Project Siren: Phase 1 Report

R&D Technical Report P358
AEA Technology Environment,
Shell Global Solutions

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This report summarises the findings of research carried out by the contractors for project P2-177. The information within this document is for use by EA staff and others involved in evaluating the use of natural attenuation for the purposes of remediating contaminated land and groundwaters.

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EXECUTIVE SUMMARY

This report describes the successful completion of Phase 1 of Project SIREN. SIREN is the acronym for the Site for Innovative Research on Monitored Natural Attenuation, a project which aims to promote the application and understanding of monitored natural attenuation in the UK. The aim of Phase 1 was to identify a site which could potentially allow the demonstration of natural attenuation under UK conditions, and act as a site for the development of research projects from the UK Science base for studying the fundamental aspects of natural attenuation processes. The SIREN site, once characterised, will be open to any *bona fide* researcher to conduct research on natural attenuation funded from other bodies.

The project team developed criteria for site selection in consultation with the Agency. These criteria were developed to locate a site available for 3-5 years, that contained a mixture of contaminants in an aquifer characteristic of UK conditions. Over 200 sites were considered from which 5 sites were identified as possible candidates for further investigation. One of the criteria was that the site should be situated on a contaminated minor sedimentary aquifer. Only 41 sites complied with this criterion, and 5 of these sites were found to comply with the remaining 10 criteria. Of the 5 short listed sites, 3 were selected for further evaluation after consultation with the Agency. The findings of the further evaluation were as follows:

1. An operating Chemical Plant in the North West of England was identified as a potential site. It was found to be the most compliant with all of the site selection criteria. This site has a diverse number of biodegradable contaminants ranging from hydrocarbons to chlorinated solvents and oxitols. It has both perched aquifers and a major consolidated aquifer that are contaminated and a number of receptors have been identified nearby. These receptors are not known to be impacted, nor has the contamination apparently migrated off site. The project team believe that the contamination could be managed successfully by monitored natural attenuation (MNA), although further evidence must be gathered before this can be demonstrated. The site owners have granted permission for Phase 2 to go ahead, and in principle they have agreed for the site to be used as a Demonstration Site for 3-5 years subject to certain conditions of confidentiality and safety. This site has an excellent potential as a demonstration site and is recommended for further studies in Phase 2. It has the further advantage that the site operator is conducting a considerable amount of additional site characterisation and monitoring, which will be made available to Project SIREN. This work will not be sufficient to fully characterise the site to a level necessary for a research project, nonetheless, it will provide valuable site data. Taken as a whole the contamination on the site is too complex to fit comfortably within Project SIREN. In Phase 2 the project will characterise 1 or 2 plumes on the Chemical Plant, and obtain sufficient information to evaluate MNA in these plumes, and to meet the objectives for this project.

2. A petroleum distribution depot in the East Midlands operated by a number of oil companies was also found to be largely compliant with the site selection criteria. At this site, contamination of the vadose zone and the groundwater has occurred with petroleum hydrocarbons. The receptor is a nearby river that as yet has not been impacted by the groundwater plume. This site has potential as a demonstration site, and could be used in particular to study vadose zone attenuation. However, as the groundwater contamination

spans sites owned by a number of companies, permission needs to be obtained to use the site from all the appropriate companies. The site owner believes that this could be achieved if the companies were approached by the Agency, and asked to be involved in a demonstration project. It is recommended that this site be investigated further in Phase 2, as a potential second site.

3. A waste transfer station situated over a consolidated aquifer of Upper Carboniferous Sandstone was also assessed. The vadose zone and groundwater were found to be contaminated by a wide range of contaminants, many of which were potentially manageable using MNA. However, it was found that the contamination had migrated off site onto land owned by another organisation, and has the potential to be the subject of legal action (contravening Criterion 4). As such the site did not sufficiently meet our site selection criteria and it was proposed that no further work should be conducted on this site.

Phase 2 will be divided into two parts: Phase 2a and Phase 2b. In Phase 2a the project team propose to concentrate on further characterisation of a number of plumes at the Chemical Plant, and establish the potential of using the Petroleum Distribution Depot as a second site. Our work programme is designed to facilitate selection of 1-2 plumes from the Chemical Plant for Project SIREN, and to decide whether to include the East Midlands site in SIREN. Upon successful completion of Phase 2a, a detailed specification for Phase 2b will be completed. Details of the Phase 2 work programme are given in the Phase 2 project proposal.

Representatives of the Project Team and the Agency met with the Chief Executive of the CL:AIRE (Contaminated Land: Applications in Real Environments) initiative, and agreed a potential formal link between SIREN and CL:AIRE. A formal collaborative agreement between CL:AIRE and SIREN has been drafted. It is proposed to conclude the negotiations with CL:AIRE in Phase 2.

List of Abbreviations

ASTM	American Society for Testing and Materials
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes (Components of Petrol)
BGL	Below Ground Level
CAHs	Chlorinated Aliphatic Hydrocarbons
CL:AIRE	Contaminated Land: Applications in Real Environments
CFCs	Chlorofluorocarbons
DIANA	Developing Innovative Approaches for Assessing Natural Attenuation
DNAPL	Dense Non-Aqueous Phase Liquids
EA	Environment Agency
GPR	Ground Penetrating Radar
HS&E	Health Safety and Environment
HVOCs	Halogenated Volatile Organic Carbons
LNAPL	Light Non-Aqueous Phase Liquids
MNA	Monitored Natural Attenuation
MTBE	Methyl Tetra Butyl Ether
NNAGS	Network for Natural Attenuation of Groundwater and Soil
NOBIS	Dutch Contaminated Land Research Programme
PAHs	Polycyclic Aromatic Hydrocarbons
RWL	Rest Water Level (groundwater)
SEPA	Scottish Environmental Protection Agency
SIREN	Site for Innovative Research on Natural Attenuation

