Management of Contaminated Soils in South Australia

A PERSPECTIVE ON THE DRIVERS, IMPEDIMENTS AND OPPORTUNITIES FOR SUSTAINABLE MANAGEMENT OF CONTAMINATED SOILS IN SOUTH AUSTRALIA

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Note: This report has been prepared by Sinclair Knight Merz for the exclusive use of Zero Waste SA, and the views expressed do not necessarily reflect those of Zero Waste SA.

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Executive summary

In South Australia, the redevelopment of contaminated land and the requirement for the reuse of remediated soils is likely to become more prevalent, when considering the development strategy for metropolitan Adelaide and the subsequent land pressures, in addition to other drivers for site clean-up.

As with several of the other Australian states, South Australia has historically maintained a prevalence towards the excavation and disposal of contaminated soils to landfill (commonly referred to as ‘dig and dump’) when remediating contaminated sites.

The remediation of low level and high level contaminated soil for reuse is a priority for action in South Australia (South Australia’s Waste Strategy 2011-15). Accordingly, Zero Waste SA (ZWSA) has committed to developing a Contaminated Soils Strategy (Business Plan 2011-12).

The content of this report provides background and contextual information on soil contamination, its management, and the impediments to sustainable contaminated soil management. The aim of this study is to assist in the development of the Contaminated Soils Strategy, via identification of relevant and feasible soil remediation techniques available in South Australia, assessment of current (and previous) remediation industry as well as research and development capabilities in the State and identifying the obstacles in terms of sustainable soil management (i.e. why the prevalence towards ‘dig and dump’?).

The assessment was largely based on the consultation of those stakeholders in South Australia that are associated with contaminated site clean-up.

Within the assessment of soil remediation techniques, high level costs and carbon footprint liabilities were also included, in order to identify optimum remediation techniques relevant to South Australia, in terms of cost, feasibility and sustainability.

Based on the general environment of South Australia, and the types and quantities of contaminants likely to be encountered during site regeneration, there would appear to be sufficient capabilities within the South Australian market currently with respect to appropriate alternative soil remediation techniques to ‘dig and dump’.

Further, South Australia also has a strong research and development base in certain remediation technologies, in both the public and private sector. Increased support and opportunity however is required to facilitate increased commercialisation of such research, to develop the technologies for field scale application in real environments.

Given that capabilities exist in private sector remediation services / technologies and public and private sector research and development, the prevalence of ‘dig and dump’ over the application of alternative (and sustainable) methods of remediation is considered to be a result of several factors:

- Low rates of landfill disposal costs for contaminated soils
- Site Contamination Auditor conservatism
- Limited risk based approaches with respect to soil classification and reuse as waste derived fill
- Lack of an overall site remediation framework / guidelines
- Limited facilities for soil treatment / recycling

Of these, the predominant factor would appear to be the low landfill disposal cost applied to contaminated soils disposal (i.e. per tonne of soil) in comparison to the cost of remediation on site, using sustainable technologies.

However, this imbalance is confounded by the other factors, which generally conspire to highlight ‘dig and dump’ as the favoured remedial option. Thus a shift to discouragement of soil disposal to landfill coupled to encouragement of alternative methods is required.

There appears to be several opportunities to address this imbalance, based on consultations and assessment of the contaminated land industries in other economies. The key opportunities to encourage diversion of contaminated soils from landfill were found to be:

1. Consideration of an increase in landfill levy (or a differential landfill levy on contaminated soils or hazardous substances) to create financial disincentive for “dig and dump”. In addition, the increase can be used to create a dedicated fund to support research and development of on-site and off-site remediation technologies and education of the land management industry with respect to their application.
2. Consideration of land remediation tax relief or ring fenced assessment fund (e.g. potentially funded through an increase in landfill levy) for site assessment and remediation (accessible by Local Authorities) to facilitate brownfield regeneration.
3. Further strengthening of risk based approaches with respect to soil classification and reuse as waste derived fill.
4. Adoption and promotion of both the upcoming national remediation framework and sustainable remediation framework
5. Investigation and consultation of development of soil treatment centres for treatment of required or surplus soils and exchange of ‘old’ for ‘new’ soils should notable cluster development be planned.

