



The processing of contaminated land in highway works

**Prepared for Geotechnics and Ground Engineering Group,
Quality Services/Civil Engineering, Highways Agency**

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Executive Summary

The Highways Agency (HA) is concerned about the cost and resources required to construct and maintain highways across areas of contaminated land. Although a number of innovative techniques are available to remediate contaminated land, traditional practice on highway schemes has been to excavate the contaminated material, dispose of it to landfill and replace it with imported natural material. This is not in agreement with the Government's policy of sustainable construction, which encourages reuse and recycling. HA therefore commissioned TRL Limited to undertake research into which methods of processing contaminated land are economically and environmentally acceptable for use in highway works. This is the final project report.

A major factor in the use of remedial technologies for contaminated land has been the legal framework. This has developed during the 1990s and is now largely complete with the implementation of the Contaminated Land Regulations and Statutory Guidance in April 2000. Further guidance in the form of model procedures and guideline values has still to be published by DETR.

The new regime is based on risk assessment using a source-pathway-receptor analysis. Consultation with the Environment Agency (EA) should take place as early as possible in the development of a scheme to assess any requirements for remediation. The EA will adopt a site-specific approach, and a risk analysis will be required in all cases. Remedial targets should be agreed with the EA at an early stage, to allow selection of the most appropriate techniques. Most remedial techniques will require a mobile plant license (MPL), and some may also require authorisation under the Integrated Pollution Control (IPC) system. Some options may require a waste management license (WML). These include constructing an engineered landfill facility on the site and moving all the contaminated material into it.

A new definition of contaminated land for use in Clause 601 of the Specification for Highway Works (MCHW 1) has been developed. This ties in with the definition of contaminated land in Part IIA of the Environmental Protection Act 1990. The new definition will reduce the amount of material classed as unacceptable due to contamination (though some of it may still be unacceptable due to adverse physical properties). Class U1 contaminated material will be material classed as 'contaminated land' under Part IIA. Class U2 contaminated material will be Special Waste and Radioactive Waste as defined under separate legislation.

A wide range of ex-situ and in-situ techniques is available for the remediation of contaminated land. Almost all of them may find some application in highways in particular circumstances. Those most likely to find widespread acceptance in highway works are considered to be: solidification/stabilisation with inorganic cementitious binders (ex-situ and in-situ); ex-situ bioremediation (especially biopiles); dry sieving and mechanical sorting; soil washing; vacuum extraction (soil vapour extraction); and hydraulic treatment of groundwater (pump-and-treat).

These are all established technologies, which can be used to treat the kind of problems commonly encountered on highway schemes. Techniques, which may have some application in highways, include stabilisation with organic binders and thermal desorption.

Some of the methods require long timescales, which can be a problem in highway works with tight programmes. These can be overcome by carrying out the works as advance contracts, which then allows the main works to be carried out much more easily. Sufficient time has to be allowed to obtain authorisations and licenses from the EA, to carry out laboratory and site trials to demonstrate that the method will work in the particular conditions of the site, and for validation and monitoring on completion of the works.

Case studies are presented of the use of stabilisation/solidification, soil vapour extraction and dry sieving in recent highway schemes. These have generally been successful so long as they have followed best practice as set out, for example, in CIRIA Special Publications SP101-112, Remedial Treatment for Contaminated Land.

A related problem to contaminated land is construction of highways through old landfill sites. Several schemes have been constructed in recent years at shallow depth in landfills, with the highway isolated from the landfill by means of an impermeable barrier. Two examples were investigated, and it was found that the control methods were still functioning effectively up to ten years after construction.

Detailed investigations were carried out to assess the long-term stability of materials treated with inorganic cementitious agents, as this technique (stabilisation/solidification) was considered to be one of the most promising for highway applications. A combination of specialised laboratory leaching tests, a pilot scale test bed to simulate accelerated weathering, and testing of materials from sites where stabilisation/solidification had been used gave information on the durability and performance of the treated materials. It was found that the physical properties of the material did not deteriorate with time, if it was properly mixed and compacted to achieve the required properties at the construction stage.

The leaching behaviour of the treated materials was more complex. In some cases, the mobility of some constituents was greater in the treated materials than in the untreated materials. This could be due in some cases to the breakdown of organic matter, to which some metals were bound, by the addition of lime or cement, resulting in more soluble organo-metal complexes. The addition of cement generally increased the mobility of aluminium. The precise effects depend on the mineralogy of the materials, the form in which the contaminants are present, the amount of cementitious agents added and the effectiveness of the mixing process. Because the treated materials are generally of low permeability, the consequences for pollution of controlled waters are generally low. However, it is important to carry out laboratory and site trials to enable

an adequate risk analysis to be undertaken whenever these techniques are proposed. Provided this is done, stabilisation/ solidification can be a very satisfactory way of dealing with contaminated materials and obtaining 'added value' materials which can be used in highway construction.

The results of this project should encourage greater remediation of contaminated land in highway works, thus contributing to sustainable construction.

1 Introduction

The Highways Agency (HA) is concerned about the cost and resources required to construct and maintain highways across areas of contaminated land. A number of innovative methods are available for treating contaminated material to render it acceptable for use in highways. However, a review of highway schemes through areas of derelict and contaminated land (Perry, 1994) showed that there was little uptake of innovative techniques; contaminated material was excavated and removed to landfill, either off-site or to specially constructed tips on site. This is not in line with the principle of sustainable construction, as the contaminated material is simply moved from one location to another, landfill space is used up, valuable natural materials are consumed to replace the excavated material, and a large number of lorry movements are involved, with attendant problems of dust, fuel consumption, congestion and disturbance to residents. The UK Government has adopted a 'suitable for use' policy with regard to contaminated land (Department of the Environment, 1994) and has acted to discourage landfill by the introduction of the landfill tax and aggregates tax. It is therefore desirable that there is greater uptake of remedial technologies for the treatment of contaminated land in highway schemes. This in agreement with the Government's strategy for sustainable construction (Department of the Environment, Transport and the Regions, 2000b), which encourages recycling and re-use over disposal to landfill.

The Highways Agency commissioned TRL Limited to undertake a research project into the methods available for the processing of contaminated land in highway schemes. The objectives of the research were to assess which methods of processing contaminated land are economic and environmentally acceptable for highway works. There was also a requirement to provide a more precise definition of contaminated land for classifying unacceptable materials in the Manual of Contract Documents for Highway Works (MCHW). The work was to be carried out by means of a literature review, consultations with relevant parties, case studies of the use of remedial technologies in highway schemes, laboratory testing and site trials of selected methods.

The project started in September 1995 and was completed in May 2000. This report presents the final results of the project. The legislation relating to contaminated land and its application to highway works is discussed in Chapter 2. Revisions to the MCHW as a result of the legislation are presented in Chapter 3. Techniques available for the remediation of contaminated land in highway earthworks are reviewed in Chapter 4, and case studies of the application of some of the techniques are given in Chapter 5. Details of experimental work on the use of lime to treat contaminated materials in highway earthworks are given in Chapter 6. Recommendations for the use of remedial technologies for the treatment of contaminated materials in highway earthworks are given in Chapter 7, and conclusions from the project are given in Chapter 8. Amendments to the MCHW as a result of the project are listed in Appendix A.

2 Legislation relating to contaminated land

2.1 Summary

The primary legislation to be considered in dealing with contaminated land is the Environmental Protection Act 1990. It is from the 1990 Act that Statutory Guidance and Contaminated Land Regulations have been developed to provide a framework for the regulation of land contamination. Part IIA of the 1990 Act was implemented through Statutory Guidance and the Contaminated Land Regulations in April 2000. With the implementation of Part IIA, the Government has put in place a more proactive regime and legal framework to deal with land which has been contaminated in the past. The new regime provides a means to enforce remediation where the old Integrated Pollution Control (IPC) and Waste Management Licensing (WML) regimes may not apply.

For new highways, the requirements for dealing with contaminated land will be agreed with the Environment Agency (EA) during scheme development, and may involve the IPC or WML regimes. For existing sites containing contaminated land or on-site waste, Part IIA or the WML regime may apply depending on the extent of the contamination.

Guidance on the new Part IIA regime re-iterates the need to encourage brownfield development and minimise new pollution. The Government has set a target of 60% of new housing to be built on previously developed land. This forms part of the drive towards sustainable construction. If land has not been classified as contaminated under Part IIA of the 1990 Act, the developer may be required to hold a WML for sites considered to contain 'waste' (see Section 2.6). The Highways Agency (HA) would act as a developer in this context when promoting a highway scheme through areas of contaminated land.

The regulatory framework now exists to enforce remediation and cleanup of contaminated land in any situation. Where regimes such as IPC or WML are in place on a particular site, they will continue to be used. Part IIA will act to 'mop up' any areas not covered, and to instigate the remediation of 'static' contaminated land, i.e. land that is not undergoing redevelopment.

This chapter outlines the legal framework for dealing with contaminated land, including an introduction to the implementation of Part IIA (Section 2.3), discussion of the waste management licensing regime (Section 2.6), groundwater protection (Section 2.8) and the guidance available to developers and enforcement authorities (Section 2.10). Particular implications for existing or proposed highway schemes are discussed. A summary of the appropriate legislation and procedures for highways is given on Figure 2.1. The discussion and guidance in this chapter is based on an interpretation of available legislation; it is not intended to provide a definitive legal interpretation.

2.2 Development of the legal framework

S143 of the Environmental Protection Act 1990 introduced the requirement for registers for land which is being used or has been used in such a way as to cause it to become contaminated with 'noxious substances'. S143 required that any land that could have previously been contaminated should be listed by a Local Authority on a register of contaminated land, regardless of the nature or severity of the contamination. This gave rise to concerns over reduced worth of developments on registered land and the fear of liability for historical contamination, which eventually led to the abandonment of S143.

S57 of the Environment Act 1995 introduced an addition to Part II (Waste on Land) of the Environmental Protection Act 1990. Part IIA (Contaminated Land) was inserted after S78 (S78A to S78YC) of the Environmental Protection Act 1990.

S57 of the Environment Act 1995 defined contaminated land more appropriately as 'any land which appears to the Local Authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land, that:

- significant harm is being caused or there is a significant possibility of such harm being caused; or
- pollution of controlled waters is being, or is likely to be, caused'.

'Harm' is defined in the Environment Act 1995 as meaning 'harm to the health of living organisms or other interference with the ecological systems of which they form part and, in the case of man, includes harm to his property'. The Environment Act 1995 states that the question of whether the harm is 'significant' or whether the possibility of significant harm being caused is 'significant' or whether pollution of controlled waters is being, or is likely to be, caused will be determined in accordance with guidance issued by the Secretary of State (see Section 2.3).

The Department of the Environment Transport and the Regions (DETR) has developed a package of guidance and regulations on contaminated land as required under S57 of the Environment Act 1995. This culminated in the Draft Circular on Contaminated Land issued in September 1999. After a consultation period, the final guidance was issued in DETR Circular 02/2000 on Contaminated Land (Department of the Environment, Transport and the Regions, 2000a) in March 2000, and the updated Statutory Guidance and Contaminated Land Regulations came into force on 1 April 2000.

2.3 Part IIA of the Environmental Protection Act 1990

The DETR Circular on Contaminated Land (Department of the Environment, Transport and the Regions, 2000a) contains the Statutory Guidance which brings into force Part IIA of the Environmental Protection Act 1990, and a guide to the Contaminated Land (England) Regulations 2000 (The Stationery Office, 2000), made under Sections 78C, 78E, 78G, 78L, 78R and 78X of the 1990 Act. This new statutory regime for the identification and remediation

of contaminated land entered into force on 1st April 2000. As well as containing the Statutory Guidance, the DETR Circular provides a summary of Government policy on the contaminated land regime and a description of the new regime. For highway construction and operation, Part IIA will only take effect when there is relatively heavy contamination on the site, which causes the land to be classified as contaminated under the definition given in Section 2.2 and Tables 1 and 2.

2.3.1 Overview of the new regime

The main objectives of the new regime are to provide an improved system for the identification and remediation of land defined as 'contaminated'. The regime is to improve the consistency of approach by Local Authorities and to ensure that they take a strategic approach to problems of land contamination. By clarifying the legal framework, the regime is intended to encourage owners, developers and companies responsible for contamination to plan their investment regarding development and remediation of contaminated land at an early stage of a project, with a secondary objective of encouraging voluntary remediation.

The definition of contaminated land detailed in Part IIA enables the identification and remediation of land on which contamination is causing unacceptable risks to human health or the wider environment. The assessment is made for the current land use or any other use for which planning permission has been granted. Contamination which is not severe enough to be classified as contaminated land under the Part IIA regime but is present on land which is to be used for highway development in the future will be assessed and dealt with during scheme development and construction (see Section 2.4). Contaminated soil which is present on a completed highway site, but is not classified as contaminated land under Part IIA, may still be regarded as waste and therefore require regulation by the waste management licensing regime (see Section 2.6).

If contaminated land under Part IIA is identified, the Local Authority will act as the enforcing authority. The Local Authority will establish who bears the responsibility for remediation and ensure that the remediation takes place, either through discussion and agreement on voluntary remediation or by serving a Remediation Notice on the 'appropriate person'. Failure of a recipient to comply with the requirements of a Remediation Notice will be a criminal offence.

The 'appropriate person' is defined in Part IIA as the original polluter, or the owner or occupier if, after 'reasonable enquiry', the original polluter cannot be found. 'Reasonable enquiry' is not currently defined and it is possible that the original polluter may be difficult to locate. The phrasing of this part of the guidance may cause problems in the identification of who polluted the ground with what pollutants and over what time period. It may be the case that the ground has been polluted by a number of different sources so a 'reasonable enquiry' would need to establish liability between different parties and may prove to be a long and costly process. It will ultimately be up to the courts to decide what would constitute a 'reasonable enquiry'.

Table 1 Categories of significant harm

<i>Type of receptor</i>	<i>Description of harm to that type of receptor that is to be regarded as significant harm</i>
1 Human beings	<p>Death, disease, serious injury, genetic mutation, birth defects or the impairment of reproductive functions.</p> <p>For these purposes, disease is to be taken to mean an unhealthy condition of the body or a part of it and can include, for example, cancer, liver dysfunction or extensive skin ailments. Mental dysfunction is included only insofar as it is attributable to the effects of a pollutant on the body of the person concerned.</p> <p>In this Chapter, this description of significant harm is referred to as a ‘human health effect’.</p>
<p>2 Any ecological system, or living organism forming part of such a system, within a location which is:</p> <ul style="list-style-type: none"> ● an area notified as an area of special scientific interest under Section 28 of the Wildlife and Countryside Act 1981; ● any land declared a national nature reserve under Section 35 of that Act; ● any area designated as a marine nature reserve under Section 36 of that Act; ● an Area of Special Protection for Birds, established under Section 3 of that Act; ● any European Site within the meaning of regulation 10 of the Conservation (Natural Habitats etc) Regulations 1994 ie Special Areas of Conservation and Special Protection Areas); ● any candidate Special Areas of Conservation or potential Special Protection Areas given equivalent protection; ● any habitat or site afforded policy Protection under paragraph 13 of Planning Policy Guidance Note 9 (PPG9) on nature conservation (ie candidate Special Areas of Conservation, potential Special Protection Areas and listed Ramsar sites); or ● any nature reserve established under Section 21 of the National Parks and Access to the Countryside Act 1949. 	<p>For any protected location:</p> <p>Harm which results in an irreversible adverse change, or in some other substantial adverse change, in the functioning of the ecological system within any substantial part of that location; or harm which affects any species of special interest within that location and which endangers the long-term maintenance of the population of that species at that location.</p> <p>In addition, in the case of a protected location which is a European site (or a candidate Special Area of Conservation or a potential Special Protection Area), harm which is incompatible with the favourable conservation status of natural habitats at that location or species typically found there.</p> <p>In determining what constitutes such harm, the local authority should have regard to the advice of English Nature and to the requirements of the Conservation (Natural Habitats etc) Regulations 1994.</p> <p>In this Chapter, this description of significant harm is referred to as an ‘ecological system effect’.</p>
<p>3 Property in the form of:</p> <ul style="list-style-type: none"> ● crops, including timber; ● produce grown domestically, or on allotments, for consumption; ● livestock; ● other owned or domesticated animals; ● wild animals which are the subject of shooting or fishing rights. 	<p>For crops, a substantial diminution in yield or other substantial loss in their value resulting from death, disease or other physical damage. For domestic pets, death, serious disease or serious physical damage. For other property in this category, a substantial loss in its value resulting from death, disease or other serious physical damage.</p> <p>The local authority should regard a substantial loss in value as occurring only when a substantial proportion of the animals or crops are dead or otherwise no longer fit for their intended purpose. Food should be regarded as being no longer fit for purpose when it fails to comply with the provisions of the Food Safety Act 1990. Where a diminution in yield or loss in value is caused by a pollutant linkage, a 20% diminution or loss should be regarded as a benchmark for what constitutes a substantial diminution or loss.</p> <p>In this Chapter, this description of significant harm is referred to as an ‘animal or crop effect’.</p>
<p>4 Property in the form of buildings.</p> <p>For this purpose, ‘building’ means any structure or erection, and any part of a building including any part below ground level, but does not include plant or machinery comprised in a building.</p>	<p>Structural failure, substantial damage or substantial interference with any right of occupation.</p> <p>For this purpose, the local authority should regard substantial damage or substantial interference as occurring when any part of the building ceases to be capable of being used for the purpose for which it is or was intended.</p> <p>Additionally, in the case of a scheduled Ancient Monument, substantial damage should be regarded as occurring when the damage significantly impairs the historic, architectural, traditional, artistic or archaeological interest by reason of which the monument was scheduled.</p> <p>In this Chapter, this description of significant harm is referred to as a ‘building effect’.</p>

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Table 2 Categories of significant possibility of significant harm

<i>Descriptions of significant harm (as defined in Table 1)</i>	<i>Conditions for there being a significant possibility of significant harm</i>
<p>1 Human health effects arising from:</p> <ul style="list-style-type: none"> • the intake of a contaminant, or • other direct bodily contact with a contaminant. 	<p>If the amount of the pollutant in the pollutant linkage in question:</p> <ul style="list-style-type: none"> • which a human receptor in that linkage might take in; or • to which such a human might otherwise be exposed, as a result of the pathway in that linkage; would represent an unacceptable intake or direct bodily contact, assessed on the basis of relevant information on the toxicological properties of that pollutant. <p>Such an assessment should take into account:</p> <ul style="list-style-type: none"> • the likely total intake of, or exposure to, the substance or substances which form the pollutant, from all sources including that from the pollutant linkage in question; · • the relative contribution of the pollutant linkage in question to the likely aggregate intake of, or exposure to, the relevant substance or substances; and • the duration of intake or exposure resulting from the pollutant linkage in question. <p>The question of whether an intake or exposure is unacceptable is independent of the number of people who might experience or be affected by that intake or exposure.</p> <p>Toxicological properties should be taken to include carcinogenic, mutagenic, teratogenic, pathogenic, endocrine-disrupting and other similar properties.</p>
<p>2 All other human health effects (particularly by way of explosion or fire).</p>	<p>If the probability, or frequency, of occurrence of significant harm of that description is unacceptable, assessed on the basis of relevant information concerning:</p> <ul style="list-style-type: none"> • that type of pollutant linkage, or • that type of significant harm arising from other causes. <p>In making such an assessment, the local authority should take into account the levels of risk which have been judged unacceptable in other similar contexts and should give particular weight to cases where the pollutant linkage might cause significant harm which:</p> <ul style="list-style-type: none"> • would be irreversible or incapable of being treated; • would affect a substantial number of people; • would result from a single incident such as a fire or an explosion; or • would be likely to result from a short-term (less than 24-hour) exposure to the pollutant.
<p>3 All ecological system effects.</p>	<p>If either: ·</p> <ul style="list-style-type: none"> • significant harm of that description is more likely than not to result from the pollutant linkage in question; or · • there is a reasonable possibility of significant harm of that description being caused, and if that harm were to occur, it would result in such a degree of damage to features of special interest at the location in question that they would be beyond any practicable possibility of restoration. <p>Any assessment made for these purposes should take into account relevant information for that type of pollutant linkage, particularly in relation to the ecotoxicological effects of the pollutant.</p>
<p>4 All animal and crop effects.</p>	<p>If significant harm of that description is more likely than not to result from the pollutant linkage in question, taking into account relevant information for that type of pollutant linkage, particularly in relation to the ecotoxicological effects of the pollutant.</p>
<p>5 All building effects.</p>	<p>If significant harm of that description is more likely than not to result from the pollutant linkage in question during the expected economic life of the building (or, in the case of a scheduled Ancient Monument, the foreseeable future), taking into account relevant information for that type of pollutant linkage.</p>

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In order to determine whether land is to be classified as contaminated, Local Authorities will be required to decide whether 'significant harm' is being caused or whether there is 'significant possibility' of such harm being caused (see Table 1 and Table 2). In determining what is 'significant', Local Authorities will act in accordance with the Statutory Guidance (The Stationery Office, 2000).

2.3.2 Categories of significant harm

According to Part 3 of Chapter A of Annex 3 of the Statutory Guidance (The Stationery Office, 2000), the Local Authority should regard significant harm as harm which is to a receptor of a type listed in Table 1; and which is within the description of harm specified for that type of receptor in the table.

For human beings, significant harm may be summarised as any serious human health effect such as disease (cancer, extensive skin ailment, liver dysfunction etc), serious injury or genetic mutation. For ecological systems, significant harm is determined with regard to the advice of English Nature and to the requirements of the Conservation Regulations 1994 (Her Majesty's Stationery Office, 1994). Generally, harm will be considered to be significant if it results in substantial adverse change in the functioning of the ecological system in areas such as nature reserves, sites of special scientific interest or protected areas. Significant harm to animals or crops may be generally defined as a 20% diminution or loss caused by a pollutant linkage. For buildings, significant harm will be defined as structural failure, substantial damage or interference causing the building to be unfit for its previously intended use. A pollutant linkage is considered to exist if all three elements (pollutant, pathway and receptor) have been identified (see Section 2.10).

Any receptors or harm not mentioned in Table 1 will be disregarded by Local Authorities when making decisions on what is to be considered as 'significant harm'. The emphasis in Part IIA is on 'current use'. Receptors that are not likely to be present given the use of the land which is currently being made, or is likely to be made within the boundaries of existing planning permission, will be disregarded by Local Authorities. However, current use will also be considered to include:

- Permitted temporary use (such as research experiments or monitoring work by authorised parties)
- Future developments permitted under existing planning permission (for example, highway maintenance or works associated with highway structures)
- Any likely informal recreational use of the land, whether authorised by the owners or not (for example, children playing on the land). In this case Local Authorities will give due attention to measures taken to restrict access to the land.

2.3.3 Categories of significant possibility of significant harm

The guidance on determining whether a particular possibility is significant is based on the principles of risk assessment. Table 2 sets out the conditions for there being

a significant possibility for the different descriptions of significant harm under consideration.

The power of Local Authorities to act under Part IIA when there is 'significant possibility' of significant harm being caused provides a means of preventing potential harm. The possibility of harm to human health will be determined in accordance with an assessment of the likely intake or exposure relative to background levels. The determination will be based on a pollutant pathway analysis and an assessment of the relevant information on the toxicological properties of the pollutant. The possibility of harm caused by explosion or fire will be assessed on the basis of previous experience and relevant information concerning the pollutant linkage. For ecological systems, crops, animals and buildings, it will be considered that there will be significant possibility of significant harm if the harm is 'more likely than not' to result from the pollutant linkage in question.

2.3.4 Completion of remediation

When the 'appropriate person' has completed any required remediation work, the enforcing authority should be notified. Although there is no formal 'signing off' procedure outlined in the Statutory Guidance, the authority may write to the 'appropriate person' stating that no further enforcement action will be required.

Enforcing authorities will maintain registers which will include details of Remediation Notices which have been served and information about the condition of the land in question. Details on the requirements for the registers are given in Regulation 16 and Schedule 3 of the Contaminated Land (England) Regulations 2000 (The Stationery Office, 2000).

2.3.5 Environment Agency role

The roles of the Environment Agency under Part IIA are to assist the Local Authorities in identifying contaminated land, to provide guidance on remediation, to act as the enforcing authority for land designated as a 'special site' and to publish periodic reports on contaminated land. 'Special Sites' are defined in Regulation 2 of the Contaminated Land (England) Regulations 2000. Special Sites are those which may be particularly hazardous such as Ministry of Defence sites or sites which may cause pollution of controlled waters.

2.4 New construction

In DETR Circular 02/2000 (Department of the Environment, Transport and the Regions, 2000a), Annex 1 - A Statement of Government Policy, the interaction of Part IIA with other regimes is discussed. This includes a section on Planning and Development Control. Land contamination is a material consideration for the purposes of town and country planning, and the Environment Agency is a Statutory Consultee under the planning system. When an application is made for planning permission, planning authorities will consider the implications of contamination and satisfy themselves that the proposed development incorporates any necessary

remediation. In accordance with the Government's 'suitable for use' approach, risks should be assessed and remediation requirements set out on the basis of the current and future use of the land. This is in contrast to Part IIA, where only the current use is considered. The procedure for identifying and assessing risks and deciding requirements for remediation, however, appears to be very similar to that set out in the Statutory Guidance and Regulations. In most cases where new development is taking place, the enforcement of remediation requirements will be through planning conditions and building control, rather than through a Remediation Notice issued under Part IIA. Planning authorities will continue to work to guidance set out in Planning Policy Guidance: Planning and Pollution Control (PPG23), published in 1994 until further guidance is issued by the DETR.

Construction of new highways is not specifically mentioned in the DETR Circular. The relation of highway construction to the planning system is complex, and will only be dealt with in outline here. Structure Plans and Part I of Unitary Development Plans should define the primary road network for an area and should set out general proposals for any major improvements. Local Plans and Part II of Unitary Development Plans should elaborate the proposals for the improvement of the primary network and indicate other proposed new roads and improvements. Trunk road proposals should be included as proposals in Structure Plans, Local Plans and Unitary Development Plans when they are included in the current Roads White Paper. These actions fall within the remit of the planning system, but the level of detail involved may be insufficient to enable judgements to be made on the level of contamination and requirements for remediation for individual sites.

