CL:AIRE

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site bulletin

CL:AIRE site bulletins provide a source of background information on contaminated sites which have been used within the scope of CL:AIRE technology demonstration and research projects. This bulletin describes Project SIReN which is a national initiative for research into monitored natural attenuation.

Project SIReN: The Site for Innovative Research into Monitored Natural Attenuation

1. INTRODUCTION

SIReN is a national initiative for research into Monitored Natural Attenuation (MNA) under UK conditions. This publication aims to provide stakeholders (e.g. site owners, regulators, consultants/contractors, developers and financiers) with an awareness and understanding of the benefits that MNA brings to contaminated land management. Ongoing research projects at the SIReN site that are helping to demonstrate the technical feasibility of this approach are also outlined.

2. MONITORED NATURAL ATTENUATION AND THE UK SITUATION

Many natural processes attenuate organic contaminants/pollutants without the need for engineered remedial solutions including:

- Biodegradation;
- Chemical degradation;
- Sorption;
- Immobilisation; and
- Dilution.

Monitoring attenuation processes and modelling their long-term performance can be an alternative risk management tool to traditional engineered solutions. It is this approach that has been termed 'Monitored Natural Attenuation'.

By harnessing these processes, which occur naturally at contaminated sites, one can mitigate the potential environmental and human health risks associated with soil and groundwater contamination.

MNA has considerable potential to sustainably treat contamination *in situ,* reducing the amount of material requiring *ex situ* treatment or disposal to landfill. As such, MNA can be a cost-effective risk management tool alternative to more traditional engineering options. Given the difficulties and costs inherent in many site remediation settings, MNA may on occasion be the only technically feasible option.

Assessment and monitoring of natural attenuation processes are well documented for shallow groundwater contaminated by benzene, toluene, ethylbenzene and xylenes (BTEX) and chlorinated aliphatic compounds in unconsolidated geology in, for example, North America and the Netherlands. However, experience is limited in made ground and dual porosity aquifers typical of UK conditions. The regulatory framework exists in which MNA is an acceptable risk management tool provided it can be demonstrated to be protective of any receptors.

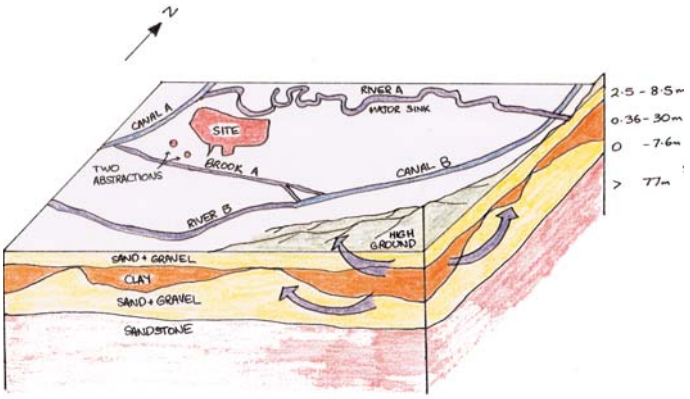

Figure 1. Sketch of the regional conceptual site model

The slow development of MNA in the UK has been compounded by a shortage of robust case studies. This has led to low confidence in the potential for natural attenuation amongst some stakeholders (BBSRC, 1999; DETR, 2001).

To this end, the project SIReN (**S**ite for **I**nnovative **Re**search into Monitored **N**atural Attenuation) was initiated in 2000 and is playing an important role in improving awareness of the technique as a potential cost-effective risk management option amongst key stakeholders, while overcoming the common misconception that it is a "do nothing" technique.

3. ABOUT SIReN AND THE SITE

3.1 Project Objectives

SIReN is a joint initiative between Shell Global Solutions UK, the Environment Agency for England and Wales (EA), CL:AIRE and AEA Technology. Administration of the SIReN project is funded by Biffaward Landfill Tax Credit Scheme with third party funding from the Energy Institute. The project's strategic objectives are to:

- Promote an awareness of the potential of MNA for cost-effective risk management amongst stakeholders;
- Facilitate the development of confidence in MNA and its acceptance as a technically defensible risk management option;
- Stimulate the development of cost-effective approaches to demonstrating the efficacy and sustainability of MNA; and
- Address some of the misconceptions about MNA.