1. Introduction

1.1 Background

Growth in South Australia (SA; both economic and population based growth) is generally increasing the development based demand for land. Most land available for development within the Adelaide metropolitan area is land that has had a former commercial / industrial use, although there are a number of urban infill and urban renewal sites. Such land generally has quality issues, having been impacted or contaminated by the processes and operations associated with commercial or industrial usage.

The remediation of contaminated urban land has potential to be used by a range of stakeholders as a means to create value from a former liability. However, in creating value, remediation (or 'clean up') must be undertaken in an environmentally sustainable manner.

It is difficult to estimate the exact number of sites where land is contaminated or their extent in South Australia. In many instances adequate information on former land-use activities was not collected, has not been retained or is not readily available. In other cases land may be contaminated to some extent but is still suitable for its existing use and is not posing a risk to public health or the environment.

However, where contaminated land in South Australia requires management to enable further use of the site, there has and continues to be a prevalence towards excavation and disposal of contaminated soils to landfill ('dig and dump').

The average annual tonnage of contaminated soil currently being disposed of to landfill in SA may be in the range of 87,000 tonnes per annum during the past five financial years (2007/08 – 2011/12). However, major dig and dump projects can affect such tonnage in any given year. For example, an estimated 462,200 tonnes of contaminated soil is expected to be removed from the new Royal Adelaide Hospital site, to be disposed of to landfill.

Globally, the dig and dump approach has largely been cast aside as being un-sustainable, and economies have shifted to a more technological based approach to land clean up, where soils are treated and re-used on or off site. In Victoria, policies and strategies have begun to be developed and implemented which deter dig and dump practices with respect to clean-up of contaminated sites.

Remediation of low level and high level contaminated soil for reuse is a priority for action (South Australia's Waste Strategy 2011-15). Accordingly, ZWSA has instigated a program of developing a Contaminated Soils Strategy project (Business Plan 2011-12).

1.2 Terms of reference and document structure

To inform development of a Contaminated Soils Strategy, Sinclair Knight Merz (SKM) was appointed to provide an overview of treatment technologies involving a review of local industry and Research & Development capabilities and financial analysis of treatment technologies.

The appointment of SKM was made based upon the delivery of the following scope of work:

- Assessment of the potential costs and benefits associated with sustainable soil contamination treatment and disposal, taking into account carbon pricing (**refer to Section 2**)
- Identification and assessment of current treatment technologies as well as local industry and R&D capabilities (**refer to Sections** 3 **and** 4)
- Identification of drivers, opportunities and impediments for contaminated soils treatment and reuse in SA (**refer to Sections** 5**,** 6 **and** 7)
- Recommended strategies and actions for the SA Government to encourage treatment and reuse of contaminated soils and reduce the amount of contaminated soils being disposed to landfills (**refer to Section** 8)

This Stage 1 study has used a high level stakeholder consultation approach to capture the current state of play with respect to contaminated soil management in South Australia, and provides a broad background to available alternatives to dig and dump, along with recommendations to guide the development of Stage 2 of the South Australian contaminated soils policy.

1.3 Stakeholders

As part of this project a number of organisations were contacted regarding their view concerning the state of play of soil remediation in South Australia. Some of these views are deemed as personal and do not represent the organisation. The stakeholder list is presented in Appendix A.

1.4 SA strategic policy context

The SA Strategic Plan (the Strategic Plan) identifies population growth as a key driver in the on-going economic development and sustainability of the State. To support this, a population target of 2 million persons by 2027 has been established (Target 45). In addition, the Strategic Plan targets exceeding the national economic growth rate over the period to 2020 (Target 35) and a reduction in waste to landfill of 35% by 2020 with a milestone target of 25% by 2014 (Target 67).