The main procedural stages for the planning and approval of trunk roads and other highways are set out in the Highways Act 1980 (Her Majesty's Stationery Office, 1980). Under the Highways Act, the Minister has power to make orders to construct new highways. The draft orders are published, and if objections are received a local inquiry will generally be held. Following the report of the inquiry, the Minister may make or confirm the order without modification or subject to such modification as he thinks fit.

In practice, extensive consultation with the public, local authorities, government departments and other bodies including the Environment Agency takes place from an early stage in scheme development, when a number of routes are under consideration. A preliminary site investigation is usually carried out at this stage, involving desk study, walkover survey and some widely spaced boreholes and trial pits. One of the aims of the investigation would be to identify any potentially contaminated sites on the various routes, and to gain some preliminary information on the nature of the contamination. An Environmental Assessment of each of the routes would also be carried out at this stage, which would include consideration of the effect of the proposed highway on any contaminated sites.

There is usually a period of non-statutory public consultation on the alternative routes, and there may be a

Preliminary Inquiry to establish a preferred corridor for the route. The preferred route is then included in the appropriate Structure Plan, Local Plan or Unitary Development Plan. Once the preferred route has been selected, detailed design work is carried out to prepare the draft line orders, side road orders and compulsory purchase orders. At this stage, there is likely to be more detailed investigation of any potentially contaminated sites and consultation with the Environment Agency as to their significance and any remedial works that may be required. A risk-based approach should be adopted, as set out in the Part IIA Statutory Guidance and Regulations, with consideration of the vulnerability of each site and the impact of the proposed construction. This should lead to an agreed course of action for each contaminated site. The orders are then published, a Public Inquiry held if necessary, any modifications made, and the Secretary of State then makes formal orders approving the proposal.

The procedure from this stage depends on the method of procurement. If it is a traditional contract, the engineer will carry out any further site investigation and detailed design necessary to produce the tender documents. If it is a D&B or DBFO scheme, the tender documents will be prepared and the tenderers given an opportunity to carry out any further site investigation they think necessary during the tender period. The successful contractor may decide to carry out further site investigation in particular areas, such as contaminated sites, subsequent to award of the contract. Whichever method is employed, close liaison with the Environment Agency will be required to ensure that any remedial work meets the agreed aims and objectives.

The above notes are not intended as a definitive guide to the procedures for obtaining approval for new highway schemes, or how the new contaminated land regime will interface with this process. They are intended to reflect general practice, and it should be understood that circumstances will vary from one scheme to another, and the amount of site investigation and risk assessment carried out at each stage will vary accordingly. The most important principle is that close liaison should be maintained with the Environment Agency on all matters relating to contaminated land, and that the risk-based approach described in the Part IIA Regulations and Statutory Guidance will be required for all contaminated sites. Guidance on the methods available is given in Section 2.10.

2.5 Integrated Pollution Control (IPC)

The IPC regime provides for the improved control of pollution arising from certain industrial and other processes and is set out in Part I of the Environmental Protection Act 1990 (S1 to S28). It is an offence under these provisions to commit 'harm' or to contravene a Prohibition Notice or Enforcement Notice. If this is deemed to occur, then the Environment Agency may arrange for steps to be taken to remedy the harm, recovering costs from the polluter (S27).

In the process of following the guidance for the implementation of Part IIA of the Environmental Protection Act 1990, the enforcing authority may deem that S27 is

applicable. If this occurs, the authority is precluded from serving a Remediation Notice by S78YB in Part IIA of the Act and should allow the Environment Agency to exercise its authority by means of S27 in Part I of the Act.

If S27 applies, then Part IIA is not required. In some cases, remediation activities, such as thermal desorption, may themselves constitute processes which require authorisation under the IPC regime. This might apply to certain techniques (see Chapter 4) which could be used to treat contaminated materials on highway schemes. As stated in the guidance to Part IIA, the Government is currently developing new regulations under the Pollution Prevention and Control Act 1999 to transpose the requirements of the Integrated Pollution Prevention and Control Directive (96/61/EC) into UK law. The new Pollution Prevention and Control (PPC) regime will replace the current IPC regime, and will include a new system of enforcement notices. The new PPC regime will have the same relationship to Part IIA as has the IPC regime.

2.6 Waste management licensing

Statutory requirements regarding waste management licenses are detailed in Part II of the Environmental Protection Act 1990 and in the Waste Management Licensing Regulations 1994. Guidance on waste management and mobile plant licensing is detailed in information sheets (Environment Agency, 1999a and 1999b), which outline the Environment Agency's approach to the question of how redevelopment activities are likely to require control under Part II of the Act.

2.6.1 Requirements for licensing

The waste management licensing regime could have a significant impact on highway schemes, both during construction and on completion, if there is controlled waste (household, industrial or commercial waste) on site. A waste management site license (WML) may be required for the treatment, keeping or disposal of any controlled waste in or on land. This may include lightly contaminated material on a highway scheme, or any spoil with a significant content of organic matter, which could generate landfill gas.

Any situation where contaminated material on a highway scheme was moved to an area within the site and deposited may require a WML, even if the level of contamination was much lower than would be required to qualify as 'contaminated land' under Part IIA. This may be a common occurrence on highway schemes where lightly contaminated materials may be deposited as general fill material and capped with landscaping fill. It would also apply to an engineered landfill created within the site to cater for the disposal of contaminated materials from excavations elsewhere on the site.

The Environment Agency states that a WML will be required for the treatment of contaminated land if 'a mobile plant license cannot be used' (Environment Agency, 1999b). Mobile plant licenses (MPLs) are issued by the Environment Agency and are intended to be held by the operators of specific land remediation plant (remediation contractors). They are applied for by application form and

fee accompanied by a generic working plan and may be surrendered when they are no longer required. For use on any specific site, the remediation contractor has to prepare an appendix to the MPL with site-specific details. This has to be approved by the local EA office before the remediation works can commence. A WML has longer-term liabilities such as requirements for continued monitoring of the site after construction to check for migration of leachate or landfill gas.

Mobile plant licenses will be required by operators of plant used for soil treatment processes where the soil is contaminated but suitable for use on the site. Processes requiring a MPL may include solidification and stabilisation, soil mixing, soil screening, bioremediation, soil washing, soil venting and thermal treatment.

Under the MPL system, consideration should be given to the classification of the final output from the mobile plant. The Environment Agency state that the classification of the output as either 'waste' or 'product' will be determined on a case by case basis and that the reduction in contamination levels alone does not render the waste into a product (Environment Agency 1999a). If the material is classed as a 'waste', a WML will be required if the material is retained on site. If it is classed as a 'product', a WML is not required if it is retained on site. It is therefore important to enter into dialogue with the Environment Agency at the outset so that the situation can be clarified before work commences.

2.6.2 Exemptions from the licensing regime

A WML (or MPL) will be required in most cases where an activity on a site involves contaminated soil. Exemptions from the requirement to have a waste management license are listed in the Waste Management Licensing Regulations 1994 (Her Majesty's Stationery Office, 1994).

2.6.3 Interaction with Part IIA

As detailed in the DETR Circular on Contaminated Land (Department of the Environment, Transport and the Regions, 2000a), there are several areas of potential interaction between Part IIA of the Environmental Protection Act 1990 and the waste management licensing system under Part II of the Act.

There may be significant harm or pollution of controlled waters arising from land which is regulated by a WML. If this harm or pollution is being caused as a result of a breach of the WML, or by an activity authorised by the license, then Part IIA does not apply. Any regulatory action on the land will be carried out in the context of the waste management licensing regime in Part II. However, if the harm is not being caused by a breach of the WML; and the harm is not being caused by an activity authorised by the license; then the land may be formally identified as 'contaminated land' and a Remediation Notice can be served under Part IIA.

Under S78YB(3), if contamination results from the illegal dumping of controlled waste then Part IIA does not apply. In this case, the Environment Agency would take action to deal with the problem under S59 of the 1990 Act.

Also, if remediation activities are being carried out on contaminated soil, then Part IIA does not necessarily apply. The activities may be classed as 'waste disposal' or 'waste recovery' operations and thus be regulated under Part II (WML) of the Act rather than Part IIA.

The flow charts in Figures 2.1 and 2.2 show how the new Part IIA regime may interact with the Part II (WML) regime for highway construction and maintenance.

2.7 Statutory nuisance

The statutory nuisance regime under Part III of the 1990 Act has been the main regulatory mechanism for enforcing the remediation of contaminated land. With the introduction and implementation of Part IIA, the statutory nuisance system no longer applies to contaminated land; this is brought into effect by amendments given in paragraph 89, Schedule 22 of the Environment Act 1995. The only situations where the statutory nuisance system will continue to apply for contaminated land issues are if an abatement notice or court order has been issued and is still in force; or if substances deposited on land constitute a nuisance due to their smell.

2.8 Groundwater protection

2.8.1 Water Resources Act 1991

The Environment Agency can serve a Works Notice on any person who has caused or knowingly permitted the pollution of controlled waters, forcing them to carry out works to remedy the problem. The Environment Agency has published a policy statement setting out how they intend to use the Works Notice powers after the implementation of the Part IIA regime.

The Environment Agency policy, as stated in the DETR Circular (Department of the Environment, Transport and the Regions, 2000a), is that Local Authorities acting under Part IIA should consult, and take into account comments from, the Environment Agency before determining that land is classified as contaminated in respect of pollution of controlled waters. If the EA identifies such land, they in turn will notify the Local Authority so that they can formally identify the land as 'contaminated land' for the purposes of the Part IIA regime. If land has been identified as 'contaminated land' under the Part IIA regime, the Part IIA enforcement mechanisms would normally be used rather than the Works Notice system. Enforcing authorities acting under Part IIA of the 1990 Act are under a duty to serve a Remediation Notice, whereas the Environment Agency is merely granted a power to serve notices under the 1991 Act, so enforcement would generally take place under Part IIA.

Works Notices may still be used in some situations. For example, if a contained body of groundwater is polluted or if the source site cannot be identified, then Works Notices may be more appropriate. The only other situation where the Water Resources Act 1991 would take precedence over Part IIA of the Environmental Protection Act 1990 is if a discharge consent has been issued under the 1991 Act. In this case, a Remediation Notice cannot be served under Part IIA of the 1990 Act if it impedes or prevents the

discharge into controlled waters. The 1991 Act will deal with any breach of a discharge consent. This would not normally apply to highway schemes.

2.8.2 Groundwater Regulations 1998

The EC passed the Groundwater Directive (80/68/EEC) in order to prevent groundwater pollution by avoiding entry of hazardous List I substances and by limiting entry of less hazardous List II substances. The UK passed the Groundwater Regulations (SI 1998 No. 2746) in 1998, which introduced a regime of authorisations and notices to implement the objectives of the EC Directive.

The Groundwater Regulations require that surveillance is carried out on potential discharges of List I and List II substances. Any person disposing of List I or II substances (sheep dip, pesticides, sewage, industrial waste) requires an authorisation granted by the Environment Agency. The Agency will carry out periodic reviews of their authorisations and prepare reports on disposal activities. Notices which prohibit activity, or authorise it subject to conditions, may also be served by the Agency for activities which may lead to an indirect discharge of a List I substance or to pollution by a List II substance.

Activities which discharge listed substances through discharge consents (Water Resources Act 1991) or IPC authorisations (Part I, Environmental Protection Act 1990) will continue to be regulated by those regimes and will not be subjected to the Groundwater Regulations.

2.9 Landfill tax

The landfill tax was introduced to discourage the disposal of waste through landfill. The Government has since recognised that the landfill tax may discourage the reclamation of contaminated land by increasing the cost of disposing of wastes arising from the necessary removal of pollutants. The law therefore provides exemption from landfill tax for such wastes.

Exemption from the landfill tax requirements can be obtained, by applying to HM Customs and Excise, if the waste to be disposed of has been removed from contaminated land in order to prevent harm, or to facilitate the development of the land for particular purposes. Exemptions will not be granted if the material is being removed in order to comply with the requirements of a Remediation Notice served under Part IIA of the Environmental Protection Act 1990 (Department of the Environment, Transport and the Regions, 2000a).

Contaminated land, which is present on land that is being redeveloped, may thus be disposed to landfill, with no landfill tax payable, as long as a Remediation Notice has not been served. This encourages developers to carry out remediation work by agreement rather than through enforcement.

Waste arising from construction activity that is not considered to be reclamation work does not qualify for exemption from landfill tax (HM Customs and Excise, 1997). Various factors may be taken into account in determining whether the waste is due to reclamation work or construction work. For an exemption from paying

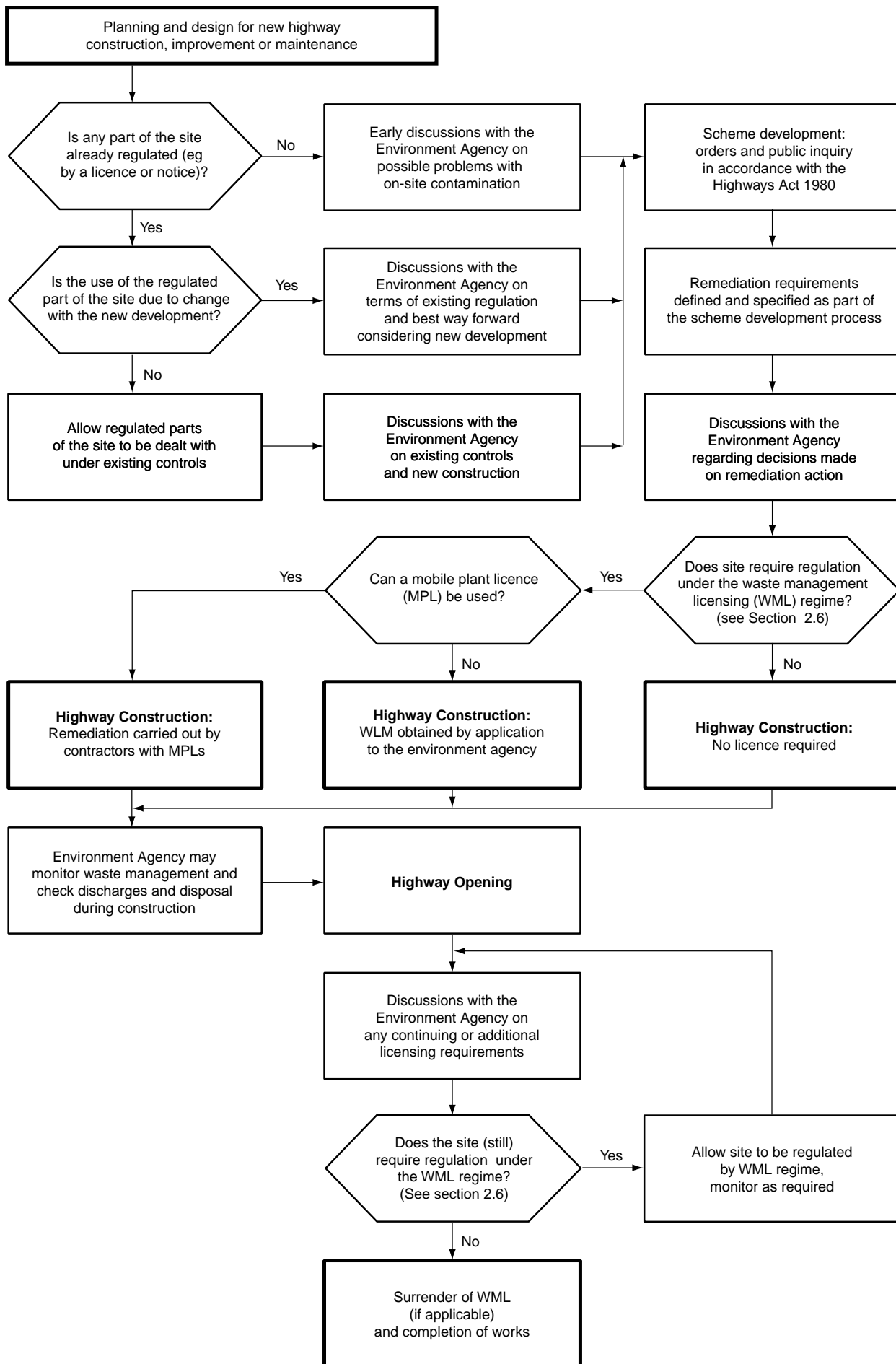


Figure 2.1 Application of legislation to highway construction improvement or maintenance

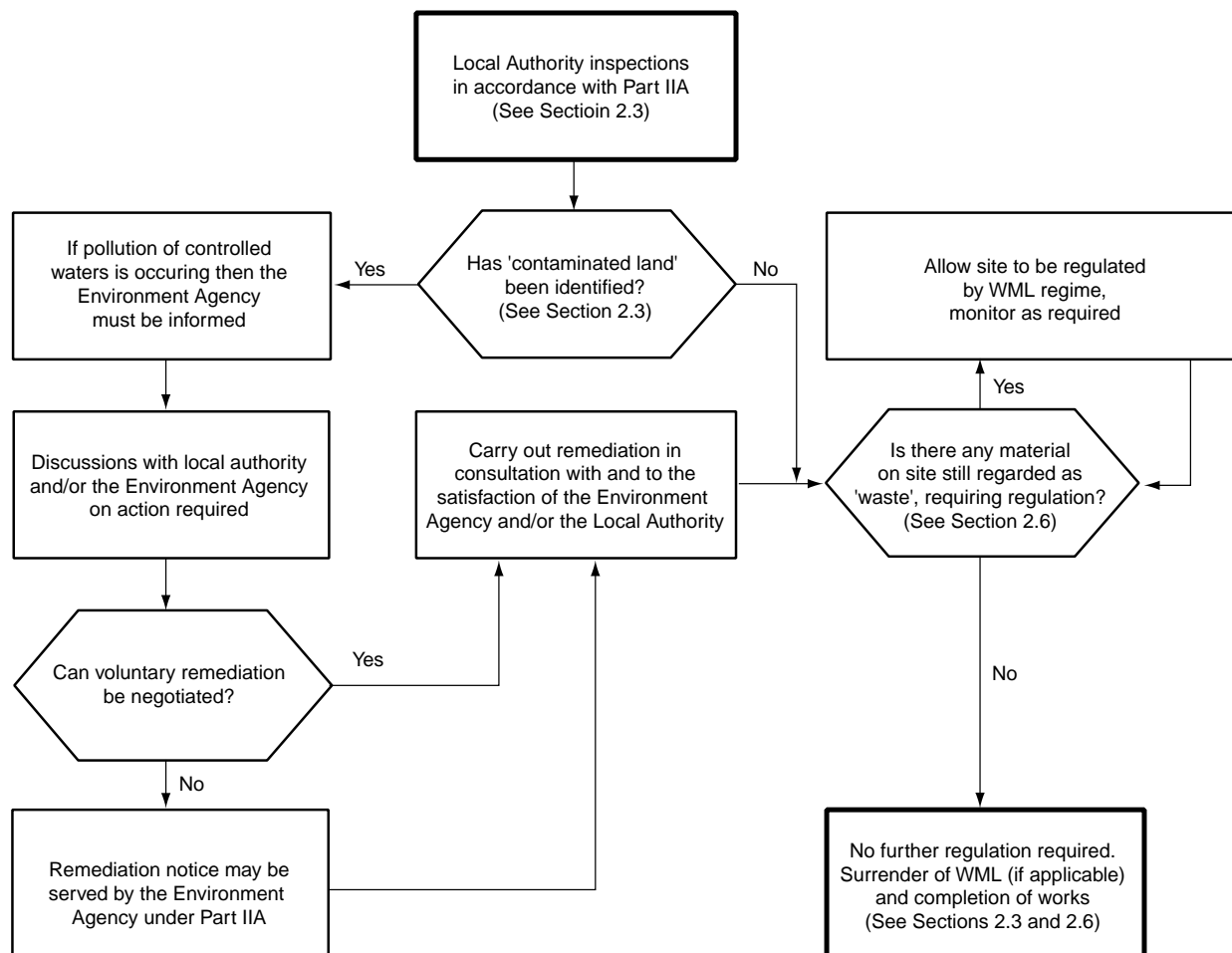


Figure 2.2 Application of legislation to existing highways

landfill tax to be granted, the developer will be required to show the following:

- that removal of contaminated soil was planned before construction started;
- that soil removal is necessary in order that pollutants are removed rather than for site levelling or removal of unstable ground;
- that not just the material in the area of construction is being removed, leaving adjacent contaminated soil in place.

Reclamation work may be defined as work which needs to take place before construction can commence, rather than work carried out as part of the construction process. For highway development, exemption from landfill tax is only likely to be granted if there is an isolated section of contaminated soil that is identified during the planning process as requiring removal by reason of potential harm being caused. Soil that would need to be removed in any case as part of the construction process would not be exempt from the landfill tax. This may be the case when a highway is being constructed in cutting.

2.10 Guidance for regulators and developers

When determining whether land is to be classified as contaminated, Local Authorities will be required to take all 'relevant and available' evidence into account and carry out appropriate scientific and technical assessment of that evidence (Department of the Environment, Transport and the Regions, 2000a). Local Authorities will be required to identify 'pollutant linkages' as defined in the Statutory Guidance to Part IIA. All three elements (pollutant, pathway and receptor) have to be identified before the land can be classified as contaminated. It is expected that these principles will also apply to new construction on contaminated land.

In the past, decisions on whether land should be regarded as contaminated were generally made by comparison with published guideline values. Examples of these include the ICRCL values (Interdepartmental Committee for the Reclamation of Contaminated Land, 1987), the GLC values (Kelly, 1980) and the Dutch A, B, C values (NVPG, 1990). These guideline values were derived on an empirical basis rather than by probabilistic risk assessment, hence they did not take account of site specific conditions and were seen as arbitrary and inflexible. They were developed for different purposes, with the result that the schemes had different values for the same contaminant. The ICRCL guidelines were primarily

concerned with risks to human health from contaminants in the ground, the GLC guidelines with disposal of material to landfill, and the Dutch values with a 'multifunctionality' approach which required the soil to be suitable for all possible future uses. The UK has always adopted a 'suitable for use' approach, which has now been adopted by other European countries. The misapplication of these guideline values has frequently caused confusion in civil engineering works. An example of this is given in Section 5.1.

The importance of the leaching behaviour of a material as opposed to total contaminant concentrations when assessing the risks to controlled waters (surface water and groundwater) has been recognised. In the UK, the EA recommend the use of a simple batch leaching test (Lewin *et al.*, 1994) to assess whether materials are likely to cause pollution of controlled waters. The results may be compared to published Environmental Quality Standards (EQS) (The Surface Waters (River Ecosystem) (Classification) Regulations, 1994) for the receiving water or drinking water standards (Water Supply (Water Quality) Regulations, 1989).

This approach was developed by Baldwin *et al.* (1997) for the use of industrial by-products in road construction. They proposed that materials be grouped into three classes based on simple leaching tests: Group 1 (no restrictions based on potential to affect water quality); Group 2 (may need some restriction based on potential to affect water quality); and Group 3 (will need restrictions based on potential to affect water quality). The criteria for each group were based on the amount of dilution of the leaching test results necessary to meet the EQS. The dilution factors varied depending on the nature of the species; tighter limits were required for black list species than for grey list ones. This is a qualitative risk-based approach, with greater weight being given to the more hazardous species and less to less harmful ones.

As more has become known about the way contaminants behave, risk-based approaches using computer models have become more common, as described below.

2.10.1 Risk assessment models for groundwater

Assessment of the risk of contamination of groundwater from contaminated soil can be made with the aid of risk assessment models. The Environment Agency has promoted the development by Golder Associates of a computer software package ConSim (Environment Agency, 1999c). The software uses a multi-level assessment approach to determine the likelihood and severity of contamination of groundwater. The levels in ConSim follow the potential contaminant pathway through the subsurface environment (Environment Agency, 1999c). Level 1 considers whether the concentrations in the contaminated soil are sufficient to impact on the receptor, ignoring any attenuation. This involves the modelling of a leaching test on the contaminated soil. If concentrations at this level exceed specified target levels then the assessment moves on to the next level. Level 2 models the movement of contaminants through the unsaturated zone with consideration of travel time,

transport processes, biodegradation and the effects of dilution. Level 3 models attenuation and retardation processes in the saturated zone. ConSim is likely to be used by the Environment Agency to assess the nature and loading of contaminants likely to arrive at the water table as a result of contaminated soil. Further information, including a demonstration version of ConSim, is available through the Environment Agency web site at www.environment-agency.gov.uk/gwcl/consim.html.

The Environment Agency R&D Publication 20 (Environment Agency, 1999d) provides a methodology to derive the level of remediation required to protect controlled waters. Similar to the approach of using 'levels' in ConSim, the R&D Publication 20 methodology is based on having a series of 'tiers' to determine risk-based remedial targets for soil and groundwater. At each tier a remedial target is derived. With successive tiers, the remedial targets become less onerous as additional processes such as dilution are taken into account. As the proposed analysis progresses through the tiers, the data requirements and the complexity of the analysis increase. The tiered approach is intended to increase confidence in the predicted impact of the contamination. With increased confidence in the processes of contaminant transport, low-risk sites should be screened out, allowing attention to be focused on the sites where the risks are greatest.

Other computer models are available such as @RISK (www.palisade.com) and BIOSCREEN (www.epa.gov). @RISK is risk analysis software developed by Palisade Corporation. It is provided in the form of a risk analysis and simulation add-in for spreadsheet programs such as Microsoft Excel. BIOSCREEN, developed by the American Environmental Protection Agency, is a tool for modelling contaminant transport through the saturated zone by means of advection, dispersion and adsorption.