If you have any questions about this Site Bulletin or would like further information about other CL:AIRE publications please contact us at:
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The technical objectives are to:

- Provide a well-characterised site for co-ordinated MNA research;
- Contribute towards defining the operating window for MNA in UK hydrogeology;
- Develop a cost-effective MNA strategy for "mega" sites addressing the challenges of multiple sources and co-mingled plumes.

3.2 SIReN Site and Characterisation

The SIReN research site is located at a large (180 hectare) operational petrochemical manufacturing plant. Large parts of the site have been decommissioned and the manufacturing plant removed facilitating access for intrusive site investigation. In consultation with the EA the site was selected for the following reasons:

- Contained potentially biodegradable contaminants in a groundwater plume;
- Was available for research for a minium of 5 years;
- Had contamination that was unlikely to impact a receptor;
- Had a limited number of identified source areas;
- Had historical monitoring data that could act as a benchmark;
- Was situated on a consolidated geological formation (sandstone);
- Had no operating remediation scheme which could interfere with the potential study area; and
- Was secure with no outstanding Health Safety & Environmental issues.

The project team believed that contamination at the site could be managed successfully by MNA and a preliminary Conceptual Site Model (CSM) was developed following characterisation of a number of plumes at the site, illustrated in Figure 1.

Site geology comprises four layers, each varying in thickness across the site:

- Layer 1 - Sand and Gravel (2.85 - 8.5 m thick);
- Layer 2 - Clay (0.36 - 30 m thick);
- Layer 3 - Sand and Gravel (0.00 - 7.6 m thick); and
- Layer 4 - Sandstone (>77 m thick).

Characterisation has revealed the site to contain extensive contamination in the shallow groundwater, including: BTEX, trimethyl benzenes (TMBs), naphthalene and other contaminants (Jones *et al.*, 2001; Lethbridge *et al.,* 2002; Swannell *et al.*, 2002). In addition, a trace of contamination was detected at the top of the deeper sandstone aquifer in a region central to the site.

Figure 2 shows a schematic map of the site.

The higher concentrations of BTEX are found in the shallow groundwater in the central parts of the site. Evidence, from vertical profiling, suggests that there has in fact been very little penetration through the clay, with the result that very few of the wells in the sandstone aquifer have measurable BTEX concentrations.

The presence of a styrene plume co-mingled with BTEX, TMBs and naphthalenes was confirmed in the shallow groundwater.

Early monitoring at the site, between 1995 and 2000, supported the applicability of natural attenuation at the SIReN site (Sheffield, 2001); indicators of the occurrence of natural attenuation were recorded as follows:

Indicators of Natural Attenuation	Present at SIReN?
The plume is stable or shrinking	stable
Decreasing contaminant concentrations	✔
Occurrence of degradation (sulphate reduction, methanogenesis)	✔
Increasing concentrations of daughter products	✔

3.3 Research at the Site

A number of research projects are ongoing at the SIReN site, covering a broad range of themes: 'Smart' monitoring/site investigation, decision-making tools for MNA.

In addition to the characterisation of the site, a number of research projects began during 2003. Among the 12 research projects on site over the past year, four major ongoing projects are as follows:

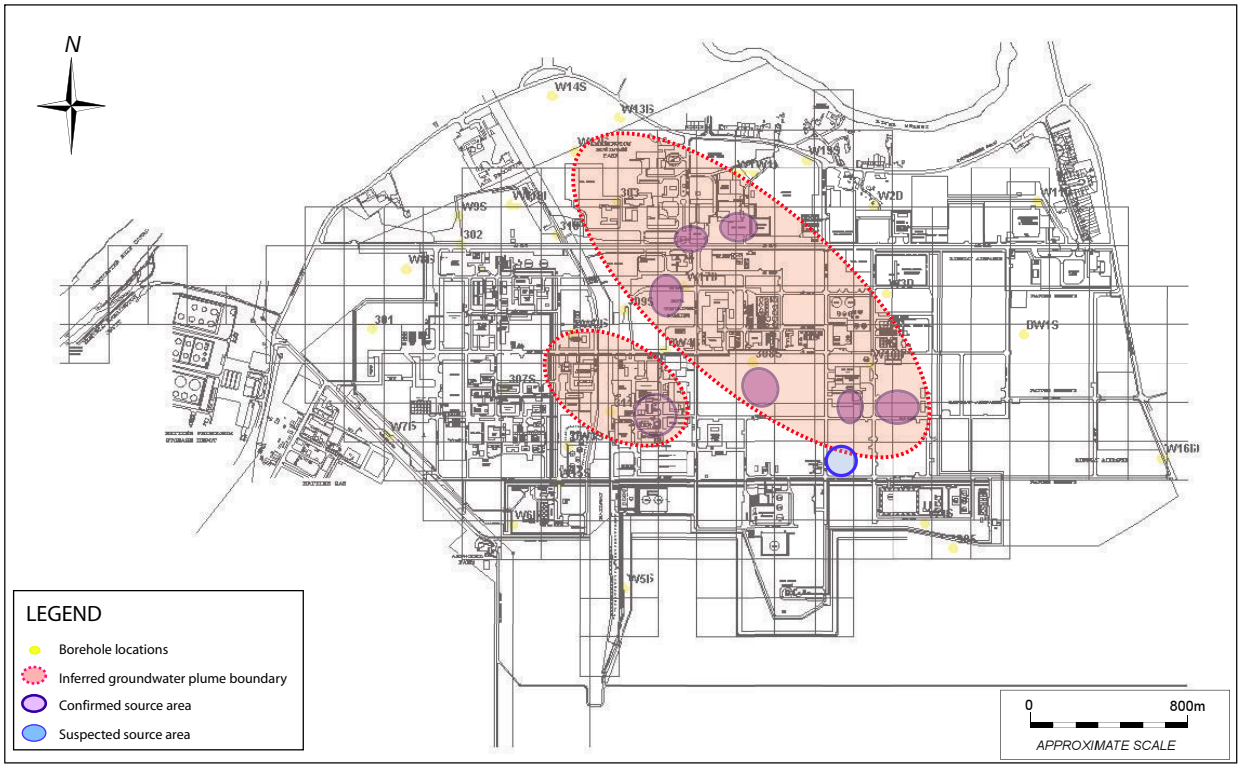

Figure 2. Schematic site map for SIReN

- Development of an *in situ* aquifer assessment tool for natural attenuation (FIRSTFARADAY - led by the University of Sheffield);
- An integrated strategy for monitoring natural attenuation of benzene-contaminated groundwater using chemical fingerprinting and molecular analysis (Bioremediation LINK - led by the University of Essex);
- A feasibility study for an innovative *in situ* bioremediation technology (DTI SMART study led by Mineral Solutions Ltd and University of Manchester);
- Rapid On-Site Toxicity Audit System (ROTAS™) (BIO-WISE demonstration project led by Cybersense Biosystems Ltd.

Additional projects have included a number of Masters and PhD projects utilising samples obtained from the site during the ongoing site characterisation. Findings from all research projects can be found at www.claire.co.uk/siren.php.

4. PROJECTS AT SIReN

4.1 Decision-Making Tools for MNA: An *In Situ* Aquifer Assessment Tool (University of Sheffield)

Researchers are working at the SIReN site to improve the risk-based assessment and remediation of contaminated land using MNA that will inform future risk assessment programmes.

The Groundwater Protection and Restoration Group at the University of Sheffield are developing a dipole flow tracer test (DFTT) - a method that aims to allow for reliable, rapid and cost-effective determination of aquifer properties and contaminant plume behaviour. Figure 3 shows a diagrammatic representation of the DFTT system and how it works.

The research consists of three components. Firstly, laboratory sand box experiments of model aquifer systems are being used to design field experiments and verify the effects of scale and reaction kinetics on transport predictions. From this, reactive tracer 'cocktails' are being used to characterise aquifer reactions and transport properties using borehole tracer injection-recovery technology on a field-scale.