Underpinning the Strategic Plan are various strategies/policies to deliver the nominated targets. Specifically, the 30 Year Plan for Greater Adelaide (the 30 Year Plan) directs the distribution and development of population and employment growth to accommodate an increase in population of 560,000 additional people, 258,000 additional dwellings and creation of 282,000 additional jobs. The 30 Year Plan aims to deliver 60% of all growth within 800 metres of existing or extended transport corridors (Target C). As such, 14 Transit Oriented Developments (TODs) are identified across the metropolitan area to support this growth (Target K). The TODs are proposed to be located at Elizabeth, Salisbury, Mawson Lakes, Modbury, Port Adelaide, West Lakes, Woodville, Bowden, Adelaide City, Keswick, Glenelg, Oaklands, Bedford Park and Noarlunga, predominately concentrated on remnant industrial and brownfield sites. These TODs are anticipated to accommodate 60,000 new dwellings over the life of the plan (Target M). A summary of three of these redevelopment projects currently occurring in SA that have or are likely to generate contaminated or surplus soils is provided in Table 1.

With regard to waste reduction, SA's Waste Strategy 2011-2015 (the Waste Strategy) supports the waste to landfill reduction target outlined in the Strategic Plan. The Waste Strategy has two core objectives; "to maximise the useful life of materials through reuse and recycling" and "to avoid and reduce waste".

Balancing population and economic growth with a reduction in waste to landfill requires implementation of innovative and sustainable approaches to waste minimisation and management. As many of the areas that are proposed for growth in the 30 year Plan are former or existing industrial or brownfield sites a significant increase in remediation of contaminated land (and associated need to deal with significant volumes of contaminated soil) is likely to be required. Given the strategic direction of developing such sites, it is apparent that the disposal of contaminated soil to landfill could jeopardize waste reduction targets, unless more sustainable approaches are implemented.

Table 1 – A selection of current redevelopment projects in SA to illustrate the potential scale of soil contamination issues

Current Redevelopment Projects	**Current Redevelopment Projects**
Bowden Village	The Bowden Village development site encompasses the former Origin and Clipsal industrial sites which have a long history of industrial activity dating back to the 1850s including being the location of a gas works. Both the soil and groundwater have been contaminated by these past uses.[1]. A Master plan has been completed for the entire 16-hectare development which will eventually be home for 3,500 people. The project is the responsibility of the Renewal SA and the Urban Design Guidelines for the site identifies a 'zero waste' goal including reducing waste, reusing where possible, and ultimately to send zero waste to landfill. The Urban Design Guidelines for Bowden identify six precincts for development with the first land release to developers underway in part of the Bowden East precinct. The guidelines state that the Bowden Later Stages precinct will be developed later in the cycle of renewal for Bowden, due to decontamination requirements.
Tonsley Park	The Tonsley Park development site is a 61 hectare site, to be redeveloped as an employment hub providing 6,300 jobs in addition to residential, education and commercial opportunities over the next 20 years. Historically, the site has been used by the motor industry, specifically Chrysler and Mitsubishi motors, with the use discontinuing in 2008. Soil at the site is recognised as being contaminated, particularly chemicals typically used in solvents[2]. A Master Plan for the Tonsley Park Redevelopment was released in March 2012 and notes that: • Reports prepared for the government at the time of purchase of the Tonsley site confirmed that the site is suitable for a commercial/industrial use providing the buildings remain in their current configuration. • Before any parts of the site are redeveloped for a residential (sensitive) use, the environmental work will be completed to the satisfaction of an EPA accredited Site Contamination Auditor.
St Clair	The St Clair Residential Development Concept Plan accommodates 1,200 dwellings, 17 hectares of open space (35% of site) and 6 hectares of wetland. 6,600m^3 of contaminated soil from a former industrial site within the redevelopment area was buried on-site in a 4m deep pit and covered with 1m of clean fill. The remaining land area was not contaminated.[3]

