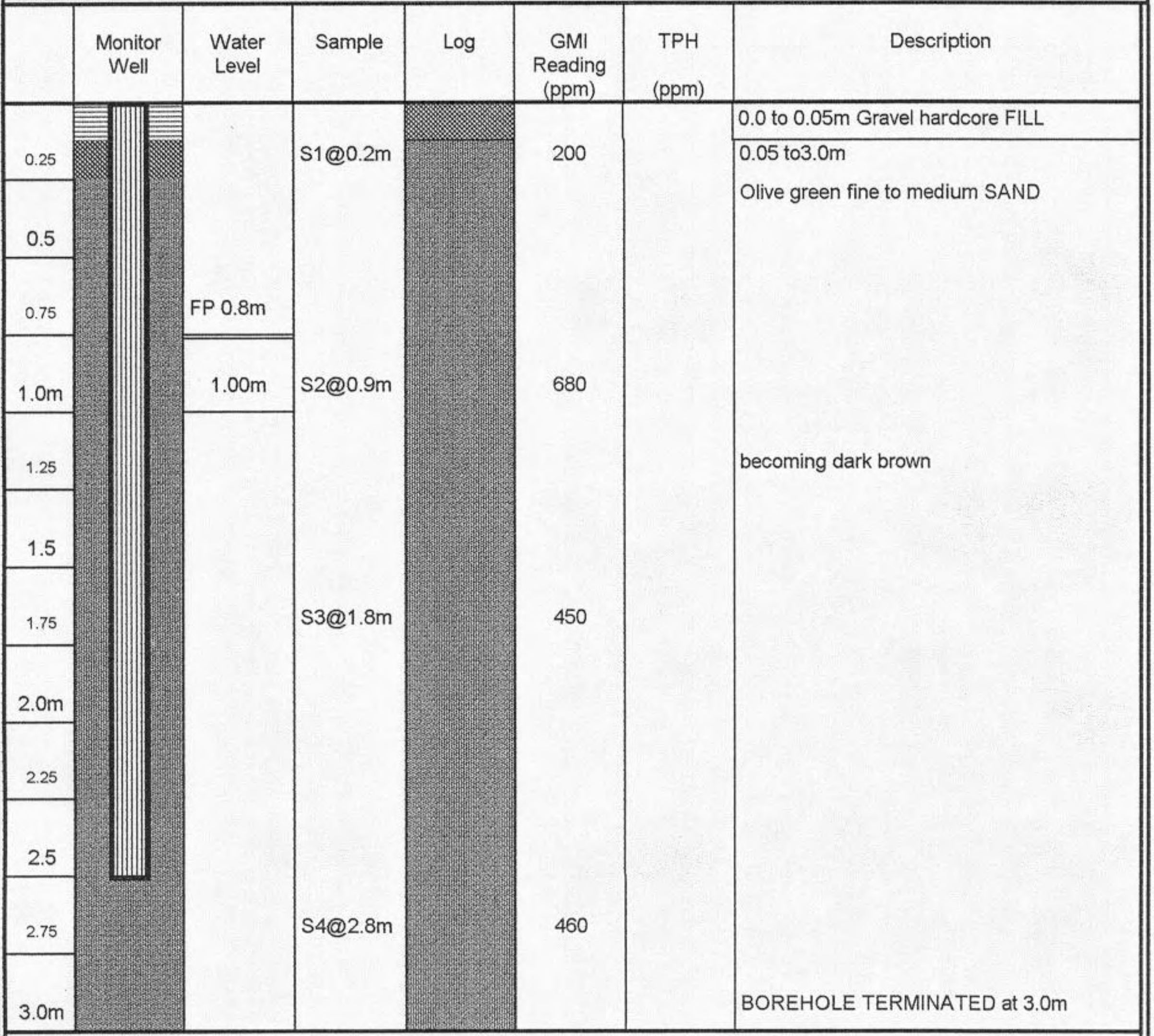
Appendix 1: Representative borehole logs
Appendix 2: Remediation trial results

APPENDIX 1
REPRESENTATIVE BOREHOLE LOGS

Ground Restoration Limited

Borehole 22

Client:	Date :9 -10 th September 1993	Sheet 1 of 1
Site:	Ground Level : +9.357m OD	Dwn : GS
Equipment 4" Hollow Stem Flight Auger(MM)	Coordinates : -	Ckd : JW