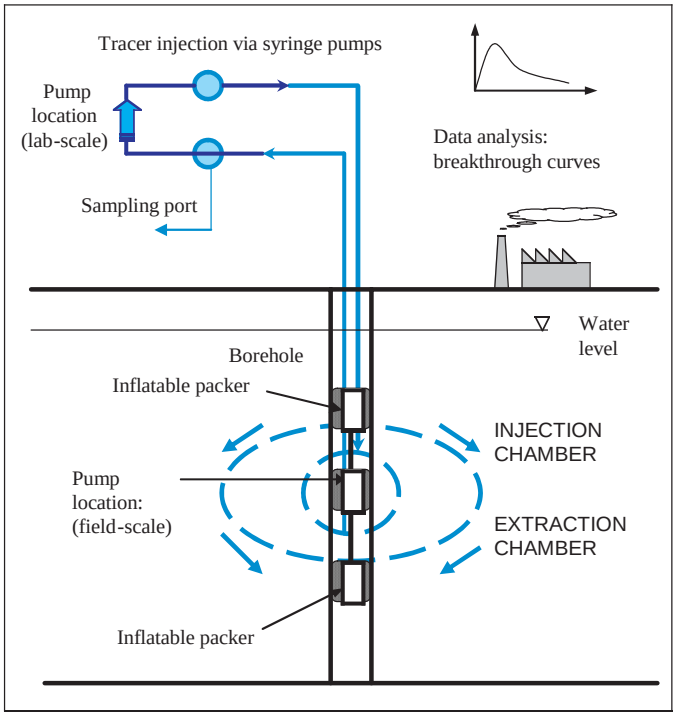

Figure 3. A conceptual model section of the dipole flow and reactive tracer test (DFRTT)

The ultimate aim will be to incorporate the three critical system components - steady-state groundwater flow, aqueous phase reactive transport and the reactive solid phase - into a single numerical model, thus facilitating the use of the DFTT as a powerful and predictive site assessment tool.

Led by the University of Sheffield, the project team includes: University of Nottingham, Queen's University Belfast, Shell Global Solutions and the Environment Agency of England and Wales. For more information contact Prof. Steve Banwart (S.A.Banwart@Sheffield.ac.uk).

4.2 MNA Using Chemical Fingerprinting and Molecular Analysis (University of Essex)

This LINK Bioremediation project is developing a strategy for monitoring natural attenuation of benzene-contaminated groundwater, using chemical fingerprinting and molecular analysis (www.clarrc.ed.ac.uk/link/).

Work is focusing on the factors limiting benzene degradation and determining the associated microbial communities and is building on from a BBSRC/Environment Agency sponsored PhD (Fahy, 2003), summarised in Box 1.

Box 1. Bacterial diversity and community dynamics at SIReN (Fahy, 2003).

This PhD project demonstrated the potential for aerobic degradation of benzene in nearly all the wells analysed from SIReN. Analysis of the microbial communities via terminal restriction fragment length polymorphism (tRFLP) showed that the communities *in situ* did not change significantly from year to year. Bacterial diversity was much reduced in wells contaminated by benzene, and the presence of this compound caused the communities to diverge in different directions. The community structure was significantly affected by perturbations (including nitrogen and phosphorus, high concentrations of benzene), although not always in a predictable way, even under laboratory conditions. Organisms associated with benzene degradation were isolated from groundwater samples.

The spatial and temporal heterogeneity of benzene degradation is being assessed, both anaerobically and aerobically using benzene sensing mini-arrays. Then the role of microbial communities involved in benzene degradation is to be analysed using stable isotope DNA probing. Data obtained from these studies will be correlated with available geochemical and hydrogeological data.

Led by the University of Essex, the project team includes Birkbeck College, Quartz Technology and Shell Global Solutions. For more information contact Anne Fahy (afahy@essex.ac.uk) or Terry McGenity (tjmcgen@essex.ac.uk).

4.3 An Innovative *In Situ* Bioremediation Technology (Mineral Solutions and University of Manchester)

4.3.1 Introduction

Using sediment from the SIReN site, researchers conducting this DTI SMART study are investigating the technical and commercial feasibility of an *in situ* bioremediation technology.

The study aims to stimulate biomineralisation of contaminated land to immobilise contaminants and act as a barrier thereby stabilising the source in the source-pathway-receptor linkage. Biomineralisation uses microbial activity to immobilise heavy metals via mechanisms such as precipitation, oxidation and reduction.

The project aims to demonstrate:

- Biomineralisation within, and cementation of, subsurface materials;
- The potential for organic contaminant degradation and heavy metal immobilisation; and
- That the technology is ready for field demonstration.

Findings from the project should aid in developing a cost-effective and sustainable approach for the remediation of contaminated sediments that capitalises on the natural processes already occurring within the subsurface. This novel approach is working towards sustainable waste management by reducing the amount of contaminated material sent to landfill.

