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Non-biological methods for assessment and remediation of contaminated land – case studies

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Summary

Traditional techniques for the assessment and remediation of contamination have technical, financial and practical limitations. An increasing number of "innovative" techniques are available within the UK, many of which have an established track record overseas. This report provides a review of such techniques and includes a series of case studies that illustrate their application to both radionuclide and non-radionuclide contamination issues in the UK. The report does not consider the use of biologically based techniques (eg biological test methods and bioremediation); such techniques are reviewed in CIRIA C575 (Barr *et al*, 2002).

The general technical consensus is that remediation should usually take place in a risk management context to break pollutant linkages, either by source removal, pathway modification or receptor control. The process of risk assessment relies on a range of site investigation techniques to characterise ground conditions adequately, both in the development of a conceptual model and in subsequent quantitative risk assessment.

Assessment

Site investigation techniques may be broadly categorised into those associated with the collection of soil, water, product and ground gas samples, the monitoring of water quality and ground gases, and non-intrusive techniques such as geophysics. A range of analytical techniques may be deployed both in the field and laboratory for the measurement and risk assessment of radionuclide and non-radionuclide contamination.

Case studies included in the book illustrate the application of the following site characterisation techniques:

- use of physiologically based extraction test (PBET) to inform the development of site-specific criteria for assessing risks to human health from naturally occurring arsenic
- application of membrane interface probe (MIP) to delineate the extent of hydrocarbon contamination and improve conceptual model
- use of a GPS-enabled real-time gamma radiation detector ("Groundhog") system to characterise the distribution of gamma-emitters at a nuclear-licensed site.

An integrated approach to selecting and using site characterisation methods that considers the needs of risk assessment of various media, the selection or design of several remediation techniques and the establishment of a baseline or post-remediation conditions will result in a cost-effective site investigation.

Remediation

Non-biological processes for the remediation of contaminated land can be broadly assigned to one or more of four basic categories: (1) chemical, (2) physical, (3) solidification/stabilisation or (4) thermal. In practice, many remedial treatments exploit processes from more than one category, for example chemical and physical processes form components of soil washing technologies. Treatments may also be "integrated" or combined to exploit the best features of several single treatments. For example, air sparging is commonly applied in combination with soil vapour extraction (SVE) to treat both saturated and unsaturated material.

Institutional controls can be an option for the long-term management of radiologically contaminated sites in the UK, for example at operational sites or where the long-term storage and maintenance of radioactive wastes in undertaken. The *remediation techniques* that are applied to radiological contamination are ones where radionuclides are concentrated and extracted from a matrix, or where a contaminated matrix is segregated from an uncontaminated matrix. For delicensing of operational sites, or disposal of a Ministry of Defence site, then remediation is undertaken by removal of material to an appropriate level.

Case studies included in the report show that non-biological remediation technologies can cost-effectively treat a range of contaminants under redevelopment, transaction or proactive risk management scenario. The case studies selected are representative of many of the technologies in commercial use in the UK, but also include a number of field trials illustrating the application of technologies that show potential for application on a commercial scale.

The case studies include:

- ozone sparging to treat chlorinated solvents in groundwater, plus dual-phase extraction to remove liquid hydrocarbons
- use of a permeable reactive barrier at a former gasworks site, installed in a funnel and gate configuration
- use of soil washing during the reclamation of a large former munitions factory, involving the treatment of approximately 290 000 t of contaminated soils
- on-site landfilling of contaminated materials to facilitate development of former explosive manufacturing site for residential development
- *ex situ* application of modified clays to reduce the mobility and availability of tributyltin contaminated sludges to facilitate reuse of the material in development works
- use of accelerated carbonation treatment in a field trial to treat soils contaminated with a range of by-products of historical soda-ash manufacturing operations
- treatment of 3700 t of PCB contaminated soils at a former aluminium works, using a rotary kiln thermal desorption unit
- application of a gamma-detector-based segregation unit to screen radioactively contaminated soils, to minimise the volume of soil requiring disposal as radioactive waste.