[1] Bowden Development Environmental Health Fact Sheet, November 2011

[2] Tonsley Park Redevelopment – Environmental Fact Sheet

[3] Report for Former Sheridan Site, Actil Avenue, Woodville SA, Separable Portion 4 - Site Contamination Audit Statement, December 2009

1.5 Site contamination and management in South Australia

1.5.1 Potentially contaminative activities

South Australia may have in the region of 1,000 actual (or potentially) contaminated sites, according to EPA records. Such sites comprise small to large scale industrial sites, landfills, petrol / service stations and gas works etc. This number is based on known records, and thus the true number is likely to be higher. Further information on the number of contaminated sites will continue to be obtained by the EPA via the ‘duty to notify’.

The ‘duty to notify’ is a relatively new provision (July 2009) which has been added to the Environment Protection Act 1993 (section 83A) that requires a site owner, occupier, auditor or consultant to notify the EPA in writing of the existence of site contamination that affects or threatens underground water, as soon as possible after becoming aware of the site contamination. The notification will be helpful in identifying related soil contamination.

South Australia, like most jurisdictions has had a notable industrial past, with key industries since settlement days comprising tanneries, foundries, chemical works and vehicle manufacture. In addition, the inner western suburbs were historically famous for their large ‘pug holes’, formed through the quarrying of clay for brick manufacture. Once exhausted of suitable clay, these pugholes were backfilled with a variety of unknown materials that were readily available. Anecdotal information indicates that backfill material ranged from standard household rubbish to a fire truck. Over time, these pug holes have mostly been remediated, though some are known to still contain contaminated soils and other materials.

Thus there are likely to be a whole range of contaminants present at actual or potentially contaminated sites across the State, associated with a range of potentially contaminating activities, similar to most developed economies.

Australian Standard AS4482 .1-2005 lists chemical contaminants by industry type, and should be referred to for a detailed understanding of such. However, based on high level assessment of potentially contaminating activities in South Australia, the most common contaminants are likely to be those listed in Table 2 (note this is a high level summary only and the occasional incidence of other and more unusual contaminants is likely).

Table 2 – Summary of potentially most common activities and associated contaminants in SA

Industry	Halogenated VOCs	Halogenated SVOCs	Non-halogenated VOCs	Non-halogenated SVOCs	PCBs	Liquid free phase / hydrocarbons	Metals / In-organics	Cyanide	Asbestos	Methanol, ethanol, esters
Airport								■	■	■
Asbestos manufacture / disposal									■	
Breweries							■			■
Chemical manufacture	■	■	■	■	■	■	■	■		■
Dry cleaning	■	■	■	■						
Engine / vehicle works	■	■	■	■		■	■		■	
Foundries					■		■	■	■	
Gas works	■	■	■	■		■	■	■	■	
Landfills	■	■	■	■	■	■	■	■	■	
Power stations					■	■	■		■	

Industry	Halogenated VOCs	Halogenated SVOCs	Non-halogenated VOCs	Non-halogenated SVOCs	PCBs	Liquid free phase / hydrocarbons	Metals / In-organics	Cyanide	Asbestos	Methanol, ethanol, esters
Rail yards			■	■		■	■	■	■	
Scrap yards						■	■		■	
Service stations and fuel storage						■	■			
Smelting							■			
Tanning							■			
Wood preservation	■	■	■	■			■			

1.5.2 Management

1.5.2.1 Legislation

The key piece of legislation with respect to site contamination in South Australia is the *Environment Protection Act 1993* (the EP Act). The assessment of site contamination is largely guided by the National Environmental (Site Contamination) Protection Measure (NEPM, 1999) which is currently undergoing revision.

