Identification of subsurface pollution transport pathways beneath two ex-oil distribution sites using non-invasive site investigation methods

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Site investigation is generally described by a number of source-pathway-target scenarios in which the sources of contamination on the site (e.g. buried waste) the transport pathways (e.g. groundwater) and the targets (e.g. nearby water bodies) are all identified. Typical commercial site investigation focuses almost exclusively on identifying contaminant sources. The only information to characterise potential subsurface pathways is that derived from a few boreholes and temporary piezometers. Yet an understanding of transport pathways both on and off site contributes substantially to any risk assessment procedure and will also improve confidence in locating existing contaminant pools that may already have migrated from the source. This research centres on the use of relatively inexpensive geophysical surveys to identify potential groundwater transport pathways. City of Edinburgh Council in conjunction with Lothian and Edinburgh Enterprise Limited are currently undertaking a redevelopment programme for the area of Granton, Edinburgh on the banks of the Forth Estuary. In particular, two ex-oil distribution terminals have been identified for redevelopment. As part of the site investigation procedure, City of Edinburgh Council commissioned research to assess the likelihood of oil products reaching the Forth Estuary via groundwater transport. A combination of geophysical surveys, laboratory techniques and groundwater modelling were successfully employed to identify potential transport pathways. The results of these investigations lead to a changed understanding of both the contaminant source distribution and the transport pathway characterisation beneath Granton.

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Regulation By Collaboration – A Pragmatic Solution

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In 1995 oily pollutants began seeping into a Devonian public water supply river, via groundwater drainage through a flood relief channel. Environment Agency (EA) investigations identified the source as a former town gas works site, since redeveloped, and now in active use under multiple ownership. Detailed site investigations by the EA and landowners found that the soil and groundwater below the site was heavily contaminated with

hydrocarbons and other pollutants related to various former operations. The groundwater supports the river's base flow and is also in continuity with a significant (500m3/day) industrial potable borehole abstraction within 600 metres.

Current operations and land ownership / liability issues at the site precluded conventional remediation techniques being implemented. In order to protect the important water sources, the EA decided that a pragmatic approach to regulation which would produce an acceptable risk-based outcome in a reasonable timeframe should be implemented. Consequently, a partnership between the landowners, local authority and led by the EA successfully applied for Supplementary Credit Approval (SCA) funding for the capital to complete site investigations and install an interim pollution management system. This would be operated by the landowners until appropriate remediation could be applied when the site is next redeveloped. Work on the scheme was completed in April 1999 with escaping pollutants being actively removed via a pump and treat system. The EA's role has now reverted to one of regulator, to ensure proper management continues. This scheme was the first to be completed through the Agency's own implementation of the SCA scheme, and represented a innovative approach to productive regulation.

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Groundwater risk assessment in a coastal aquifer affected

by short and long term head reversals

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The gravels of the Denge Peninsular, Kent have been an important source of groundwater in the Folkestone district since the early 1900s. The aquifer has been subject to historic contamination and is vulnerable to contamination from surface activities and saline intrusion. In response to a hydrocarbon spill in the late 1990's, site investigation and remediation strategies were implemented and a quantitative risk assessment was carried out. Close consultation with the Environment Agency and other stakeholders was maintained throughout the project. Evaluation of groundwater data from over 100 monitoring wells, supported by groundwater modelling studies, shed new light on the processes controlling groundwater heads. Groundwater head gradients are generally directed towards the coast, however, dramatic short term head reversals occur during periods of extreme tides and rainfall events. Assessment of longer term data indicate that inland directed head gradients

have also occurred during historic droughts. Understanding these groundwater reversals was an essential step in defining risk scenarios and their return periods. The risk associated with these scenarios was then simulated and quantified using a 3-dimensional groundwater model in association with a probabilistic risk assessment tool.

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Site practises for the treatment / disposal of contaminated groundwater during the remediation of contaminated land – a selection of case studies

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Options for the treatment / disposal of contaminated groundwater encountered during contaminated land remediation projects include; pump and treat on site, pump down foul sewer, and remove from site by tanker to licensed waste treatment facility. Selected case studies are presented to illustrate the procedures taken and factors considered when selecting the most suitable option. Excavation, haulage and disposal, and soil washing remedial methods were employed in these projects, where relatively small but significant volumes of perched groundwater were encountered.