The applicability of remediation techniques to any particular site will depend on a range of factors, including driving forces and goals of the remediation, the risk management objectives, technical suitability and feasibility of the application, stakeholder satisfaction, sustainable development issues and, often most importantly, the costs and benefits of the remediation.

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Research programme	CIRIA's research programme on contaminated land aims to provide guidance for the construction industry, its clients and other interested parties and consists of a series of research and information projects dealing with the various aspects of treating and reusing land that is either derelict or contaminated or both.
Research contractors	This book is the main output from CIRIA Research Project 640 and was prepared by Mr D Barr, Professor R P Bardos and Dr C P Nathanail under contract to CIRIA

Authors

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David is a consultant specialising in the risk assessment and remediation of contaminated sites, working predominantly for the property and finance sectors. Previous publications include CIRIA Publication C575 Biological methods for assessment and remediation of contaminated land: case studies, co-authors of which included Paul Bardos and Paul Nathanail.

Professor **R P Bardos** of r3 Environmental

Paul Bardos is special Professor in Environmental Engineering at the University of Nottingham, and has worked for many years on contaminated land and waste management issues. Paul has published widely within these sectors, including the preparation of many guidance documents. He is one of the UK scientific representatives to CLARINET (The Contaminated Land Rehabilitation Network for Environmental Technologies in Europe).

Dr **C P Nathanail** of Land Quality Management at the University of Nottingham

Paul Nathanail's research interests include human health, ecological and financial risk assessment and management and sustainable brownfield regeneration. He is active in the management of UK and European networks such as FIRST Faraday and CABERNET, and currently works closely with local authorities in implementing Part IIA and reviewing reports for planning purposes.

Steering group

Following CIRIA's usual practice, the research project was guided by a steering group, which comprised:

Steering group chair	Dr G Bullock	BAE Systems
	Mr S Amos	AWE
	Mr D Claxton	BNFL
	Dr M Dyer	University of Durham
	Dr T Kearney	Environment Agency
	Mr M Pearl	UKAEA
	Mr B Pope	Arcadis Geraghty and Miller
	Mr K Potter	ICI C & P
	Professor W Radley	EB Nationwide
	Mr S Redfearn	The BOC Foundation
	Mr D Rudland	Halcrow Group Ltd
	Mr M Summersgill	VHE Technology
	Dr J Wilson	WS Atkins on behalf of DTI
	Mr P Wood	Lattice Properties.

CIRIA manager

CIRIA's research manager for this project was Ms J C T Kwan.

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Technical contributors

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- Keller Ground Engineering
- Golders Associates
- McCallan Bros

Several other individuals and organisations assisted in the preparation of this publication, for example by volunteering case studies for inclusion and allowing access to case study information.

Note

Recent UK Government reorganisation has meant that DETR responsibilities have been moved variously to the Department of Trade and Industry (DTI), the Office of the Deputy Prime Minister (ODPM), the Department for Environment, Food and Rural Affairs (DEFRA) and the Department for Transport (DfT). References made to government agencies in this publication should be read in this context.

For clarification, readers should contact the Department of Trade and Industry.