1. INTRODUCTION

Many organic contaminants degrade naturally in the biosphere without the interference of man. In fact, human life on our planet could not be sustained without the global biogeochemical pathways that recycle organic and inorganic compounds. These processes occur naturally on many contaminated sites and can be harnessed to mitigate risks to human health and the environment associated with the contamination. Monitoring such transformations, and modelling their long term performance can be a cost-effective alternative remedial tool especially when compared with more traditional engineered solutions. This approach has been termed "monitored natural attenuation" (MNA) and has been effective for a range of sites particularly in North America. Assessing natural attenuation requires knowledge of the *in situ* contaminant mobility, and the biological, chemical and physical decomposition processes of the contaminants. Although there has been some experience of assessing and monitoring natural attenuation processes in the saturated zone in North America and the Netherlands, relatively little work has been done in the vadose zone. There are significant technical difficulties in estimating such processes in saturated zones showing considerable heterogeneity in terms of physical structure and chemical speciation. Such conditions are not uncommon in the UK. Moreover, there is growing awareness of MNA amongst regulators, problem owners, property developers, future property owners, and consultants in the UK, however a well-documented demonstration of MNA will have an important role in improving further understanding of this approach. This constituency also has a lack of confidence in the approach owing to its limited track record and a misconception that the approach is a "do nothing" technique.

1.1 Project Structure

This project aims to identify, document and develop a UK demonstration site for MNA and is divided into three Phases, as follows:

- Phase 1: Locate a site for the long term study of natural attenuation
- Phase 2: This Phase is divided into 2 parts. Phase 2a will assess the rate of natural attenuation of contaminants, and predict future contamination migration. Phase 2b will verify these predictions with time.
- Phase 3: Encourage and co-ordinate innovative research projects using the field site and the data generated from it. Disseminate the results of the research widely.

Each Phase is divided into Tasks, and in Phase 1 the following Tasks were identified:

- Task 1.1 – Develop site selection criteria
- Task 1.2 – Conduct an initial sift of potential contaminated sites
- Task 1.3 – Conduct an evaluation of the short-listed sites
- Task 1.4 – Submit the Project for consideration by the CL:AIRE initiative

This report details the findings of these 4 tasks. The site selection criteria (Task 1.1) are presented in Section 2. This was discussed with and approved by the Agency in September 1999. The findings of Task 1.2 are presented in Section 3. These were presented to the

Agency on 1st November 1999. The presentation and the minutes of the meeting are given in Appendix 1. The findings of Task 1.3 are given in Section 4 and the conclusions and recommendations arising from this are given in Section 6. Section 5 outlines the progress on Task 1.4. The Phase 2 project proposal will give details of the plans for Phase 2a and 2b.

1.2 Project Acronym

The project was initially entitled Developing Innovative Approaches for assessing Natural Attenuation (DIANA). This acronym did not receive universal approval. As a result the project team and the Agency brainstormed new names and came up with an alternative title, the "Site for Innovative REsearch on Natural attenuation" or "SIREN". This has been regarded more positively and as such for Phase 2, the project will be known as SIREN.

2. SITE SELECTION CRITERIA

The project team were clear that in order to find a suitable demonstration site for MNA there would be a need to assess and make a selection from a number of potential candidate sites. So a set of criteria were agreed with the Agency and these are described in the following sections. Using these criteria 203 sites in the UK were reviewed (section 3) and a final short list of 3 sites prepared for further yet more detailed consideration (section 4). The findings from this more detailed desk top review were used to propose site(s) for further consideration in Phase 2 (section 6).

2.1 Summary of Criteria

To find a suitable demonstration site for monitoring natural attenuation, a number of sites were reviewed. Criteria were identified to assess the suitability of the sites for Project SIREN, and these were agreed with the Agency. These criteria are summarised below. The site should:

1. contain potentially biodegradable contaminants in a groundwater plume and should not contain large amounts of free product;

2. be available for research for at least 3 years, although preferably 5 years;

3. have a plume of contamination which will not impact a receptor within the 3 years of the project. The plume should be contained within the site boundary or access should be available to areas of the plume off-site;

4. have no current or impending legal and/or regulatory disputes;

5. have a limited number of identified source areas;

6. have sufficient initial site characterisation information to identify sources, pathway and receptors;

7. have historical monitoring data which could act as a benchmark;

8. be situated on a minor sedimentary aquifer, with preference given to a consolidated formation such as a sandstone;

9. have groundwater within 10 m to 15 m of the surface, and the water table should not be subject to wide fluctuations with recharge;

10. have no operating remediation scheme which could interfere with the potential study area;

11. be securable with no outstanding HS&E issues.

2.2 Source Criteria

It is essential to this project that the main contaminant or contaminants have the potential to be degraded by biological processes (Criteria 1). The project has sought to find a single source of contamination that has originated at the surface and migrated through the entire unsaturated zone to the saturated zone. However, in the final analysis this ideal situation could not be found and a limited number of sources were accepted (Criteria 5). Both LNAPL and DNAPL organic contaminants are to be considered.

The existence of an extensive pool of free product is not desirable, since such a pool could act as a second source area and present problems in defining concentration gradients and contaminating investigation bore-holes. However, it has been agreed with the Environment Agency that monitoring the fate of a product layer is desirable to demonstrate what may happen when unrecoverable product remains in the aquifer.

The source history and constituents were required to be well characterised (Criteria 6), and removal of any active source of contamination was acceptable as long as the defined plume of contamination is not being affected by any remediation process (Criteria 10).

2.3 Pathway Criteria

Sufficient site investigation information needed to be available to define the contaminant migration pathways (Criteria 6), but it is anticipated that this information will be supplemented by detailed studies associated with this project. To monitor natural attenuation and determine the complexity of the operating processes, it is advisable to keep the environment in which these processes are occurring as simple as possible. Shallow (Criteria 9), minor sedimentary aquifers (Criteria 8), where the sediments are reasonably homogeneous, and the groundwater flow is through a porous medium with no preferential flow paths were pre-requisite. A shallow, easily penetrated geology will aid the physical installation of monitoring equipment, and a simple geology will facilitate prediction and modelling of contaminant behaviour. Historical monitoring of the site, particularly groundwater levels and chemistry, was required to identify the dynamics of the groundwater regime in the potential study area (Criteria 7).