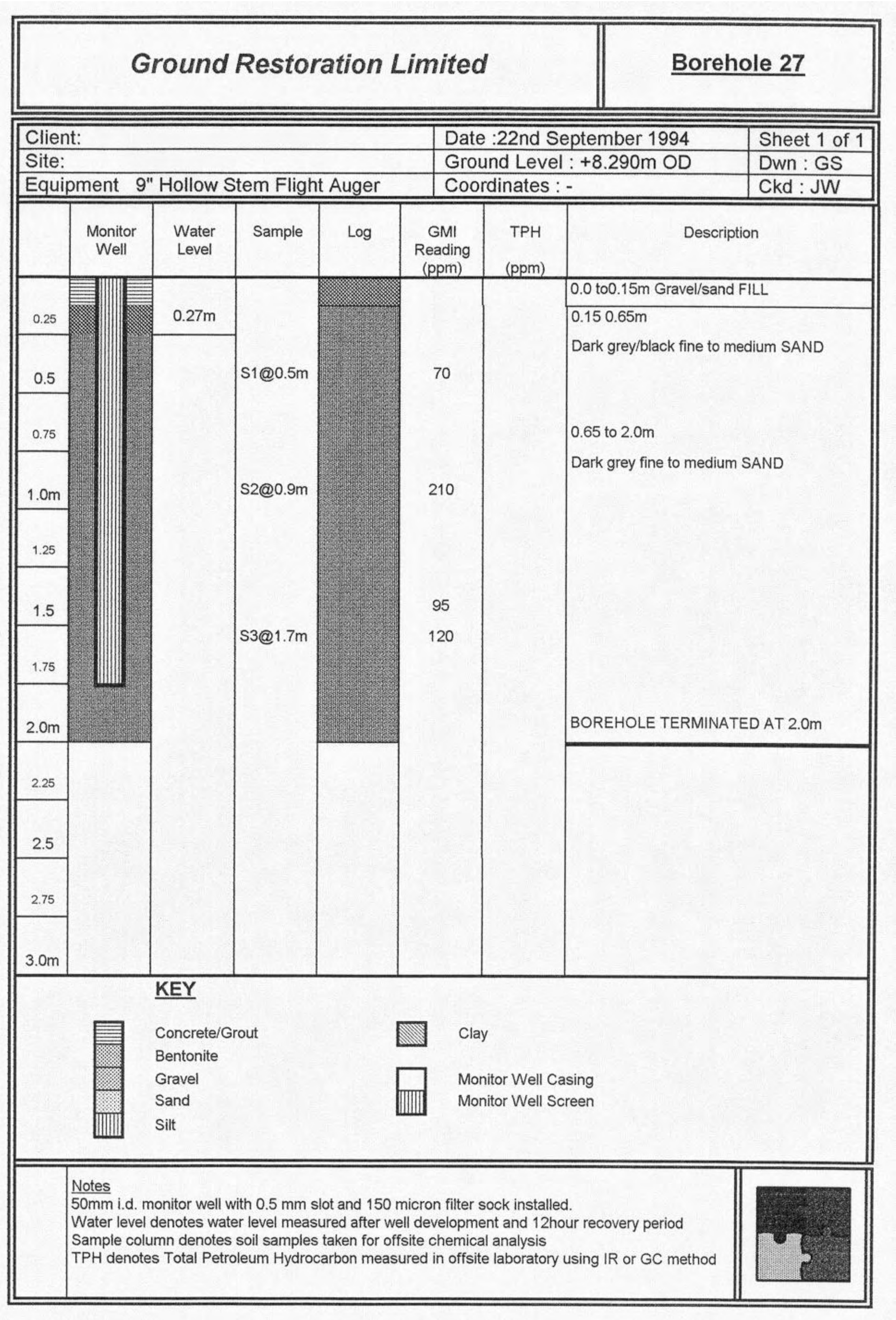


	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
							0.0 to 0.05m Gravel hardcore FILL
0.25			S1@0.2m		200		0.05 to3.0m Olive green fine to medium SAND
0.5							
0.75		FP 0.8m					
1.0m		1.00m	S2@0.9m		680		
1.25							becoming dark brown
1.5							
1.75			S3@1.8m		450		
2.0m							
2.25							
2.5							
2.75			S4@2.8m		460		
3.0m							BOREHOLE TERMINATED at 3.0m

KEY

- ▤ Concrete/Grout
- ▦ Bentonite
- ▦ Gravel
- ▒ Sand
- ▥ Silt
- ▨ Clay
- □ Monitor Well Casing
- ▥ Monitor Well Screen

Notes
50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC method



Ground Restoration Limited

Borehole 27

Client:	Date :22nd September 1994	Sheet 1 of 1
Site:	Ground Level : +8.290m OD	Dwn : GS
Equipment 9" Hollow Stem Flight Auger	Coordinates : -	Ckd : JW

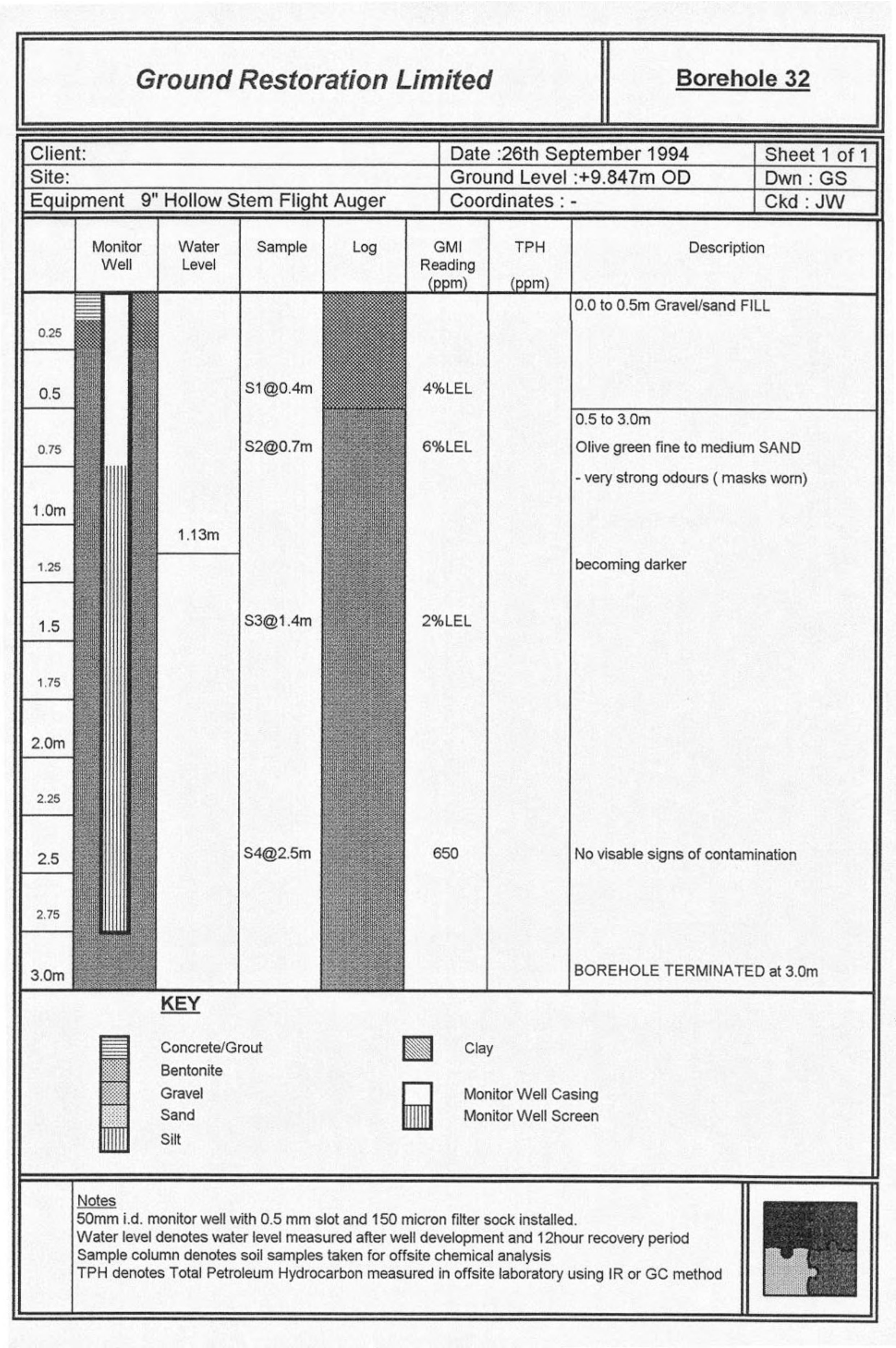
	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
							0.0 to0.15m Gravel/sand FILL
0.25		0.27m					0.15 0.65m Dark grey/black fine to medium SAND
0.5			S1@0.5m		70		
0.75							0.65 to 2.0m Dark grey fine to medium SAND
1.0m			S2@0.9m		210		
1.25							
1.5					95		
			S3@1.7m		120		
1.75							
2.0m							BOREHOLE TERMINATED AT 2.0m
2.25							
2.5							
2.75							
3.0m							

KEY

- ▤ Concrete/Grout
- ▩ Bentonite
- ▩ Gravel
- ▒ Sand
- ▥ Silt
- ▨ Clay
- ☐ Monitor Well Casing
- ▥ Monitor Well Screen