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Glossary

Accessibility	Accessibility of contamination to a treatment regime describes the extent of its contact with air or water (carriers of a treatment effect in the ground) and is limited by the physical properties of the ground environment, and discontinuities in subsurface conditions
Availability	Availability describes the ease of liberation of contamination to a treatment process in contact with it and is limited by factors such as physical/chemical interactions between the contaminant substances and the surfaces of the solid phases in the subsurface, solubility, or phase differences, eg where NAPLs are present
Bioavailability	Degree of ability to be adsorbed and ready to interact in organism metabolism
Capillary zone/ fringe	The zone above the water table within which the porous medium within which the porous medium is saturated by water under less than atmospheric pressure
Chemical processes	Destroy, fix or concentrate toxic compounds by using one or more types of chemical reaction
Chronic effect	An adverse effect on a human or animal in which symptoms recur frequently or develop slowly over a long period
Cone of depression	A depression in the water table that develops around a pumped well
Cone penetrometer testing	A direct push system used to measure lithology based on soil penetration resistance
Control surface	This describes a section through the aquifer downstream of the PRB, by which time an acceptable treatment effect has taken place
Dechlorination	Removal of chlorine from a substance
Free product	A petroleum hydrocarbon in the liquid, free or non-aqueous phase
Hazard	Substance with the potential to cause harm
Headspace	The vapour mixture trapped above a solid or liquid in a sealed vessel
in vitro	Treating or action outside an organism (eg inside a test tube or culture dish)
in situ	*In situ* approaches use processes occurring in unexcavated soil, which remains relatively undisturbed.
ex situ	*Ex situ* remediation approaches are applied to excavated soil and/or extracted groundwater.
Monitored natural attenuation	Monitoring of groundwater to confirm whether natural attenuation processes are acting at a sufficient rate to ensure that the wider environment is unaffected and that remedial objectives will be achieved within a reasonable timescale; this will typically be less than one generation or 30 years

On-site techniques	These take place on the contaminated site, and may be *ex situ* or *in situ*.
Organophyllic	A substance that easily combines with organic compounds
Permeable reactive barrier	A PRB is an engineered treatment zone of reactive material(s) that is placed in the subsurface to remediate contaminated fluids as they flow through it.
Physical processes	Separate contaminants from the soil matrix by exploiting physical differences between the soil and contaminant (eg volatility, behaviour in electric fields) or between contaminated and uncontaminated soil particles (eg density)
Radionuclide	Radioactive particle, man-made (anthropogenic) or natural, with a distinct atomic number
Radius of influence	The maximum distance from a well that an acceptable treatment affect is manifest, this is dependent on the physical properties of the surrounding matrix
Rebound	The re-emergence of undesirable levels of contamination in groundwater (or other monitored parameters such as soil atmosphere) following the switch off of a treatment system
Solidification and stabilisation processes	Solidification reduces the physical accessibility of contaminants by encapsulating them in a monolithic solid of high structural integrity; stabilisation reduces the chemical availability contaminants. In practice, stabilisation is often accompanied by solidification and vice versa, but this is not always the case, particularly in the case of organic contaminants
Surfactant	A detergent compound that promotes lathering
Thermal processes	Exploit physical and chemical processes occurring at elevated temperatures
Viscosity	The molecular friction within a fluid that promotes flow resistance
Zeta potential	Zeta potential, or electrokinetic potential, is defined as the electrical potential at the surface of shear between the two parts of the electrical double layer in the electrolyte at the surface of a solid particle

Acronyms and abbreviations

AC	alternating current
AR	augmented reality
ALARP	as low as reasonably practicable
APEG	alkaline polyethylene glycol
AS	arsenic
ASTM	American Society for Testing and Materials
BGS	British Geological Survey
BNFL	British Nuclear Fuels Limited
BPEO	best practicable environmental option
BTEX	benzene, toluene, ethylbenzene, xylenes
CAPEX	capital expenditure
CDM	Construction (Design and Management) Regulations 1994
CEC	cation exchange capacity
CIWM	Chartered Institute of Waste Management
CIRIA	Construction Industry Research and Information Association
CL:AIRE	contaminated land: applications in the real environment
CLEA	contaminated land exposure assessment
CO_2	carbon dioxide
COC	contaminant of concern
CPT	cone penetration test
CVOC	chlorinated volatile organic compounds
DQO	data quality objective
DCE	dichlorothene
DEFRA	Department of Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Regions (formerly DoE and now DEFRA)
DNAPL	dense non-aqueous-phase liquid
DOE	Department of the Environment (now DEFRA)
DOE (NI)	Department of the Environment (Northern Ireland)
DRO	diesel range organics
DVE/ DPVE	dual-phase vacuum extraction
DPE	dual-phase extraction
EA	Environment Agency
EC	European Community
EHO	environmental health officer
EPA 1990	Environmental Protection Act 1990
EU	European Union
EO	Exemption Order
FID	flame ionisation detector
GAC	granular activated carbon
GC/MS	gas chromatography mass spectrometry
GPS	global positioning system
HCBD	hexachlorobutadeine
HMET	heavy metal extraction test
H_2O_2	hydrogen peroxide
ICRCL	Interdepartmental Committee for the Redevelopment of Contaminated Land
IPPC	integrated pollution prevention and control
IVG	*in vitro* gastrointestinal