2.4 Receptor Criteria

Again from Criteria 6, sufficient knowledge of the site was required to identify potential receptors. For the study area, the groundwater pathway and its impacts on surface waters and any users of the groundwater, surface waters and coastal waters form the critical path. Other receptors will be affected via volatilisation pathways and exposure to contaminated soil, although these are anticipated to be of less importance in the context of this study. Therefore, in order to select a site, any plume of contamination in the groundwater was required not to have reached a Controlled Water receptor or users of these waters. Although this criteria provided an opportunity to demonstrate control of migration by natural attenuation, and also to provide scope for modifying the natural system without threatening a receptor (Criteria 3) the selected sites have impacted the underlying groundwater and at one site the nearby

watercourse. No pending legal or regulatory action was desirable, since this could affect the long-term prospects of any monitoring experiments (Criteria 4).

2.5 Site Criteria

The size of the site is not important. However, there is a need to be able to access all portions of the plume, including the uncontaminated area in front of the plume. It is important that the site is secure to prevent vandalism of experiments (Criteria 11), and that the long term (3-5 years) future of the study area is guaranteed by the owner (Criteria 2).

3 INITIAL SELECTION OF SITES

3.1 Findings of the Selection Process

An initial assessment of sites was made and the results presented to the Agency in a presentation on 1 November 1999 at the Solihull office. A summary of the presentation is given in Appendix 1.

The sites were provided by two organisations concerned with transport and fuel distribution. Their locations are therefore related to operational activities within the main transport corridors and major industrial areas in the UK. Eighty six sites were reviewed from Organisation 1 and 117 sites from Organisation 2. The data available for all the sites identified were reviewed and a short list was produced for more detailed evaluation (section 4).

In order to demonstrate the types of sites reviewed they were segregated into distinct categories (table 1). The sites in Scotland were separated due to their regulation by SEPA. Those in England and Wales have been combined to relate to the regulatory area of the Agency. An important category was to identify the number of sites situated directly on a minor sedimentary aquifer (Criterion 8), as it became rapidly apparent that most sites failed to comply with this criterion. A category of sites on a significant thickness of drift over major aquifers was also created as the drift may limit the vulnerability of the site. Sites in valleys over significant thickness of alluvial and other valley deposits were recognised as a separate aquifer category. A final category described those that were located on strata which do not have an aquifer.

The results show that less than 10% of the sites are on vulnerable major aquifers. Many of the sites are located in regions without aquifers, or in coastal or valley deposits. At these latter sites the nearby surface waters maybe at risk.

Table 1 Hydrogeological classification of the Reviewed Sites

Groundwater classification	Number of sites Organisation I	Number of sites Organisation II	Total Number of sites
Scotland coastal	9	2	11
Scotland non-aquifer	3	4	7
Scotland minor consolidated aquifer	2	11 (8 being on Coal Measures/ Millstone Grit)	13
Scotland valley deposits	1	1	2
Scotland major aquifer with significant drift cover	1	0	1
Scotland high vulnerability major aquifer	0	0	0
England and Wales coastal	11	15	26
England and Wales non-aquifer	24	27	51
England and Wales minor consolidated aquifer	15 (10 being on Coal Measures/ Millstone Grit)	26 (16 being on Coal Measures/ Millstone Grit)	41
England and Wales valley deposits	8	7	15
England and Wales major aquifer with significant drift cover	8	9	17
England and Wales highly vulnerability major aquifers	4	15	19
TOTAL SITES	86*	107	203

* An additional two sites were located in Northern Ireland but not considered, and three sites did not have sufficient information to make a classification.

We therefore found that out of 203 sites only 41 complied with Criterion 8 (Figure 1). Of these 41 sites, 26 were on Coal Measures and Millstone Grit. This type of geology is not ideal for a research project such as Project SIREN owing to its complexity and heterogeneity. However, these sites were not excluded and were further studied.

Eleven of the 41 sites had been sold or were in the process of being sold and therefore failed Criterion 2 (Figure 1). Of the residual 30 sites, 12 did not have sufficient contamination to merit any form of remediation (failing on Criteria 1 and 5). Of the remaining 18 sites, 14 could not be considered further because of pending remediation schemes (Criterion 10), because the plume had migrated off -site (Criterion 3), or because of current or impending legal disputes (Criterion 4).

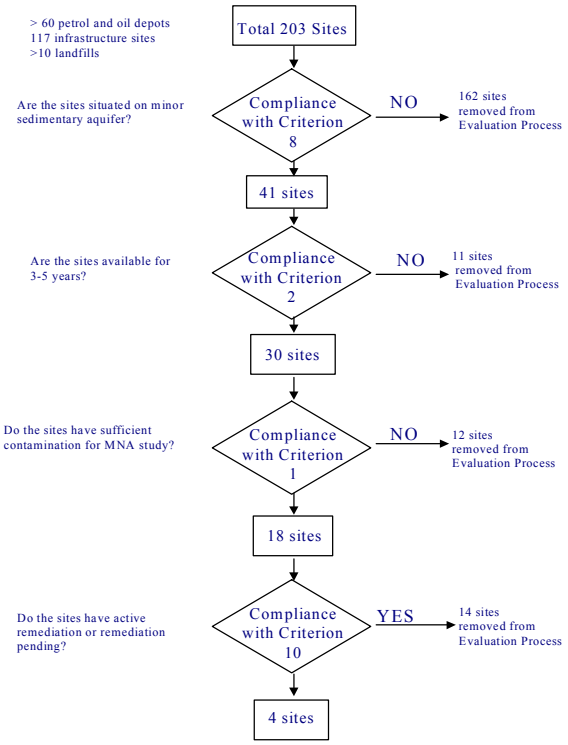

Figure 1- Site Selection Flow Chart

The parallelograms describe the assessment criterion and the rectangles describe the number of sites passing the criterion.