The processes undertaken and the procedures followed by the users of risk assessment tools need to be transparent in order that analyses may be compared and assessed with regard to their determination of the impact of contamination. Analytical risk assessment models and software packages should be regarded as tools in the assessment process. Professional judgement and practical analysis are required in order to put results from analytical assessments into the correct context.

2.10.2 Exposure assessment models

As well as assessment of the risk of contamination of groundwater, the risks to human health need to be assessed. To support the Environment Agency and Local Authorities in their enforcement of the new contaminated land regime, and to provide a means of assessment of risk to human health, probabilistic methods are likely to be used. The Contaminated Land Exposure Assessment model (CLEA) was developed by the late Professor Colin Ferguson for DETR. It is expected that the CLEA-based guideline values and algorithm report will be published by DETR in 2001 as Contaminated Land Report 11 (CLR 11). Model Procedures for identifying, making decisions about and taking action to deal with contamination, are also expected to be published by DETR in 2001 as

Contaminated Land Report 12 (CLR 12). The Statutory Guidance to Part IIA suggests that any guideline values should be relevant to the judgement on pollutant linkage being made, but does not specify which guideline values should be used. As the CLEA model is owned by DETR, it is likely to be the most readily accepted by regulators.

The CLEA model allows the derivation of guideline values for concentration of contaminants for their effect on human health. The model makes a probabilistic exposure assessment based on an analysis of the 'pollutant-pathway-receptor' mechanism. CLEA guideline values should be confirmed as appropriate on a site specific basis. Soil concentrations can be compared to the guideline values, if concentrations exceed the guideline values then remediation or a site specific assessment is recommended.

The CLEA model relates only to direct human health risks, it does not relate to groundwater protection, ecosystem protection, occupational risks or acute risks. It should also be noted that the CLEA guideline values may vary according to pH, organic matter and other soil properties. They will not be a simple list of values like the ICRC values.

An alternative model, outlined in a current (May 2000) research report, is the SNIFFER model (SNIFFER, 1999). This model was developed as part of the Framework for Delivering Numeric Targets to Minimise the Adverse Human Health Effects of Long-term Exposure to Contaminants in Soil. As with CLEA, the SNIFFER model assesses direct risks to human health from contaminants in soil through specific pathways. Further information about SNIFFER and their research can be found on their web site at www.sniffer.org.uk.

2.10.3 Model procedures

Model Procedures have been developed under the DETR and Environment Agency research programme and will provide a systematic, model process for dealing with contaminated land. The Model Procedures, due to be published in 2001 as CLR 12, will be consistent with UK legislation and will provide a suggested good practice framework for the process of dealing with contamination.

The Model Procedures will be split into three main sections:

- **MP 1: Risk assessment**
Hazard identification and assessment through desk study and site investigation. Risk estimation and evaluation through site investigation, data collection, review and analysis.
- **MP 2: Evaluation and selection of remedial measures**
Assessment of management requirements; review of data and identification of potential remedial options; analysis of alternative options and selection of preferred strategy.
- **MP 3: Implementation of risk management action**
Design and procurement; implementation and validation; and monitoring and maintenance.

2.10.4 DD 175 and further guidance

Review of the development document DD 175 (British Standards Institution, 1988) for investigation of potentially contaminated sites is nearing completion. It is expected that it will be published as BS10175: Investigation of potentially contaminated sites - Code of Practice in late 2000.

As discussed in a seminar entitled Contaminated Land in the Millennium (AGS, February 2000), the British Standard provides guidance on the investigation of contaminated land and gives recommendations for investigation design, field sampling, sample handling, sample analysis and on-site testing. The Standard does not give recommendations on other problems affecting sites, such as geotechnical aspects, which are covered by BS 5930, nor the legal aspects, including the need for licenses, permits or authorisations.

The British Standard does not cover procedures for risk assessment, but gives guidance on obtaining data required for risk assessment. It should be used alongside other procedures (such as the Model Procedures, see Section 2.10.2), standards and codes of practice where risk assessment and geotechnical investigation are required. As well as the available guidance documents and exposure assessment models, outputs from research programmes and workshops commissioned by DETR, the Environment Agency and CIRIA will assist regulators, practitioners and developers in their approach to the new regulatory regime and to dealing with contaminated land.

Figures 2.1 and 2.2 provide some guidance on the possible application of the waste management licensing regime and the new Part IIA regime for the enforcement of remediation and control of contaminated land in the context of highway construction.

2.11 Future developments

The field of contaminated land legislation is a fast-moving one, and further developments may be expected. This report presents a summary of the situation as of Summer 2000, with the Contaminated Land Regulations and Statutory Guidance in force in England but the Model Procedures and revised guideline values not yet available. Further developments in the PPC legislation are expected, and the situation with regard to the use of MPLs and WMLs for remediation activities is not fully resolved. Further legislation to resolve conflicts between existing legislation and to pick up minor points may be anticipated in due course. However, the broad picture of legislation relating to contaminated land is now clear. This should lead to greater use of remediation in highways as well as other areas of construction.

3 Specification of contaminated materials in Highway Works

The use of materials in highway earthworks in the UK is set out in the Specification for Highway Works (SHW) (MCHW1), eighth edition, 1998. Materials are classified as acceptable or unacceptable for a range of uses depending

on their geotechnical properties. The document is written and structured to allow the maximum use of materials. At present, contaminated materials may be classified under Clause 601 as either:

Unacceptable material Class U1

- ii material, or constituents of materials, composed of the following unless otherwise described in Appendix 6/1:
 - (f) non-hazardous materials other than those permitted in Table 6/1 and Appendix 6/1.

Unacceptable material Class U2

- i materials having hazardous chemical or physical properties requiring special measures for its excavation, handling, storing, transportation, deposition and disposal.

A classification for contaminated materials was first introduced in the sixth edition of the SHW in 1986, which included the current Class U2 definition. Class U1 (ii) (f) was introduced in the seventh edition (1991), as a classification for materials with low concentrations of contaminants. The perception of contaminated materials has changed and scientific understanding of their behaviour has increased in recent years and a revised classification is now required. This should reflect the change in emphasis from the levels of contaminants in a material to the assessment and management of the risks posed by the contamination on a site-specific basis. Section 78 of the Environmental Protection Act 1990, introduced by Section 57 of the Environment Act 1995, includes a definition of contaminated land which reflects this approach (see Chapter 2). This definition has been incorporated into a suggested revision of Clause 601, based on limiting values for pollution of controlled waters and harm to human health and the environment. The suggested amendments are detailed in Appendix A.

Information on the selection of limiting values is given in a suggested revision to the Notes for Guidance (NFG) (MCHW2). The limiting values should be derived by means of a site specific risk assessment, and details of how they were obtained should be given in Appendix 6/14 and Appendix 6/15 of the tender documents. However, there is provision for the use of generic guideline values as default values. The generic values should have themselves been produced by a risk assessment model, such as the guideline values for human health currently under development by the Department of the Environment, Transport and the Regions (DETR). For general fills, the limiting values for harm to human health should normally be based on the commercial/industrial end use category, as there is a very low risk of exposure of the public to any contaminants in the fill. Provision for treatment of contaminated materials to render them acceptable is included, subject to a satisfactory risk assessment.

It is hoped that the suggested amendments to the SHW and NFG clauses will encourage more re-use and treatment of materials on site and less excavation and disposal.

The revised classification has been trialed on a major highway scheme in England. As the Statutory Guidance and guideline values were not available at the time, default

values for Appendices 6/14 and 6/15 were taken from Table 1 of Interim Guidance on the Disposal of 'Contaminated Soils' (Environment Agency, 1997). These values have not been derived by a quantitative risk analysis process and are hence somewhat conservative. The values for Appendix 6/14, Pollution of Controlled Waters were based on the Leachate Quality Threshold values, and those for Appendix 6/15, Level of Contamination of Material on the Upper Threshold Concentrations (Environment Agency, 1997). The system worked well on site, with all parties being clear about which category materials were in.

The revised Specification and Notes for Guidance will be considered for inclusion in the next revision to the MCHW.

4 Techniques for remediating contaminated land in highway earthworks

4.1 Aspects particular to highways

Highways are an attractive use of contaminated land for a number of reasons:

- i highway earthworks provide one of the least sensitive end uses for contaminated land with respect to human health, as the materials are covered by the road pavement above and by topsoil and vegetation on the side slopes;
- ii siting highways on contaminated land preserves adjacent greenfield sites;
- iii the provision of infrastructure enables the regeneration of surrounding derelict or contaminated land - e.g. the Black Country New Road;
- iv contaminated land may be cheaper to purchase than green field land;
- v the use of innovative remedial technologies allows contaminated land to be processed and re-used on site, thus reducing the need for material to be sent off-site to landfill;
- vi it may be economic to construct a highway on contaminated land whereas redevelopment for other end uses may be too costly.

There are a number of ways in which the remediation of contaminated land as part of a highway scheme differs from remediation of a site for redevelopment:

- i the highway might only intersect part of the site, and the effect of the rest of the site on the works has to be considered- e.g. landfill gases, migration of contaminated groundwater;
- ii conversely, the effect of the works on the rest of the site has to be considered- e.g. diversion of existing flow paths for gas and leachate and consequent effects on neighbouring properties;
- iii as a result, requirements for remediation of contaminated sites may be more onerous in some ways for highways than for redevelopment of the whole site, in spite of the less sensitive end use. There is less flexibility because the alignment is fixed and space may be restricted.

The main concerns regarding the use of remedial techniques to process contaminated land are listed below:

- i hazards to workmen during construction;
- ii pollution of the environment during construction;
- iii control of emissions from remediation processes;
- iv long term stability of solutions with respect to:
 - a leaching of pollutants;
 - b loss of geotechnical properties.

Items (i) to (iii) are covered by legislation such as the Construction (Design and Management) Regulations 1994, the Control of Substances Hazardous to Health Regulations (1994), the Health and Safety at Work Act 1974, the Environmental Protection Act 1990 and the Environment Act 1995. The main regulatory authority is the Environment Agency (EA). Some of the processes available for treating contaminated land will require authorisation from the EA under the Integrated Pollution Control system set up by the Environmental Protection Act of 1990. This will be replaced by the new PPC system from 2001 (see Section 2.5). Mobile plant licenses (MPLs) will also be required for many techniques (see Chapter 2.6). In all cases, the EA will be concerned to avoid the release of contaminants to controlled waters either during construction or in the long term.

A risk assessment approach will be required by the Regulatory Authorities, and has been encouraged by the DETR through the development of models such as CLEA (see Section 2.10.2), which covers human health. However, some generic guidelines will be available for human health, which could be used as default values in Appendix 6/15 (see Chapter 3). Model procedures for risk assessment are being developed, which could be adapted to cover highway schemes (see Section 2.10). Aspinwall (1994) developed a methodology for risk assessment for surface water and groundwater. A further model and computer program, ConSim has been developed for the EA (see Section 2.10). It is likely that the use of CLEA and ConSim will find most ready acceptance from the regulatory authorities.

In terms of the CLEA model and guideline values for human health, highways will fall in the 'commercial and industrial' end use category. This is the least sensitive category, as the exposure of the population to the contaminants is extremely low because the materials are covered. Consequently, the guideline values are much higher than for more sensitive end uses, such as gardens and allotments, and only very heavily contaminated materials are likely to exceed them. Pollution of controlled waters - surface water and groundwater - is likely to be the critical factor in the acceptability of remediating contaminated land for highways. The sensitivity of the underlying strata to pollution is thus at least as important as the leachability of the materials. It is likely that a site-specific risk assessment will be required in all cases where controlled waters are at risk.

Remedial works require a long time scale to prepare, carry out and validate, as the following activities have to be undertaken (Harris *et al.*, 1995):

- i thorough investigation and characterisation of each site;
- ii selection of appropriate methods;
- iii treatability studies;
- iv detailed design and risk assessments;
- v obtain authorisations;
- vi implementation (may take months or years);
- vii validation and long-term monitoring.

It may be difficult to reconcile this extended timescale with the short timescale normally associated with highway schemes, particularly Design and Build (DB) and Design, Build, Finance and Operate (DBFO) contracts. However, tenders for DB and DBFO contracts will be assessed on the risk and liabilities for HA, and a choice made accordingly. If a scheme involving contaminated land processing offers significant whole life cost advantages it may be preferred, even if it takes longer to construct. Processing contaminated land may be more suitable for traditional contracts or as advance works contracts; this would allow the main contract to proceed unhindered by uncertainties as to timescale and efficiency of the remedial works. On the Black Country New Road, a number of reclamation schemes on areas of contaminated land were carried out as advance contracts (Russell, 1995).

Methods, which allow re-use of the treated contaminated material in the works, are likely to be preferred. A single method is seldom likely to be sufficient; normally a combination of methods will be required (Armishaw *et al.*, 1992). This will be particularly true for old industrial sites with a mixture of contaminants.

In-situ methods are likely to be of limited use on many old industrial sites because:

- i the presence of underground pipes, tanks, foundations and structures may interfere with the processes;
- ii if there is a high water table it may be necessary to dewater the site to enable the process to work satisfactorily;
- iii it may be necessary to install barriers to prevent migration of contaminants off-site during the remediation works;
- iv the heterogeneity of made ground and natural strata may limit the effectiveness of techniques developed from laboratory scale tests.

Contaminated groundwater from adjacent sites may recontaminate the cleaned material. This is particularly a potential problem for highways, where the route may pass through extensive areas of contaminated land. Any proposed solutions must take this into account. In all sites, there is a need to keep clean and contaminated waters and materials separate and arrange for treatment of the contaminated waters and materials.

Contaminated land is a widespread hazard for civil engineering operations in the UK. However a number of methods have been developed for remediating contamination, allowing sites to be brought into productive use again. The methods, which are available, are as varied as the types of contamination encountered, so that appropriate treatments can be devised for almost any

situation. The main ex-situ and in-situ processes are reviewed briefly in the following sections for their applicability to highway works. Standard civil engineering solutions such as excavation and containment by barriers have not been included.

A number of publications on remediation of contaminated land have been released in recent years, including CIRIA reports SP101-112, Remedial Treatment for Contaminated Land (Harris *et al.*, 1995), and other state-of-the-art reviews and case studies (e.g. Armishaw *et al.*, 1992; Boyle, 1993; MacKay and Emery, 1993; Pearl and Wood, 1994; and Martin and Bardos, 1996). The description of techniques in the following sections follows the categories used in the CIRIA Special Publications, namely: thermal; physical; chemical; biological; and solidification/stabilisation.

4.2 Ex-situ process

4.2.1 Thermal methods

Thermal desorption

Description: The soil is heated to up to 600°C and volatile organics and metals are drawn off in a vapour stream. Mobile plant is available, but needs 1 to 2 ha of space. The vapours are either distilled or destroyed.

Advantages: This is a proven technology and is standard in the US. It removes a wide range of organic contaminants, including PCBs, pesticides, diesel, oil and grease. It removes volatile metals such as arsenic and mercury, but not heavy metals. The use of thermal desorption at 400°C to treat 2,300 tonnes of boulder clay contaminated with PCB is described by Norris *et al.* (1997). The treatment unit is based at a central facility in Chorley, owned by British Aerospace Royal Ordnance and the contaminated soil was delivered to the unit by lorry. The material was treated at a rate of 12 tonnes per hour

Problems: There is concern over the production of toxic gases such as dioxins during the process. A licence is required under the Environmental Protection Act 1990, Part I Integrated Pollution Control. The soil requires pretreatment to ensure an even feedstock. Transport costs may be significant if material has to be transported to the treatment facility and then returned to site. A MPL is required.

Solutions: Careful monitoring of emissions to prove compliance with regulatory requirements. Once the process has been shown to be safe and efficient it should become more widely available. The emissions in the case study above were carefully monitored and shown to be within the consent limits set by the regulatory authorities (Norris *et al.*, 1997).

Incineration

Description: The soil is heated to between 800 and 1200°C to destroy all organic compounds.

Advantages: This is a standard method in the US. It can be carried out on-site or at a central treatment facility. It is effective in destroying most organic contaminants.

Problems: As for thermal desorption, there is concern over emissions of dioxins and other toxic compounds. This may lead to difficulties in obtaining an IPC licence from the regulatory authorities, as required under Part I of the Environmental Protection Act 1990. A MPL is required. The process changes the physical properties of the soil significantly, and this may reduce the potential for re-use of the cleaned material. Pretreatment of the soil is required. The method is more expensive than thermal desorption and was rejected because of this in the case study by Norris *et al.* (1997).

Solutions: Careful monitoring of emissions to prove compliance with regulatory requirements. Use for materials with high organic content, which are unsuitable for treatment by other methods.

4.2.2 Physical methods

Soil washing

Description: This is a very versatile technique which can be used either as a pretreatment step or to reduce the volume of contaminated material for disposal. The soil is mixed with water and treated either with chemicals or physical agitation. Contaminants are concentrated in the washwater and fine fraction of the soil, leaving a clean granular fraction, which may be suitable for re-use. Oversize material and the organic fraction of the soil are also separated and require further treatment or disposal. Mobile plant is available.

Advantages: The technique has been used widely in Europe and has been chosen for remediation by the US EPA. It has been applied in several cases in the UK and can be regarded as an established technology. It was used as a volume reduction step to treat contaminated canal sediments in Birmingham (Pearl and Wood, 1994). On the Greenwich Millennium Experience Site soil washing was used to treat 22,000 m³ of mainly granular material contaminated with PAH's, phenol, benzene, ammonia and heavy metals (Griffin, 1998). The plant was operated for 101 working days. Of the treated material, about 65% was utilised on site for backfilling or temporary works and 35% was sent off-site for disposal to landfill. Grading according to particle size was used on some of the contaminated sites on the Black Country New Road to separate clean and contaminated materials (Russell, 1995). Similar 'dry sieving' techniques have been used on redevelopment sites (Cairney, 1996). On-site applications aim for 70-90% recovery of input as clean material. Mobile plant is available and requires 1-2 ha of space depending on the site. Soil washing is likely to be a part of most remedial strategies on old industrial sites. It minimises the amount of material needing landfilling or further treatment and yields a 'value added' product of clean granular material, thus minimising the import costs.

Problems: The method does not work well with fine-grained or organic soils, though recent developments at AEA Technology demonstrate that it can be applied to

material from gasworks sites and other fine grained materials (Pearl and Wood, 1994). Contaminants are not destroyed, only concentrated, and require further treatment or disposal. The concentration process may produce Special Waste, which is more expensive to dispose of to landfill. The residual material after treatment may still have contaminant concentrations in excess of those required for sensitive end uses (Martin and Bardos, 1996). The relatively slow rate of treatment may cause problems if the works were carried out as part of a highway construction scheme. A MPL is required.

Solutions: Optimise the process to obtain best results on a site-specific basis. Use soil washing in combination with other methods such as thermal desorption or solvent extraction for fine-grained soils; it will provide a good quality feedstock which will enable the processes to be more efficient. Residual contamination is likely to be less of a problem for insensitive end uses such as highways. The slow rate of treatment may be dealt with by carrying out soil washing – and other remedial works – as an advance contract. This would allow the main works to proceed more rapidly and easily at a later date.

Solvent extraction

Description: In this process the soil is mixed with an organic solvent to extract organic compounds such as PCBs and hydrocarbons. Biosurfactants can be used to remove heavy metals from oil-contaminated soils (Mulligan *et al.*, 1999a).

Advantages: The process is particularly useful for sludges, sediments and fine-grained soils.

Problems: The use of toxic organic solvents creates hazards. Biosurfactants, however, are biodegradable and allow inorganic contaminants to be removed. The contaminated process water has to be treated. The methods have not yet been used in the UK. A MPL is required.

Solutions: Use as part of an overall package of treatment measures for dealing with fine grained material either directly from site or the residue from soil washing. Ensure proper precautions are taken when using toxic chemicals.

Electro-remediation

Description: The soil is placed in a container and a DC current passed through it. Metals migrate to the cathode and anions to the anode, where they are removed for treatment. Some organic compounds are also mobilised. Electro-remediation is more usually carried out as an in-situ process, but better control can be achieved in ex-situ applications.

Advantages: It is most effective in fine-grained soils, sludges and sediments. Inorganic contaminants are removed or destroyed.

Problems: Flammable gases (H_2 , CH_4) are produced during the process. Maintenance of the electrodes and removal of

product is required. Can be slow and expensive. There have been numerous laboratory studies (e.g. Wu *et al.*, 1999) but no field trials of ex-situ processes have yet been carried out. MPL required.

Solutions: Apply in appropriate situations, e.g. sludges from industrial processes, and allow adequate time and supervision to ensure the process is successful.

4.2.3 Chemical methods

Oxidation/hydrolysis, reduction, dechlorination

Description: These methods all involve the addition of chemicals to soil to destroy or immobilise particular classes of contaminants. Oxidation is used to break down organic compounds such as phenols, aldehydes and cyanide. It is less effective with other organic compounds. Oxidation may also be used to increase the mobility of metals prior to soil washing, as a pretreatment step. Reduction is principally used to decrease the mobility of metals such as chromium and selenium, by reducing Cr^{VI} to Cr^{III} and Se^{VI} to Se^{IV} . Dechlorination is used to degrade toxic chlorinated organics such as PCBs. Various proprietary methods are available.

Advantages: Chemical methods are useful in specific situations that cannot be dealt with by other methods, such as treating the contaminated residue from soil washing.

Problems: Chemical methods all suffer from a number of disadvantages. The reactions are very sensitive to environmental factors such as temperature and pH. Many of the reactions are reversible (e.g. Cr reduction) and could return to the original state in the long term. The chemicals will react not only with the contaminants, but also with other compounds in the soil. Various toxic compounds may be formed as by-products of the reactions. The processes themselves involve the use of toxic reagents, with attendant health and safety risks. Pretreatment is generally necessary, and the soil properties may be adversely affected by the chemical reactions. A MPL is required.

Solutions: Use only in well-controlled situations to achieve clearly identified aims. Carry out extensive pretreatment studies to ensure the method will be successful.

4.2.4 Biological methods

Treatment beds (land farming) and biopiles

Description: Treatment beds consist of large open areas where contaminated soils are placed with microbes and nutrients in a series of layers. The microbes degrade organic contaminants to water and carbon dioxide over a period of time that may take months or years. Leachate and gases are removed and treated or recycled. Biopiles are a development of the treatment bed concept where the material to be treated is piled in large rows which are covered to retain heat, and fungus is added to boost the indigenous microbial population. The rows are turned regularly to keep the material aerated. Using biopiles,

bioremediation can continue throughout the year and short treatment times can be achieved, whereas treatment beds will only work effectively in the summer months.

Advantages: Treatment beds and biopiles are established techniques for many organic compounds, especially low molecular weight hydrocarbons, aromatics (BTEX) and PAHs. Sites up to 34,000 m³ with a mixture of contaminants have been successfully treated in recent years (Kean, 1999). Complex molecules such as PCBs are less amenable to treatment.

Problems: Behaviour can be highly site-specific. Residual concentrations may be above acceptable limits (e.g. Dutch C levels) (Martin and Bardos, 1996; Taylor, 1996) and ecotoxicological testing may be required to prove the treatment is satisfactory. Inorganic compounds are not destroyed and may inhibit the biological reactions. The process requires large areas for the treatment beds and takes a long time; it is not generally possible to predict accurately how long it will take in advance. However, the new biopile methods are much faster and more predictable, and the technology is developing rapidly. A MPL is required.

Solutions: Use in situations where time is not critical. Most bioremediation schemes will be successful given sufficient time and supervision. As with other techniques like soil washing, it is particularly suitable for advance contracts for highway schemes. The development of the biopile method has overcome many of the problems encountered with the early treatment beds.

Bioreactors

Description: The processes are essentially the same as for treatment beds, but the soil is mixed into a slurry in an enclosed vessel. This allows better control of the reactions and reduces the timescale for the treatment.

Advantages: As for treatment beds, but require less area and less time.

Problems: As for treatment beds, except that the area required is much less and the timescale shorter. The volume, which can be treated, is less than in treatment beds and closer control is required. MPL required.

Solutions: As for treatment beds. The choice between treatment beds and bioreactors will depend on a number of factors, including the amount of material requiring treatment and the space and time available. The development of biopiles, with the ability to treat large volumes throughout the year and achieve targets in short treatment times has resulted in bioreactors being less advantageous.

4.2.5 Solidification/stabilisation

Inorganic cementitious agents

Description: These methods involve mixing contaminated soil with materials such as Portland cement, fly-ash,

hydraulic slags and lime. The reagents may be used singly or in combinations along with other proprietary materials; the GEODUR process is an example of this type. The aim is to immobilise the contaminants in a dense, low permeability material, which can be either landfilled or re-used in construction.

Advantages: The technique has been in use for some time in the US and Europe. In America, it is estimated that stabilisation with cement is used in up to 30% of site clean-up cases (Jones and Hopkins, 1997). It is similar to established techniques such as lime and cement stabilisation, which are widely used on highway schemes, and hence is more likely to gain acceptance than some of the more exotic methods of treating contaminated land. It is also a very rapid technique, unlike many of the other methods discussed here, and this is a major advantage in highway works where programmes are often very tight. The materials continue to gain in strength with time, providing added security as to their performance. Stabilised soils can be used in construction, e.g. as capping layers or general fill, and hence provide a 'value added' product, reducing costs of imported material as well as avoiding export of unsuitable material to landfill. Treatment of contaminated silt mixed with pfa and lime was used successfully on the A13 Improvement scheme at Rainham Marshes, Essex (Nettleton *et al.*, 1996).

Problems: Organic compounds are not destroyed, and can adversely affect the setting and durability of the mixtures if present in high concentrations. Doubt has been cast on the long-term effectiveness of these techniques in recent years. This arises from uncertainties in the test methods, observed deficiencies in the application of the processes and an observed lack of chemical binding in crushed samples of treated material, suggesting that the contaminants could leach out under certain circumstances (Harris *et al.*, 1995). This is an area where TRL have carried out laboratory tests as part of this research project (Chapter 6). A MPL is required.