Notes

50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC method



Ground Restoration Limited

Borehole 32

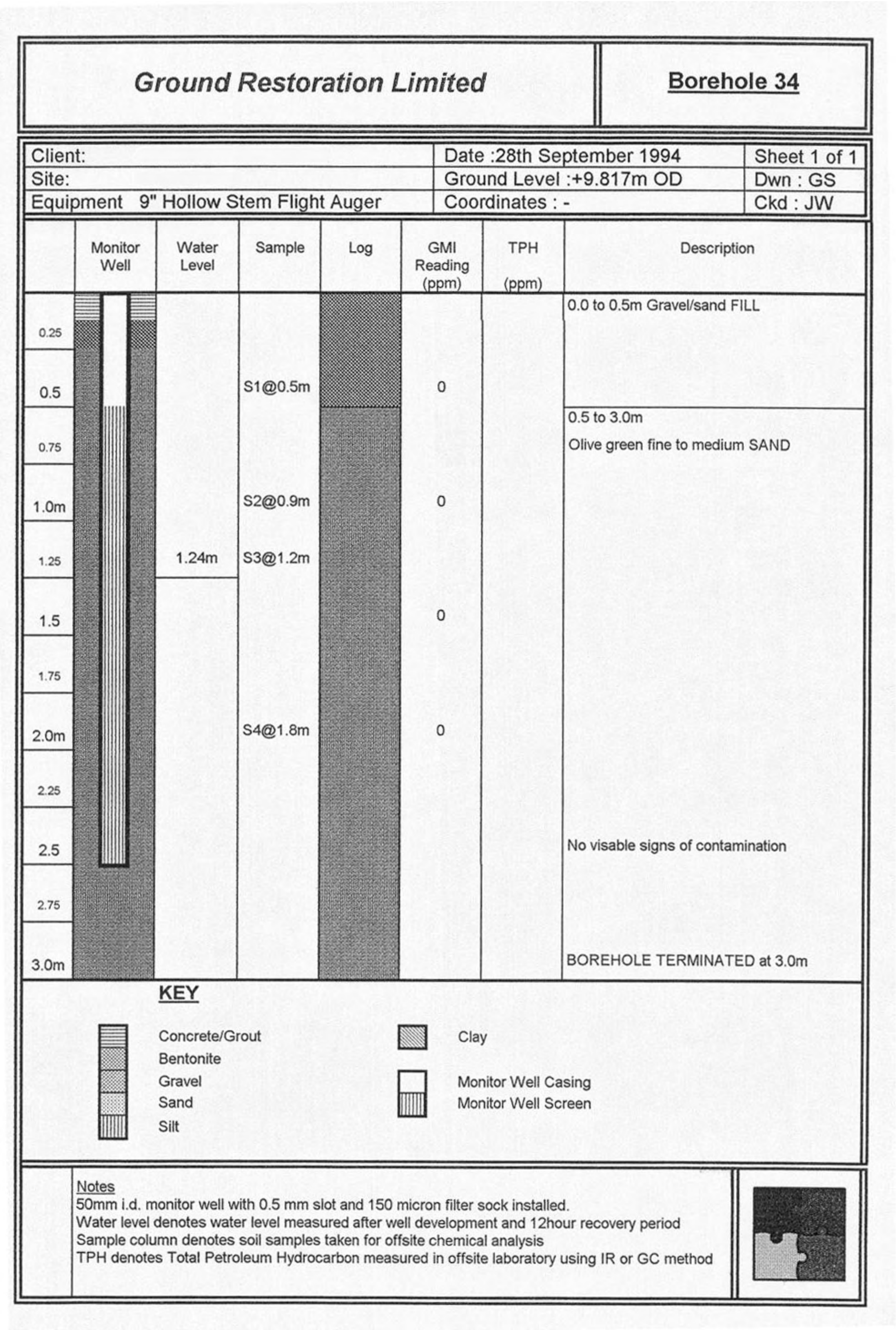
Client:	Date :26th September 1994	Sheet 1 of 1
Site:	Ground Level :+9.847m OD	Dwn : GS
Equipment 9" Hollow Stem Flight Auger	Coordinates : -	Ckd : JW

	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
0.25							0.0 to 0.5m Gravel/sand FILL
0.5			S1@0.4m		4%LEL		
0.75			S2@0.7m		6%LEL		0.5 to 3.0m Olive green fine to medium SAND - very strong odours (masks worn)
1.0m		1.13m					
1.25							becoming darker
1.5			S3@1.4m		2%LEL		
1.75							
2.0m							
2.25							
2.5			S4@2.5m		650		No visable signs of contamination
2.75							
3.0m							BOREHOLE TERMINATED at 3.0m

KEY

▤	Concrete/Grout
▦	Bentonite
▩	Gravel
░	Sand
▥	Silt
▧	Clay
☐	Monitor Well Casing
▥	Monitor Well Screen

Notes
50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC method



Ground Restoration Limited

Borehole 34

Client:	Date :28th September 1994	Sheet 1 of 1
Site:	Ground Level :+9.817m OD	Dwn : GS
Equipment 9" Hollow Stem Flight Auger	Coordinates : -	Ckd : JW