Thus of the total of 203 sites only 4 complied with most of the selection criteria: 2 from Organisation 1 and 2 from Organisation 2. Even with these sites, they did not necessarily comply completely with all our criteria. One additional site has been considered because it could potentially act as a UK Case Study for MNA (making a total of 5 sites). This site, a petroleum storage depot, located in the south of England, contaminated a minor sandstone aquifer with BTEX. There is a large amount of data on the site history, hydrogeology and the attenuation of the plume. Unfortunately, the MNA on the site is nearing completion and the site has recently been sold (therefore rendering the site ineligible based on Criterion 2). The site was jointly owned. The data for the collapsing plume of BTEX resulting from MNA is convincing and would make an excellent Case Study for Monitored Natural Attenuation in the UK. It is recommended that the data held could be written up and presented as a separate MNA case study. Preliminary discussions suggest that the organisations involved would be happy for this work to be written up as a paper in the public domain. The results from this site could also be used to benchmark the ASTM, NOBIS, and draft UK procedures for assessing MNA in Phase 2a.

The main reason why Criterion 8 was so difficult to comply with was because the vast majority of the sites were situated on unconsolidated deposits or low vulnerability geology in river valleys and coastal situations. The geographical distribution of the major concentrations of population, industry and transport in the UK tend to be in these low lying areas, and in

areas where coal is present. The trend is for the majority of contaminating activities not to be directly located on areas where consolidated minor or major aquifers are directly exposed.

The initial short list selected comprised five sites:

- a petroleum storage depot in the South of England where there is documentary evidenced that MNA is taking place, but has recently been sold (detailed description above);
- a petroleum distribution depot in the East Midlands where MNA of free product in the unsaturated zone could be studied (3.2);
- a landfill in the South of England which has received liquid solvent wastes (3.3);
- a waste transfer centre which has given rise to solvent contamination of groundwater (3.4), and
- a chemical plant in the North-West with multiple sources (3.5).

3.2 Petroleum Distribution Depot (East Midlands)

This site is a complex of oil distribution depots. There is BTEX contamination and possibly MTBE in the shallow groundwater (3-4 m below ground level (bgl)) below the site, which is situated in the drift deposits of the Trent valley. Groundwater flow is to the River Trent, some 150 m away, and oily seepages have been observed in the river bank. The local Agency officers are aware of the situation and have recently commissioned a Ground Penetrating Radar survey. Given these characteristics, this site warrants further investigation. However, the project team will need to establish if all the site owners would consider being involved in SIREN.

3.3 Landfill (South England)

Although a typical landfill produces a mixed and poorly quantifiable source, this particular landfill situated on Lower Chalk was reported to have received large quantities of liquid solvent waste, mainly toluene. This waste stream arose from a vehicle manufacturing plant in the early to mid 1970s. The site was included in a Department of the Environment study into landfill attenuation processes in 1976. Monitoring at the site has been maintained, but the plume of contamination may have been attenuated or is ill-defined by the present monitoring programme. A major drawback to this site is the depth of the unsaturated zone, which is 40 m bgl, making investigation costs high (and which contravenes Criterion 9). It was agreed at the meeting on 1st November that this would not be a priority candidate site owing to the uncertainty associated with the plume location, and the contamination depth. However, if further information became available through revision of the local authority monitoring data, then the Agency would wish to be kept informed of developments, and reconsider the site to investigate MNA in chalk.

3.4 Waste Transfer Centre

This site was leased to a chemical company that operated a solvent waste transfer business, which has caused contamination of the soil and groundwater in the 9 m deep blown sand minor aquifer overlying Upper Carboniferous Sandstone. The site groundwater lies between 2-4 m bgl and has been well characterised by site investigation. There is a large range of

contaminants on this site including Polycyclic Aromatic Hydrocarbons (PAH), chlorinated hydrocarbons, and chlorofluorocarbons (CFCs). The CFCs are not regarded as biodegradable and therefore physical attenuation mechanisms will predominate for these compounds.

3.5 Chemical Plant (North West)

This site has been operated for 50 years, and both currently and historically has manufactured a wide variety of chemical products. BTEX, Halogenated Volatile Organic Carbons (HVOC), Light Non-Aqueous Phase Liquids (LNAPL) and Dense Non-Aqueous Phase Liquids (DNAPL) are present in multiple plumes in three aquifers at the site. There is an upper aquifer in alluvial deposits, separated by boulder clay from a river gravel intermediate aquifer, which in turn overlies the Sherwood Sandstone major aquifer. The depth of unconsolidated deposits varies across the site from approximately 7m to an excess of 35m. Nested monitoring wells are arranged in a network across the site, and this is currently being extended. The site is within 150 m of the River Mersey to the north of the site.

3.6 Summary

From these five sites, a short list of three were selected for further evaluation: the waste transfer centre, the petroleum distribution site, and the chemical plant. The findings of this evaluation are given in Section 4.

The extensive review of over 200 sites revealed some interesting information. Most of the sites were actually on low lying river valleys and coastal plains on unconsolidated aquifers or low vulnerability deposits (and thereby failing to comply with Criterion 8). This is perhaps unsurprising. The reviewed sites are located on the major transport corridors and near urban centres. The geographical distribution of the major concentrations of population, industry and transport in the UK tend to be in these low-lying areas, and in areas where coal is present. Thus for these sites, the majority of polluting activities are not directly located on areas where consolidated aquifers are directly exposed, which is fortunate from a groundwater protection perspective. Moreover, it means that natural attenuation experience on similar geological deposits in North America is likely to be of relevance to these UK sites. Nonetheless, as part of developing confidence in MNA in the UK there is good reason to study MNA on both consolidated and unconsolidated materials.

4 DETAILED EVALUATION OF THE SHORT LISTED SITES

4.1 Introduction

Three sites were reviewed in this section: the chemical plant, the waste transfer centre, and the petroleum distribution centre. A summary of our findings is presented at the end of the section.

4.2 Chemical Plant (North West)

The site occupies 180 ha on the southern bank of the River Mersey and is an operational chemical works.

4.2.1 Sources

The site has been used as a chemical works and storage depot for over fifty years. In the petrochemical plant area all current operations are located on sound concrete hardstanding, and served by a drainage system specifically designed to enable containment of spillages in interceptors. The risk of significant environmental impact from current activities has been reduced by these measures.

Recent site investigations indicate that there are high concentrations of hydrocarbons throughout the operational area of the site. These are likely to have been caused by spillages during the early days of operations, and due to lower standards of plant construction which were typical of the day. Storage facilities dating back to the late 1940s and 1950s have soil bunding that may permit contaminant migration, as for example probably occurred at the old styrene tanks in the Tank Farm. Over the years the site has been used to produce a wide variety of chemical products (Table 2).