The pumping and treatment of contaminated groundwater on site was not carried out in these excavation, haulage and disposal projects due to a lack of space on sites and the small volumes of water present. Where the chemical composition of the groundwater lay within local water company discharge limits (e.g. no 'red list' substances such as cadmium compounds), pumping to foul sewer generally proved the most economic option. However in the case of some water companies, excessive charges to discharge water, regardless of the contaminants present, rendered this option uneconomic unless vast quantities of water were involved. Where this option was discounted on compositional or economic grounds, the groundwater was removed from site by tanker to a licensed treatment facility.

During a recent soil washing project, hydrocarbon contaminated groundwater was treated on site. The water was circulated through the soil washing plant where a solvent was used to extract hydrocarbons. The end products included clean soil, a low grade fuel and clean water suitable for discharge down the foul sewer.

A detailed site investigation prior to the commencement of any remedial project is invaluable for the economic and structured treatment / disposal of groundwater. Hydrogeological and

geochemical data provide information on; the chemical composition of groundwater, water table depth, and groundwater flow rates. Direct chemical analyses of groundwater are important as the composition of contaminated rock, soil or waste may not be reflected in the water depending on the mobility of contaminants. This information can be used to determine the most suitable treatment / disposal option and to estimate costs prior to the contract starting.

It is important that contractors and consultants clearly convey this site-specific information to clients prior to contracts being agreed, particularly the estimated costs of water treatment. It is not uncommon for the cost implications of groundwater to be greatly underestimated during the pre-contract stage of contaminated land remediation projects.

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Risk Management Strategy for DNAPL: A Staged Approach

(Dordrecht Site, Netherlands case study)

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Throughout Europe many sites have experienced decades of multi-purpose industrial use where DNAPL chemicals have been manufactured, used or stored. Recent EC and national legislation and quality standards have raised society's awareness of the human health and the environmental risks associated with this industrial heritage. Management of the risks, by the regulator and consultant alike, has resulted in the development of new procedures and methods to investigate and remediate these often difficult and complex soil and groundwater problems. The adoption either of a 'risk based corrective action' or 'flexible emission control' approach to these problems has resulted in the development and implementation of staged risk management strategies often incorporating phased site investigations and tiered risk assessments. In the UK this general strategy is now embodied within the Risk Assessment Methodology published by the Environment Agency in 1999, but has been widely applied by GeoDelft both in the Netherlands and in the UK since the mid 1990s. GeoDelft, through a case example, will outline the nature of this strategy and highlight the potential benefits and problems associated with this approach.

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Risk Management Options (1995-2000): The Dutch Experience

(Joh. Enschedé - site, Haarlem, Netherlands)

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It is frequently the perception that inner city brownfield sites, contaminated with such chemicals as aromatic hydrocarbons and chlorinated solvents, are hindered by ever more demanding environmental legislative controls and a limited choice of remedial options. The presentation outlines an exception to this rule. A 1.5 hectare site in the centre of Haarlem, in the Netherlands, was polluted over a 200 year period and was investigated by GeoDelft between 1991 and 1995. An inventory of alternative remedial actions was prepared on completion of these works. The chosen remedial option, for 5,000 m^2 of the site, was limited 'dig and dump' of contaminated soils supplemented by a programme of groundwater flushing (i.e. abstraction of groundwater and infiltration of clean drinking water). Though originally planned for a duration of 10 years and a cost of 1 million euros 5 years on it has now been possible to reduce the remedial timescale to 6 months and the costs to 0.6 million euros. These substantial improvements to the remedial action plan has resulted from developments in legislation, techniques and a monitoring system based on the Flexible Emission Control approach.

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CLAIRE – A programme for sustainable remediation

Paul Beck

CLAIRE

CLAIRE (Contaminated Land: Applications In Real Environments) was established in March 1999, to encourage research, practical demonstrations, and applications of remediation technologies to clean up contaminated soil and groundwater. CLAIRE is a public/private partnership and a company limited by guarantee. It is an Environmental Body registered with ENTRUST and a Registered Charity.