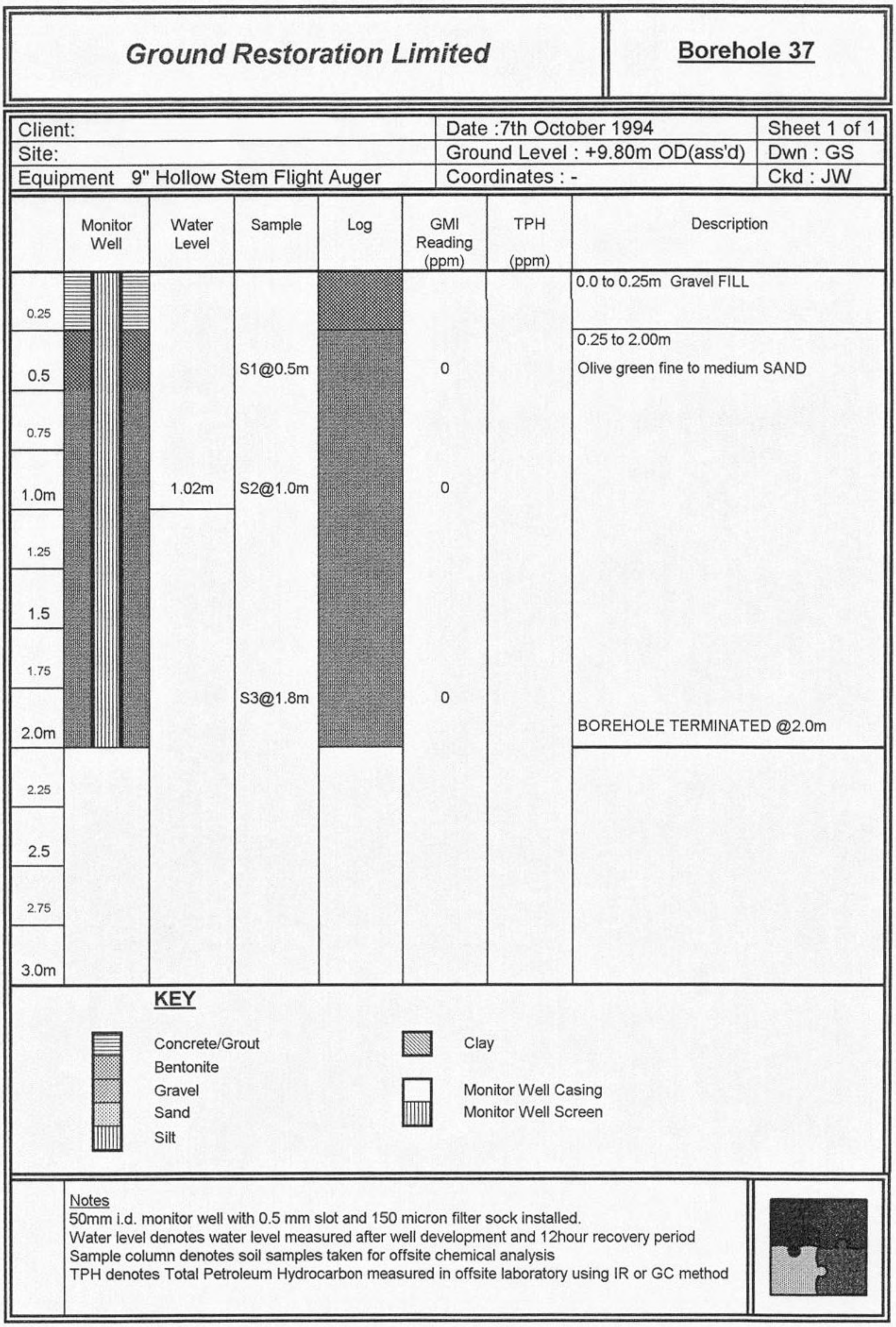
	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
0.25							0.0 to 0.5m Gravel/sand FILL
0.5			S1@0.5m		0		
0.75							0.5 to 3.0m Olive green fine to medium SAND
1.0m			S2@0.9m		0		
1.25		1.24m	S3@1.2m				
1.5					0		
1.75							
2.0m			S4@1.8m		0		
2.25							
2.5							No visable signs of contamination
2.75							
3.0m							BOREHOLE TERMINATED at 3.0m

KEY

- ▤ Concrete/Grout
- ▩ Bentonite
- ▦ Gravel
- ░ Sand
- ▥ Silt
- ▧ Clay
- ☐ Monitor Well Casing
- ▥ Monitor Well Screen

Notes

50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC method



Ground Restoration Limited

Borehole 37

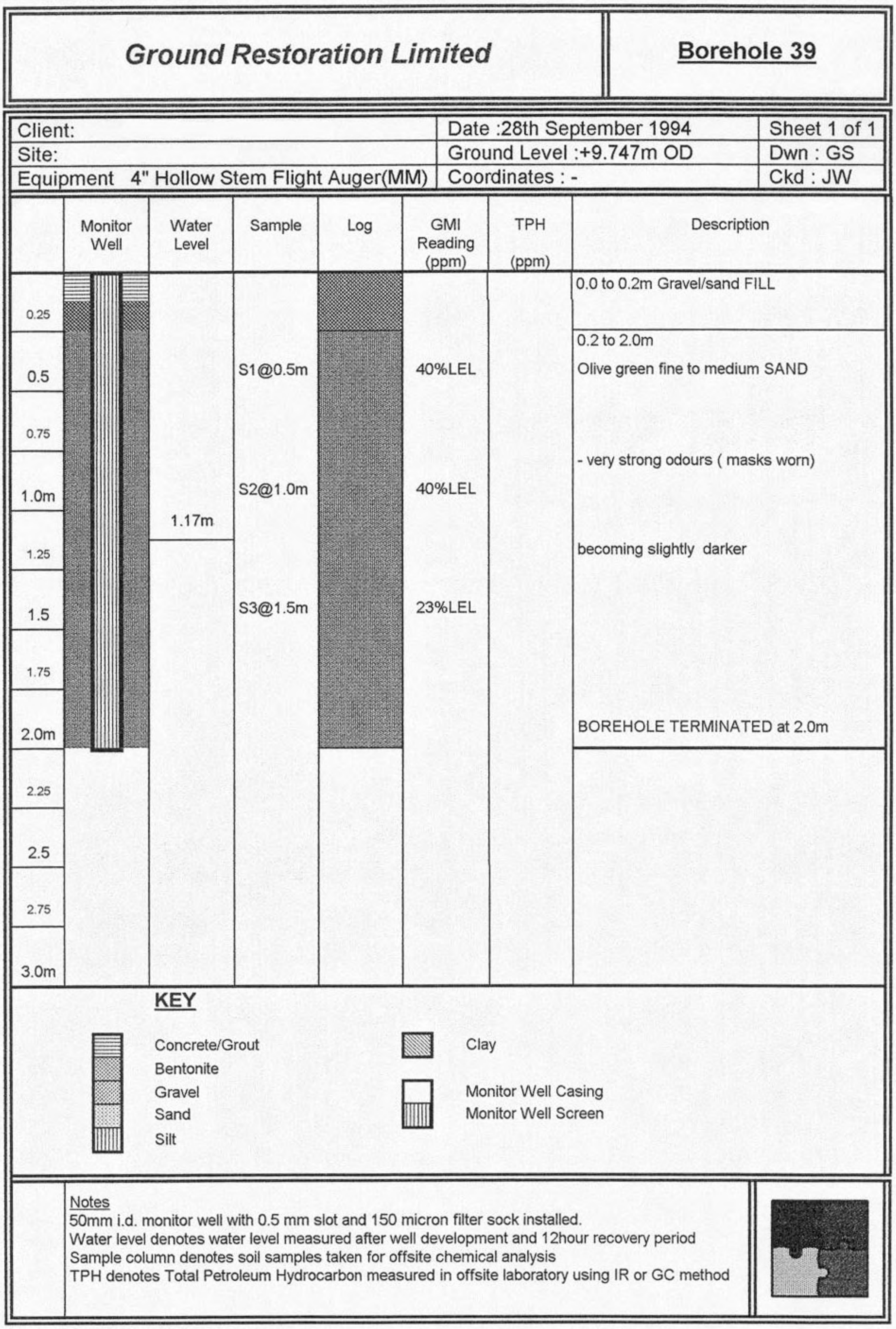
Client:	Date :7th October 1994	Sheet 1 of 1
Site:	Ground Level : +9.80m OD(ass'd)	Dwn : GS
Equipment 9" Hollow Stem Flight Auger	Coordinates : -	Ckd : JW