Table 2. Chemicals known to have been manufactured at the site

Catarole	Alkanolamines	PAHs
Ethylene oxide	Detergents	Tar/pitch
Polystyrene	Resins	Teepol 610s
Polylefins	di-cyclopentadiene	Glycols
Iso-propyl alcohol	BTEX	Styrene

In groundwater beneath the former Ethylene and Styrene Monomer plants and in other areas, very high concentrations of BTEX compounds, naphthalene, styrene and chlorinated solvents have been found. Free hydrocarbons have been noted floating on top of groundwater in the west of the site and on the site of the former Ethylene III and Styrene Monomer plants. These compounds are potentially biodegradable, thereby complying with Criterion 1.

4.2.2 Pathways

There are believed to be two main pathways for contaminant migration at the site to Controlled Waters. These are migration into the subsurface and thence into the groundwaters, and migration along an old drain along the line of the former site railway towards the nearby river.

Previous site investigations have revealed the following soil and geological profile across the site (Table 3, Figure 2). Borehole details are provided in Appendix 2.

Table 3. Soil and geological strata below the site

Stratum	Description	Thickness (m)
Made ground/top soil/peat	Sandy organic topsoil with peat lenses	0.8 - 3
Silty sand	Fluvioglacial sand	3-6
Glacial clay (lenses and beds alternating with the sands and gravel)	Dark brown laminated silty clays	1-20
Sands and gravels (alternating with the clay)	Dense sand, fine to coarse gravels	1-9
Sandstone	Upper Mottled Sandstone, Sherwood Sandstone Formation	

Three distinct groundwater regimes are believed to be present on the site:

- A series of discontinuous perched water bodies within the Made Ground and silty sands;
- A shallow aquifer within the Sands and Gravels, and
- A deep aquifer within the Sherwood Sandstone.

The unsaturated zone is approximately 1.5 – 2.5 m bgl. It is not known if the aquifers are in hydraulic continuity, but there are indications that the clay layers may be discontinuous. The groundwater flow in all aquifers is in a westerly and north westerly direction towards the Mersey Valley (Figure 3).

Areas of high contaminant concentrations (>1000mg/l) appear relatively localised in the upper aquifer, the main contaminants of concern being BTEX, naphthalene, styrene and Chlorinated Aliphatic Hydrocarbons (CAHs). These contaminants have also been found in the three deep wells located in the centre of the historical production areas indicating vertical migration of contaminants into the sandstone aquifer.

A total of 37 groundwater monitoring wells had been installed at the site, prior to September 1999, at 23 separate locations. Sixteen are located along the perimeter (W1 to W14, W16 and W19), and 7 within the site (W15, W17, W18, and DW1 to DW4), with nested piezometers at a number of locations. Sampling has been concentrated in the upper drift deposits above the glacial clay, but four deep wells sample the sandstone groundwaters (DW1 to DW4) (Figure 4).

A summary of groundwater monitoring data is given in Appendix 2. These data show the presence of BTEX, styrene, alkyl benzene, naphthalenes, and chlorinated and brominated aliphatics particularly in the western half of the site in the shallow aquifer(s). Similar types of compounds, although with fewer species, were found in the consolidated aquifer. The contamination has therefore entered a consolidated aquifer (Sherwood sandstone) complying with Criterion 8, is within 10-15 m bgl (complying with Criterion 9) and there appear to be a limited number of sources (complying with Criterion 5).

In November and December 1999 a further five deep monitoring wells (Figure 4) were being installed to monitor the sandstone aquifer, with nested piezometers being drilled at three locations to the east of the site for sampling the perched, intermediate and sandstone aquifers. The drilling program is supported by groundwater monitoring, test pumping, vapour surveying and topographic surveying. The objectives of this most recent work is to:

- Fully delineate the sources of contamination;
- Provide sufficient data for the development of a groundwater/contaminant transport computer model;
- Determine if the drainage line to the north west of the site is acting as a preferential migration route, and
- Define the future groundwater monitoring strategy for the site.

This work is described in more detail in the Phase 2 project proposal.

Figure 2

Figure 3

Figure 4

4.2.3 Receptors

It is believed that all groundwaters at the site are flowing in a westerly to north westerly direction towards the River Mersey which lies within 500 m of the site. This is the nearest main surface water body. As yet there is no evidence that the receptors (other than the groundwater itself) are impacted or are likely to be impacted, complying with Criterion 3. There are also thirteen licensed abstractions in the area.

4.2.4 Potential Use as a Demonstration Site

The site owner has given permission for Phase 2 to proceed and have agreed in principle to the site being used as a demonstration site for up to 5 years, subject to certain conditions of confidentiality and safety, complying with Criterion 2. Access to the site will be reviewed on a project by project basis. The site is secure and has no outstanding Health and Safety issues (Criterion 11), is not subject to any current or impending regulatory disputes (Criterion 4), and no remediation scheme is operating or is planned to operate at the moment (Criterion 10).

The contaminants are by and large biodegradable and there is some evidence from the groundwater results that biodegradation is occurring *in situ* (Criterion 1). Contamination has reached a consolidated aquifer which lies within 10-30 m of the surface (complying by and large with Criterion 8). At this stage the data is not conclusive that natural attenuation processes will prevent significant impact of the contaminants on the receptors. However, the project team think there is at least a reasonable chance that MNA is an appropriate strategy (Criterion 3). It is anticipated that sufficient data will be collected during the current sampling in order to establish baseline conditions for the site (see Phase 2 project proposal). Initial studies have been conducted, including historical monitoring, which have established the sources, pathways and receptors (thereby complying with Criterion 6 and 7).

The site is complex and therefore, it would be impractical for Project SIREN to work on all of the contamination. We propose to select specific plumes (1 or 2) for this project and conduct additional work on these plumes (over and above the work that the owner and operators would normally do) to generate sufficient data for a research projects on MNA. Further details on the proposed next phase of the project are in the Phase 2 project proposal. In conclusion, this site complies with nearly all aspects of the site selection criteria, and is therefore a promising site for Project SIREN.