LIF	laser-induced fluoroscopy
LNAPL	light non-aqueous-phase liquid
MEL	maximum exposure limit
MIP	membrane interface probe
MNA	monitored natural attenuation
MoD	Ministry of Defence
MPL	mobile plant licence
MTBE	methyl-tertiary butyl ether
NAPL	non-aqueous-phase liquid
NATO/CCMS	North Atlantic Treaty Organisation/Committee on the Challenges of Modern Society
NRA	National Rivers Authority
O_2	oxygen
P&T	pump and treat
PAH	polynuclear aromatic hydrocarbons
PCB	polychlorinated biphenyl
PCE	perchloroethene
PCR	polymerase chain reaction
PIC	products of incomplete combustion
PFS	petrol filling station
PDB	passive diffusion bag
PRB	permeable reactive barriers
PBET	physiologically based extraction test
QRA	quantitative risk assessment
Redox	reduction/oxidation reactions
RBCA	risk-based corrective action
RF	radio frequency
RSA	Radioactive Substances Act 1993
SBET	simple physiologically based extraction test
SCF	supercritical fluid
SEPA	Scottish Environment Protection Agency
SGV	soil guideline value
SNIFFER	Scottish and Northern Ireland Forum for Environmental Research
S/S	solidification and stabilisation
SSTL	site-specific target level
SVE	soil vapour extraction
SVOC	semi-volatile organic compounds
TCE	trichloroethene
TEA	triethanolamine
TPH	total petroleum hydrocarbons
TBT	tributyl tin
TOC	total organic carbon
UKAEA	United Kingdom Atomic Energy Authority
UST	underground storage tank
UV	ultra-violet
UVB	Unterdruck-Verdampfer-Brunnen or ‘deep well’ stripping
VC	vinyl chloride
VOC	volatile organic compound
WAMITAB	Waste Management Industry Training Advisory Board
WML	Waste management licence
WRA	Water Resources Act, 1991
XRF	X ray fluorescence
ZVI	zero valent ion

OVERVIEW

1 Introduction

1.1 BACKGROUND

Past industrial activities, such as waste disposal and mining, have left the UK with a legacy of soil and groundwater contamination. A wide range of potentially contaminative former land uses exists, for example:

- gasworks, coking plants and other coal processing industries
- metalliferous mining, metal smelting, metallurgical industries
- waste disposal activities
- agricultural practices (via fertilisers, pesticides or organic wastes etc)
- fossil fuel combustion
- petrochemical industry
- electronics and printing industries.

The range of contaminants potentially present at a site will depend on the precise nature of processes undertaken, and are typically associated in broad terms with the delivery, handling and storage of raw materials, manufacturing processes, and the disposal of wastes. Industry Profiles published by the DoE (now DEFRA) provide information on potential range of contaminants associated with a range of industries. However, land not previously used for contaminative activities may still become contaminated as a result of the migration of contaminated groundwater or surface water from other sites. Hazardous substances, such as heavy metals, may also be naturally present in soils at elevated concentrations.

As can be seen from the above list, radionuclide contamination can occur from both civil and military use of radioactive substances (Baker *et al*, 2000). Where radionuclide contamination does occur it is often associated with contamination by toxic substances, and radionuclides themselves can present hazards from toxicity as well as radioactivity.