	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
0.25							0.0 to 0.25m Gravel FILL
0.5			S1@0.5m		0		0.25 to 2.00m Olive green fine to medium SAND
0.75							
1.0m		1.02m	S2@1.0m		0		
1.25							
1.5							
1.75							
2.0m			S3@1.8m		0		BOREHOLE TERMINATED @2.0m
2.25							
2.5							
2.75							
3.0m							

KEY

▤ Concrete/Grout
Bentonite
Gravel
Sand
▥ Silt
▨ Clay
□ Monitor Well Casing
▥ Monitor Well Screen

Notes
50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC method



Ground Restoration Limited	**Borehole 39**

Client:	Date :28th September 1994	Sheet 1 of 1
Site:	Ground Level :+9.747m OD	Dwn : GS
Equipment 4" Hollow Stem Flight Auger(MM)	Coordinates : -	Ckd : JW

	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
0.25							0.0 to 0.2m Gravel/sand FILL
0.5			S1@0.5m		40%LEL		0.2 to 2.0m Olive green fine to medium SAND
0.75							
1.0m			S2@1.0m		40%LEL		- very strong odours (masks worn)
1.25		1.17m					becoming slightly darker
1.5			S3@1.5m		23%LEL		
1.75							
2.0m							BOREHOLE TERMINATED at 2.0m
2.25							
2.5							
2.75							
3.0m							