4.3 Petroleum Distribution Site (East Midlands)

4.3.1 Source

The site has been a multi-occupant fuel distribution centre for many years. Different parts of the site are occupied by a number of petroleum companies. Refined products were originally taken to the site by barge along the nearby river Trent and landed via jetties. A rail terminal was then built to bring in product by train. This has now been removed. Transport to and from the site in recent years has been by road and by pipeline. Storage facilities exist for a wide range of fuels including fuel oils, petrol, and diesel. Much of the site has been cleared ready

for remediation and sale, although some parts of the site are still operational. Access to the entire groundwater plume would require the support of all the site owners, although one portion of the site could be made available for research for at least 3 years (Criterion 2).

Over the years there have been spills of free product in a number of areas of the site. This has resulted in hydrocarbon contamination of the vadose zone and of the groundwater. The bulk of the source term is in the centre of the site (Figure 5), where free product (LNAPL) remains floating on the groundwater. The contamination consists of aliphatic and aromatic hydrocarbons (including BTEX), as well as other petroleum hydrocarbons. Our experience has shown that the fuel additive Methyl Tetra Butyl Ether (MTBE), more recalcitrant than BTEX, is likely to occur on this site, but a detailed survey has yet to be conducted. An extensive borehole monitoring network is already in place and historical data is available. The site therefore contains biodegradable contaminants (Criterion 1), has a limited number of source areas (Criterion 5), and has sufficient historical data to identify sources, pathways and receptors (Criteria 6 and 7).

4.3.2 Pathway

The site is located on alluvial and channel deposits of the River Trent over Mercia Mudstones (Criterion 8). Groundwater (RWL 3-4 m bgl) flow in the deposits is towards the Trent (complying with Criterion 9). The contamination is within 150 m of the river. There are some unconfirmed suggestions that the contamination has already impacted the river as a number of seepages into the river have been reported. It is possible that these arise from historical river bank contamination or from a preferential flow of contaminants along pipeline trenches that were installed to transport fuel to and from the site. Additional site investigations, including a survey using Ground Penetrating Radar (GPR) are being carried out to understand linkage between the contamination and the receptor.

It is not therefore certain that the site complies with Criterion 3, but the information available to the project team suggests that the additional investigations will show that the bulk of the contamination has not impacted the receptor. There are no current legal or regulatory disputes (Criterion 4), no remediation scheme which will impact on Project SIREN (Criterion 10) and is securable with no outstanding HS and E issues (Criterion 11).

4.3.3 Receptor

The River Trent is the main receptor for this site. It is located approximately 150 m from the source of the contamination, and may already have been impacted by contamination arising from this site (contravening Criterion 3). However, the evidence suggests that the seepages noted in the river were not a result of contaminated groundwater reaching the river, but may have been due to contaminated river sediments or flow down pipeline trenches.

Figure 5 Map

4.3.4 Potential Use as a Demonstration Site

By and large this site complies with the site selection criteria. However there are some important points about the site, for example MNA has not been investigated in detail at this site as yet. Traditionally, sites with free product have been thought of as unsuitable for MNA. However, in the experience of the project team, it is possible that the natural biodegradative processes in the groundwater and in the vadose zone could restrict the migration of the contamination significantly enough to prevent receptor impact. As such, there is MNA potential strategy for this site. Moreover, a demonstration of MNA would lead to significant improvement in our understanding of the MNA potential for the treatment of free product and residual phase contamination in the vadose zone and groundwater. MTBE may also be present, which would allow the study of the natural attenuation of this compound under UK conditions.

The site is also largely clear of buildings and therefore access is good. There is reasonable potential for the installation of additional monitoring points if necessary. The main difficulty with the site is the fact that there are multiple site owners. The view of one site owner was that getting all the owners to work together on a demonstration project should be possible, but that such an initiative should be lead by the local Environment Agency representative. If this were to fail it is possible that MNA in the vadose zone could be studied in one part of the site. Overall therefore, given that the site does fit well with the site selection criteria, it is proposed that this site be considered in Phase 2a.

4.4 Waste Transfer Centre

4.4.1 Source

This site was leased to a solvent company who operated it as a waste transfer station. As a result of these activities over many years the soil and groundwater became contaminated with a wide range of compounds including: polynuclear aromatic hydrocarbons, chlorinated solvents and chlorofluorocarbons (CFCs). Many of these compounds are biodegradable, but the CFCs will not be. Attenuation of the CFCs will not be by a biological route. Thus the site conditions do not completely agree with Criterion 3. The geology of the site consists of 9 m of blown sand overlaying Upper Carboniferous Sandstone (complying with Criterion 8). The groundwater is freshwater, but is possibly subjected to tidal pressure. The site geology is well characterised. The site contamination however, is subject to additional investigation. Thus the site does in part comply with Criteria 5, 6 and 7. The site is also securable and does not have any outstanding HS & E issues (Criterion 11).

4.4.2 Pathway and Receptor

The groundwater (3-4 m bgl) flows towards a nearby river, complying with Criterion 9, and has no current remediation schemes which could influence an MNA study (Criterion 10). However recent site investigations have shown that the flow path is off-site through adjacent properties owned by other organisations, and that contamination has migrated in this direction. The site owners believe it unlikely that access to the off-site plume will be readily approved (contravening Criterion 3).

4.4.3 Potential Use as a Demonstration Site

Subsequent to inclusion on the short list, the project team has found that the main plume has migrated to an adjoining site owned by another organisation. As a result of this migration the site may well be the subject of civil action (contravening Criterion 4). The site no longer meets the criteria set for this project and no further action is proposed. Given the sensitivities associated with this site owing to the civil action, it is not appropriate to include any further details of the site investigation in this report.

5. INCORPORATION OF SIREN INTO CL:AIRE

A key part of generating a successful demonstration project is ensuring that the project has a high profile within the UK, and that information from the project is widely disseminated. As part of this strategy the project team has been forging links with the CL:AIRE (Contaminated Land: Applications in the Real Environment) initiative which aims to promote the development, demonstration and use of innovative methods of treating contaminated land and groundwater.