A number of projects investigating contaminated land are being developed through research organisations as potential CLAIRE projects. Specific groundwater remediation techniques that are being considered include: constructed wetlands to control acid mine water discharge; permeable reactive walls to treat contaminants in-situ; in-situ methods of measuring biological activity; and natural attenuation. Project proposals are first submitted to CLAIRE in the form of a brief outline questionnnaire and more formally using the CLAIRE project application form. Project applications are evaluated by CLAIRE's Technology and Research Group. Once the project has been completed a comprehensive Research or Technology Demonstration report is prepared for publication and distribution by CLAIRE.

CLAIRE has a number of sites that are available for research and is interested in developing additional groundwater projects. Interested parties can find out more about CLAIRE by visiting our Web site at: www.claire.co.uk. Project questionnaires and application forms can be downloaded from the Web site.

CLAIRE publishes a quarterly newsletter, *CLAIRE view,* which provides viewpoints, news and information on a broad range of topics relating to contaminated land. Free copies of the newsletter can be obtained by contacting CLAIRE.

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The use of remediation by natural attenuation (RNA) as an accepted remediation technology for groundwater contamination

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Remediation by natural attenuation can be successfully applied as an accepted remedial strategy for petroleum hydrocarbon impacted groundwater in the UK. A standard approach in the US in the last decade to remediation at LUST sites is monitored natural attenuation (MNA), which relyies on the in-situ retardation and biodegradation of petroleum hydrocarbons to allow groundwater to be passively remediated. This paper looks at one case study to illustrate the successful integration of MNA/RNA into a corrective action plan (CAP) at a former service station in the UK. The key project milestones will be discussed including: scheme approval by the Environment Agency, integration of MNA with more conventional civil engineering works, development of a defensible justification for MNA as an appropriate remedial option, and the close-out of the site. The paper will seek to evaluate the potential significance of MNA/RNA strategies within the framework of UK environmental regulation and the remediation of petroleum hydrocarbon impacted soil and groundwater.

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Controls on spatial variation of natural attenuation in a contaminated aquifer

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Assessing the performance of natural attenuation is important when this technology is used as part of a remediation strategy for contaminated groundwater. However, approaches currently available for site characterisation and performance monitoring of natural attenuation are difficult to apply at complex sites typically found in the UK.

This paper presents some new methodologies developed to examine the natural attenuation of a complex plume of phenolic compounds in the Permo-Triassic Sandstone aquifer. Particular attention is given to understanding the hydrogeological and environmental controls on the spatial variation of biodegradation processes, and how this information can be integrated to provide a prediction of contaminant fate for risk assessment. The approaches presented will include the calculation of plume-scale mass balances, high-resolution profiling of plume chemistry and reactive transport modelling. The issues addressed in the case study will include the determination of contaminant plume source terms, oxidant and contaminant turnover, plume status and aquifer potential for natural attenuation.

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Migration of NAPL and groundwater in a fractured aquifer

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Comprehensive investigations were undertaken at a site, which is contaminated by coal tars and their derivatives, with a density similar or slightly greater than water. The site is located on the outcrop of one of the UK's major aquifers, the Sherwood sandstone, close to the feather edge of the aquifer. Investigation techniques included drilling, geophysical logging, laboratory testing of cores, chemical analyses of soil and groundwater, and 3 years' monitoring of groundwater levels and quality. The results indicate that the occurrence of free phase NAPL is rare, and the volume is extremely small. However, the NAPL has migrated downwards along a few, vertical and high angle fractures, which allow access to interconnecting, sub-horizontal fractures. NAPL can only enter the sandstone matrix of a few, coarse grained bands with larger pore throats, while occasional unfractured, fine grained beds prevent further downward movement. Comparison of hydraulic conductivities from cores and pumping tests suggest that the fractures make only a small contribution to bulk transmissivity. The consequences of these results for the distribution and migration of both free phase and dissolved contaminants are discussed, together with consideration of the implications for future evolution of groundwater quality and options for remediation.