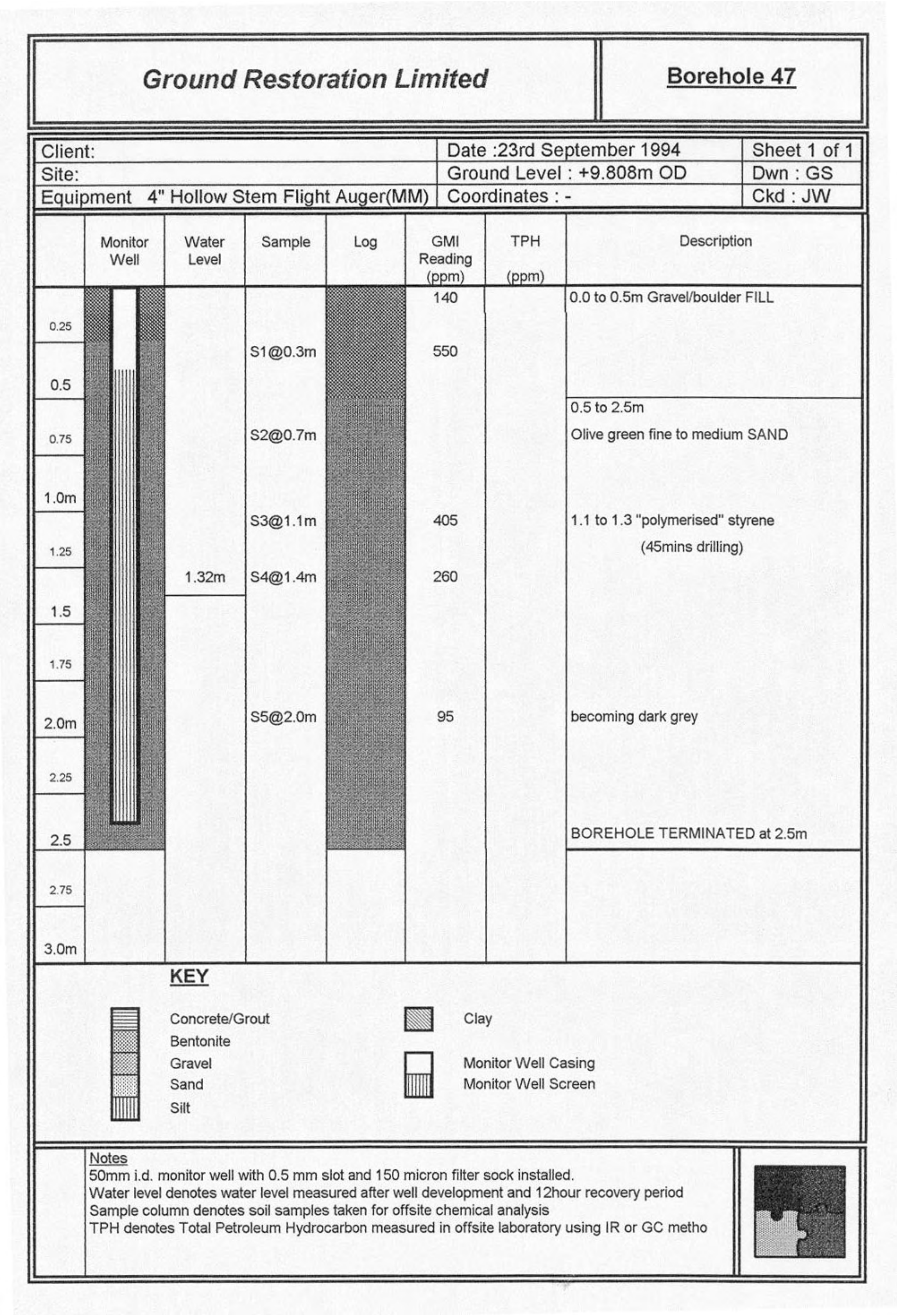
KEY

Concrete/Grout
Bentonite
Gravel
Sand
Silt

Clay

Monitor Well Casing
Monitor Well Screen

Notes
50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC method



Ground Restoration Limited

Borehole 47

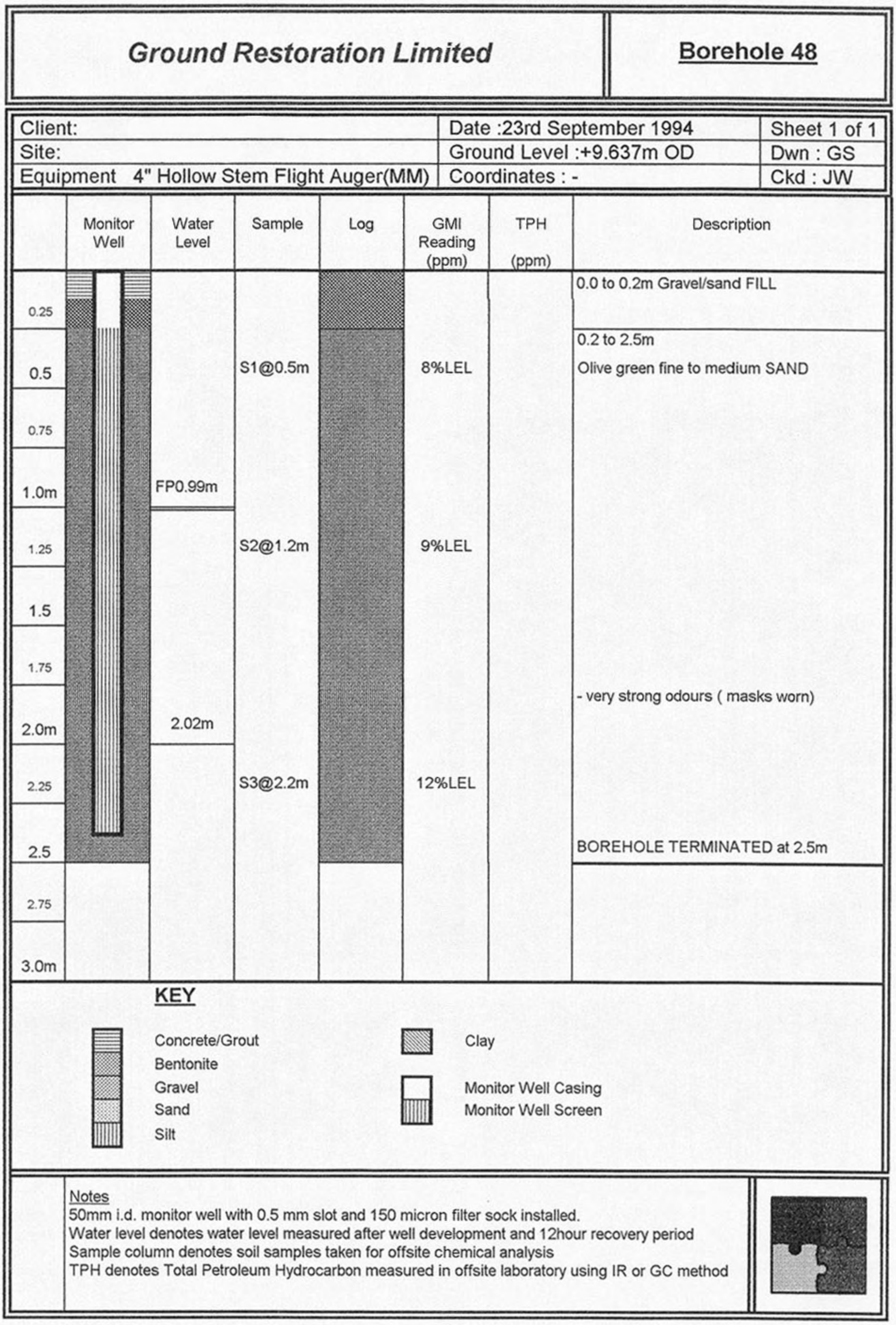
Client:	Date :23rd September 1994	Sheet 1 of 1
Site:	Ground Level : +9.808m OD	Dwn : GS
Equipment 4" Hollow Stem Flight Auger(MM)	Coordinates : -	Ckd : JW

	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
					140		0.0 to 0.5m Gravel/boulder FILL
0.25							
			S1@0.3m		550		
0.5							
							0.5 to 2.5m
0.75			S2@0.7m				Olive green fine to medium SAND
1.0m							
			S3@1.1m		405		1.1 to 1.3 "polymerised" styrene (45mins drilling)
1.25							
		1.32m	S4@1.4m		260		
1.5							
1.75							
2.0m			S5@2.0m		95		becoming dark grey
2.25							
2.5							BOREHOLE TERMINATED at 2.5m
2.75							
3.0m							

KEY

▤	Concrete/Grout	▨	Clay
▒	Bentonite		
▒	Gravel	☐	Monitor Well Casing
░	Sand	▥	Monitor Well Screen
▥	Silt		

Notes
50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC metho



Ground Restoration Limited | **Borehole 48**

Client:	Date :23rd September 1994	Sheet 1 of 1
Site:	Ground Level :+9.637m OD	Dwn : GS
Equipment 4" Hollow Stem Flight Auger(MM)	Coordinates : -	Ckd : JW

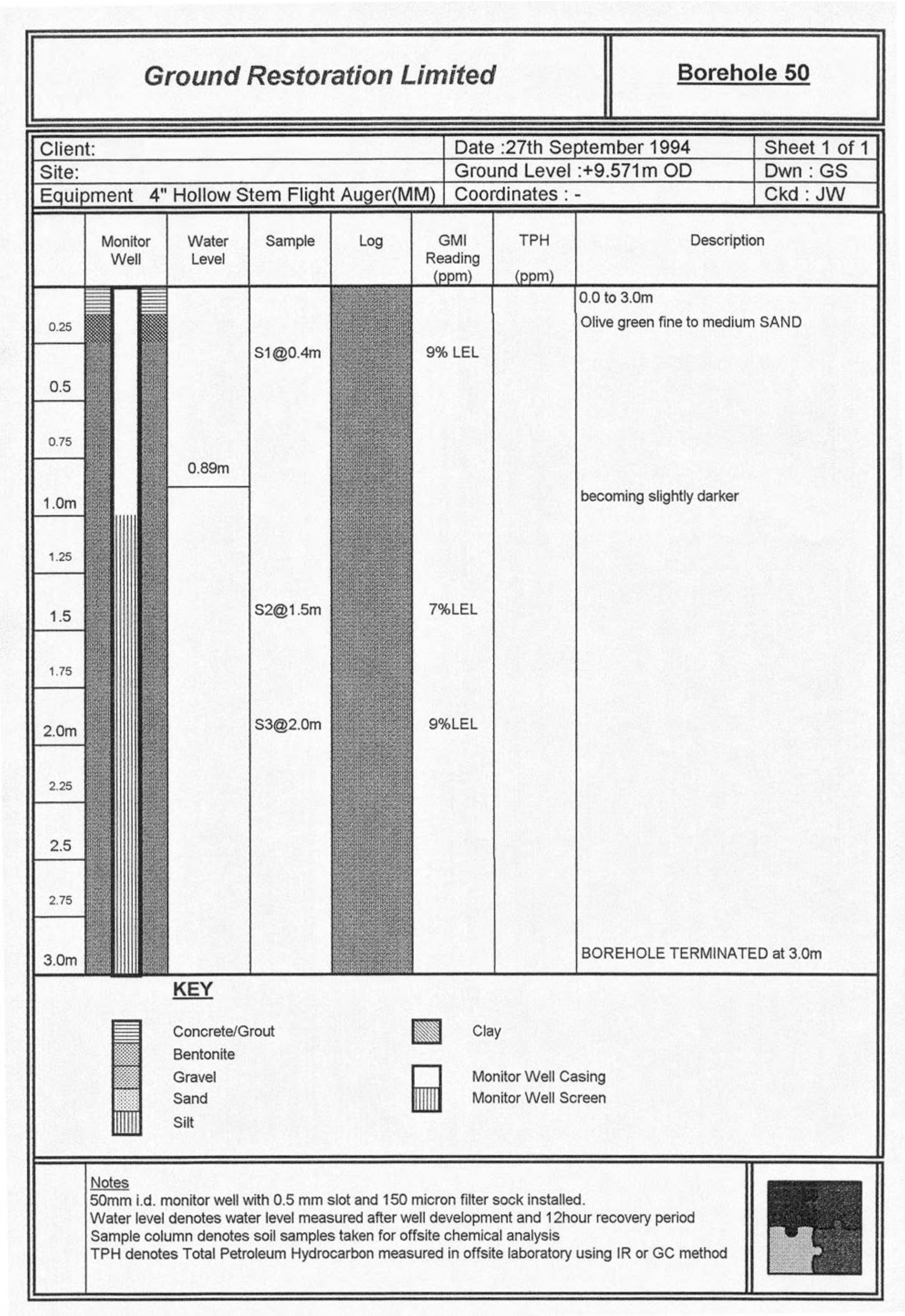
	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
0.25							0.0 to 0.2m Gravel/sand FILL
0.5			S1@0.5m		8%LEL		0.2 to 2.5m Olive green fine to medium SAND
0.75							
1.0m		FP0.99m					
1.25			S2@1.2m		9%LEL		
1.5							
1.75							
2.0m		2.02m					- very strong odours (masks worn)
2.25			S3@2.2m		12%LEL		
2.5							BOREHOLE TERMINATED at 2.5m
2.75							
3.0m							