The EP Act defines site contamination as the presence of chemical substances on or below the surface of a site in concentrations above background concentrations where the substances have come to be present as a result of an activity at the site or elsewhere. The presence of the substances in those concentrations has resulted in:

a) Actual or potential harm to the health or safety of human beings that is not trivial, taking into account current or proposed land uses, or
b) Actual or potential harm to water that is not trivial, or
c) Other actual or potential environmental harm that is not trivial, taking into account current or proposed land uses.

The EP Act defines site remediation as a “means to treat, contain, remove or manage chemical substances on or below the surface of the site” and therefore recognises that remediation of contaminated soils is not restricted to ‘dig and dump’.

The *Environment Protection Regulations 2009* (EP Regulations), clause 3(1) defines Waste Fill as: waste consisting of clay, concrete, rock, sand, soil or other inert mineralogical matter in pieces not exceeding 100 millimetres in length and containing chemical substances in concentrations (calculated in a manner determined by the Authority) less than the concentrations for those substances set out in the chemical substance table (but does not include waste consisting of or containing asbestos or bitumen). Refer to clause 3(1) of the Regulations for the chemical substance table.

The remediation of site contamination (specifically soil) often necessitates the removal of a significant proportion of the contaminant, replaced by a non-contaminated product. At present, the contaminated soil is often disposed of to landfill. Given the strategic directions outlined above, the change in use of remnant industrial/brownfield land to residential use is likely to result in the requirement to remediate extensive site contamination to accommodate a more sensitive land use.

1.5.2.2 Financial instruments

The solid waste levy is established under the EP Act. The waste levy requires the licence-holder of a waste depot to pay a levy to the EPA based on the type of and amount of waste received. However, there is no levy on material classified as waste fill (i.e. material classified as exceeding waste fill criteria attracts a levy via the licensed facility).[4]

The levy is collected by the EPA, and 50% is transferred to the Waste to Resources Fund, a portion of which is allocated to Zero Waste SA to achieve its objectives.

The solid waste levy for the financial year 2012-13 is:

- For a non-metropolitan depot disposing of non-metropolitan waste (non-metro rate) $21
- For a metropolitan depot disposing of non-metropolitan waste brought to the depot by or on behalf of a wholly non-metropolitan council (non-metro rate) $21
- Any other case (metro rate) $42

State Government has foreshadowed further increases of the waste levy with a commitment to progressively increase the levy to at least $50 per tonne by 2014-15 in metropolitan Adelaide.

1.5.2.3 EPA guidelines

In order to facilitate the reuse of soil removed from contaminated sites (or reuse on site) to accommodate a more sensitive land use, the material must meet certain requirements under the EP Act to constitute appropriate fill. The EP Act defines waste, whether of value or not, as:

> *Any discarded, rejected, abandoned, unwanted or surplus matter, whether or not intended for sale or for recycling, reprocessing, recovery or purification by a separate operation from that which produced the matter; or*
>
> *Anything declared by regulation (after consultation under section 5A) or by an environment protection policy to be waste.*

According to the above definition, soil removed (or reused) from sites that have had a potentially contaminating activity occurred on them would be considered waste. To reuse waste soil, EPA approval is required based on classification of the material as 'waste derived fill' (WDF). Waste derived fill is classified based on the source, chemical and physical composition criteria set by the EPA.[5] The three levels of chemical criteria are:

(1) WDF that does not exceed the chemical criteria for Waste Fill, as specified in clause 3(1) of the EP Regulations. This WDF is indicative of a low-risk material for use as fill.
(2) WDF that exceeds these low-risk criteria, but does not exceed upper level criteria (i.e. Intermediate Waste Soil or Level 1 Waste criteria). For this WDF, the standard provides a mechanism for a site-specific risk-based approach for the proponent to employ to assess the potential to allow the use waste as a fill product. [Refer to Appendix 2 of Standard for criteria for Intermediate Waste Soil and Level 1 Waste]
(3) Finally, waste materials that exceed the criteria for Intermediate Waste Soil or Level 1 Waste are not permitted to be used as WDF. This is to ensure these higher-risk waste materials are disposed to a specifically authorised and secure landfill, noting that the bulk of soil disposed of to landfill is likely to be Level 1 / High level waste .