Traditional techniques for the assessment and remediation of contamination have technical, financial and practical limitations. An increasing number of “innovative” techniques are available within the UK, which under certain conditions can offer advantages over traditional techniques. The term “innovative” is generally used to refer to technologies that are not in routine use, commonly as a result of lack of data on performance and cost. As a consequence, the confidence in such techniques is often relatively low compared with established techniques.

For example, site investigation techniques that were developed or adapted for geotechnical purposes have been mobilised over the past 15 years to address land contamination problems. It is now better known that there are fundamental differences in the objectives, data requirements and method of execution of geotechnical and land contamination investigations. Increasingly, tools are being made available that are designed to address specific land contamination issues such as the detection of heavy metals, hydrocarbons, radioactivity or ground gases, and offer potential advantages over traditional methods of investigation.

Remedial options have generally fallen into one or more of the following broad categories (Bardos *et al*, 2002):

- removal to landfill: the disposal of material to void space excavated in land, generally with a view to combining the disposal of waste with the reclamation of land area from the void space. Related to landfill is the practice of land-raising, where materials are deposited on the land surface to make a hill or mound above the natural surface level
- containment-based approaches (including those used in landfilling) are designed to prevent or limit the migration of contaminants left in place or confined to a specific storage area, into the wider environment. Approaches include barriers, capping and hydraulic measures
- site rehabilitation measures are those used to bring back some measure of utility to a site where contamination cannot be fully treated for technical or economic reasons. Examples include growth of grass cover tolerant of contaminants, covering with soil or soil substitute, liming and other cultivation measures
- more recently, treatment-based approaches, which destroy, remove or detoxify the contaminants contained in the polluted material (eg soil, groundwater) have become more widely used. Using treatment technologies in contaminated land remediation is encouraged by agencies in many countries, because they are perceived as having added environmental value compared with other approaches to remediation such as excavation and removal, containment or covering/revegetation. The "added" environmental value is associated with the destruction, removal or transformation of contaminants into less toxic forms.

1.2 AIMS AND SCOPE OF THE BOOK

Aims of the book

The primary objective of this book is to promote and provide guidance on appropriate selection of non-biological techniques for assessing and managing risks on contaminated site projects. It aims to do so by:

- reviewing the key features of the principal techniques available
- describing a selection of case studies where non-biological techniques have been used successfully to assess and/or manage the risks posed by land contamination
- using the case studies to highlight the actual, rather than the perceived, constraints on using non-biological methods, demonstrating circumstances where the constraints may or may not be overcome on a site-specific basis
- demonstrating the benefits that were generated by using non-biological methods.

This report focuses on the selection and application of non-biological treatment-based approaches to land remediation. A similar study of the use of biological techniques for soil and groundwater treatment has previously been published by CIRIA (Barr *et al*, 2002).

Scope of the book

The book is focused on UK case studies involving the use of innovative techniques for the characterisation of contaminated sites, as well as the application of non-biological remedial technologies to contaminated sites. This publication also reviews the application of non-biological techniques for the assessment and remediation of sites contaminated by radionuclides.

This book considers ground contamination problems that might be encountered on civil sites, including manufacturing facilities (which may produce weapons). However, it does not consider the assessment or remediation of munitions, propellants, biological or chemical warfare agents or other contamination resulting specifically from military sources. This has been reviewed elsewhere (eg NATO/CCMS, 2000). Where such contaminants are encountered in the UK the police must be informed immediately.

The SAFEGROUNDS Learning Network (www.safegrounds.com), managed by CIRIA, provides guidance on radiological and chemical contamination on nuclear-licensed and defence sites. Technical guidance on the complexities and features of nuclear-licensed sites has been published recently (Environment Agency, 2001).