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Sampling for chlorinated solvents in the unsaturated zone of a sandstone aquifer:

a case study

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ICI

The Permo-Triassic sandstone aquifer underlies many of the industrial areas of northern and western England. This aquifer, has a complex structure with fractures superimposed on fining upwards sequences particularly in the upper formations. There is evidence that there have been many spillages of chlorinated solvents into the aquifer. Assessing the risk posed by such spillages requires knowledge of the concentration and distribution of contaminants in the subsurface.

Core drilling and pore-fluid sampling in conjunction with evaluation of aquifer characteristics and heterogeneity can help to provide an understanding of the processes controlling contaminant migration. Contaminant migration in the unsaturated zone of the Permo-Triassic sandstones is discussed and the requirements for successful investigation methodologies considered.

A case study is presented of a disused quarry used to dispose of chemical wastes in the first half of this century. The results indicate that the unsaturated zone is still contaminated and show how the distribution of contaminants is strongly influenced by the lithology. The frequency of sampling is shown to be crucial to interpretation of the data and needs to be related to the lithological complexity. At frequencies of 2 m or more considerable resolution is lost, potentially leading to erroneous interpretation of data.

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Predicting dissolved solvent plume migration: From Borden (Canada) to Birmingham

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Groundwater contamination by dissolved plumes of chlorinated solvents such as trichloroethene (TCE) and perchloroethene (PCE) is extremely common. Processes that control the migration of dissolved plumes include advection, dispersion, sorptive retardation, biodegradation and chemical reaction. The primary focus of this presentation is the influence of retardation due to sorption on dissolved plume transport. Highly monitored controlled field experiments at the Borden aquifer research site in Canada have yielded reliable plume migration parameters. Data are presented from two natural gradient groundwater tracer tests conducted in the Borden aquifer that have provided data on the migration of dissolved PCE. PCE retardation due to sorption differs significantly between the two tests. Laboratory sorption studies on core material obtained from the second test site illustrates the importance of considering non-linear concentration dependent sorption and competitive sorption between different solutes present. Spatial variability of sorption, the nature of sedimentary organic carbon present and non-equilibrium sorption are additional processes observed to influence sorbing plume transport. Solvent contamination of the Birmingham aquifer has long been established, however, predicting plume migration rates in the aquifer is still very uncertain. Birmingham data are presented from surveys undertaken a decade apart (1987 & 1998). The

following is considered– can we confidently predict dissolved-solvent plume migration in the Birmingham aquifer and indeed the wider real world?

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Contaminated land meets groundwater: where to next?

Bob Harris

Environment Agency - National Groundwater & Contaminated Land Centre

Now that the long-awaited Part IIA regulatory regime has been introduced, regulators are coming to terms with the complexity of the legislation and its associated guidance. What may be a significant issue is the way in which each significant pollutant linkage is addressed and how the objectives for dealing with these are compared. Will the health-related issues provide a more significant driver for action overall than the water pollution pathway? How much knowledge and certainty do we have about the ability of the unsaturated zone to attenuate pollutants and thereby protect the underlying groundwater from the polluted soils above? These, and other issues, are all today's problems that all parties involved in the process will have to work together to solve. However, looming over the horizon is another tranche of legislation that has not been drafted specifically with contaminated land in mind but which nevertheless could provide a significant driver for change.

The European Water Framework Directive will require more integrated thinking about the way rivers work and the influences of groundwater and land quality upon them. Objectives for achieving good status in groundwater bodies will not only relate to the quality and level regime of the groundwater itself but will also be associated with ecological objectives in hydraulically linked surface water systems. The major issues that remain to be addressed for surface water quality, post AMP III, largely relate to diffuse pollution, but we have little understanding in the UK of the overall importance of diffuse groundwater inputs (baseflow support). How much can the deterioration of river water quality in urban areas be attributed to the legacy of contaminated land? If it is significant how will this affect our remediation programmes? If it isn't how will it affect them? Apart from the mine-drainage issues resulting from coal-mine abandonment there has been little research or operational work to understand the pollutant flux from historically polluted land to surface waters. This must form an important part of the UK's research activity if we are to be prepared for the implementation of the new Directive.

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