When the WDF is waste soil sourced from a site where a potentially contaminating activity (as defined in regulation 50 and schedule 3 of the *Environment Protection Regulations 2009*) has or is occurring, only a site contamination auditor (auditor) accredited under Division 4 of Part 10A of the EP Act is permitted to certify its

[4] EPA Waste Guidelines – Waste Levy Regulations, updated June 2012

[5] South Australian EPA "Standard for the production and use of Waste Derived Fill" 2010

use at a sensitive site. A site contamination consultant can only certify its use at a non-sensitive site. This is consistent with the requirements that only an auditor can certify a change in land use to a more sensitive use.

The environmental management which is applied to on-site remediation is implemented through the EPA Guidelines for Environmental Management of on-site remediation (EPA623/06). The guidelines provide advice on the environmental management of on-site contamination remediation such that any actual or potential impacts are minimised and adequate protection of the community is implemented.

Additional detail about the regulatory framework relevant to the reuse of contaminated soil, including the guideline on classification of waste fill, is provided in Appendix B.

1.6 Sustainable remediation industry in South Australia

A 2010 Survey of the South Australian Remediation Industry carried out by researchers at Flinders University (Masters research project; Conroy, 2010) was geared toward a characterisation of stakeholder perceptions of the sustainable remediation paradigm in SA. For the purpose of the task, a stakeholder was considered any individual who could reasonably claim to have an on-going professional association with the SA remediation industry

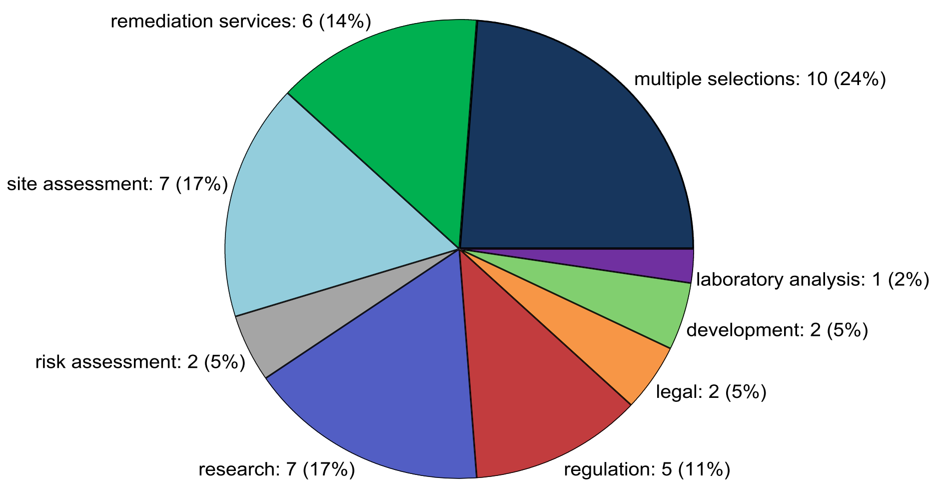
In essence, the survey states sustainable remediation is defined as:

> *"a remediation solution selected through the use of a balanced decision making process that demonstrates, in terms of environmental, economic and social indicators, that the benefit of undertaking remediation is greater than any adverse effects".*

In essence, a move away from 'dig and dump' towards onsite based soil remediation/reuse is in line with global and national drives towards making contamination site remediation more sustainable.

Scoping revealed that the industry contained approximately 250 surveyable stakeholders across several professional disciplines, including remediators, auditors, contractors, regulators, lawyers, and scientists/researchers (refer Figure 1).