KEY

- ▤ Concrete/Grout
- ▩ Bentonite
- ▦ Gravel
- ░ Sand
- ▥ Silt
- ▧ Clay
- ☐ Monitor Well Casing
- ▥ Monitor Well Screen

Notes

50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC method



Ground Restoration Limited

Borehole 50

Client:	Date :27th September 1994	Sheet 1 of 1
Site:	Ground Level :+9.571m OD	Dwn : GS
Equipment 4" Hollow Stem Flight Auger(MM)	Coordinates : -	Ckd : JW

	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
							0.0 to 3.0m Olive green fine to medium SAND
0.25							
			S1@0.4m		9% LEL		
0.5							
0.75							
		0.89m					
1.0m							becoming slightly darker
1.25							
1.5			S2@1.5m		7%LEL		
1.75							
2.0m			S3@2.0m		9%LEL		
2.25							
2.5							
2.75							
3.0m							BOREHOLE TERMINATED at 3.0m

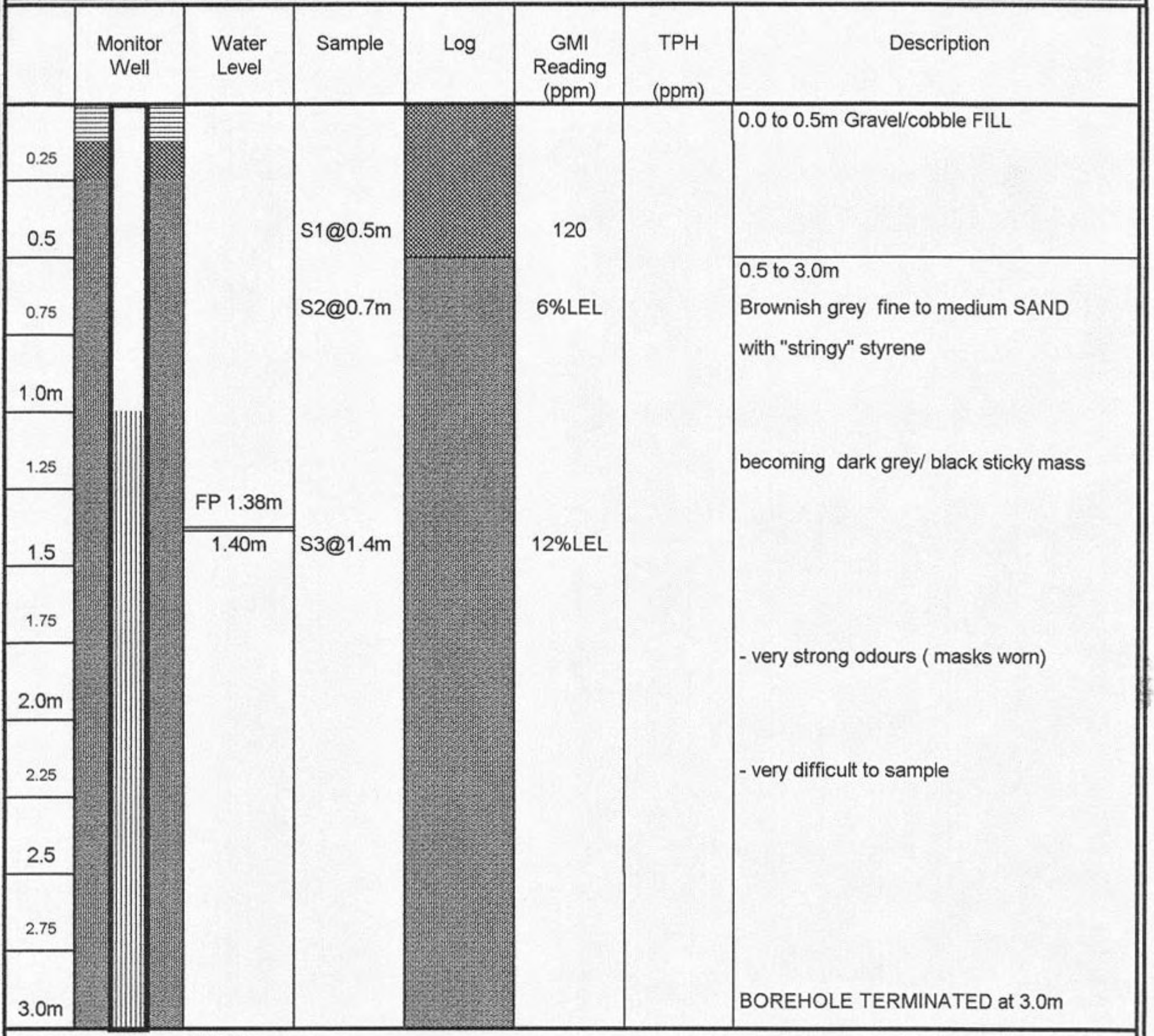
KEY

▤ Concrete/Grout
▒ Bentonite
▒ Gravel
░ Sand
▥ Silt
▨ Clay
☐ Monitor Well Casing
▥ Monitor Well Screen

Notes
50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC method

Ground Restoration Limited	**Borehole 52**

Client:	Date :28th September 1994	Sheet 1 of 1
Site:	Ground Level :+9.746m OD	Dwn : GS
Equipment 9" Hollow Stem Flight Auger	Coordinates : -	Ckd : JW