A copy of the initial proposal was sent to CL:AIRE and circulated around its Board and consultee group. The response to this initial proposal was positive.

Representatives of the Project Team and the Agency met with the CL:AIRE on the 26th November 1999 to discuss the matter further (for a list of Actions see Appendix 3). The meeting concluded that it would be beneficial for SIREN to have a formal link with the CL:AIRE initiative. A formal collaboration agreement between CL:AIRE and SIREN has been drafted.

It was proposed that the SIREN Project Steering Board will initially consider projects which intend to use the SIREN site(s), to determine if the projects are appropriate for SIREN. The Project Steering Board will be chaired by the site owner or their representative, and will consist of the Agency, Shell Global Solutions, and the National Environmental Technology Centre. The main assessment criteria for SIREN will be scientific (*i.e.* is the project tackling an issue of relevance to Monitored Natural Attenuation?), and the implications of the research project for the SIREN site, in terms of the requirements for: power, water, site access, frequency of sampling, and additional boreholes etc. Once approved by SIREN, it is proposed that the project idea will be referred to CL:AIRE for detailed scientific evaluation and approval. In terms of fees, it was suggested that SIREN and CL:AIRE should split the project fee on some agreed basis. These ideas were communicated to the CL:AIRE Board in January 2000 and were approved in principle, although they requested further details on the justification for the split of the project fee. These discussions will therefore continue during Phase 2.

6 CONCLUSIONS

The project team have successfully completed Phase 1 of Project SIREN. The project team developed criteria for screening a large number of sites as potential candidates for hosting the project. These were approved by the Agency (Section 2). Over 200 sites were considered in the initial sift. They found it very difficult to find sites which complied with all the site selection criteria, particularly Criterion 8 on the required hydrogeology. Five sites were considered as possible candidates, although even these 5 did not all comply completely with the site selection criteria. Of these, the 3 which best fitted the site selection criteria were selected for further evaluation. The findings of the further evaluation were as follows:

1. An operating Chemical Plant in the North West of the UK was identified as a potential site. It was found to comply with all of the site selection criteria, except that the sandstone aquifer was in places deeper below ground than the 10-15 m specified in Criterion 9. This site has a diverse number of biodegradable contaminants ranging from hydrocarbons to chlorinated solvents and oxitols. It has both perched aquifers and a major consolidated aquifer that are contaminated and a number of receptors nearby. The vadose zone may also be contaminated. These receptors are to the best of our knowledge not known to be impacted, nor has the contamination migrated off site, and the project team believe that the contamination could be treated successfully by monitored natural attenuation (MNA), although further evidence must be gathered before this can be demonstrated. The site owners have given their permission for Phase 2 to go ahead and in principle for this site to be used as a Demonstration Site for 3-5 years subject to certain conditions of confidentiality and safety. This site has excellent potential as a demonstration site and should be further studied in Phase 2. It has the further advantage that the site operator is conducting considerable amount of additional site characterisation and monitoring, which will be made available to Project SIREN, free of charge (see Phase 2 report). This work will not be sufficient to fully characterise the site to a level necessary for a research project, nonetheless, it will provide valuable site data. Taken as a whole, the contamination on the site is too complex to fit comfortably in Project SIREN. It is therefore proposed in Phase 2 to focus on 1 or 2 plumes on the Chemical Plant, and obtain sufficient information to evaluate MNA in these plumes, to a level suitable for Project SIREN. It is proposed that these plumes be selected in consultation with the Agency in Phase 2a of the project (see Phase 2 report).

2. A petroleum distribution depot in the East Midlands operated by a number of oil companies was also found to comply with most of the site selection criteria. At this site, contamination of the vadose zone and the groundwater has occurred with petroleum hydrocarbons. The receptor is a nearby river which as yet has not been impacted by the groundwater plume. This site has potential as a demonstration site, and could be used in particular to study vadose zone attenuation. However, as the groundwater contamination spans sites owned by a number of companies, permission to use the site is required from all the companies (Criterion 2). One site owner believes that this could be achieved if the companies were approached by the Agency, and asked to be involved in a demonstration project. It is proposed, therefore, that this site is also investigated further in Phase 2, as a potential second site (see Phase 2 proposal).

3. A waste transfer station situated over a consolidated aquifer of Upper Carboniferous Sandstone was also assessed. The vadose and groundwater were found to be contaminated by a wide range of contaminants, many of which were potentially treatable using MNA. However, the project team found that the contamination had migrated off-site on to land owned by another organisation, and is potentially the subject of legal action (contravening Criterion 4). As such the site did not sufficiently meet our site selection criteria and it is proposed that no further work should be conducted on this site.

In Phase 2 the project team intend to concentrate activity on the Chemical Plant, and do additional work on the petroleum distribution depot. The petroleum storage depot (south England) site will be written up as a case study in Phase 2. No further investigation of the waste transfer station is appropriate. Detailed recommendations for Phase 2 work programme are given in the Phase 2 project proposal.

Appendix 1
Presentation on Task 1.2

CONTENTS

AEA TECHNOLOGY
THE INNOVATION BUSINESS

DIANA PROJECT MEETING

Meeting reference AEAT ED12043001/2

Date Monday 1st November 1999

Present Alwyn Hart (EA)
Theresa Kearney (EA)
Gordon Lethbridge (Shell)
Chris Neaville (Shell)
Philippa Towler (AEA Technology)
Richard Swannell (AEA Technology)

MINUTES

1. The aim of the meeting was to discuss Milestone 1.2, the short list of sites to be considered in Task 1.3. RS presented details of Task 1.2 and gave details of 5 sites which could potentially be considered as candidate sites for Project Diana. Copies of the presentation were circulated to all participants. The site in Dumfries was discounted on the basis that it was unlikely to generate any particularly new data, and the site in Oxfordshire was discounted mainly because of the uncertain location of the plume. Three sites were therefore selected for further evaluation: the chemical site, the depot in the East Midlands, and the old solvent recovery plant owned by a major infrastructure company.