Solutions: Carry out trials and monitoring to ensure adequate geotechnical properties and durability of stabilised material.

Organic binder systems

Description: These include asphalt emulsions, bitumen and other thermoplastics. The soil is heated to 130-230C with bitumen or is mixed with an asphalt emulsion at ambient temperature. The contaminated soil is encased in a layer of bitumen or asphalt, immobilising the contaminants.

Advantages: Uses known technology, as for inorganic systems. Can yield high value end product, which can be used in road pavements.

Problems: As for inorganic systems. In addition there is a risk of fire, explosion and release of toxic volatile substances with the bitumen method. This method is likely to be more expensive than the use of inorganic cementitious systems. MPL required.

Solutions: Use in situations where a high value end product is produced, e.g. with aggregate to produce sub-base and road base. Potentially applicable to sand contaminated with oil or other organic compounds.

4.3 In-situ processes

4.3.1 Thermal methods

Thermal desorption

Description: This method consists of injecting steam and hot air at 150-200°C through a drill system rotated into the ground. Blocks of soil 1m x 2m and 8-9m deep are treated at each setting. Volatile organics are removed in the vapour stream. Other organics and inorganics are not removed.

Advantages: The system is more rapid than soil vapour extraction and more effective in removing organics because of the higher temperatures involved.

Problems: As for vacuum extraction. Expensive and little field experience. Possibility of chemicals being leached off site by the steam. A MPL is required.

Solutions: Useful as an alternative to vacuum extraction, especially where time for treatment is limited. Little experience in the UK.

Vitrification

Description: This technique involves the melting of a block of soil by passing an electric current through it between electrodes. The soil is heated to between 1600-2000°C. Organic compounds are vaporised or destroyed, and the melted soil solidifies to form a vitrified monolith stronger than concrete, with inorganic contaminants immobilised. An area 8.5m in diameter by 6m deep can be treated in one setting; the block can take up to a year to cool.

Advantages: The technique works on a wide range of materials and deals with almost all common contaminants. Materials with organic contents of greater than about 5% and metal contents of greater than 16% cannot be treated. Only soil above the water table can be treated; if necessary a site could be dewatered in advance. Wet soils require more energy, and hence are more expensive than dry soils. The method provides a highly effective way of destroying or immobilising contaminants. There are fewer concerns about the long-term stability of the resulting vitrified soil and leaching of contaminants than for methods such as stabilisation with lime or cement.

Problems: Underground fires could be started if the soil contains large amounts of combustible solids or liquids. Large metal objects can cause short-circuiting. It will not work on carbonate soils, rocks or fill materials, as these will sublime rather than vitrify. The treatment area should be at least 5m from all structures and services. Not suitable for use in areas where a cutting is proposed! Otherwise potentially a very effective method of treating contaminated ground. The method is expensive and slow because of the time needed for the vitrified material to cool. IPC authorisation and possibly WML, as opposed to MPL, required.

Solutions: This method may find a specialised application, e.g. for immobilisation of material contaminated with asbestos. Otherwise the timescale involved and limited applicability in old industrial sites with basements, tanks and buried pipes may limit its suitability for highway applications.

4.3.2 Physical methods

Soil leaching and washing/flushing

Description: In this method water, often with added chemicals, is infiltrated or injected into the unsaturated zone and collected from wells or trenches, having removed contaminants from the soil. Leaching is the technique used to remove soluble compounds, such as inorganics and some organics. Washing/flushing is used to remove non-aqueous compounds such as mineral oils. Biosurfactants may be used to solubilise non-aqueous phase liquids (NAPLs), which are hard to treat by other means.

Advantages: The techniques have been used in several countries. Useful in situations where there has been a leak or spillage of a specific chemical and the ground conditions are favourable. CIRIA SP109 (Harris *et al.*, 1995) gives examples of its use to clean up two sites contaminated with cadmium and chromium respectively. Mulligan *et al.* (1999b) summarise experience with surfactants in the United States and Canada.

Problems: High soil permeability is required for the technique to be successful. Difficulties arise if the permeability is less than 1×10^{-6} m/s (Mulligan *et al.*, 1999b). The technique is only applicable to soils above the water table. Field applications are often less successful than laboratory treatability studies. There may be difficulties in obtaining approvals from regulatory authorities because of the risk of spreading contaminants. There is a narrow range of contaminants and physical conditions in which the methods will work. A MPL is required.

Solutions: Use only in suitable situations, e.g. those described above. Use non-toxic biodegradable surfactants to limit impact on the environment.

Vacuum extraction (Soil vapour extraction)

Description: In vacuum extraction, air is drawn through the soil to an extraction well or series of wells to remove volatile organic compounds and free phase liquids such as petrol and diesel. Groundwater is often treated at the same time. Air injection wells may be installed around the edge of the site. The vapours are then treated to remove the organic compounds.

Advantages: The technique is applicable to permeable, unsaturated soils and may be used in conjunction with air sparging to treat both the saturated and unsaturated zones. It is particularly useful on active sites, e.g. refineries and petrol stations, as it can be carried out without suspending operations. It may be used as a preliminary step to remove organics, prior to further treatment for other contaminants

such as metals. It is widely used in the UK, America and Europe for cleaning up petrol filling stations, refineries and spills of oil or similar organic chemicals (e.g. Blonc *et al.*, 1996). It was used at the Greenwich Millennium Experience Site to treat deep deposits of volatile organic compounds (VOCs) including benzene from both soils and groundwater (Adams and Cartwright, 1998). The area treated was 4.5 ha and the timescale was 4 months. The system worked by direct removal of product (25%) and by stimulating the aerobic biodegradation of the remaining product in the ground (75%).

Problems: The technique is not effective at removing organics trapped in the soil matrix. Hence concentrations in monitoring wells often rise after pumping ceases. It may be necessary to go to a pulsed system of pumping to ensure complete removal of volatiles. The timescale for treatment is often long - months or years - and difficult to predict in advance. This may limit its application in highway works. MPL required.

Solutions: Use as an advance contract to clean up sites contaminated with volatile organics prior to main highway works or further remediation. Ensure that the treatment is continued long enough to reduce residual contamination to an acceptable level. This is likely to involve a pulsed pumping system activated by monitoring of soil vapour and groundwater quality. Combine with other treatment systems as necessary.

Electro-remediation

Description: This method is the in-situ version of the technique described in Section 4.2.2. A low level DC current is passed through the soil between sets of electrodes. Contaminants are removed by a combination of electrokinetic and electrochemical processes. Metals and hydrogen are liberated at the cathodes, anions and hydroxyl at the anodes. Low molecular weight organic compounds are also mobilised. The technique works best in fine-grained, saturated soils. To date, the maximum depth to which the technique has been applied is about 4.5m. Field trials at a silt loam site in Germany are described by Haus *et al.* (1999). Chromium^{VI} was successfully reduced to the much less toxic chromium^{III} form over a 3-month period.

Advantages: Technology familiar from electro-osmosis dewatering applications. Relatively low cost. Achieves destruction of contaminants. Suitable for fine grained soils and sludges.

Problems: The products have to be continually removed to avoid fouling the electrodes. Flammable gases are produced. Buried drums and live services interfere with the process. The timescale is often in excess of 100 days for completion. A MPL is required.

Solutions: Provided the above points are noted and adequate time is available, the method has considerable potential, especially for fine-grained soils which are difficult to treat by other methods.

4.3.3 Chemical methods

Description: A variety of processes are available, similar to those for ex-situ chemical treatment. They include oxidation, reduction, dechlorination, polymerisation and disinfection. The chemicals may be mixed with the soil by surface ploughing, as for agricultural lime application, or added in solution as a variant on soil leaching methods.

Advantages: A wide range of contaminants can theoretically be treated but only a few methods have been used widely. The addition of lime or organic matter to reduce the availability of heavy metals are established techniques, though the effect is only temporary and regular retreatment is necessary. Disinfection was successfully used to destroy anthrax spores on Gruinard Island. The techniques are relatively straightforward and familiar to most contractors, and many of the methods are rapid in their effect.

Problems: The reactions occurring during chemical treatment are often complex and difficult to control in a field setting. Toxic gases or leachates may be formed during some processes. The regulatory authorities are likely to set very strict standards for the use of many of these processes; it may be necessary to install ground barriers in some cases to prevent migration of contaminants or reactants. Design and monitoring costs are likely to be a significant proportion of total costs. A MPL is required.

Solutions: Chemical methods are likely to be effective and economic only in specific, limited cases.

4.3.4 Biological methods

Description: The principles of in-situ biological treatment are the same as for ex-situ treatment, namely the use of microbes to degrade toxic organic compounds to harmless substances. The microbes may be added at the surface with nutrients using agricultural equipment. Application at depth using a water recirculation system is also possible; treatment depths of up to 30m have been recorded. The soil must have a permeability of at least 1×10^{-2} m/s, which equates to clean sands and gravels. Oxygen and nutrients are added with the water.

Advantages: The method works well for simple, light compounds such as oil, but is less effective for complex compounds such as PCBs and PAHs. It is often used in conjunction with other in-situ methods such as soil washing, soil vapour extraction and groundwater remediation.

Problems: The processes are less effective than ex-situ methods because of poorer contact between contaminants and microbes. Concentrations of contaminants after treatment may still be above guideline values, and special testing may be required to prove the soil is satisfactory. The methods may also be susceptible to particular site conditions, and the timescales for treatment are often long by highway construction standards. A MPL is required.

Solutions: The method has considerable potential in the right situation, e.g. cleaning up fuel oil spills. Care should be taken to ensure that the site conditions are favourable before selecting biological methods.

4.3.5 Solidification/stabilisation

Description: This involves mixing reagents with soil by means of hollow stem augers or similar equipment. It is claimed that soils can be treated to a depth of 30m by this method. The reagents typically consist of cement, lime, pfa and proprietary chemicals. The aim is to produce a dense, homogeneous material with favourable leaching characteristics. The method is applicable to metals, inorganics, asbestos, cyanide and some organics such as PCBs. A volume increase of about 8.5% occurs, which has to be allowed for.

Advantages: The method is established in America and a successful case study of an application in the UK is given by Barker *et al.* (1996). It allows treatment of contaminated material to much greater depth than is possible with ex-situ methods. The method is rapid and the product will gain strength with time. A site trial in West Drayton, Middlesex is described by Al-Tabbaa and Evans (1998a and b), where a range of heavy metals and organic compounds was successfully treated. Research into the long-term durability of the stabilised materials is ongoing.

Problems: As for ex-situ methods, the long-term effectiveness of the technique has yet to be established. Thorough mixing of soil and reagents is essential. Provided these limitations are addressed the method has considerable potential. For highway works, the immobilisation of contaminants could be combined with strengthening of compressible foundation soils to limit settlements of embankments, particularly in sensitive areas such as adjacent to bridge abutments. A MPL is required.

Solutions: Ensure adequate site supervision so that soil and reagents are thoroughly mixed. Carry out research on long term stability of the products.

4.4 Groundwater remediation

Description: Treatment of contaminated groundwater may be required in many contaminated land situations. Numerous ex-situ methods are available, mostly based on wastewater treatment technology. These techniques are generally known as 'pump and treat' methods. A variety of in-situ methods are also available, and may be used in conjunction with some of the methods given above for processing solid materials. Methods include oxidation, enhancement of natural biological degradation processes, air stripping of volatile organics, adsorption on, or reaction with reactive materials, and biological degradation within an active barrier. A review of available techniques is given in Holden *et al.* (1998). The use of scrap iron as a reactive barrier to catalyse the breakdown of chlorinated solvents in groundwater is described by Roper *et al.* (1997).

Advantages: In-situ and on-site methods avoid the need for off-site tankering and treatment. Ex-situ methods reduce the likelihood of introducing contamination into the aquifer as a result of the process. On-site groundwater treatment has been carried out on several recent redevelopment sites in the UK in association with dewatering schemes to allow excavation of contaminated material (Croft *et al.*, 1996; Fletcher and Jones, 1996; Taylor, 1996).

Problems: It will be necessary to convince the Environment Agency that any in-situ groundwater remediation scheme will not result in further pollution of any aquifers in order to obtain a license to operate the system. Ensuring adequate contact between reagents and contaminants may be difficult. Flow in made ground aquifers is not well understood; plug flow may occur, resulting in little mixing of the waters. This is an area where development is required, probably involving complex groundwater/contaminant modelling. Experience of 'pump and treat' systems indicates that unless measures are taken to deal with the contaminants in the ground, the quality of the effluent improves only very slowly and pumping has to be continued indefinitely (Harris *et al.*, 1995). MPL required.

Solutions: Pump and treat is a proven technology and is applicable to a wide range of contaminants. By using complementary in-situ techniques such as soil vapour extraction or reactive barriers, its effectiveness can be optimised (Holden *et al.*, 1998). In many cases groundwater control and remediation works will be carried out in conjunction with one or more of the remedial methods for soils described in the previous sections.

4.5 Discussion

As can be seen, a wide range of techniques is available for processing contaminated land. Most of the techniques are suited to a specific range of soil conditions and types of contaminant. Some have a very limited range of applicability, especially some of the in-situ processes, which require favourable ground conditions to be effective.

In practice, it is likely that a combination of techniques will be required on many sites, especially where both inorganic and organic contaminants are present. Site specific strategies need to be developed, taking into account the remedial targets, nature of the contamination, ground conditions and any restrictions imposed by the regulatory authorities; these might affect the use of processes which release gases to the atmosphere in built-up areas for example, or in-situ groundwater remediation techniques which might affect sensitive aquifers or nearby structures.

The cost of the various methods will also affect the selection process. Costs can vary widely from site to site even for the same technique, so it is difficult to give clear guidance on this point. A range of prices for each technique are quoted in Harris *et al.* (1995) and Martin and Bardos (1996), but the range for each technique is generally greater than the difference between techniques. As more experience of the application of the various

techniques in UK conditions is gained, it is likely that the relative costs will become clearer. However, it is important to emphasise that a specific strategy should be developed and costed for each site, based on those techniques which will achieve the required standard of clean-up, not on those which are cheapest or most familiar. Nearly all of the methods described above may have an application on some highway schemes in the UK.

A factor, which may complicate the choice of method, is that a number of methods are subject to proprietary restrictions and can only be operated by one company. The GEODUR process, a stabilisation method where proprietary components are mixed with cement, lime and contaminated soil is an example. However, proprietary restrictions tend to be limited to specific versions of general processes rather than generic methods. Proprietary restrictions may cause difficulties in obtaining competitive tenders for particular sites. This can be avoided by specifying remediation targets for sites rather than particular methods of clean-up. There may still be problems of availability of particular techniques because of the limited number of licensed practitioners.

A further factor to be considered is whether a mobile plant licence or a site licence will be required for the particular remediation scheme proposed. Some general guidelines based on the current state of legislation are given in Section 2.6. However, all decisions will be made on a site-specific basis and it is therefore important to open discussions with the Environment Agency at as early a stage in scheme development as possible. Where a mobile plant licence (MPL) is required, the plant operator holds the licence and there is no residual liability on the site once the process has been completed and validated. Where a waste management site licence (WML) is used, there is a requirement to monitor the site after completion of the works to demonstrate that migration of leachate or landfill gas is not occurring.

The usage of remediation techniques will depend to a large extent on how they are viewed by civil engineering contractors. The factors that are likely to be critical are listed below:

- i reliability of the method;
- ii availability and ease of operation of plant;
- iii timescale required;
- iv saving on lorry journeys and import of materials;
- v reuse of remediated materials in the works;
- vi difficulties in obtaining licenses and authorisations from the Environment Agency;
- vii cost of disposal to landfill if remediation not adopted;
- viii cost of remediation;
- ix cost of, and disruption due to, validation and monitoring;
- xi savings in ease of construction of rest of works if contaminated material is remediated.

It should be noted that the cost of the remediation may not be the most critical factor; additional costs due to remediation may be more than offset by increased ease of

working and resulting savings by avoiding disposal to landfill. Unless the remediation costs are extremely high, the limiting factors are likely to be uncertainty about the reliability and timescale of the techniques and difficulties in obtaining approvals from the regulatory authorities. Thus techniques which are familiar, reliable, rapid, relatively cheap and which yield a product which can be re-used in the works are most likely to find favour with contractors. Cairney (1996) quotes a financial break-even reclamation cost of about £30 per cubic metre of soil as a criterion for remediation process acceptance on development sites in the UK private sector.

The indications are that there is still a reluctance to use innovative methods of processing contaminated land. At a conference on 'Re-use of Contaminated Land and Landfills' held at Brunel University in July 1996, 7 out of 13 case studies utilised excavation and removal of heavily contaminated material as the method of redevelopment. This was often driven by a requirement in the brief to remove all contamination from the site and the very short timescale often imposed on the works. These constraints may not be as strict for highway schemes as for the redevelopment schemes presented at the conference. The use of risk assessment models may allow the use in highways of materials with higher concentrations of contaminants than would be acceptable for residential housing with gardens, providing the risk of contamination of controlled waters is acceptable.

The main techniques which were adopted in the case studies described were mechanical sorting techniques to separate clean and contaminated material on site. This ranged from stockpiling and testing to dry sieving, which was used in a further 2 cases (Cairney, 1996). Similar techniques were used on the Black Country New Road (Russell, 1995). These techniques result in reduced volumes of material being sent to landfill and greater re-use of clean materials on site without the perceived high costs, uncertainties and long timescales associated with more complex techniques.

The other technique adopted commonly was on-site treatment of contaminated groundwater, in association with dewatering to allow excavation of the contaminated material (Croft *et al.*, 1996; Fletcher and Jones, 1996; Taylor, 1996).

Only three cases of actual treatment of contaminated materials were presented: the first was a bioremediation contract using treatment beds on an old gasworks site (Taylor, 1996); the second was a vacuum extraction contract to remove hydrocarbon contamination from beneath an operational petrol station (Blonc *et al.*, 1996); and the third was an in-situ stabilisation of an acidic landfill with a lime/cement/pfa mixture (Barker *et al.*, 1996). These provide some guidance to the techniques which are likely to be used and the situations where they are appropriate.

The uptake of remedial technologies and the barriers to this are discussed by Martin and Bardos (1996). They list seven full-scale demonstration and remedial action projects, which have taken place in the UK. The technologies used were: solidification and stabilisation/vitrification (asbestos); vacuum extraction (petroleum spillage); bioremediation/

land farming (gas works waste); soil washing (metal contaminated silt); thermal desorption (diesel contaminated soil); vitrification (asbestos and metals); and vacuum extraction/ex-situ bioremediation (coke works). The sites included dockyards, gas and coke works, canals and a petroleum storage facility. No highway schemes were included, and the list does not overlap with the case studies presented at the conference in July 1996.

Martin and Bardos (1996) noted many of the constraints to uptake of treatment technologies given above. They state that an underlying problem is the heterogeneity of both made ground and natural ground at contaminated sites, which makes the transfer of laboratory based processes to successful field implementation extremely difficult, particularly for in-situ processes. They also note the conflict between the time required for treatments to reduce contaminant levels to acceptable concentrations and the timescales often available for site redevelopment.

The uptake of remedial technologies in the UK has been relatively slow considering the wide range of techniques available. This has been partly due to uncertainties about the reliability of some methods and general concerns about the costs and timescales required. However, probably the greatest inhibiting factor has been uncertainty about the legislative position and potential liabilities. The situation in this respect is now much clearer with the implementation of the Contaminated Land Regulations and Statutory Guidance from 1st April 2000 (see Chapter 2). Model procedures for risk assessment, the CLEA model and revised guideline values are due to be published by DETR during 2001. This should encourage greater use of remedial technologies in the future.

On the basis of the information summarised in the preceding sections, remedial techniques have been classified in terms of the likelihood of their finding widespread acceptance in highway schemes. The results are shown in Table 4.1. This can be used as a guide to potential techniques which might be utilised on highway schemes, but the list is not exhaustive and the categories should not be regarded as fixed. Technologies are developing all the time, and methods, which are regarded as unlikely to be suitable at present, may become more attractive in the future. Specialised advice should always be taken when considering options for remedial treatment. This should include consultation with the Environment Agency as well as specialised environmental consultants and remediation contractors. At present, the technologies which have greatest application to highways appear to be:

- Solidification/Stabilisation with lime/cement (ex-situ and in-situ).
- Ex-situ bioremediation.
- Soil washing.
- Dry sieving/mechanical sorting.
- Vacuum extraction (Soil vapour extraction).
- Hydraulic treatment of groundwater (pump and treat).

5 Case studies

5.1 Modification of contaminated silt with lime

This case study refers to the transformation of very soft, slightly contaminated silt dredgings to an acceptable lightweight embankment fill material by treatment with quicklime and pulverised fuel ash (pfa) on the A13: Contract 2: Thames Avenue to Wennington highway scheme in Essex. The project has been described by Nettleton *et al.* (1996).

The line of the new road cuts across the edge of Rainham Marshes, which consist of a series of silt lagoons used to dispose of silt dredged from the River Thames. The silt beneath the proposed road embankment was 4.5m deep with high moisture content, low shear strength and some contamination. Under the original scheme design, the silt was to be excavated and removed from site. However, the contractor proposed an alternative, which was to treat the silt so that it could be re-used. This would reduce the number of lorry journeys on and off site by about 10%, a significant factor as there was only one access road.

5.1.1 Mechanical performance

Initial laboratory tests were carried out mixing the silt with various combinations of lime, cement, clay, pfa and special chemicals. The most effective combination was found to be lime and pfa. This gave a material with the required geotechnical properties for a lightweight embankment fill and provided additional strength by the pozzolanic reaction between the lime and the silt and pfa. The aim was to *modify* the silt, that is to improve its physical properties by reducing the moisture content, not to *stabilise* it, in the sense of forming cementitious compounds. A large scale field trial was carried out in September 1994. This was not completely successful, although it did point out some of the shortcomings and gave direction for a workable solution. The trial did, however, show that it was possible to produce a bulk lightweight fill with the required geotechnical properties.

The use of the treated silt was formally proposed to the Highways Agency (HA) after the field trial. More testing was required to ensure the scheme would be satisfactory, and there was a long-term commitment to monitor the embankment for contaminated leachates and degradation of the material. A detailed programme of laboratory testing was carried out to assess the geotechnical and contamination properties of the proposed mix, and a second large scale field trial was carried out in March 1995. This trial was highly successful, the experience from the first trial having led to the use of the most appropriate plant.

A detailed method statement and specification was produced for mixing and placing the material, including a testing and monitoring programme. The material was classified as Class 2G general cohesive fill, modified silt/pulverised fuel ash/lime cohesive material. The specification was end-product, requiring the dry density to be not less than 95% of the maximum dry density determined by BS 1377: Part 4 (2.5kg rammer test). The aim was to ensure an air voids ratio of less than 10%, to

Table 4.1 Classification of remedial techniques for application to highway schemes

<i>Technique</i>	<i>Comments</i>
<i>Widespread application to highway schemes</i>	
Solidification/Stabilisation with lime/cement (ex-situ and in-situ).	Ease of execution, rapid rate of reaction, ability to immobilise contaminants, yield 'value added' product, relatively low cost.
Ex-situ bioremediation.	Satisfactory, low cost and environmentally friendly way of destroying organic contamination. Widely used on redevelopment sites in the UK in recent years, methods developing to shorten the timescale of treatment and extend the range of contaminants that can be treated.
Soil washing.	Applicable to a wide range of soils, plant and expertise available in America and Europe, minimises waste product and/or prepares an even feedstock for further processing, yield of 'value added' clean granular material, relatively low cost.
Dry sieving/mechanical sorting.	Likely to be used as a cheap alternative to soil washing and to minimise quantity of material going to landfill.
Vacuum extraction (Soil vapour extraction).	Established technique for dealing with spillages of organic chemicals, can allow subsequent excavation or treatment of contaminated material, generally of relatively low cost.
Hydraulic treatment of groundwater (pump and treat).	Likely to be required on schemes where contaminated groundwater is present.
<i>Possible application to highway schemes.</i>	
Stabilisation with organic binders.	Uses familiar technology, can yield high value end product suitable for use in road pavements.
Thermal desorption (ex-situ and in-situ).	Deals with organic contamination, possibly in conjunction with soil washing for ex-situ applications.
<i>Unlikely to find application in highway schemes</i>	
Electro-remediation (ex-situ and in-situ)/solvent extraction.	Can be used for fine grained soils and sludges with inorganic contamination.
In-situ vitrification.	Use for securely immobilising inorganic contaminants such as asbestos, as an alternative to excavation and disposal to landfill.
Chemical methods (ex-situ and in-situ).	Reactions too uncertain and possibility of producing toxic by-products too great, especially for in-situ applications.
Incineration.	Concern over toxic by-products (dioxins), process alters soil significantly, likely to require sending material off site to a central processing unit, high cost.
In-situ soil washing/leaching.	Limited field applicability, especially in made ground, risk of introducing or spreading contamination to groundwater.
In-situ biological methods.	Results too uncertain given generally low ground temperatures in the UK and difficulty of adequate mixing of reagents and soil, timescale likely to be extended.

limit potential swelling. In addition, limits were specified on the following properties:

- i mix proportions (lime, silt, and pfa);
- ii MCV before compaction;
- iii bulk density;
- iv effective shear strength (peak and residual);
- v sulfate and total sulfur;
- vi organic content;
- vii swell at 28 days.

On the basis of the test results and the field trial, approval of the method was given by HA. The main site works were carried out between May and September 1995,

during which time a total of approximately 100,000m³ of the silt was treated to produce around 150,000m³ of lightweight fill. Most of the silt was treated in a ratio of 2:1 (silt:pfa) with the addition of 3% lime by wet weight of silt. Testing showed that the treated silt had properties within the specified limits.

Monitoring of the modified silt fill was by means of extensometers in the embankments; these allowed the internal self-settlement of the material to be measured, any large increase in this suggesting breakdown of the material. Up to 1% internal compression of the fill occurred as the embankment was raised, with a further 0.2% in the following 9 months. The results are considered acceptable and confirm that significant degradation is not occurring.