4.3.2 Objectives

The technical objectives of the project include laboratory simulations that should:

- Enhance microbial populations capable of dissimilatory Fe(III) reduction;
- Show microbial reduction of Fe(III) oxides in subsurface materials;
- Show formation of biogenic Fe(II) minerals;
- Alter the structural properties of subsurface material;
- Degrade model organic contaminants; and
- Reduce and precipitate a model redox active metal.

The project team is led by Mineral Solutions Ltd (www.mineralsolutions.co.uk) and Dr Jon Lloyd from the Earth Sciences Department of the University of Manchester www.earth.man.ac.uk/.

4.4 ROTAS™ - A BIO-WISE Demonstration Project (Cybersense Biosystems Ltd)

SIReN is a field site for the Cybersense Biosystems Ltd Rapid On-site Toxicity Audit System (ROTAS™), a DTI BIO-WISE Demonstrator project. ROTAS™ is a portable biosensor that allows rapid, on-site toxicity testing of contaminated land and water.

The ROTAS™ system uses naturally occurring, bioluminescent bacteria that emit varying degrees of light depending on the toxicity of their surroundings (see Figure 4). Soil samples are mixed with the biosensor reagent and the change in light output is recorded by a ROTAS™ luminometer and subsequently analysed by specially developed software.

The system was developed to give additional information to complement chemical analyses, and to help save money on analytical costs by more effectively targeting sampling and analysis.

The purpose of the project is to field test and validate the ROTAS™ system. This is being achieved through a series of field trials with each end-user collaborator, in which analyses using ROTAS™ are compared with and calibrated against chemical/Ecotox analyses.

The SIReN site trials indicated that the ROTAS™ assay can be used to rapidly screen for BTEX compounds in groundwater as measured by their acute toxicity.

For more information contact Dr Tim Hart at Cybersense Biosystems Ltd (tim@cysense.com).

5. COMPLETE PROJECTS

SIReN based projects completed thus far include the following:

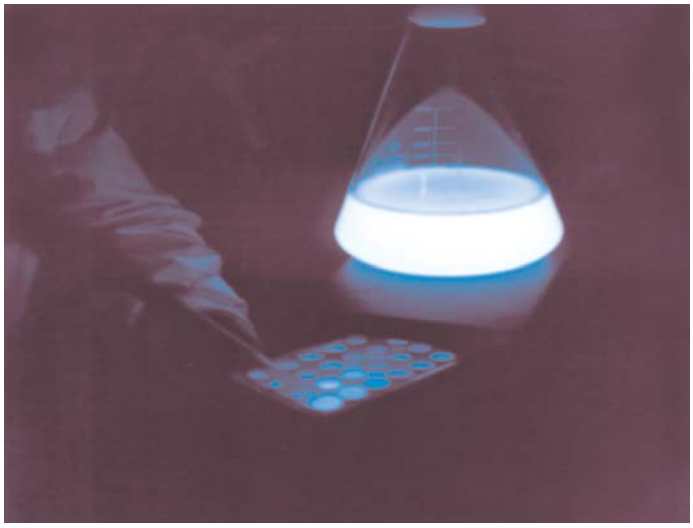

Figure 4. ROTAS™ system uses naturally occurring, bioluminescent bacteria

- Analysis of the microbial ecology of the site (Anne Fahy, Terry McGenity, Andrew Ball and Ken Timmis, University of Essex); also "Bacterial diversity and community dynamics in a benzene-contaminated sandstone aquifer" Anne Fahy (PhD Thesis, 2003).
- Investigation into methods for speciating iron in the groundwater (MSc student supervised by Simon Bottrell, University of Leeds);
- Monitored Natural Attenuation (MNA): Application of the Environment Agency (for England and Wales) MNA Guidance to the SIReN Site - Angela Sheffield (MSc Thesis, 2001), Nottingham Trent University.
- Variability of cation exchange capacity beneath the Site for Innovative Research in Natural Attenuation - Robert Michael Smith (MSc Thesis, 2003), University of Reading, Post Graduate Research Institute for Sedimentology.
- Predictive modelling of organic contaminant migration at a petro-chemical site - Daniel Bentiez Galvez (MSc Thesis, 2001), Imperial College of Science, Technology and Medicine, University of London.

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For further information and contact details please visit the SIReN website at www.claire.co.uk/siren.php