Target readership

The book is targeted at developers, regulatory bodies, consultants, contractors and other practitioners involved in contaminated land projects, and owners of contaminated sites planning to take remedial action in advance of property transactions, as a precursor to redevelopment or as part of a proactive environmental risk management strategy.

1.3 BOOK STRUCTURE

This book is divided into three sections.

1. **Overview** (Chapter 1) provides the background to the project including the objectives, context and method and approach.
2. **Site characterisation** provides an introduction to the theory and application of innovative site characterisation techniques (Chapter 2), descriptions of some applications of such techniques (Chapter 3), guidance on the selection and use of the techniques (Chapter 4), and conclusions (Chapter 5).
3. **Remediation** provides an introduction to the theory and application of non-biological remediation (Chapter 6), descriptions of a series of case studies (Chapter 7), guidance on selection of non-biological remediation techniques (Chapter 8), and conclusions (Chapter 9).

Figure 1.1 provides a report map, indicating where the reader can find information on site assessment and remediation techniques, and case studies illustrating the application of such techniques. Thus a general introduction to remedial technologies exploiting chemical processes can be found in Section 6.3.1, and case studies in Sections 7.2, 7.3 and 7.4. Sections of the book detailing issues to be considered during the selection and implementation of site assessment or remedial technologies are listed separately.