In 1998, an opportunity arose to sample some of the lime-modified material. The material is surrounded by a 4m zone of pfa on the embankment shoulders, but during construction of Contract 1 of the scheme, some of the material was exposed during excavations for a viaduct abutment at the junction of Contract 1 and Contract 2. Undisturbed block samples were taken by TRL using the method of Barton *et al.* (1986). Small (60mm) shear box tests were carried out on the material to compare with similar tests carried out during construction. All tests were carried out in accordance with BS 1377 (British Standards Institution, 1990).

A comparison of the results from 1995 (from Nettleton *et al.*, 1996) and 1998 are given in Table 5.1. Very little, if any change has occurred in the strength of the material since 1995. The marginal differences recorded are nearly all within the range of values obtained in 1995, and the material remains within the specification limits. The only exception was the lower apparent residual cohesion value obtained from the single series of residual strength tests carried out in 1998. This may be attributable to the different test procedure (multi-reversal) used in 1998, which gives a more accurate figure for the residual cohesion.

A photograph of one of the block samples of modified silt is shown on Plate 1. The soil is quite variable and includes many fragments of clinker, which contain discrete voids. The degree of mixing between the silt and the pfa is as good as could be expected given the equipment available, but distinct lumps of clay are visible. In the field, the material appears a homogeneous black, friable, fine-grained mass (Plate 2).

The project was very successful and may lead to further applications of solidification/stabilisation techniques for the treatment of unacceptable materials for use as bulk fill. Some of the main conclusions are listed below:

- i there were significant differences between the material mixed by hand in the laboratory and that produced by machine in the field. This highlights the need for full-scale field trials as part of the treatment process;
- ii the MCV test was useful in controlling moisture content of the treated material prior to compaction;
- iii observations on site, based on material up to 3 years old, indicate that the material appears to be stable with time;
- iv use of the treated silt offered considerable environmental benefits, by reducing import of material to site and export of contaminated silt to landfill.

Table 5.1 Engineering properties of lime modified silt, A13 Rainham Marshes, 1995 and 1998

Soil property	Units	Mean value		Range of values	
		1995	1998	1995	1998
Bulk density	Mg/m ³	1.55	1.70	1.41-1.64	1.61-1.76
Dry density	Mg/m ³	1.14	1.08	1.03-1.25	1.00-1.14
Void ratio e		1.02	1.20	nd	1.06-1.46
Apparent cohesion peak c'	kPa	24	26	13-38	23-27
Apparent cohesion residual c'	kPa	25	7	16-32	*
Angle of internal friction peak ϕ'	°	34	32	30-38	30-34
Angle of internal friction residual ϕ'	°	31	31	30-32	*

* Single series of tests.

nd = not determined.

1995 figures from Nettleton *et al.* (1996), reproduced by kind permission of Hyder Consulting.



Plate 1 Block sample of lime modified silt from A13 three years after construction



Plate 2 Lime modified silt *in-situ* nine months after construction

5.1.2 Environmental issues

The major concern on the A13 project was improvement of the physical properties of the dredgings, which were so wet initially as to be almost unhandleable. By mixing with pfa and quicklime, the moisture content was reduced to such an extent that the material became a satisfactory general fill. The material was essentially modified rather than stabilised, any improvement in strength as a result of pozzolanic reactions being regarded as a bonus. However, there were also significant issues regarding the contamination of the dredgings.

The London Waste Regulation Authority (LWRA) classified the dredgings in the lagoons in its *in-situ* state as a hazardous industrial waste. The classification of a material by the local Waste Regulation Authority depends not only on the concentrations of contaminants in it, but also on the availability of suitable licensed waste disposal sites in the area and the composition of the waste streams they are handling. Thus, a material with high metal concentrations might be a hazardous waste in one area where the disposal sites were already receiving high quantities of metals, but not in another where these contaminants were less common.

The chemistry of a mix of 50% silt, 45% pfa and 5% lime is shown on Table 5.2. The silt generally has low levels of contamination. The main contaminants are organic compounds (toluene extract), mainly mineral oils, sulfate, sulfide, copper, zinc, arsenic, mercury and cadmium. Using the Greater London Council (GLC) guidelines for contaminated soil (Kelly, 1980), sulfide is the main contaminant, the maximum recorded value falling in the range indicating 'heavy contamination'. The concentrations of toluene extract, sulfate, copper, zinc, nickel, mercury, cadmium and chromium fall in the range indicating 'contaminated'.

A slightly different picture emerges if the guideline values given in ICRCL Guidance Note 59/83 are used

Table 5.2 Chemical analyses of soil and leachate, A13 Rainham Marshes

Determinand	Soil (1995) (mg/kg)	Soil (1998) (mg/kg)	Leachate (1995) (µg/l)	Leachate (1998) (µg/l)	Drinking water (µg/l) ⁽ⁱ⁾
pH (units)	10.7	8.2	11.75	7.6	9.5
Arsenic	31	36	2	25	50
Cadmium	2.4	3.9	<1	<1	5
Chromium	118	59	<10	<20	50
Lead	170	99	28	<20	50
Mercury	2.6	1.6	<0.4	0.4	1
Selenium	1.3	8	<2	<20	10
Boron	nd	38	nd	2,916	2,000
Copper	122	85	230	256	3,000
Nickel	59	48	70	76	50
Zinc	342	205	42	11	5,000
Iron	nd	30,279	nd	12	200
Manganese	nd	341	nd	<10	50
Aluminium	nd	19,382	nd	46	200
Sulfate	9,017	2,661	36,000	525,000	250,000
Chloride	nd	656	nd	89,000	400,000
Ammonium	nd	16	nd	100	500
Nitrate	nd	259	nd	35,000	50,000
Total cyanide	<1	<1	<10	<5	50
Total phenols	<0.7	<1	16	<0.5	0.5
Total PAHs	<50	13	nd	<1	0.2
Total organic carbon	61,100	18,000	26,000	21,700	nd

(i) From Water Supply (Water Quality) Regulations 1989.

nd = not determined.

1995 data reproduced by kind permission of Hyder Consulting.

(ICRCL, 1987). These guidelines are primarily concerned with the threat to human health from *in-situ* contaminants, and hence the trigger concentrations are dependent on the end-use of the site, whereas the GLC classification depends purely on the concentration of the individual contaminants. In the ICRCL scheme: copper and zinc exceed the threshold concentrations for any uses where plants are to be grown; arsenic, mercury and cadmium exceed the threshold values for domestic gardens and

allotments but not for parks, playing fields and open space; and total sulfate and total sulfur exceed the threshold value for all end uses. Sulfide is below the threshold value for all proposed uses.

The varying results obtained using different classification systems indicate that contamination is not an absolute property of a material, but depends on the proposed use, the hazards involved and the classification method used. Whichever system is used, it is evident that the silt does contain some contamination, that is, elevated concentrations of certain substances. It was therefore classed as Class U2 material under the contract. This illustrates some of the weaknesses of the current definition of Class U2 material in the MCHW 1, 'material having hazardous chemical or physical properties requiring special measures for its excavation, handling, storing, transportation, deposition and disposal'. The silt could hardly be described as having hazardous chemical or physical properties; the level of contamination was too low, the MCHW 1 definition implying a Special Waste under the Special Waste Regulations 1980. The silt did require special measures for its excavation, handling, storing, transportation, deposition and disposal, but these were due to its physical nature - very high moisture content and high in-situ water table - rather than to its chemical properties. Under the proposed new classification for contaminated land (Chapter 3), it would probably not be regarded as unacceptable due to its level of contamination, as it would not be classified as 'contaminated land' under Section 78 of the Environmental Protection Act. However, it would be classed as unacceptable, Class U1 because of its high moisture content. The new system would thus result in a more appropriate classification of this lightly contaminated material.

Batch leaching tests similar to the NRA test (Lewin *et al.*, 1994) (see Section 2.10) were carried out on the treated silt prior to construction in 1995. These showed that the leachate met the Water Quality Standards for irrigation (Nettleton *et al.*, 1996). The NRA leaching test was conducted on a sample of the material in 1998 and chemical analysis of the soil and leachate carried out. The results are shown in Table 5.2. The leachate was relatively innocuous. Only potassium, boron, sulfate and nickel concentrations exceeded the UK drinking water standards, and then only marginally. The most significant change in leachate quality since 1995 was in the pH. In the 1998 tests, the leachate had a pH of 7.6 and the soil pH was 8.2. This compares with values of 11.75 for leachate and 10.7 for soil in 1995. Associated with the drop in pH is a large increase in the solubility of sulfate in the 1998 leachate. The drop in pH suggests that all free lime has been leached out of the material or been carbonated between 1995 and 1998, and confirms that the effect of the lime has been to *modify* the soil rather than *stabilise* it. In remediation terminology, the process has been *solidification*, not *stabilisation*. The process has been very satisfactory, as the formerly unacceptable material has been rendered into an acceptable general earthworks fill which has retained its geotechnical properties and is unlikely to cause significant pollution of controlled waters.

5.2 Vacuum extraction of petrol spillage

This case study refers to the clean-up of ground and groundwater below a petrol filling station. The site had become contaminated due to leakage of petrol from underground storage tanks in November 1993, and various investigations revealed a plume of product beneath the site, surrounded by a larger area of polluted groundwater.

The site lies immediately to the north of a road improvement scheme, which was under construction in 1995 and 1996. Demolition of the station was required to allow the construction of a slip road onto the northbound carriageway. The site was to be remediated and cleared by 1 April 1996 to accommodate the construction programme. The site owners decided to undertake the remediation works using their own specialised contractors.

The site occupies an area of level ground on a broad flood plain, with the nearest river 3km to the south. Ground conditions consist of made ground associated with the petrol station underlain by brown and grey very silty sand. The sand is thought to be an alluvial deposit. It is underlain at depth by glacial till and sandstone bedrock of the Sherwood Sandstone Group of Triassic age. The water table is between 1.0m and 1.7m below ground level and shows seasonal fluctuations. A small stream runs along the western border of the site and flows south to the major river. The alluvium is classified by the Environment Agency (EA) as a minor aquifer. The Sherwood Sandstone Group is classified as a major aquifer, and there are three licensed groundwater abstractions within a 2km radius of the site, all for industrial purposes. However, the presence of the layer of glacial till will attenuate the downward movement of any pollutants from the alluvium.

Investigations in February and March 1994 revealed a plume of petroleum hydrocarbons up to 730mm thick floating on top of the groundwater in the pump islands, forecourt and tank farm area, surrounded by a wider area of polluted groundwater. It was estimated that about 2000 litres of product had been lost. Four groundwater monitoring wells were installed during the investigations.

The owners of the site instigated a programme of remedial works to clean up the site prior to handing it over to the Highways Agency. The works were designed and implemented by a specialised contractor, with project management and independent testing being carried out by an environmental consultant, who had also carried out the investigation work at the site. A firm of consulting engineers, commissioned by the Highways Agency (HA) as consulting engineers for the road improvement scheme, supervised the remediation works.

HA were concerned that there should not be any future environmental liabilities associated with the site. The proposed end use was not sensitive, the most critical periods being during demolition of the petrol station and excavation of the underground tanks, when petroleum fumes from contaminated ground could cause a health hazard for construction workers. There was also the risk that pollution of surface waters or groundwater could occur. Target clean-up levels for the site were proposed by the environmental consultant and are listed below:

- a removal of all free phase product;
- b soil vapour volatile organic compounds (VOCs) less than 50 ppm at 1.0m depth;
- c soil total petroleum hydrocarbons (TPH) less than 1000mg/kg;
- d groundwater TPH less than 10mg/l;
- e groundwater benzene-toluene-xylene (BTEX) less than 5mg/l.

The prime requirement was the removal of all free phase product, as this would greatly reduce the risk of concerns over safety during excavation and pollution of controlled waters. The other target levels were largely designed to ensure that all free product was removed. They were derived from consideration of the composition of the product, solubility and volatility of the individual compounds, Maximum Exposure Limits and Occupational Exposure Standards, and internationally recognised target concentration levels such as the Dutch standards and UK ICRCCL trigger concentrations. However, a detailed risk assessment was not provided.

The method proposed by the specialised contractor was to use vacuum extraction to remove free product, soil vapour and contaminated groundwater from the affected area. Contaminated soil would then be removed from site when the underground storage tanks were excavated. A system of 20 vertical wells was installed, and operation of the system commenced in October 1995. In one area where it had been proposed to install wells, the ground was found to be saturated with product when the surface brickettes were removed. As this posed a health risk, the brickettes were replaced and the wells were not installed in this area until January 1996, by which time the vacuum extraction treatment had significantly reduced the concentration of product. A further 5 horizontal wells were installed in this area in January 1996, and the system was operational until mid February. The petrol station remained open until 5 January 1996.

The remedial system was based upon proprietary technology developed by a Dutch company, who have

considerable experience in dealing with similar sites in the Netherlands. The wells were approximately 60mm diameter and 3m length, and were spaced at 2m centres. The well screens were designed to suit the fine grained soils, assuming a permeability of 10^{-5} m/s to 10^{-6} m/s. These values seemed reasonable in the light of the available information, which was very basic; the only soils information was the drillers logs of the boreholes for the groundwater monitoring wells. No grading analyses, permeability tests or SPTs had been carried out and there were no engineering geological descriptions of the strata.

The system operates by applying a vacuum of 0.5 to 0.6 bar to the wells to extract soil vapour, free product and groundwater. The vacuum is applied to individual wells or groups of wells in turn; the settings are adjusted during the commissioning period of about two weeks in response to the amount extracted from each well. Pumping times varied from two minutes to over ten minutes. The pulsed pumping allowed diffusion of product from the soil matrix into the pore space between periods of pumping. This is more efficient at removing contaminants from the soil than continuous pumping (Harris *et al.*, 1995 (SP109)).

The combined groundwater, petrol and soil vapour from the wells was drawn to a container on the site, which contained a treatment unit. The petrol was separated from groundwater by means of a series of tilting plates and baffles. The water was then sparged with air to volatilise the hydrocarbons until it contained less than 1mg/l TPH; it was then discharged to a foul sewer. The vapours were passed through a biological filter, consisting of layers of activated sludge and bark. This destroyed about 60% of the TPH, and the rest were vented to the atmosphere at a concentration of less than 5 ppm VOC.

A limited amount of monitoring was carried out during the operation of the system. The thickness of free product decreased to zero in all monitoring wells by January 1996. Laboratory analyses of TPH concentrations in groundwater were made on four occasions. The results are shown on Figure 5.1. Two of the monitoring wells were outside the

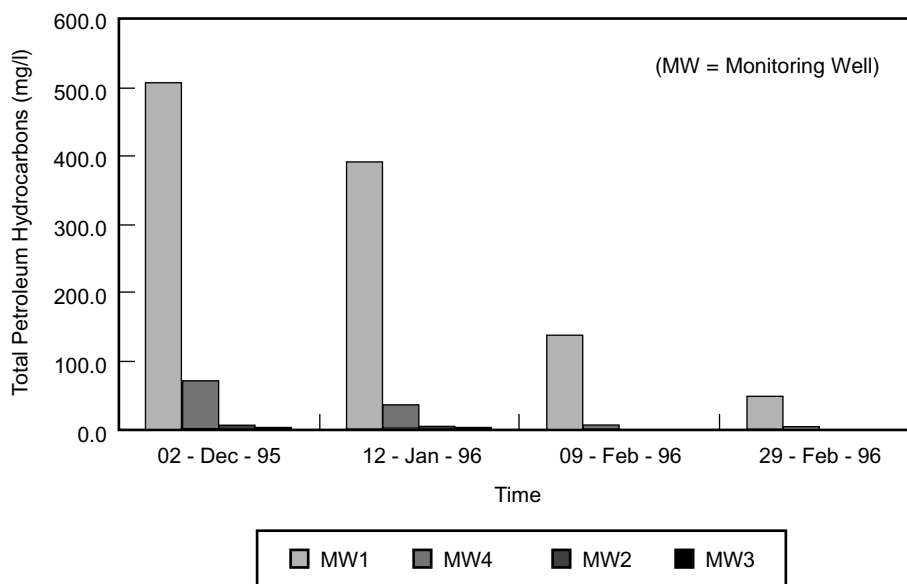


Figure 5.1 Total petroleum hydrocarbons in groundwater vs. time at petrol station site

zone of contamination and gave values below the target level of 10mg/l on all occasions. In the remaining two wells, TPH concentrations dropped markedly with time, but at the end of the treatment period concentrations were still above the target level in one of the wells. Despite this, the vacuum extraction operation was stopped in mid February 1996 and the plant was demobilised from site. The specialised contractor reported that 906 litres of product was recovered, 1276m³ of groundwater treated and approximately 734kg of product recovered in the vapour phase.

Demolition of the site buildings and excavation of underground storage tanks commenced at the end of February. The groundwater monitoring wells were destroyed in the course of these works. The soil was screened with a Hanby Test Kit for TPHs, and material exceeding the target level of 1000mg/kg TPH was removed from site and sent to a licensed landfill site. A total of 240m³ of contaminated soil was removed from site; this agreed well with the pre-contract estimate of 250m³ made by the environmental consultant. During the tank removal procedure, a small amount of free phase product was encountered within the main tank farm excavation. This product and associated groundwater was pumped out of the pit and removed from site. Two groundwater samples were taken from the open excavations in mid March and tested; one gave a TPH of 10mg/l, the other 170mg/l. The site was then backfilled with granular Class 1A fill.

Following removal of the tanks and contaminated soil, a soil gas survey was carried out. Areas where soil VOCs exceeded the target level of 50ppm were excavated and turned a number of times to allow the vapours to vent to the atmosphere. A further soil vapour survey was carried out in late March. This survey indicated significantly reduced VOC concentrations at all of the locations tested. Two isolated hotspots were encountered, but the environmental consultant considered that they were unlikely to be significant or indicative of any major residual contaminants on site.

The environmental consultant submitted a Completion Survey and Verification Report for the site in April 1996, in which they concluded that, 'the site has been remediated sufficiently for the proposed non-sensitive end use'. No further activity has occurred since that date, and there are still no groundwater monitoring wells at the site.

Spillages of petrol and other volatile and semi-volatile organic compounds are common at petrol stations and many other industrial sites. As such, they are likely to be encountered frequently on highway schemes in urban and industrial areas. The problems encountered on this site may thus be replicated elsewhere.

The first complicating factor was that the clean-up was commissioned and carried out by the owners of the land, and not by HA. This is in accordance with the 'polluter pays' principle. Therefore the methods and standards were dictated by the owners, with HA able to observe but not significantly influence the works. The standard of the initial investigations and the monitoring during the site works was below what would be acceptable in a project carried out directly for HA and short of the levels

suggested in CIRIA Special Publications SP 104 Classification and selection of remedial methods, SP 109 In-situ methods of remediation and SP 111 Planning and management (Harris *et al.*, 1995).

Where remediation works are carried out directly for HA, e.g. in the case of old derelict land where no owner or polluter can be found, proper standards of investigation and validation can be applied as part of the Specification. Where the responsibility for clean-up lies with another party, however, the HA may find that lower standards are applied and the consequent level of clean-up is unsatisfactory.

The installation and operation of the vacuum extraction system appears to have been in accordance with best practice. The monitoring of soil and soil vapour contamination levels during excavation also appears to have been satisfactory. The system was certainly effective in greatly reducing the level of contamination at the site, and in conjunction with the subsequent removal of contaminated soil and pumping of contaminated groundwater from open excavations has removed the bulk of the contamination. The main purpose of the vacuum extraction was to allow the excavation and removal of underground storage tanks and contaminated soil to be carried out in safety, and this was satisfactorily achieved. However, the decision to stop the system before the target groundwater TPH levels were achieved in one monitoring well in the contaminated area will probably lead to higher levels of residual contamination than would otherwise have occurred, and the absence of any replacement monitoring wells means there is no way of establishing the actual levels of contamination.

The case study also highlights the importance of consulting the regulatory authorities before commencing any remedial works. It is recommended that HA insist that any proposed remedial works and risk assessments for contaminated land be submitted to EA for approval in advance of the works being carried out.

5.3 Recycling of landfill materials

The A12 Hackney to M11 Link Road, Contract 1 - A102(M) to Temple Mills is a short section of road, which crosses the valley of the River Lea in east London near Hackney Marshes. Work on the site commenced in the spring of 1997. It was carried out for the Highways Agency by a Joint Venture of contractors Fitzpatrick and McAlpine, with W S Atkins as the Engineer.

The route cuts through a Victorian landfill and other areas of made ground, much of it thought to consist of demolition rubble from bomb damaged houses during the Second World War. High approach embankments are required for bridges over the River Lea and an existing railway. In the original design, the excavation materials were classified as unacceptable because of contamination, and were to be removed from site and the embankments constructed with imported materials. However, the Joint Venture submitted an alternative design to reprocess the excavation materials on site and use them for embankment construction. This was approved by the Highways Agency subject to the reprocessed material being covered by a

layer of natural Class 1A fill. The approval of the Environment Agency was obtained at an early stage in the process, subject to leaching tests being carried out on a regular basis to identify potentially polluting materials.

The areas to be excavated were first investigated by trial pits on a 30 m grid. Samples were taken for total chemical analysis and for the NRA leaching test (Lewin *et al.*, 1994). In nearly all cases the values obtained from the leaching tests were below the drinking water standards and the material was classified as suitable for reprocessing. 'Hot spots' of contaminated material were identified by the trial pit survey and the material was excavated and sent to a licensed landfill site.

The reprocessing system uses basic quarrying technology such as crushers and grading screens. The material from the excavations was fed into a hopper with an 80 mm screen. Material not passing this screen passed along a conveyor belt, where unacceptable materials such as timber, paper, plastic, sacking and metal wires were removed manually and dumped in a skip. The quality control at this stage was vital to the success of the operation. The material passing the 80 mm sieve formed a well-graded Class 1A fill material, which was stockpiled and used as general embankment fill. In addition to the 80 mm sieve, 125 mm and 6 mm sieves were available and had been used from time to time, depending on the grading of the incoming material. The plant is shown on Plate 3. The oversize material was sent to the crusher, where it was crushed to produce Class 6F2 capping material.

The material processed was mainly a mixture of dark grey ash material and demolition rubble. This proved suitable for treatment, with very little material being rejected. However, the material had a significant fines content, and work had to be suspended in wet weather. The plant was handling an average of 400 m³ per day, and was reported to have a maximum capacity of 650 m³ per day. These rates are much lower than would be achieved on a greenfield earthworks site. However, in the context of this

particular site, the reprocessing was economic. This was due to several factors. First, the high cost of sending all the excavated material to landfill and importing acceptable material; in this inner city location, the distances to suitable landfill sites and sources of acceptable natural material are very large, and haulage costs are increased by the congested nature of the roads and consequent high journey times. Second, the constricted nature of the site meant that it was only possible to carry out small amounts of earthworks operations at any one time; hence, the restrictions on working rate imposed by the reprocessing plant did not hold up the earthworks in the same way as they would on a greenfield site. By keeping the plant working steadily and stockpiling the reprocessed materials, the contractor was able to keep the earthworks on schedule.

From the Highways Agency point of view, while there was general approval of the principle of reprocessing the material, there were concerns that HA might end up with long term liabilities because of the presence of 'contaminated' materials on the site. This was particularly acute in the case of excavations for services, which would encounter the reprocessed material. The excavated material might be classified as contaminated, with consequent high costs of disposal. This point was resolved by installing a layer of natural Class 1A fill to cover the reprocessed material; all excavations for services will be confined to the layer of natural material.

The earthworks were completed in 1998. The quantities involved were estimated to be roughly 35,000 m³ of nominally contaminated site won material, reprocessed as Class 1A general fill; approximately 25% of the total general fill. In addition, roughly 15,000 m³ of concrete was crushed and reprocessed as Class 6F2 capping; approximately 55% of the total capping material. The case study indicates how reprocessing of old landfill material with low levels of contamination as general fill can be economic in inner city locations, where the distances to landfill sites are great and the rate of earthmoving is constrained by the limited space available.



Plate 3 Mechanical sorting of old landfill material for use as Class 1A fill

5.4 Construction through old landfill sites

In many urban areas, highway schemes now follow corridors of dereliction, including landfill sites and contaminated land, in order to minimise environmental impact or because no alternative routes are available. As a result, a number of highway schemes in recent years have been constructed in or adjacent to landfill sites. The highway design has in many cases involved isolation of the highway from the waste by means of barriers to prevent leachate and landfill gas from migrating into drains and services. Because of the compressible nature of the waste, however, there is always a concern that in the long term the barriers might deform and allow leakage of gas or leachate. A review of some of these sites was carried out to give an indication of how they have performed and to assess the likely level of future maintenance requirements.

5.4.1 A650 Drighlington bypass

The Drighlington bypass on the A650, south west of Leeds, was opened to traffic in November 1991; the site is one of the case studies of highway schemes through areas of contaminated land described by Perry (1994). The route passed for 600m through a recently completed industrial waste tip, which contained a variety of putrescible and non-putrescible materials. The older parts of the tip consisted mainly of foundry sand, but the more recent layers contained materials such as polythene, paper, cardboard, cans, bottles, textiles, sawdust, wood, fibreglass and plastics. The landfill reached a maximum depth of 13.5m near the eastern end. This material had the potential to generate significant quantities of landfill gas and leachate.

Two alignments through the tip were considered; a high route passing through the tip in a shallow cutting, and a low route founded at the base of the tip. It was decided to adopt the high level route, with the construction of a barrier

system to isolate the carriageway from the tip material and allow the gases to vent to the atmosphere. This was significantly cheaper than the option of excavating all the landfill material and disposing of it elsewhere.