Figure 1 - Range of professional associations of respondents to remediation survey



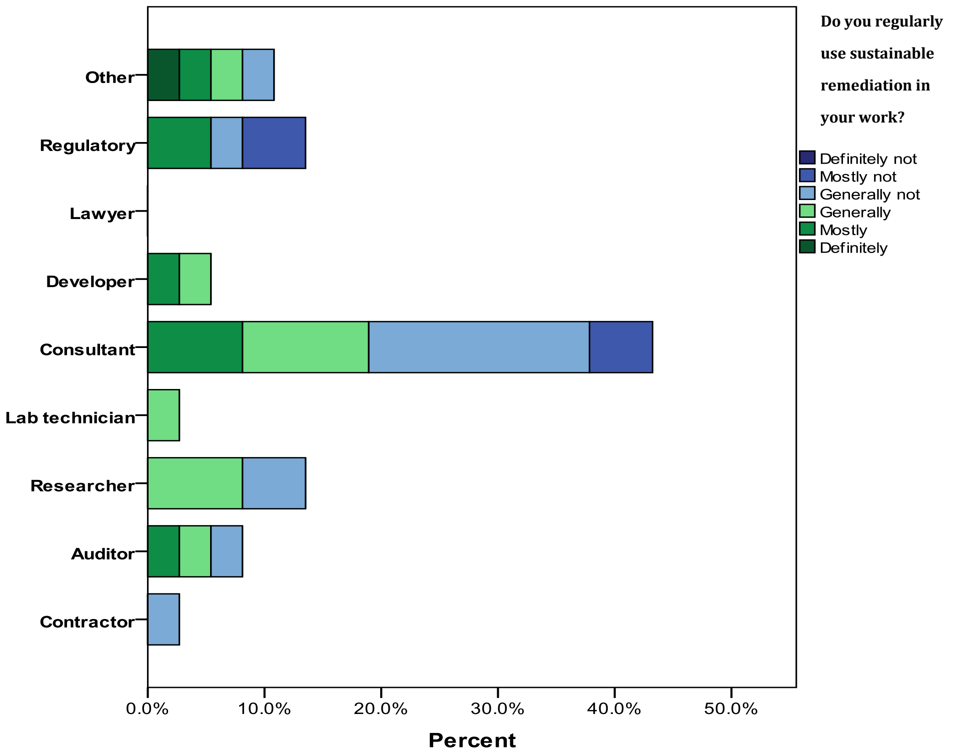
Key findings from the survey included:

- Over three quarters of respondents indicated that they sufficiently understand sustainable remediation to apply it in their work
- The vast majority of SA industry stakeholders associate carbon valuation as a core issue in the success of sustainable remediation
- Implementation of sustainable remediation was mostly predominant in consultancy (Figure 2)
- The survey revealed a consensus agreement amongst respondents in relation to the adoption of triple bottom line values in assessment of sustainable remediation.

A detailed summary of the survey is presented in Appendix C.

A more detailed discussion on the benefits of sustainable remediation is presented in Section 2.

Figure 2 – Implementation of sustainable remediation



2. Benefits of sustainable soil remediation

The benefits of sustainable soil remediation, either on site or off site are numerous. When assessing the sustainability of a remediation proposal the social, environmental and economic costs and benefits need to be considered (Figure 3). Estimating the overall costs and benefits of sustainable remediation requires consideration of these three components.