	Monitor Well	Water Level	Sample	Log	GMI Reading (ppm)	TPH (ppm)	Description
0.25							0.0 to 0.5m Gravel/cobble FILL
0.5			S1@0.5m		120		
0.75			S2@0.7m		6%LEL		0.5 to 3.0m Brownish grey fine to medium SAND with "stringy" styrene
1.0m							
1.25		FP 1.38m					becoming dark grey/ black sticky mass
1.5		1.40m	S3@1.4m		12%LEL		
1.75							
2.0m							- very strong odours (masks worn)
2.25							- very difficult to sample
2.5							
2.75							
3.0m							BOREHOLE TERMINATED at 3.0m

KEY

- ▤ Concrete/Grout
- ▦ Bentonite
- ▩ Gravel
- ░ Sand
- ▥ Silt
- ▨ Clay
- □ Monitor Well Casing
- ▥ Monitor Well Screen

Notes

50mm i.d. monitor well with 0.5 mm slot and 150 micron filter sock installed.
Water level denotes water level measured after well development and 12hour recovery period
Sample column denotes soil samples taken for offsite chemical analysis
TPH denotes Total Petroleum Hydrocarbon measured in offsite laboratory using IR or GC method

APPENDIX 2
REMEDIATION TRIAL RESULTS

Trial 1 Input Sample Analysis Results

Lab. Ref.	Sample Ref.	Benzene mg/kg	Toluene mg/kg	Ethyl Benzene mg/kg	Styrene mg/kg	Diethyl Benzene mg/kg	Sum of Aromatics mg/kg	% Weight Loss on cold extraction by Methanol	Weight Loss after CH_3Cl Extraction Based on original Weight mg/kg	Weight Loss after CH_3Cl Extraction Based on Weight after MeOH extraction mg/kg
1951	IN 1	<10	<10	120	150	140	410			
1952	IN 2	<10	20	550	540	300	1410	4.5	640	710
1953	IN 3	<10	<10	290	300	210	800			
1954	IN 4	<10	<10	140	140	110	390	4.6	210	210
1955	IN 5	<10	<10	200	200	150	550			
1956	IN 6	<10	<10	100	110	90	300	4.8	440	460
1957	IN 7	10	30	650	550	280	1520			
1958	IN 8	60	80	1510	1460	560	3670	4.9	880	960
1959	IN 9	80	120	2130	2200	730	5260			
1960	IN 10	20	40	910	890	360	2220	6.0	680	740
1961	IN 11	-	-	-	-	-	-			
1962	IN 12	130	190	3050	2950	960	7280	5.0	1280	1370
1963	IN 13	160	270	4330	4250	1230	10240			
1964	IN 14	320	390	5360	5670	1360	13100	6.5	1670	1790
1965	IN 15	130	220	3490	3590	970	8400			
1966	IN 16	360	390	5230	5590	1270	12840	6.3	1560	1800
1967	IN 17	280	330	4540	4740	1180	11070			
1968	IN 18	50	100	2000	2210	750	5110	4.9	1120	1190
1969	IN 19	200	300	4990	4380	1620	11490			
1970	IN 20	460	480	6630	6840	1910	16320	5.8	2440	2610
1971	IN 21	980	910	10800	11600	2570	26860			
1972	IN 22	1020	930	11100	12400	3060	28510	7.7	2800	3080
1973	IN 23	870	820	10200	10700	2640	25230	7.6	2810	3210

Trial 1 Output Sample Analysis Results

Lab. Ref.	Sample Ref.	Benzene mg/kg	Toluene mg/kg	Ethyl Benzene mg/kg	Styrene mg/kg	Diethyl Benzene mg/kg	Sum of Aromatics mg/kg	% Weight Loss on cold extraction by Methanol	Weight Loss after CH_3Cl Extraction Based on original Weight mg/kg	Weight Loss after CH_3Cl Extraction Based on Weight after MeOH extraction mg/kg
1927	OUT 1	<1	<1	1.5	1.7	1.0	4			
1928	OUT 2	<1	<1	1.3	2.1	1.0	4	4.7	<200	<200
1929	OUT 3	<1	<1	2.1	2.3	1.0	5			
1930	OUT 4	<1	<1	1.1	1.1	<1	2	6.3	<200	<200
1931	OUT 5	<1	<1	<1	<1	<1	0			
1932	OUT 6	<1	<1	<1	<1	<1	0	6.9	<200	<200
1933	OUT 7	<1	<1	<1	<1	<1	0			
1934	OUT 8	<1	<1	1.6	<1	1.1	3	3.9	200	220
1935	OUT 9	<1	<1	3.5	4.7	1.6	10			
1936	OUT10	<1	<1	2.7	3.9	1.7	8	7.3	<200	<200
1937	OUT11	<1	<1	4.1	11.4	2.4	18			
1938	OUT12	<1	<1	4.3	8.4	2.8	16	4.9	560	670
1939	OUT13	<1	<1	3.4	8.5	1.8	14			
1940	OUT14	<1	<1	3.0	8.5	1.5	13	3.6	960	1000
1941	OUT15	<1	<1	2.2	6.7	1.5	10			
1942	OUT16	<1	<1	2.1	7.7	1.2	11	4.0	680	720
1943	OUT17	<1	<1	<1	<1	<1	0			
1944	OUT18	<1	<1	<1	<1	<1	0	6.2	320	350
1945	OUT19	<1	<1	3.7	1.7	1.5	7			
1946	OUT20	<1	<1	3.4	3.1	2.4	9	5.6	680	750
1947	OUT21	<1	<1	5.0	13.7	2.6	21			
1948	OUT22	<1	<1	4.1	9.4	2.2	16	6.8	1120	1220
1949	OUT23	1.2	<1	8.2	13.4	4.1	27			
1950	OUT24	<1	<1	4.1	10.5	2.2	17	7.7	1640	1990

Trial 2 Sample Analysis Results

Input Samples

Lab. Ref.	Sample Ref.	Benzene mg/kg	Toluene mg/kg	Ethyl Benzene mg/kg	Diethyl Benzene mg/kg	Other Aromatics mg/kg	Total Aromatics mg/kg
2047	IN 25	90	180	3370	1320	2940	7900
2048	IN 26	60	160	3070	1120	2810	7220
2049	IN 27	30	100	2720	1290	2480	6620
2050	IN 28	70	200	4040	1530	3750	9590

Output Samples

Lab. Ref.	Sample Ref.	Benzene mg/kg	Toluene mg/kg	Ethyl Benzene mg/kg	Diethyl Benzene mg/kg	Other Aromatics mg/kg	Total Aromatics mg/kg
2051	OUT 25	<1	<1	3.8	2.4	4.4	11
2052	OUT 26*	4.7	2.4	33.2	15.6	35.3	91
2053	OUT 27	<1	<1	2.1	1.1	3.0	6
2054	OUT 28	<1	<1	2.1	<1	4.1	6

* Suspected cross contamination due to sampling being carried out by same person wearing same pair of gloves and OUT sample being taken immediately after IN sample.