Crawshaw (1993) and Perry (1994) have described the design and construction. The carriageway was isolated from the landfill by an impermeable membrane and clay fill, with an underlying layer of rockfill to allow gas to escape via a series of 14 venting columns. A typical section through the tip is shown on Figure 5.2 (from Crawshaw, 1993). Maximum settlements of up to 1350mm were anticipated, based on the waste thickness. The road was therefore surcharged by 5m of fill for two years to consolidate the fill and reduce long term settlements. Up to 700mm settlement was recorded during placement of the surcharge material, with up to 500mm further settlement in the main body of the tip during the two-year monitoring period. The drainage design allowed for up to a further one metre of settlement between the centre of the tip and the eastern end, where large settlements were forecast. A continuously reinforced concrete roadbase was constructed to accommodate ongoing differential settlement within the landfill. Crawshaw (1993) stated that 'cost effective maintenance to the vertical alignment would be limited to regulating in basecourse, replacing the wearing course and asphalt kerb when the ride quality deteriorated to an unacceptable standard'.

After the road had been open for seven years, the long-term effectiveness of the protective measures was assessed. The site was visited in July 1998 and discussions were held with the Maintaining Agents (Leeds City Council) and the Resident Engineer for the construction of the scheme. The Maintaining Agents stated that no problems with settlement had been reported. Readings of gas levels were taken quarterly in the gas venting columns and in lighting columns sited inside the impermeable membrane. The readings show high concentrations of methane and carbon dioxide, typical of landfill gas, in some of the gas vents.

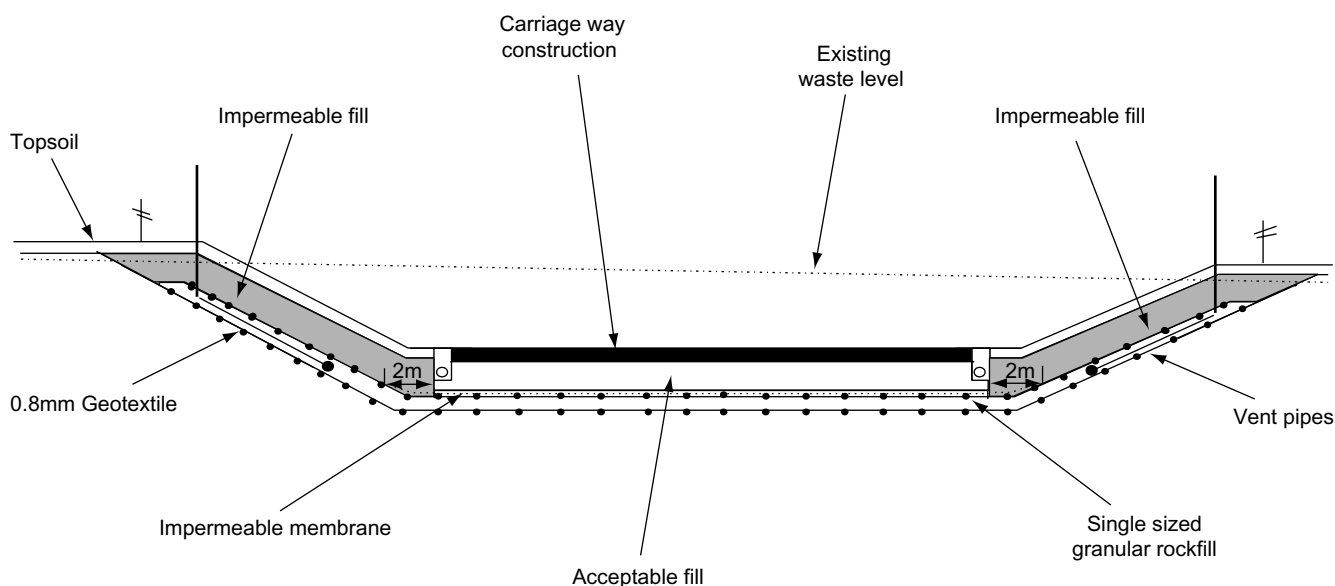


Figure 5.2 Cross section of gas protection measures at Drighlington bypass (from Crawshaw, 1993, reproduced by kind permission of M D E Crawshaw)

No gas was detected in the lighting columns, which are inside the gas protection system. This indicates that the system is still working satisfactorily in isolating the carriageway from the landfill.

Low levels of gas were consistently recorded in the gas venting columns at the western end of the site, where the fill was thinnest, but in all other areas significant gas levels were recorded. The levels recorded varied considerably between readings, and there did not appear to be any systematic pattern. The gas levels showed no correlation with atmospheric pressure or season, nor was any clear trend with time apparent. Clearly, high levels of gas are likely to continue to be present in the tip for some years. This implies that considerable degradation of the fill has taken place since construction, and is liable to continue. This in turn implies continued settlement of the waste.

On site, it was noted that several of the gas venting columns were off the vertical. This may be due to settlement of the underlying fill. The lighting columns, which are much closer to the carriageway, did not show any signs of movement. This would appear to confirm that the measures taken to isolate the carriageway from the landfill are still performing satisfactorily. It was not anticipated that any leachate would occur in the higher levels of the landfill, but one of the functions of the rockfill layer was to allow any which did form to drain down into the landfill without entering the carriageway drainage system. No signs of leachate were observed on the cutting slopes or in the road gullies, providing further indirect evidence that the measures are still functioning as intended.

A 'step' was visible in the carriageway at the eastern end of the landfill section; traffic coming from the east was observed to dip visibly as it crossed this step. This corresponds to the location where the thickness of landfill decreases rapidly from its maximum of 13.5m to zero. The section on the landfill has continued to settle relative to the section on natural ground. The road surface did not show any indication of cracking, nor did the kerbing; however, the continuously reinforced concrete roadbase must be under considerable stress due to this rapid change in level.

Signs of settlement were also noted on the eastbound carriageway near the western end of the section on landfill and between some of the gas vents. These were much less pronounced than the settlement at the eastern end. Cracking of the road surface was observed around almost all the gullies.

The design of the road pavement and drainage allowed for a considerable amount of settlement between the centre and the eastern end of the tip. It is not known how much the road has settled as a whole since construction. However, the sharp differential settlement at the east end may cause problems if it continues to develop.

In conclusion, the isolation measures are still proving effective in allowing gas to vent from the tip and preventing leachate entering the carriageway area. Settlement is continuing, and resurfacing may be required at some point. However, this appears to be well within what was anticipated at the design stage.

5.4.2 A46 Coventry eastern bypass

The A46 Coventry eastern bypass passed through a landfill site over a length of 300m immediately north of the A427. Gabryliszyn (1987) describes the design of the scheme. The tip was formerly a sand and gravel quarry infilled with a complex mixture of bomb damage clearance, industrial and chemical waste deposited over a period of 30 years up to 1980. A site investigation was carried out, and the fill was found to consist of a matrix of grey/black foundry sand with variable amounts of gravel, clay, hardcore, concrete, slate, slag, clinker, glass, timber, cardboard, paper, metal, wire, rubber, plastic, paint sludge and traces of asbestos. The groundwater level was about 3m above the base of the tip and the groundwater was in places contaminated with oil and other organic compounds. Some of the fill materials were putrescible, and flammable gases were found in 6 out of the 15 boreholes, generally at low concentrations. This suggests a relatively low rate of gas production under the prevailing conditions, reflecting the age of the tip and the limited amounts of putrescible material.

The original vertical alignment passed below the base of the tip; the pavement level was in the underlying Mercia Mudstone, about 4m below the groundwater level and involving cutting slopes up to 10m high in the landfill material. Various options were considered to deal with the landfill. Two options involved retaining the vertical alignment, dewatering and treating the contaminated groundwater both during construction and in the long term, and installing various measures to isolate the carriageway and cutting slopes from the landfill. Both options involved the excavation and removal of over 100,000m³ of contaminated material from the tip.

The third option, which was adopted and constructed, involved changing the vertical alignment so that the road passed through the tip in a shallow cutting above the water table. An impermeable clay seal was laid on the cutting slopes to keep the road drainage separate from the tip. The subgrade now consisted of the tip material, which consisted mainly of foundry sand. Although not an engineered fill, this material was stated to be not very compressible. A 1m layer of rock fill was placed on top of the tip material to provide a firm platform for the carriageway. This option greatly reduced the amount of fill material which had to be exported from the tip. The change in vertical alignment had other side effects; the A427 now passed below the bypass, and a cut-off wall had to be constructed between the southern edge of the tip and the top of the A427 cutting slope to prevent contaminated groundwater from the tip seeping into the A427 cutting. Despite this, the high level option was considerably cheaper than the two low-level options, and was selected for construction.

The situation has some similarities to the Drighlington bypass; a shallow cutting through a gas-producing landfill with impermeable barriers to keep the drainage from the road separate from that of the tip. There are significant differences, however; settlement and gas were not considered serious problems on the Coventry eastern bypass, no venting columns for landfill gas were included, and no monitoring boreholes for gas, leachate or settlement were installed. The layer of rock fill below the

carriageway was not installed to provide an escape route for landfill gas, but to increase the strength of the subgrade. This may have been because the waste was mainly foundry sand and was not considered to have a high potential for decomposition and gas production, compared to the more putrescible material at the Drighlington bypass.

The current Maintaining Agents, W S Atkins, were contacted and stated that they were not aware of any settlement problems on this section of road.

Several other schemes in the West Midlands pass through landfill sites. The M40 south of Warwick passes through a tip, but the road level is in the Mercia Mudstone below the base of the tip so no problems of settlement are anticipated. The M42 east of Bromsgrove goes through three adjacent tips. One consisted of putrescible waste and tyres; the road was above the tip level, and a rock mattress 150-200mm thick was placed on top of the tip. It is anticipated that any settlement will be made up by maintenance over time. The second tip consisted of domestic refuse and sewage sludge; this was removed completely from the line of the road and replaced elsewhere in the tip. The third tip consisted of plating liquids for metals, including drums of cyanide. This was also removed. No specific measures to control landfill gas were included in any of the schemes, and no long-term problems have been reported.

The conclusion from the two sites is that engineering methods, if properly designed and constructed, can be successfully used to construct roads through old landfill sites. While some long-term settlement does occur, it appears to be within predicted values and does not adversely affect the performance of the road.

5.5 Stabilisation/solidification of contaminated slags with cement and additives

The use of cement and proprietary additives to treat contaminated metal working slags and made ground was investigated as part of the CIRIA programme of case study demonstrations of remediation of contaminated land (Jardine and Johnson, 2000). The trial involved treating a total of six materials with the commercial GEODUR solidification/stabilisation system. The materials were mixed and placed as ground slabs in a site at Wath Manvers, West Yorkshire in December 1994, and left exposed to the weather. They were sampled and tested over a period of 18 months after construction.

In 1998, the materials were sampled and tested as part of the present project, to obtain evidence on the effects of age on stabilised/solidified (S/S) contaminated materials. Because the S/S materials have been left exposed to the weather, they have been subjected to more severe weathering conditions than fill materials would normally encounter in a highway earthwork. The trial thus represents an accelerated weathering test for the S/S materials, simulating the effects of a much longer timescale than the 1200 days between placing the slabs and sampling for this project.

The trial was not designed with highway earthworks in mind as a specific end use for the materials. However, the

experience from the trial is of general benefit for the understanding of the long term behaviour of S/S contaminated materials. The results are reported in TRL Report 451 (Board *et al.*, 2000), and the main points are summarised below:

- The early (7-day) strength of the S/S contaminated materials was low. This was ascribed to the effect of contaminants on the hydration of the cementitious compounds. This would limit the use of the materials as cement bound materials (CBM) in highway construction.
- After 28 days, all the materials had developed significant compressive strength. The strength of all the materials increased with time, and there was no indication of any physical breakdown or loss of strength in the long term.
- One of the S/S materials was crushed after one year and left on the site. This material was found to be acceptable for Class 1 and Class 6 earthwork applications, as unbound Type 1 sub-base and as an aggregate in a CBM.
- Leaching tests showed that Cd, Hg, Ni, Zn, hydrocarbons and PCBs were effectively immobilised by the S/S treatment. However, Al, Pb, Cr, phenols and polycyclic aromatic hydrocarbons (PAHs) were leached from one or more of the materials at concentrations greater than environmental quality standard values.
- Using the scheme proposed in CIRIA Report 167 (Baldwin *et al.*, 1997) for alternative materials in highway construction, four of the materials fell in Group 1 (no restrictions to use based on potential to affect water quality) and two fell in Group 2 (may require some restrictions to use based on potential to affect water quality). Samples of drainage water from the site were of high quality, suggesting little leaching of contaminants was taking place.

The study confirms that S/S can be satisfactorily used to treat contaminated materials for highway works provided adequate trials are carried out to determine the best mix and to enable a site-specific risk assessment of leaching potential to be carried out. In particular, the trial gave no indication of any long-term breakdown in either the physical properties or the potential leaching of contaminants from the materials.

6 Treatment of fine grained contaminated materials with lime

The use of stabilisation/solidification techniques using inorganic cementitious materials was identified at an early stage in the project as a potentially important remedial technology for contaminated materials in highway schemes. It was therefore decided to carry out detailed research on this method. The experimental work concentrated on the use of lime for treating fine-grained materials, but the conclusions are applicable to other cementitious agents, and to other construction applications.

The processes by which cementitious agents act on contaminated materials are *stabilisation* - changing the chemical form of the contaminants to render them less

mobile - and *solidification* - changing the physical properties of the material (Harris *et al.*, 1995). The processes are referred to as stabilisation/solidification, or s/s methods, and most applications involve a combination of both effects. There is potential confusion with the terms *stabilisation* and *modification* which are used in civil engineering in regard to the improvement of the physical properties of soil by the addition of lime or cement (MCHW 1). In this terminology, *modification* refers to the reduction in moisture content and plasticity index which occurs immediately on addition of the cementitious agent, whereas *stabilisation* refers to the formation of cementitious compounds, which develop over time in the material (Sherwood, 1993). However, the formation of cementitious compounds does not necessarily mean that the chemical form of the contaminants has been altered, which the use of the term *stabilisation* implies, and *modification* is essentially an example of a *solidification* process.

One of the advantages of s/s is that it is familiar to contractors and consultants from civil engineering works. However, this familiarity may lead to an incorrect understanding of what s/s technology does and how it should be implemented. Each case has to be considered individually to see what effects the addition of cementitious agents will have for the particular material under consideration.

6.1 Objectives

The objectives of the experimental work were to establish the long-term mechanical and environmental stability of fine grained contaminated material that had been treated with lime. The long-term stability of such material is unclear. Contaminants are not destroyed by the process of stabilisation with lime, but are thought to be held only by entrapment in the cementitious compounds (Harris *et al.*, 1995). There is therefore a possibility that they could be leached out in the long term if the cementitious compounds start to break down. This could also affect the geotechnical properties of the material, which would be a source of concern in a highway earthwork. Any material incorporated in a highway earthwork would be expected to be stable for 60 years, so the long-term effects are particularly important.

The materials chosen for the study consisted of contaminated silts and sludges from the A13 Improvement Scheme at Rainham Marshes, Essex. The lightly contaminated silt was mixed with pfa on site to produce a material with lower moisture content, which could be handled more easily. At TRL a proportion of contaminated sewage sludge was added to the mixture to produce a more heavily contaminated material. The material was unsuitable for general fill due to its low strength, indicated by its CBR value of less than 1% (Table 6.1).

6.1.1 Mechanical stability

The main objective in terms of mechanical stability was to establish the long-term effects of leaching and weathering on the physical properties of lime treated material. The

Table 6.1 Acceptability criteria for lime treated material

Property	Untreated material	Treated material	
		Lower bound	Upper bound
Prior to lime addition:			
Grading	Class 7E	Class 7E	Class 7E
Plasticity index	36%	10%	–
Prior to final compaction:			
MCV	6.7	8.5	12
After final compaction:			
Immediate CBR	0.8%	3%	–
Immediate air voids	–	–	10%
7 day CBR	–	5%	–
28 day swell	–	–	5mm

lime treatment was carried out in order that the material could be classified as suitable for general earthworks fill in highway works (MCHW 1). Acceptability criteria are listed in Table 6.1. It should be noted that these criteria are different from those which would be used for lime stabilised capping material, where a minimum CBR of 15% is required (DMRB 4.1.6). They are also different from those that would be applied if the stabilised material was to be sent to a landfill site for disposal. It is important that acceptability criteria match the requirements for the treated material, and are not simply taken from a standard list without consideration of the particular application.

6.1.2 Environmental stability

The makeup of the test material, including the proportion of lime to be added, was determined in accordance with the objectives for initial mechanical stability. The objectives in terms of environmental stability were to determine the extent to which treatment with lime acts to entrap contaminants within the soil, preventing leaching of contaminants into the environment, both initially and in the long-term. The aim was to establish whether lime treatment could render an unsuitable, contaminated material suitable for general earthworks fill.

6.2 Test programme

A research programme was devised to address the objectives of the experimental work. Tests were carried out on natural material and lime treated material under both controlled laboratory and site conditions. The programme consisted of four main parts:

- trial mixes;
- laboratory leaching tests;
- experimental test bed;
- site tests.

The trial mixes, leaching tests and experimental test bed are described in the following sections. The site tests were described in Sections 5.1 and 5.5.

6.2.1 Trial mixes

Tests were performed on trial mixes to determine the best mix, which could satisfy the general criteria for earthworks fill. The aim was to establish an acceptable mix with as high a percentage of sewage sludge, and as low a percentage of lime as possible. The proportion of sludge was maximised in order that the soil was as contaminated as possible, and the amount of lime minimised on the grounds that excessive lime content would render the process uneconomic.

6.2.2 Leaching tests

Leaching tests are frequently used to predict the long-term behaviour of materials, because they allow a much greater degree of contact between solid and leachant than generally occurs in nature. Hence they can be used to simulate in a relatively short period of time changes which would take many years to occur in the field. However, the nature and the scale of the reactions which occur in leaching tests may be significantly different from those which occur in the field. Care is therefore required in the selection, design and interpretation of leaching tests if useful results are to be obtained.

Leaching tests fall into the two broad categories of extraction tests and dynamic tests. Dynamic tests, which include flow-through tests, are closer to the field situation than extraction tests. They allow the kinetics of the reactions to be examined, as the composition of the leachate can be monitored during the test. Extraction tests simulate equilibrium conditions, where given quantities of solid and leachant reach a chemical 'balance point'. After a reasonable contact time, the composition of the leachate will remain constant. Dynamic tests simulate natural, non-steady-state conditions, where concentrations vary with time as weathering proceeds, soluble products are removed and further reactions take place.

It was decided that the type of test used in this investigation should reflect as closely as possible the field conditions to which stabilised contaminated material will be exposed in highway earthworks, and also address the aim of the experiment, which is to assess the long term stability of the material in terms of geotechnical properties and release of contaminants. In a highway, stabilised material is most likely to be placed above the water table in an embankment or as a replacement for unacceptable material below formation level. It will therefore be subject mainly to unsaturated flow via downward percolation from surface drains, granular capping layers, cracks in the road pavement and from rainfall on embankment shoulders. A dynamic test with monitoring of leachate quality during the test seemed to be the most appropriate method.

6.2.3 Pilot scale test bed

Laboratory tests are very helpful in assessing the behaviour of materials under controlled conditions. Conditions which prevail in the field are significantly different from those in the laboratory, and hence the results of laboratory tests cannot simply be scaled up to predict the field behaviour. Unlike the constant temperature and full saturation of the laboratory

tests, in the field the materials will be subject to variable temperatures and degrees of saturation. This could lead to differences in their physical and chemical performance. In order to address these differences and determine the effects of natural weathering on the strength and drainage products of the stabilised material, a pilot scale outdoor test bed of the same test material was constructed at TRL in July 1997. The test bed was monitored for 15 months.

6.3 Materials and trial mixes

6.3.1 Materials

The materials studied consisted of contaminated silts and sludges from the A13 Improvement Scheme described in Chapter 5. The silt is only slightly contaminated, having elevated concentrations of some metals, sulfate and sulfide, and organic matter. The main contaminant is sulfide, which oxidises to sulfate on exposure to air. The silt was mixed with pfa prior to lime addition to produce a material with a lower moisture content, which could be handled more easily.

The contaminated sludge, which was mixed with the silt/pfa mixture to produce a material more representative of a significantly contaminated site, is a sewage sludge from the drying beds of a sewage works which underlies part of the A13 site. The sludge contains high concentrations of metals, sulfate, sulfide and toluene extractable organic matter. In order to determine the optimum mix proportions required to achieve the objectives for mechanical stability described in Section 6.1.1, different mixtures of silt/pfa/sludge and lime were prepared and tested.

6.3.2 Testing of trial mixes

For a range of mixtures of silt/pfa/sludge and lime, samples were tested for MCV and CBR after a mellowing period of 24 hours. The samples were then compacted in CBR moulds, cured in air-tight containers for 3 days, then put in a tank to soak, following the procedure of BS 1924: Part 2 (British Standards Institution, 1990). After 4 days soaking, samples were tested for the 7 day CBR and swelling. Further samples were tested after 14 and 28 days from the end of the mellowing period.

Tests indicated that a sample with 5% lime and either 5 or 10% sludge would yield an acceptable general fill material based on the criteria outlined in Section 6.1.1. It was decided to use the 5% sludge, 5% lime, 90% silt/pfa mixture for the laboratory tests, as there would be a risk of the sample not meeting the CBR requirements with the higher sludge content, and in view of lower swelling values of the 5% sludge mix.

Quick undrained triaxial compression tests were carried out on untreated silt/pfa samples and a silt/pfa mixture with 5% sludge and 5% lime after a 7 day curing period exactly similar to that used for the CBR samples. Treatment with lime results in shear strength of about 155kN/m², nearly three times the strength of the silt/pfa mixture. The shear strength values are consistent with the 7 day CBR values of 6%, and confirm that the stabilised material has satisfactory geotechnical properties for a general fill material.

6.4 Leaching tests

In order to represent as closely as possible the field conditions, to which stabilised contaminated material would be exposed in highway earthworks, it was decided to undertake flow-through dynamic leaching tests. The interim NRA recommended test (Lewin *et al.*, 1994) which is a single stage extraction test, was also carried out to provide a comparison with the flow through tests. The tests carried out at TRL are described in detail in Reid and Brookes (1999). Specially designed permeameter moulds were prepared to allow testing of duplicate 100mm diameter samples under controlled conditions. The apparatus is shown on Plate 4.

Sets of tests were run on both stabilised and unstabilised samples using both distilled water and dilute sulphuric acid as leachants. Distilled water was used as it gives the best indication of the intrinsic solubility of the stabilised materials, allowing comparison between samples. However, water percolating into a highway embankment would be expected to be largely rainwater, with contaminants picked up from the road surface and embankment topsoil. Rainwater will generally be fairly low in dissolved solids (<50mg/l) and weakly acidic (pH 4 to 6). As acid attack was considered to be a potential cause of degradation of the stabilised material, leaching tests with dilute acid as the leachant were also carried out.

The permeability of the samples and the pH and conductivity of the leachate was monitored regularly during the tests, and samples of leachate sent for chemical analysis. A final leachant to solid ratio of 10:1 was selected for the flow through tests as this is the ratio used in the NRA test and would allow comparison between the two test methods.

On conclusion of the permeability and leaching tests, the samples were extruded and mounted in a triaxial compression machine for determination of their undrained shear strengths. Testing followed the method described in BS1377: Part 7:1990 (British Standards Institution, 1990b).

In order to determine the effects of a diesel spillage on the mechanical strength of stabilised material, a test was set up where four compacted, stabilised samples were soaked in diesel for a period of 28 days. Samples were then extruded, mounted in a triaxial compression machine and tested for their undrained shear strengths. Results were compared to those of four control samples soaked in water for the same period.

6.5 Pilot scale test bed

A pilot scale outdoor test bed (5.0 m x 1.7 m x 0.2m) containing the same material as was used for the laboratory tests was constructed at TRL. The test bed consisted of a 200 mm deep bay with concrete base and surround. The base of the bay, which was constructed at a slight gradient, was lined with an impermeable rubber membrane to intercept drainage and direct it towards a grille at one end, where it was collected for chemical analysis. The surface was left open to the atmosphere. A batch of the lime treated material was mixed, placed and compacted in thin layers (50 mm to 100 mm) with the aid of a JCB and a small vibrating plate compactor. The test bed is shown on Plate 5. The conditions to which the test bed was exposed represented a more severe environment than the material would normally be exposed to in a highway earthwork, where it could be covered with a capping layer, road pavement or topsoil.



Plate 4 Apparatus for dynamic leaching tests in the laboratory



Plate 5 Test bed of contaminated silt treated with lime (sample being taken for triaxial testing)

Soil samples were taken from the test bed for shear strength testing at specified time intervals in order to monitor the development in strength of the material. Samples of the material (taken before compaction in the test bed) were compacted and cured in the laboratory in accordance with BS 1924: Part 2 (British Standards Institution, 1990a). In order to compare the field and laboratory test results, testing of both the laboratory and field samples was carried out at the same time intervals.

The drainage from the test bed was collected and samples taken for chemical analysis at regular intervals over a period of 15 months. Most of the water collected was probably runoff rather than percolation, given the low permeability of the material (see Section 6.6.1).

6.6 Results

6.6.1 Leaching tests and mechanical stability

Using distilled water as leachant

The results of the initial tests using distilled water as leachant are shown in Figure 6.1. The permeability of the lime treated material was very low, with k values decreasing slightly from 2×10^{-9} m/s to 9×10^{-10} m/s by the conclusion of the test. Whilst the pH remained constant at around 12.6, the conductivity peaked rapidly at 1460 mS/m before falling to about 500 mS/m when the leachate/soil ratio reached 3:1. Thereafter the rate of decrease steadied, falling only another 200 mS/m by the end of the test. Conductivity is an approximate measure of the dissolved solids content of the leachate; using a standard correlation (Todd, 1980), the peak conductivity corresponds to a dissolved solids content of about 9,300 mg/l and the conductivity at the end of the test to a dissolved solids content of about 1,900 mg/l. The values of pH and conductivity obtained in the NRA test are also shown on Figure 6.1. The pH in the NRA test was identical

to that in the dynamic test, but the conductivity in the NRA test underestimates the peak value and overestimates the final value.