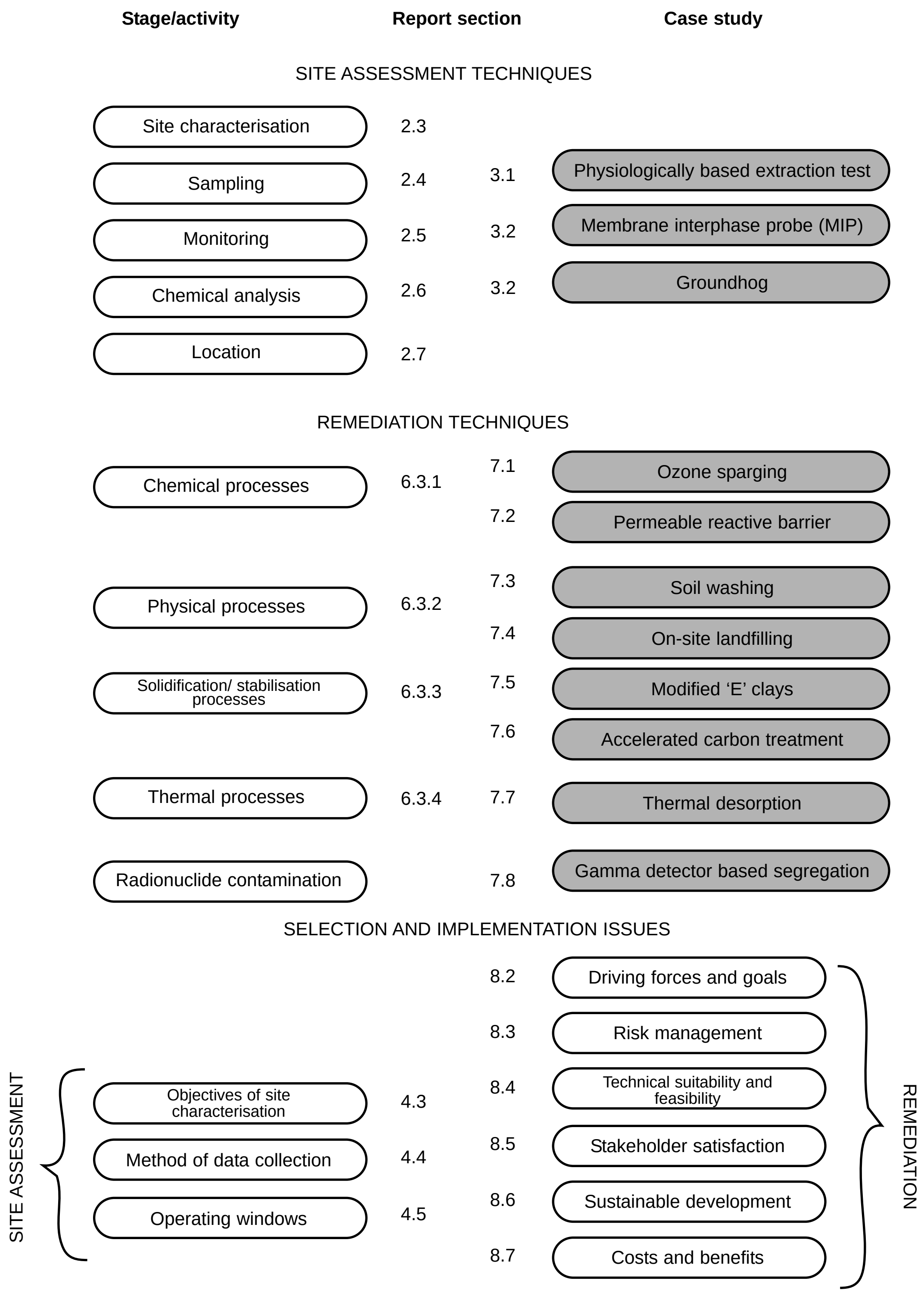

Figure 1.1 *Report map*

1.4 RISK MANAGEMENT AND THE USE OF TREATMENT-BASED REMEDIATION

1.4.1 UK remediation market

The UK market for contaminated land assessment and remediation is estimated to have increased by 20 per cent in value during the late 1990s. It is projected to increase further, leading to a total market value of approximately £770 million by 2001 (Environment Business Intelligence, 2002). It is considered that this reflects changes in legislation, principally the introduction of the Contaminated Land Regime, coupled with the buoyancy of the UK construction industry during 2001.

The majority of the contaminated land market is accounted for by remediation. In recent years, though, the assessment market has increased at the expense of the remediation sector. Engineered containment techniques and landfill continue to be the favoured remedial options in the UK, being used at least as part of the remediation strategy in 94 per cent and 75 per cent of all remediation projects respectively (Environment Agency, 2000b). Alternative, process-based technologies have however emerged as viable, cost-effective options for which there is a growing track record of successful implementation in the UK.

1.4.2 Risk management objectives

Risks to human health (and other receptors such as groundwater) that may be caused by contamination have become the primary basis for supporting decisions on remediation (Ferguson *et al*, 1998, Ferguson and Kasamas, 1999). In this process of *risk management*, risk assessment is used to provide an objective, scientific evaluation of the likelihood of unacceptable impacts to human health and the environment. The process of contaminated land risk assessment of contaminated is described in Rudland *et al*, 2000.

The goal of risk management is to support decisions on risk acceptability for specified land uses and to determine the actions to be taken. It is the process of making informed decisions on the acceptability of risks posed by contaminants at a site, either before or after treatment, and how any needed risk reduction can be achieved efficiently and cost-effectively. In this way, the overriding needs for the protection of human health and the environment can be clearly identified and work prioritised accordingly. Remediation activities are therefore employed to reduce risks, as illustrated in Figure 1.2.

While the precise mechanism used to break the pollutant linkage will depend on site-specific circumstances, in general the primary choice will be the reduction or removal of the contaminant source. It should be noted that where a proportion of a primary source has migrated to create a secondary source, as in the case of a DNAPL migrating to the base of an aquifer, a combination of source removal (to treat the primary source) and reduction (to treat the secondary source) may be required. Complete removal of DNAPL sources is rarely feasible (Darnison *et al*, 2002).

Pathway management is of secondary preference, while modifying the receptor is typically the least satisfactory option at providing long-term environmental protection. However, a combination of source, pathway and receptor management techniques will be applied in a remediation project. It is possible depending on the nature of the contamination and the geological/hydrogeological setting.

The understanding of risk assessment as a decision-making principle and the capacities of natural systems to effect their own remediation (natural attenuation) has