Action 1. Project team to complete evaluation of the 3 selected sites in Task 1.3. The report on Task 1.3 should be delivered electronically to the EA on the 8 December 1999. The report will considered at a meeting with the EA on Monday 13 December at 09.30 am at the EA's offices in Solihull

Action 2. RS to inform Mark Kibblewhite and Sue Herbert (EA) about this project.

2. RS noted that Project DIANA had been sent to Paul Beck of CL:AIRE for him to consider for incorporation into the CL:AIRE program (Task 1.4). No reply had yet been received.

Action 3. RS to contact Paul Beck to ascertain progress.

3. A number of adverse comments had been received about the acronym DIANA. A short brainstorm was held, to come up with alternatives. Two promising acronyms were produced: SEMINAR (SitE for MonItored Natural Attenuation Research) or SIREN (Site for Innovative Research on Natural attenuation).

Action 4. These acronyms would be discussed with the colleagues of all attendees and final decision on the acronym would be made at the meeting on the 8th December.

4. RS noted that in order to promote the project we should hold a workshop under the auspices of NNAGS (and CL:AIRE?) which gave more information on the DIANA sites and encouraged researchers to put in collaborative projects. RS suggested that this should happen in Feb 2000.

Action 5. Approved. RS to liase with NNAGs and possibly CL:AIRE to arrange a date.

Richard Swannell
Project Manager

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Date of issue 12 November 1999

Appendix 2
Borehole Details and Groundwater Contamination

CONTENTS

Summary of Groundwater Monitoring Data from October 1996

Installation	Compound	Concentration (mg/l)
W4	Benzene	0.42
	Naphthalene	0.14
	1,2,3 –Trichlororpropane	0.17
	1,2-Dibromo-3-chloropane	0.12
W5	Benzene	0.6
	1,2-Dibromo-3-chloropane	0.28
W11	1,1,1-Trichloroethane	0.13
W15	Benzene	1.1
	Xylene	0.12
	Bromethane	0.18
	Methalyene chloride	0.2
	1,1,1-Trichloroethane	0.38
	1,2,3-Trichloropropane	0.2
	1,2-Dibromo-3-chloropane	0.32
W17	Benzene	49.0
	Toluene	1.1
	Ethyl benzene	28.0
	Xylene	1.2
	Styrene	1.3
	Napthalene	7.3
	Isopropylbenzene	0.12
	1,2,4-Trimethylbenzene	0.3
	tert-Butylbenzene	0.4
	Methylene chloride	0.22
	1,2-Dichloroethane	2.4
	1,2,3-Trichloropropane	0.28
	1,2-Dibromo-3-chloropane	0.32

Summary of Groundwater Monitoring Data from October 1996 (continued)

Installation	Compound	Concentration (mg/l)
W18	Benzene	460
	Toluene	54.0
	Ethyl benzene	9.4
	Xylene	1.5
	Napthalene	13.0
	Chloroethane	0.23
	1,2-Dichloroethane	23.0
	Isopropylbenzene	0.35
	1,2,4-Trimethylbenzene	0.65
	Methylene chloride	0.22
	1,2,3-Trichloropropane	0.4
	1,2-Dibromo-3-chloropane	0.32
	tert-Butylbenzene	0.65
DW2 (shallow)	Benzene	0.95
	Toluene	1.9
	Ethyl benzene	0.32
	Styrene	0.7
	Napthalene	0.38
	1,1-Dichloroethane	0.25
	1,2,3-Trichloropropane	0.48
	1,2-Dibromo-3-chloropane	0.3
DW3 (shallow)	Benzene	58.0
	Ethyl benzene	22.0
	Xylene	0.6
	Napthalene	0.12
	1,2-Dichloroethane	2.8
	1,2,3-Trichloropropane	0.38
	1,2-Dibromo-3-chloropane	0.28
DW3 (deep)	Benzene	91.0
	Ethyl benzene	3.5
	Xylene	0.25
	Napthalene	0.18
	1,2-Dichloroethane	4.4
	Methylene chloride	0.22
	1,2,3-Trichloropropane	0.25
	1,2-Dibromo-3-chloropane	0.35
DW4 (shallow)	Benzene	12.0
	Toluene	1100
	Ethyl benzene	10.0
	Xylene	1.4
	Styrene	45.0
	Napthalene	1.8
	1,2-Dichloroethane	0.55
	Isopropylbenzene	0.22
	1,2,4-Trimethylbenzene	0.34
	Methylene chloride	0.22
	1,1,1-Trichloroethane	0.25
	Chlorobenzene	0.15
	1,2,3-Trichloropropane	0.20
	1,2-Dibromo-3-chloropane	0.48
	tert-Butylbenzene	0.4
DW4 (deep)	Benzene	0.12
	Ethyl benzene	0.21
	Xylene	0.17
	Styrene	0.76
	Napthalene	0.78
	1,2-Dichloroethane	0.55

Appendix 3
Minutes of Meeting with CL:AIRE

CONTENTS

AEA TECHNOLOGY
THE INNOVATION BUSINESS

SIREN PROJECT MEETING

Date Monday 26 November 1999

Present Paul Beck (CL:AIRE)
Gordon Lethbridge (Shell)
Alwyn Hart (EA)
Richard Swannell (AEA)

ACTIONS ARISING FORM THE MEETING

1- Paul Beck to send a draft agreement for inclusion of the SIREN Project in CL:AIRE by mid-January 2000.

2- Richard Swannell to supply a copy of the Phase 1 report to Paul Beck by mid-December 1999. This report would act a baseline information for CL:AIRE's evaluation.

3- Paul Beck will supply a draft of the standard CL:AIRE agreement with the site owner by mid-January 2000.

4- Paul Beck to supply copies of the CL:AIRE forms, which are used for R&D projects.

5- Paul Beck to talk to the CL:AIRE Board about splitting the management fee for research projects operating at SIREN 50:50 between SIREN and CL:AIRE. Paul to complete this by end of January 2000.

6- Richard Swannell to put in the Phase 2 of SIREN that CL:AIRE and the EA will develop the web site jointly. SIREN would therefore sit on the web site as a CL:AIRE project

7- Paul Beck to attend workshop promoting SIREN on 17th February 2000, once the CL:AIRE Board, has approved SIREN .

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Date of issue 8 December 1999