The results of shear strength tests for leached and unleached samples tested seven days after compaction are shown in Table 6.2. The increase in shear strength in the stabilised material over the duration of the leaching test suggests that the formation of cementitious compounds has continued despite the leaching process.

Table 6.2 Shear strength of test samples

<i>Material</i>	<i>Shear strength (kPa)</i>
Untreated	25
Treated (distilled water leached)	230
Treated (dilute acid leached)	145
Treated (unleached)	155
Test bed as placed	98
Test bed after 1 year	232
Diesel soaked (treated, unleached)	139
Water soaked (treated, unleached)	142

The untreated material (control sample) was much softer than the lime treated samples with an undrained cohesion (c_u) of around 25 kPa. Because of this, much lower hydraulic pressures had to be used to avoid leakage round the edges of the samples. The test established that the permeability of the untreated material was approximately 1.5×10^{-9} m/s. This is very similar to the permeability of the lime stabilised material when leached with distilled water.

Using dilute acid as leachant

The results of the second series of tests using dilute sulphuric acid at pH 4.0 as the leachant are also shown on Figure 6.1. The permeability rose from initial values

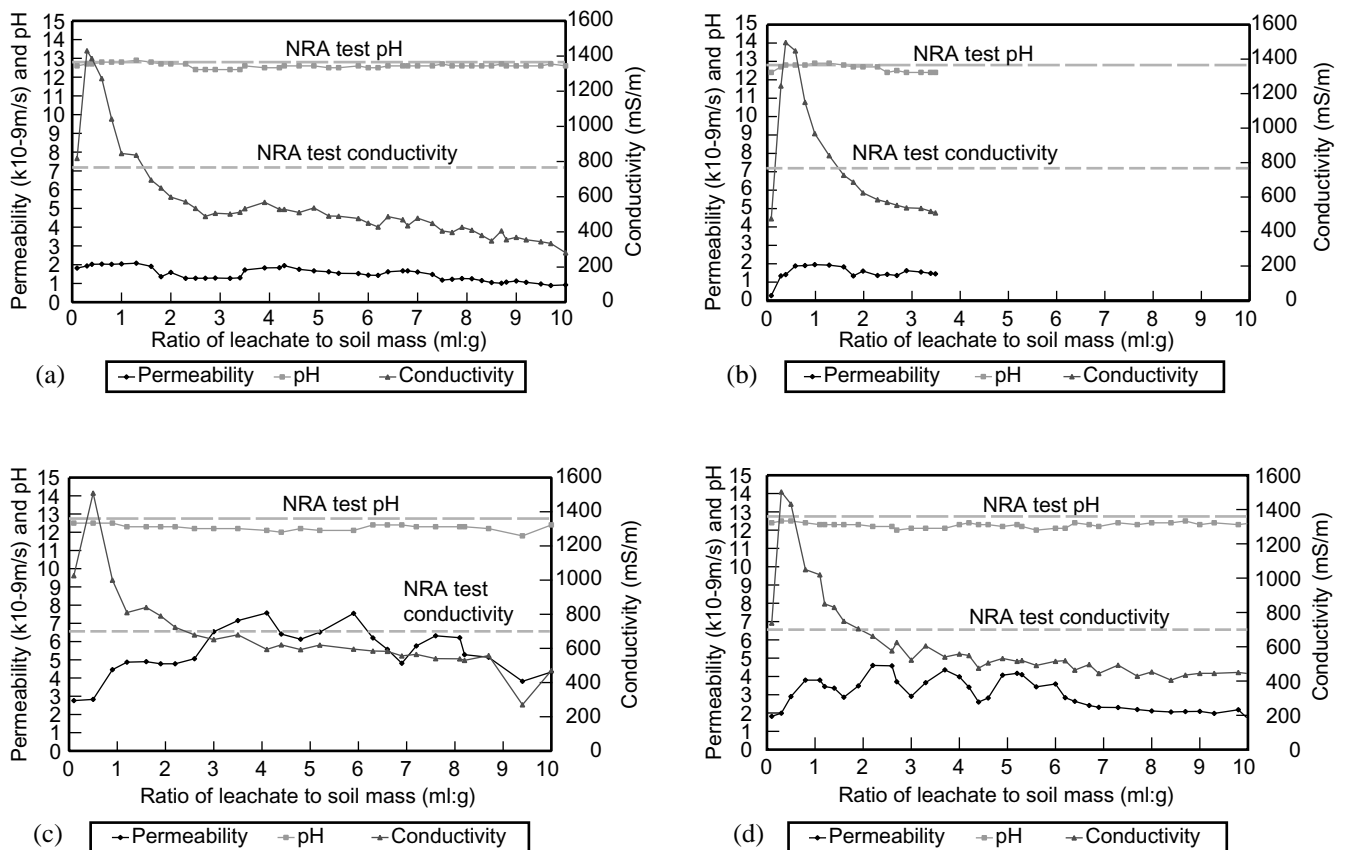


Figure 6.1 Results of dynamic leaching tests: (a) distilled water, sample 1; (b) distilled water, sample 2; (c) dilute acid, sample 1; (d) dilute acid, sample 2.

of 2×10^{-9} m/s to 6×10^{-9} m/s by the middle of the test, then decreased to 3×10^{-9} m/s by the end of the test. The use of dilute acid thus seems to have had only a minor effect on the permeability of the material. The pH of the leachate remained above 12 throughout the test, as with distilled water, and the conductivity showed a very similar pattern, though it was somewhat higher than for distilled water in the later stages of the test. As before, the NRA test gives an identical pH to the dynamic test but underestimates the peak conductivity and overestimates the long-term value.

The leached samples gave a mean c_u value of 145 kPa (Table 6.2), similar to that for unleached samples seven days after compaction. There was however a considerable difference between the two samples, one giving a c_u of 184 kPa and the other 108 kPa. The c_u values do not show any correlation with the dry density or moisture content of the samples.

Diesel tests

The comparison of results of shear strength tests on stabilised samples soaked in diesel for 28 days with similar samples soaked in water show that the diesel has no significant effect on the soil strength (Table 6.2). The diesel-cured samples gave a mean c_u value of 139 kPa and the water-cured samples gave a mean c_u value of 142 kPa.

6.6.2 Chemical tests and environmental stability

Leachates derived from NRA tests

The results of chemical analyses on samples from the NRA

tests and the control tests on unstabilised material are shown in Table 6.3. The concentrations of most metals in the leachates from the lime treated material were low, often below detection limits. However, concentrations of copper, nickel, ammonium, phenol and calcium were higher than in the leachate from the untreated material. From the chemical analyses of the solid materials and the leachate from the NRA tests, the percentage of each determinand mobilised can be calculated. The results are shown in Table 6.3. The percentage of metals, sulfate and total organic carbon mobilised in the NRA test was very low. By contrast, the proportion of chloride and sodium mobilised was very high in both the treated and untreated material. The percentage of calcium, copper and nickel mobilised in the treated material is higher than in the untreated material. This is logical for calcium, because of the addition of lime, but was not expected for copper and nickel.

Leachates derived from dynamic leaching tests

Leachate samples were taken during the test with dilute sulphuric acid to determine the variation in chemistry with time. Results for the major ions are shown on Figure 6.2. The initial peak in conductivity is clearly seen to be due to sodium and chloride. These highly mobile ions were almost completely leached out of the material in the first two sample volumes of leachate. These ions were probably present in the pore water of the silt, which was dredged from the Thames estuary and would thus be partly saline. Potassium, nitrate, ammonium, fluoride and total organic

Table 6.3 Chemical analyses of materials and NRA leaching test results

Contaminant	Untreated material (mg/kg)	Treated material (mg/kg)	NRA test eluate: untreated material (µg/l)	NRA test eluate: treated material (µg/l)	Percentage mobilised: untreated material (%)	Percentage mobilised: treated material (%)
pH (units)	8.3	12.5	8.1	12.4	–	–
Arsenic	64	51	33	16	0.75	0.40
Cadmium	4.3	3.5	< 1	< 1	< 0.4	< 0.4
Chromium	73	65	< 20	< 20	< 0.4	< 0.4
Lead	139	108	< 20	< 20	< 0.2	< 0.2
Mercury	4.4	4.3	< 0.2	< 0.2	< 0.07	< 0.06
Selenium	5.7	5.2	< 20	< 20	< 5.1	< 4.8
Boron	38	7	2292	103	88	17
Copper	116	92	59	410	0.7	5.5
Nickel	58	48	22	75	0.6	2.0
Zinc	270	224	106	49	0.6	0.3
Iron	28100	23400	120	38	0.01	< 0.01
Manganese	754	600	60	< 10	0.12	0.02
Aluminium	19900	16500	150	80	0.01	< 0.01
Calcium	42400	72900	227000	748000	7.8	12.7
Magnesium	5800	5100	19700	60	5.0	0.02
Sodium	5600	4600	173000	166000	45	46
Potassium	5200	4200	22000	27000	6.1	7.4
Sulfate	25000	20400	735000	10000	44	0.7
Sulfide	< 2	< 2	< 0.1	< 0.1	–	–
Chloride	4900	3300	289000	289000	87	95
Ammonium	10.5	14	400	2700	56	> 100
Nitrate	609	277	1400	47800	3.4	> 100
Total cyanide	4	2.4	10	8	3.7	5.3
Phenols	< 1	< 1	< 0.5	282	Not defined	> 100
Total PAHs	1.8	2.0	12	9	10	4.3
Organic carbon	46800	34500	200	400	0.01	0.02

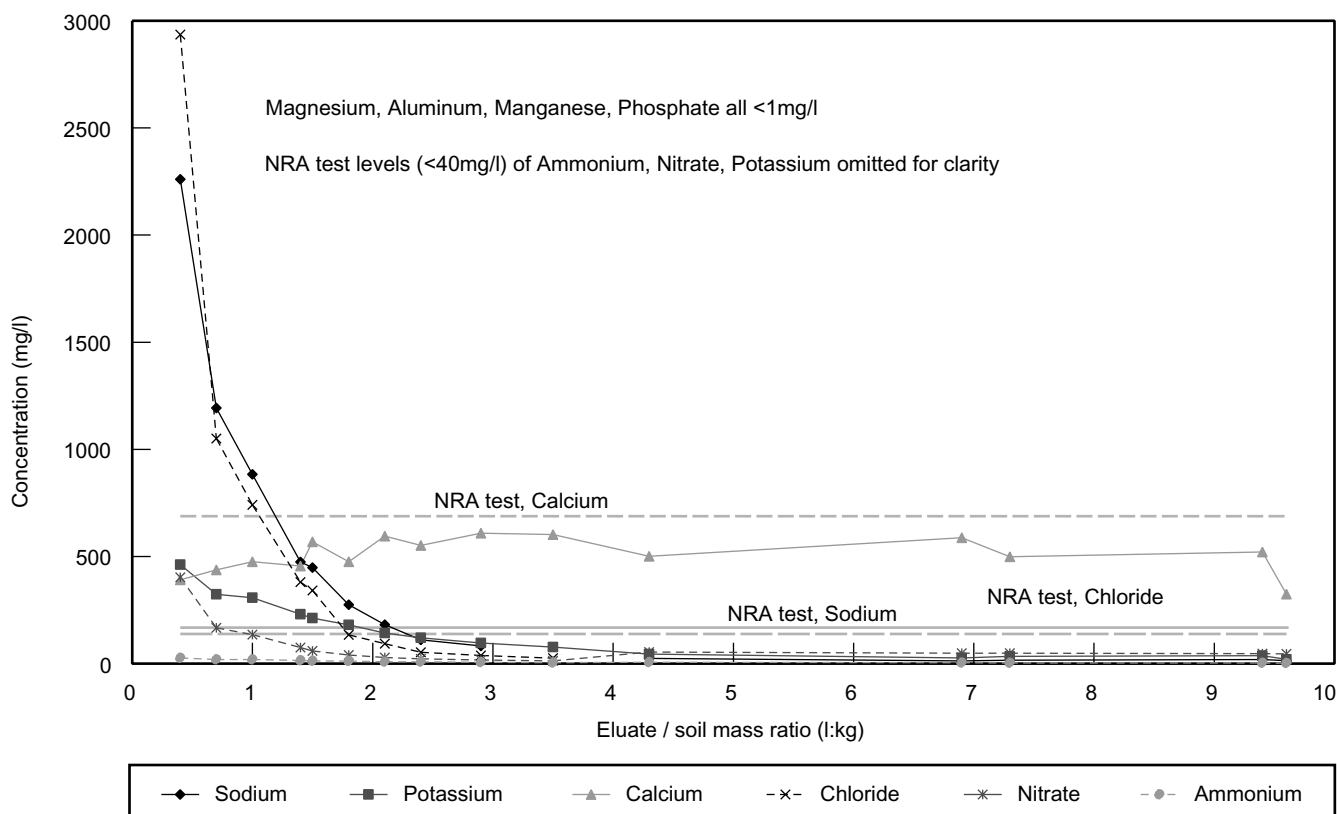


Figure 6.2 Dynamic leaching tests: major ions

carbon showed a less marked initial peak and decreased more slowly as the test continued. The concentration of calcium showed a slight increase during the first two sample volumes and then remained reasonably constant, suggesting it is controlled by the solubility of free lime in the treated material. This correlates with the constant pH of the leachate. Calculations based on the calcium concentration suggest that by the end of the test about 16% of the lime, which was added, would have been removed by leaching. Concentrations of other major ions such as magnesium and sulfate were very low throughout the test.

The values obtained from the NRA test for sodium, chloride and calcium are also shown on Figure 6.2. For sodium and chloride the NRA test underestimates the initial concentrations by an order of magnitude, though the total amount extracted by the two tests is approximately the same. The NRA test gave higher concentrations of calcium than were found in the flow-through test.

The results for minor elements and compounds are shown on Figure 6.3. For most of the species, concentrations were at or below detection limits throughout the test. However, copper, nickel and phenols showed high concentrations in the initial leachate, dropping to much lower concentrations as the test continued. The NRA test results for these species are also shown on Figure 6.3; as with sodium and chloride, they significantly underestimate the initial concentrations.

6.6.3 Pilot scale test bed

The geotechnical properties of the test bed material are summarised in Table 6.4. Frost heave tests were carried

out on the treated test bed material according to BS 812: Part 124 (British Standards Institution, 1989). The tests found that the material was non-frost susceptible. The development of strength in the test bed compared to the samples allowed to cure in the laboratory is shown on Figure 6.4. The test bed showed a rapid gain in strength over the first two months, corresponding to the warmest summer weather. The shear strength decreased during the winter months, and remained variable during the spring, before increasing to a maximum in July 1998. By contrast, the saturated samples were slow to increase in strength, reached a maximum after six months and then decreased. The influence of atmospheric conditions on shear strength is evident. However, despite being open to the weather, the shear strength of the test bed did not drop below 140 kPa.

Table 6.4 Geotechnical properties of test bed material

Material	Dry		MCV	CBR (%)	Shear strength (kPa)	pH
	mc (%)	density (Mg/m ³)				
Untreated	53	1.03	6.7	0.8	25	8.1
Treated, laboratory	44	1.10	10.0	4.5	129	12.2
Test bed as placed	44	0.98	11.7	7.4	98	12.5
Test bed after 1 year	39	1.07	11.4	10.7	232	10.6

The average pH of the test bed material decreased over the period from 12.5 to 10.6. This suggests that free lime has been leached out of the material or converted to calcite by carbonation. The variation in pH of the test bed soil with depth is shown in Figure 6.5. This shows how the pH has decreased to less than 9.0 at the surface, where

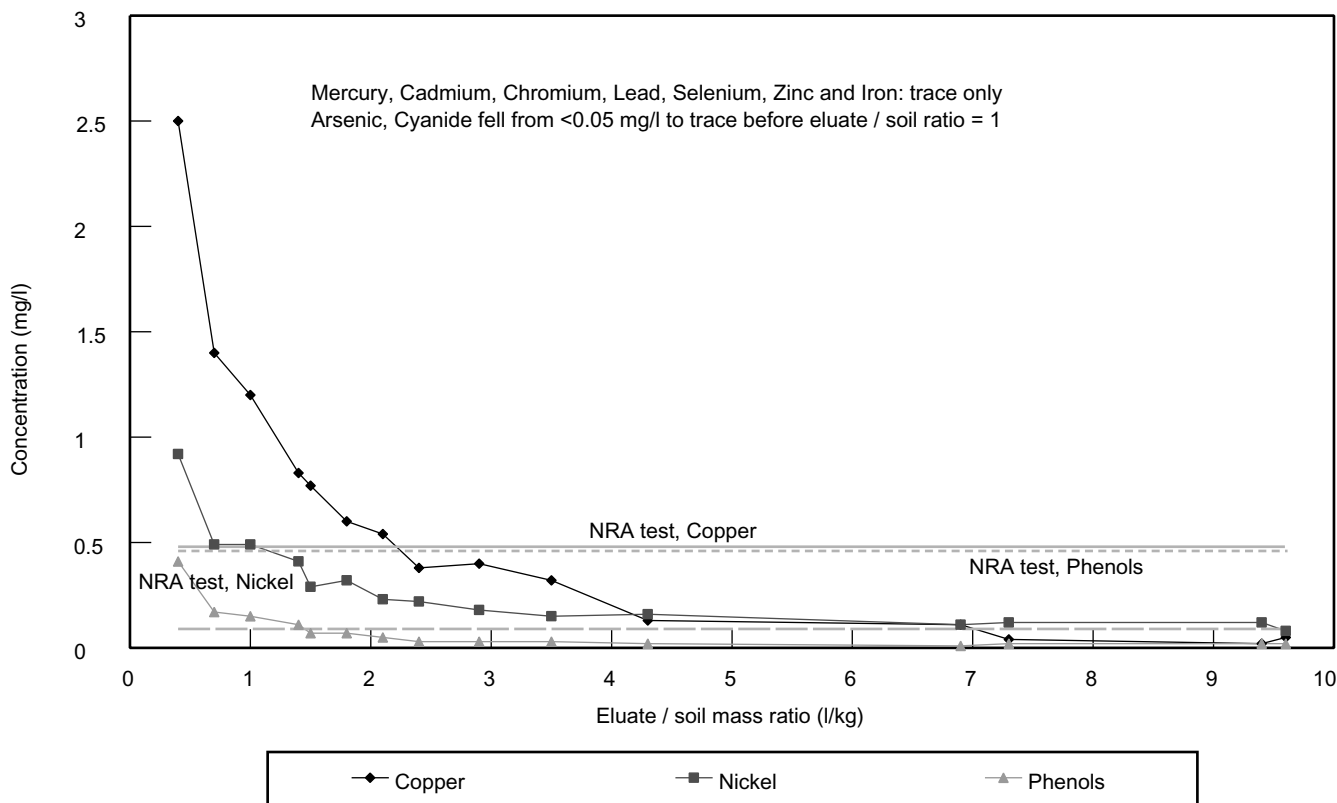


Figure 6.3 Dynamic leaching tests: contaminants

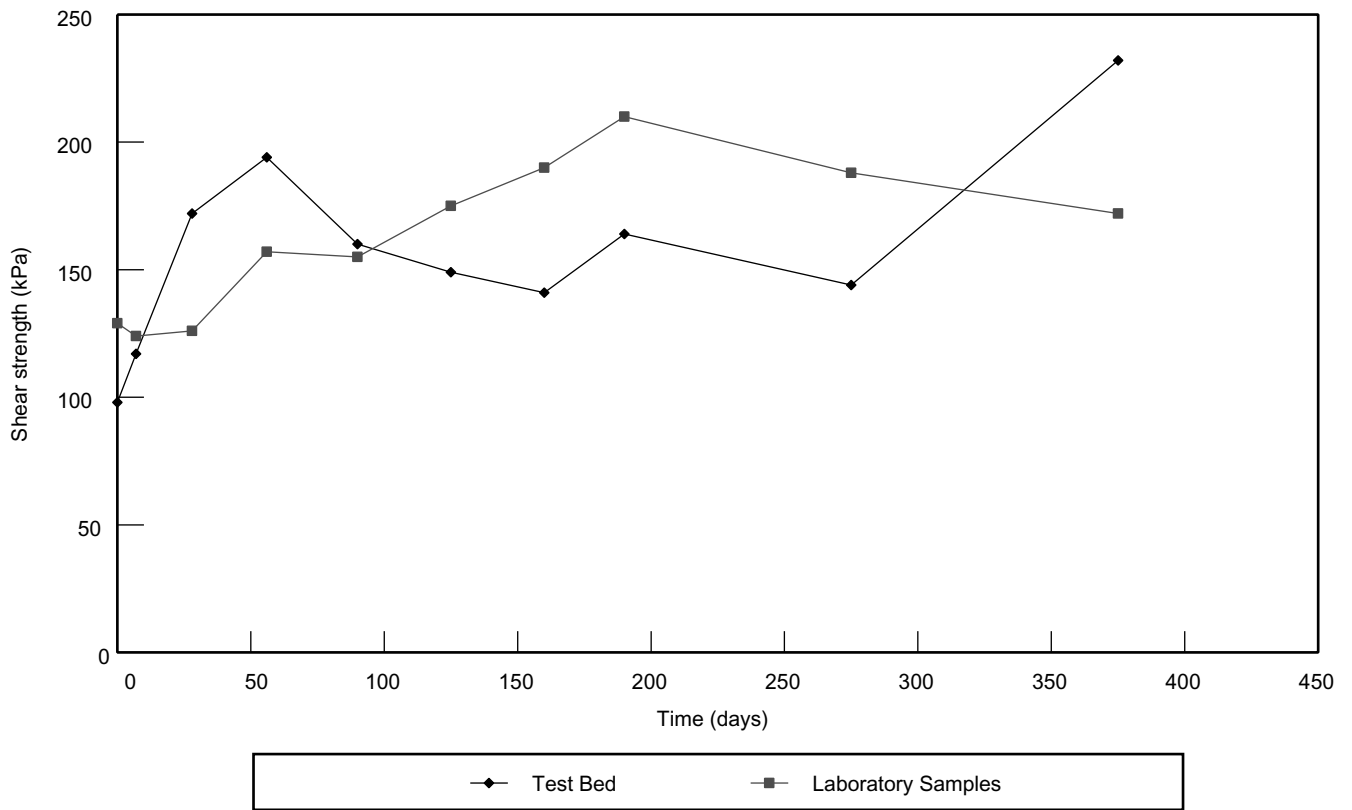


Figure 6.4 Development of shear strength in test bed material

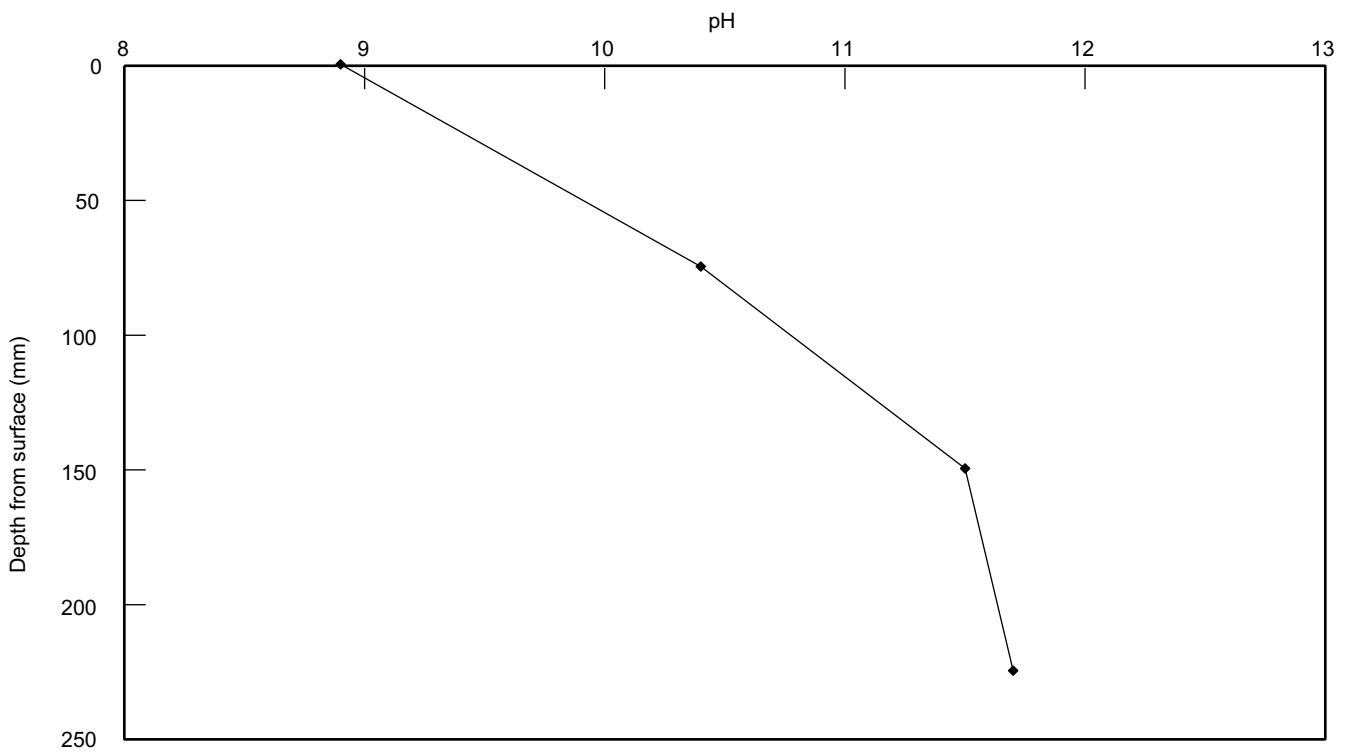


Figure 6.5 Variation in pH of test bed material with depth after one year (initial pH = 12.5)

exposure to the atmosphere is greatest, but even at the base of the test bed there has been a noticeable decrease in pH.

The results of tests on the test bed drainage for selected species are shown on Figures 6.6 and 6.7. The most immediately noticeable feature about the test bed drainage compared to the laboratory tests is that the pH decreases with time from 12.2 at the start of the test to 7.5 after one year. In the laboratory tests, the pH remained greater than 12 throughout (Reid and Brookes, 1997). The concentration of calcium in the drainage rapidly drops to much lower levels than in the laboratory tests. This is attributed to uptake of carbon dioxide by the drainage, and white precipitates of calcium carbonate were found in the collection vessel each month.

6.7 Summary

6.7.1 Generalities

Leaching test results indicate that the physical integrity of the treated material is not significantly affected by prolonged leaching with distilled water or dilute acid. Field tests have also shown that the strength of the treated material develops despite exposure to natural conditions. The concentrations of contaminants in the leachate at the end of the leaching tests were at or below the levels given in Environmental Quality Standards for water such as the drinking water standards (House of Commons, 1989). However, the concentrations of some species in the initial leachate were significantly in excess of these standards, notably for sodium, chloride, ammonium, nitrate, nickel and phenols. The calcium concentration and pH remained in excess of the drinking water standards throughout the leaching tests.

6.7.2 Interpretation of results

The significance of these results needs to be seen in the context of the chemistry of the treated material and leachate and the low permeability of the stabilised material. Because of the low permeability, the amount of leachate that would be generated from the treated material is very small. It would thus be diluted to acceptable levels before it could cause pollution of controlled waters in most circumstances. Natural biodegradation of organic species such as ammonia and phenols would be expected to occur. As was seen in the results from the test bed trial, the pH would be expected to drop to near neutral as carbon dioxide is absorbed, resulting in the precipitation of calcium carbonate and a corresponding drop in the calcium concentration. The drop in pH was noted in 3 year old lime modified material from the A13 site (see Section 5.1). The precipitation of calcium carbonate from leachate from the stabilised material could cause problems if it occurred in drains or drainage blankets. This should be taken into account in the earthworks design if it is proposed to use treatment with lime.

6.7.3 Leachate chemistry

The high initial concentrations of phenol, ammonium, nitrate, copper and nickel in the test leachate were not

anticipated. The high phenol concentration may be explained by formation of the soluble phenate anion at high pH, probably as the sodium salt; this is a by-product of the use of strongly alkaline materials in the stabilisation process. The ammonium and nitrate were also probably generated by the reaction of the quicklime on organic compounds in the sewage sludge.

The reason for the solubility of copper and nickel is less clear. The conventional belief is that high pH reduces the mobility of metals (Yong *et al.*, 1993; Stumm and Morgan, 1996); while this appeared to apply to the other metals in the test material, it did not apply to copper and nickel. To investigate this anomaly, a programme of detailed chemical testing of the material was carried out by the Geoenvironmental Research Centre at Cardiff University on behalf of TRL. This work is reported in TRL Report 424 (McKinley *et al.*, 1999). The results point towards complexation of copper and nickel with organic material in the untreated material. The organic matter breaks down at the high pH induced by lime treatment, leading to the formation of soluble organic-metal complexes for these metals. The other metals are thought to be less strongly bound to organic matter, and hence their solubility is not increased. The mineralogy of the untreated material consisted mainly of quartz, calcite and hematite, none of which have a high capacity to sorb metals (McKinley *et al.*, 1999). If the material had a significant clay mineral content and low organic content, a very different pattern of leaching behaviour might have been observed. This illustrates the importance of looking at the particular circumstances of each case and avoiding 'black box' assumptions about how remedial methods work.

6.7.4 Conclusions

The TRL research has shown that, for the trial materials studied, treatment with lime produces a material with low permeability and high shear strength which is not broken down by exposure to natural conditions or by prolonged leaching with distilled water or dilute (pH 4) acid. The amount of water passed through the material in the dynamic test is much greater than is likely to pass through a highway embankment of the same material, given its low permeability, and hence the tests give confidence in the long-term physical integrity of the stabilised material.

High concentrations of some species were found in the leachate in the early stages of the leaching tests. These included mobile ions such as sodium and chloride, which would not be retarded by the stabilisation process. High concentrations of copper, nickel and phenol were also found in the initial leachate. The mobility of phenol is probably a function of the high pH and the high copper and nickel concentrations are attributed to the effects of lime on heavy metal complexation with organic material (McKinley *et al.*, 1999).

Because of the low permeability of the material, the amounts of leachate produced would be small and dilution with surface waters and lowering of the pH by absorption of carbon dioxide as observed in the field trial would render the leachate acceptable in most situations.

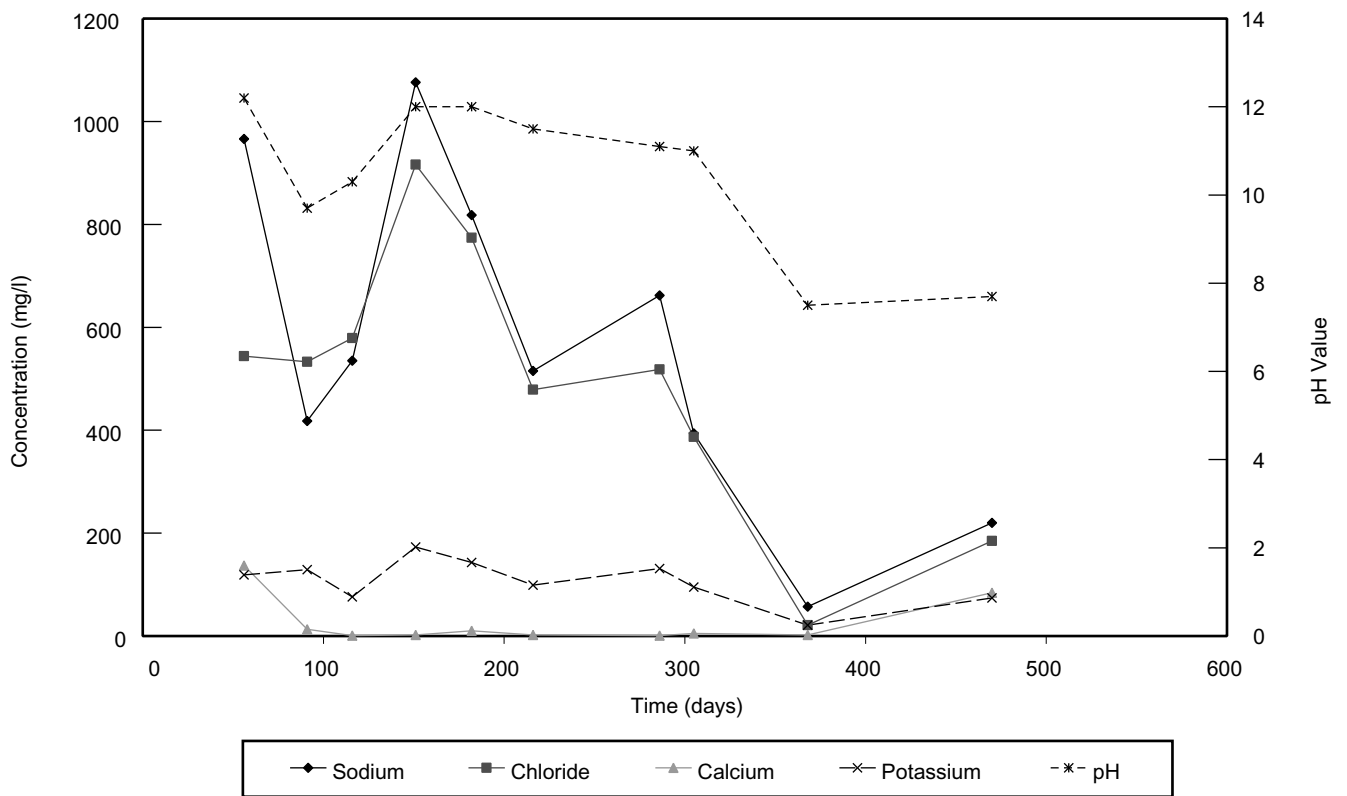


Figure 6.6 Test bed drainage: major ions and pH

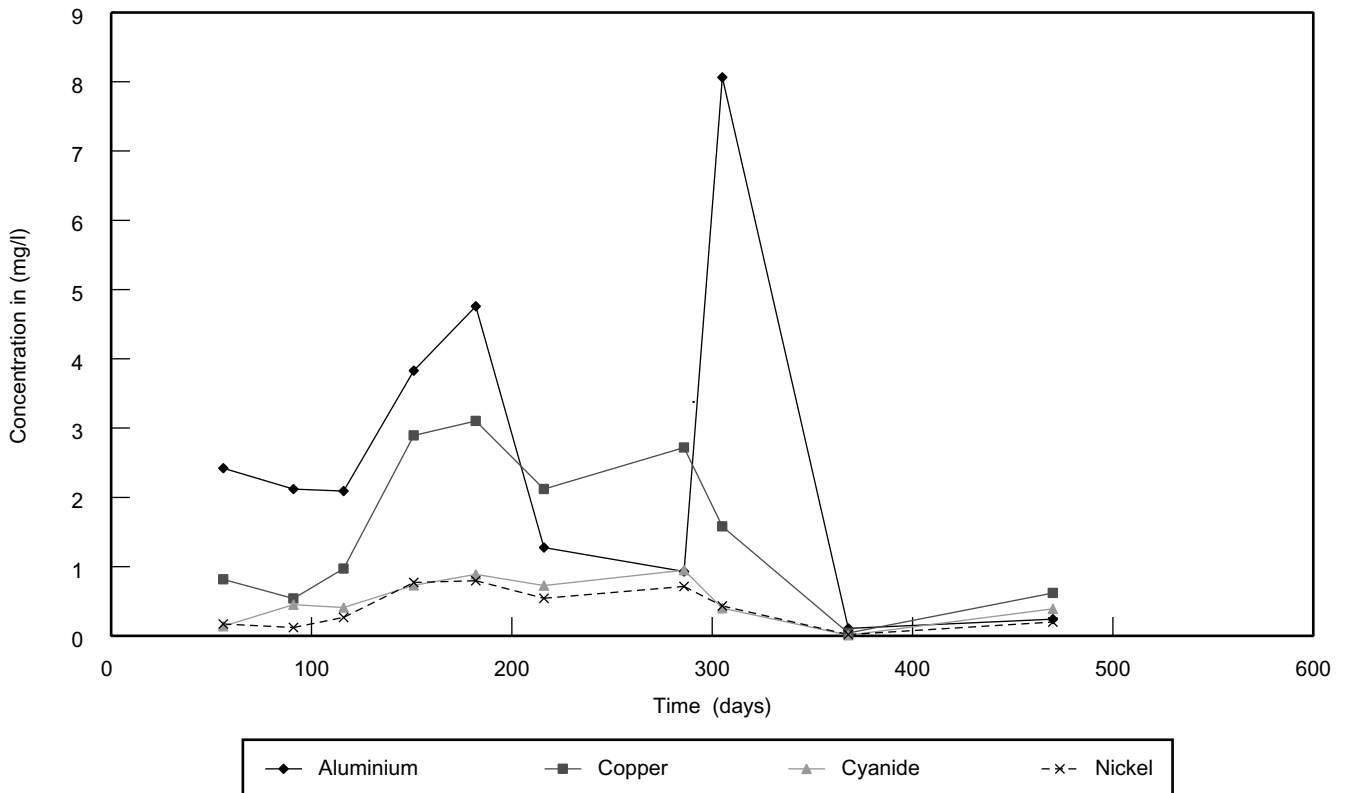


Figure 6.7 Test bed drainage: contaminants

The studies presented are examples of *solidification*, or *modification* rather than *stabilisation*. In order to achieve *stabilisation*, in the sense of changing the chemical form of contaminants to reduce their mobility, it would be necessary to use much higher levels of cementitious agents than the 3% to 5% w/w used in these examples. However, this would have resulted in a material with much higher strength and less flexibility, which would have exceeded the geotechnical requirements for general earthworks fill. An example of this process is given in Section 5.5. It would also have been much more expensive, and might have rendered the work uneconomic. The evidence from the A13 site is that the modification with lime has successfully achieved its aim, with no indication of significant loss of strength or release of contaminants in the three years since construction. Similarly the test bed, exposed to more extreme conditions of temperature and humidity over a period of 15 months, shows no loss of strength and the leaching of contaminants follows a similar pattern to that observed in laboratory leaching tests.

The major difference found between laboratory tests and field performance is the pH of the leachate. This is strongly alkaline in the laboratory tests, but in the field uptake of carbon dioxide occurs and the pH drops to near neutral. This is much less harmful to controlled waters and construction materials. However, in the test bed drainage this was accompanied by precipitation of calcium carbonate in the collection vessel, and there is a risk that this could occur in any drains adjacent to lime-modified material. No calcium carbonate was observed on the A13 site, and it may be that under natural conditions the carbonate redissolves as the pH falls to near neutral. This is predicted by speciation modelling carried out by McKinley *et al.* (1999).

The case studies indicate that treatment with lime can be an effective way of dealing with contaminated fine-grained material for earthwork purposes. However, at the low levels of cementitious agents normally used for earthwork purposes it should be appreciated that the effects are primarily *solidification* or *modification* rather than *stabilisation*. Thus it may be found that some contaminants are more mobile in leaching tests on the modified material than on the original material, as with copper and nickel in the example above. This effect will generally be negated by the low permeability of the modified material. Further precautions against pollution of watercourses can be taken by installing a break layer of inert material around the modified material to limit contact with percolating water.

Each material will react differently when treated with inorganic cementitious agents. The simplistic assumption that raising the pH will automatically reduce the mobility of contaminants is unsustainable. However, the leaching behaviour of a material can be predicted by simple multi-stage leaching tests such as the draft CEN test (CEN, 1998). The evidence from the studies reported is that this will give a generally accurate picture of leaching behaviour in the field, but that the high pH values found in the leaching tests will not occur in the field. Tests of this sort should be carried out whenever it is proposed to use s/s technology for contaminated materials.

7 Discussion and recommendations

The preceding chapters have shown that there are a number of methods for the remediation of contaminated land, which are suitable for use on highway schemes. Experience to date has been limited but has generally been satisfactory, provided the design and execution of the work was carried out to a high standard. There is now a comprehensive framework of legislation surrounding the issue of contaminated land and its remediation. It is possible to negotiate this successfully if consultations are held with the relevant authorities from an early stage in the development of a scheme, as discussed in chapter 2. The main recommendations arising from the project are summarised below:

- Consultations should be held with the Environment Agency on all aspects relating to contaminated land, landfills and waste management licences as soon as possible in the development of a scheme, whether it is new construction, widening or repairs to existing construction. Liaison should be maintained throughout the scheme design, ground investigations, risk assessment, remediation, construction and validation so that common objectives are agreed at every stage.
- The ground investigation must be adequate to provide the information that is required for the risk assessment. This may involve tests not normally carried out as part of a routine geotechnical investigation (e.g. porosity, hydraulic gradient and hydraulic conductivity, chemical tests) and may require monitoring boreholes to be sited outside the area of the proposed scheme.
- If contamination is present, a risk assessment should be carried out to establish the risk of significant harm to human health and the environment and pollution of controlled waters. Use the Model Procedures being developed by DETR, approved models such as CLEA (human health) or ConSim (groundwater) or appropriate guideline values.
- If remediation is required, the target concentrations and validation procedures should be agreed with the Environment Agency and included in the Specification for the works. The normal geotechnical requirements for the material should also be included in the Specification. It is essential that the objectives of the work should be clearly stated at the tender stage. The contractor should then be allowed to choose whatever method would best meet these objectives.
- For all proposed remediation methods, sufficient laboratory and site trials should be carried out to give confidence in the ability of the technique to deal with the particular site conditions before proceeding with the works. Ensure that the principles and practicalities are thoroughly understood by all parties before commencing.
- Remediation contracts are particularly suited to the Design and Build method of procurement because of the specialised nature of the works. Requirements for quality assurance and validation should be clearly stated. The contractor should be required to submit a detailed method statement, including a plan for what to do in the event of the works not achieving the required target concentrations.

- It is particularly useful to carry out remediation works as advance contracts. This overcomes some of the problems of timescale and interference with the main construction works, which can then proceed much more easily.
- Appendices 6/14 and 6/15 (MCHW 1) should be prepared from the results of the risk assessment and included in the contract documents. Different values may be required for different areas of the site depending on the sensitivity of the underlying strata and the form of construction proposed. Use the revised U1/U2 classification system to identify contaminated materials in the schedules and drawings.
- Establish with the Environment Agency whether a mobile plant licence or a waste management site licence is required for any proposed remediation works. Different methods of remediation have different requirements, see Chapters 2 and 4.
- Sufficient time must be allowed for remediation activities, including obtaining approvals and licences, laboratory and site trials, treatment and validation. An allowance for long-term monitoring should be included where appropriate, e.g. where contamination of groundwater is involved.
- Liaise with the Environment Agency to develop procedures to deal with U2 contaminated materials (Radioactive Waste and Special Waste).
- Record the position, amount and condition of contaminated and remediated materials on As-Built Drawings and comment on the success of the works in the Geotechnical Feedback Report. Include the data in the Geotechnical Data Management System (GDMS).
- Check records of existing schemes for information on contamination and remediation and include in the GDMS. Carry out investigations where appropriate to establish the presence and nature of contaminated material.

8 Conclusions

The study has shown that a wide range of techniques have potential application to highway schemes. The systems most likely to be applied are considered to be stabilisation/solidification with inorganic binders, ex-situ bioremediation, dry sieving, soil washing, soil vapour extraction and hydraulic control of groundwater (pump-and-treat). Techniques such as thermal desorption or stabilisation/solidification with organic binders may have application in particular situations. The long-term integrity of stabilised/solidified materials has been demonstrated by the work described in Chapters 5 and 6. The case studies in general give confidence in the use of the techniques if they are carried out to correct professional standards, as set out in CIRIA Reports SP101 – 112 (Harris *et al.*, 1995).

Future drivers which are likely to encourage greater use of remedial techniques include: economic instruments such as the landfill tax and aggregates tax, both of which are set to increase with time; public pressure for more recycling and national targets set by Government; the settled legislative situation now that the contaminated land regime

is in place and companies can assess their liabilities; and increasing familiarity of all parties with the techniques. Demonstration projects are very helpful in showing that remedial technologies can be used successfully in civil engineering works. Factors which should be taken into account when the use of remedial techniques is being considered include: the cost and timescale required for the techniques; continuing uncertainties as to the performance of some techniques in difficult or variable materials; the requirements of the regulatory authorities; and the timescale for obtaining approvals and licences. As the techniques become more familiar and the new legislative regime settles down, it is likely that there will be a considerable increase in the use of remedial techniques for contaminated land in construction generally, and that highways will see a fair share of this.

As a result of this study, a number of amendments to the MCHW are suggested. These are listed in Appendix A.

9 Acknowledgements

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Appendix A: Amendments to the Manual of Contract Documents for Highway Works

A.1 Manual of contract documents for Highway Works

The Specification for Highway Works (MCHW 1), which is used within the contract documents for major highways in the UK, is written and structured to allow the maximum use of materials. Within the MCHW 1, contaminated materials are defined as either Class U1 or Class U2 depending on their degree of contamination. There is a need to update these definitions in line with the definition of contaminated land in Part IIA of the Environmental Protection Act 1990.

A new classification for unacceptable materials is presented which defines Class U1 and Class U2 materials more clearly. The proposed classification is related to the definition of contaminated land in current legislation and embodies the principles of risk assessment.

Amendments to the existing Specification for Highway Works (MCHW 1) and Notes for Guidance (MCHW 2) are shown in *italics* in the following text.

Draft Specification Clauses (MCHW 1)

#601 Classification, Definitions and Uses of Earthworks Materials

General Classification

2 Unacceptable material Class U1 shall be:

- i material which does not comply with the permitted constituents and material properties of Table 6/1 and Appendix 6/1 for acceptable material;
- ii material, or constituents of materials, composed of the following unless otherwise described in Appendix 6/1:
 - a peat, materials from swamps, marshes and bogs;
 - b logs, stumps and perishable material;
 - c materials in a frozen condition;
 - d clay having a liquid limit determined in accordance with BS1377: Part 2, exceeding 90 or plasticity index determined in accordance with BS1377: Part 2, exceeding 65;
 - e material susceptible to spontaneous combustion except unburnt colliery spoil complying with sub-Clause 15 of this Clause;
 - f *contaminated materials, including controlled wastes (as defined in the Environmental Protection Act 1990), whose level of contamination is above that given in Appendix 6/14 [limiting values for pollution of controlled waters] or Appendix 6/15 [limiting values for harm to human health and the environment], and excluding all special wastes (as defined in the Special Waste Regulations 1996) and radioactive wastes (as defined in the Radioactive Substances Act 1993).*

3 Unacceptable material Class U2 shall be:

- i *special waste (as defined in the Special Waste Regulations 1996) and radioactive wastes (as defined in the Radioactive Substances Act 1993).*

Draft Notes for Guidance (MCHW 2)

NG 601 Classification, Definition and Uses of Earthworks Materials and Table 6/1: Acceptable Earthworks Materials: Classification and Compaction Requirements

- 8 *The definition of contaminated materials in Class U1 is based on the concept of risk assessment and is in accordance with the definition of contaminated land in Section 78A(2), (5) and (6) of the Environmental Protection Act 1990 and associated statutory guidance.*
- 9 *A site specific risk assessment should be undertaken for each earthwork section, as the degree of exposure to living organisms or the hydrogeological conditions can vary significantly within a scheme, leading to different limiting values in different sections. However, appropriate generic guideline values, which are based on a risk assessment model, may be used as default values.*
- 10 *For general fills, the limiting values for harm to human health should normally be based on the 'commercial/ industrial' end use category of guideline values, as there is a very low risk of exposure to the public from any contaminants in the fill. For landscaping fills, considerations of phytotoxicity will be important. Where slopes are to be returned to agricultural use, the limiting values should be based on the 'residential with gardens' end use. The appropriate category should be decided for each section or sub-section of the scheme.*
- 11 *Details of the limiting values adopted and explanations of their derivation should be given in Appendix 6/14 and Appendix 6/15.*
- 12 *Materials, which would be classified as Class U1 because of contamination using generic guideline values, may be rendered acceptable by remedial techniques such as stabilisation with cement or lime. The contaminant levels are not changed by the stabilisation process, and remain above the generic guideline values, but their ability to migrate is reduced. A site specific risk assessment must be carried out to demonstrate whether the risk to human health and living organisms, and of pollution of controlled waters, is acceptable before the remediated materials can be reclassified as acceptable fill materials.*

NG sample Appendix 6.14: Pollution of controlled waters

[Note to compiler. This should include:]

- 1 *Limits on the amount of contaminants in a material above which there is a significant possibility that controlled waters (surface water and groundwater) will be polluted.*
- 2 *An explanation of the derivation of the limits (e.g. generic guideline values for given soil conditions, or values derived from site specific risk assessment quoting relevant input parameters and methods).*

NG sample Appendix 6/15: Level of contamination of material

[Note to compiler. This should include:]

- 1 Limits on the amount of contaminants in a material which, if exceeded, will lead to a significant possibility of significant harm to human health or the environment.*
- 2 An explanation of the derivation of the limits (e.g. generic guideline values for given soil conditions, or values derived from site specific risk assessment quoting relevant input parameters and methods).*

NG sample Appendix 6/2: Requirements for dealing with Class U1(f) and AND Class U2 unacceptable material

Note: The change in title is necessary because the revised definition of Class U1(f) now covers material which is classified as 'contaminated land' under Section 78 of the Environmental Protection Act 1990. It therefore includes material which has hazardous chemical properties and requires special measures for handling and disposal (the original definition of Class U2 material). The revised definition of Class U2 also includes materials (radioactive and special waste) which fall into this category. The text of the Sample Appendix is unchanged.

Abstract

A review of the processing of contaminated land in highway earthworks was undertaken by TRL for the Highways Agency. The traditional approach to contaminated land in highway construction has been to excavate, remove to landfill and replace with acceptable material. However, a number of techniques are now available whereby the contaminated land can be remediated and utilised in the construction works. This is more environmentally friendly than the 'dig and dump' approach, but there has been relatively little utilisation of these techniques to date. With the implementation of the Contaminated Land Regulations and Statutory Guidance on 1 April 2000, greater use of remediation techniques is anticipated in the future. A guide to the current legislation on contaminated land as it relates to highways is given, and changes are proposed to the definition of contaminated land in the Manual of Contract Documents for Highway Works. A review of available techniques for the remediation of contaminated land and their advantages and limitations for highway works was undertaken and case studies of various methods are presented. Technologies, which have potential for use in highway schemes, include stabilisation/solidification, ex-situ bioremediation, soil washing, mechanical sorting, soil-vapour extraction and hydraulic control of groundwater (pump-and-treat). Detailed work on the durability of lime-stabilised contaminated material is described, comprising laboratory trials, long-term leaching tests, a pilot scale test bed and sampling of lime-modified material which had been utilised in a highway scheme. The results indicate that the treated material retains its strength in the medium term and does not release significant amounts of contaminants to groundwater. Recommendations are given for the use of remedial measures for contaminated land in highway earthworks.

Related publications

- TRL451 *The effect of age on cement stabilised/solidified contaminated materials* by M J Board, J M Reid, D S J Fox and D I Grant. 2000 (price £35, code H)
- TRL424 *Detailed chemical analysis of lime stabilised materials* by J D McKinley, H Thomas, K Williams and J M Reid. 1999 (price £25, code E)
- TRL306 *Laboratory trial mixes for lime-stabilised soil columns and lime piles* by A H Brookes, G West and D R Carder. 1997 (price £25, code E)
- TRL305 *Review of lime piles and lime-stabilised soil columns* by G West and D R Carder. 1997 (price £25, code E)
- TRL192 *Sources of information for site investigations in Britain (revision of Laboratory Report LR403)* by J Perry and G West. 1996 (price £25, code E)
- CR151 *Stabilized capping layers using either lime, or cement, or lime and cement* by P T Sherwood. 1992 (price £50, code N)

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