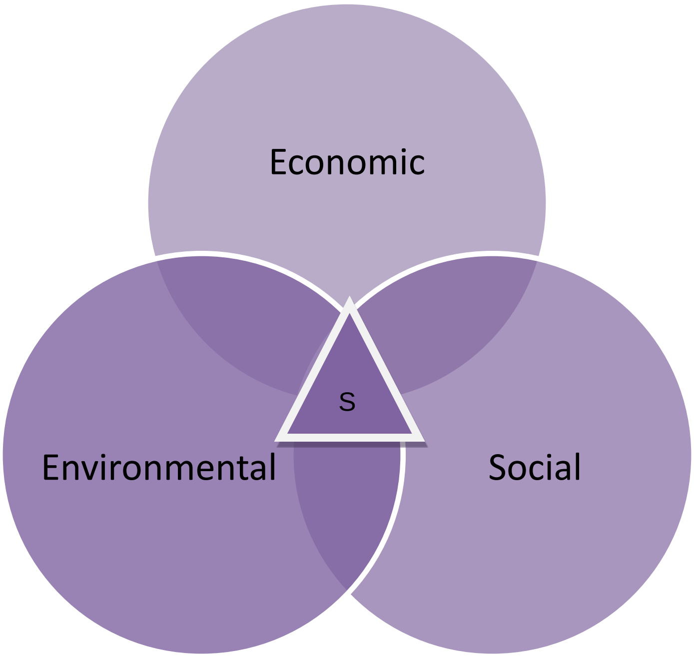


Figure 3 – Components of sustainable remediation (SR = sustainable remediation)

2.1 Economic

The economic component is concerned with remedial actions that reduce site risks and provide economic benefits, while being suitably cost effective. The economic aspects of such an evaluation include but are not limited to the project capital and operational costs. The evaluation ideally should also include an estimation of the potential changes in the cost of future liabilities (e.g. financial assurance requirements or employee health issues; reporting / regulatory costs, changes in perceived property value and associated neighbourhood values; and reduction in regulatory penalties and compliance costs and special assessments).

In summary, typical economic factors (and benefits) that should be considered in metrics evaluation include:

- Technology construction / implementation cost
- Technology operation and maintenance cost
- Change in economic resource value of land
- Change in economic resource value of groundwater affected by soil source
- Variable cost scenarios for carbon offsets
- Variation of energy cost over remedial lifecycle

Technology cost evaluation is likely to include an assessment of whether a balance of capital and operating costs can be achieved that will reach the cleanup target goals at the lowest overall cost.

Sustainable remediation should also improve the area, as well as the target site. For example, the remediation and productive use of a site can provide jobs or needed services to the area as well as reduce the poor image caused by the existence of blighted property in the area (i.e. this overlaps into 'social'). Further, if the property is developed but vacant, new occupants are likely to be more willing (or able) to move in since potential health issues have been addressed. Local governments should be able to obtain higher council rates since the property would be worth more.

2.2 Social / community

The social component is concerned with community engagement and regeneration of a site for community benefit. There is no known quantitative tool for assessing benefits to the community from sustainable remediation as the benefits (besides economic) are likely to vary amongst various stakeholders within the community, on a case by case basis. Established and draft sustainable remediation frameworks (Ref. 28) provide the following social indicators with respect to assessment of remediation options:

- Impacts on human health and safety
- Ethical and equity considerations
- Impacts on neighbourhoods
- Community involvement / satisfaction
- Compliance with policy objectives and strategies
- Uncertainty and evidence

A key element of the assessment of the social / community component with respect to sustainable remediation is likely to be the involvement / consultation of stakeholders:

- Stakeholder opinions can be an important source of information concerning particular aspects of sustainability or with regards to identifying the objectives of the (wider) community.
- Inclusive consultation and decision making improve the robustness of decisions and objectives (and is seen to be part of good governance).

2.3 Environmental

The environmental component considers technologies, approaches and designs that reduce the scale of the environmental clean-up of a site, and reduce the environmental footprint of the process.

There are many 'off the shelf' tools for selecting metrics and completing environmental footprint calculations, such as:

- Sustainable remediation tool (SRT^{TM})
- SiteWise^{TM}
- SURF Metrics Toolbox
- Lifecycle Assessment (LCA) Tools (e.g. Simapro, Gabi)

Essentially, sites are required to be assessed on a case by case basis as there are numerous factors required to populate such calculators (e.g. geographical, temporal, selected technologies based on contaminant profile) noting that there are over 2,400 metrics potentially applicable to sustainable site cleanup (Ref 22). However, use of such tools allows comparison of alternatives as well as optimisation of existing systems.

Example metrics used in various evaluation tools include:

- Natural resources impact
- Energy use

- Economics
- Greenhouse gas emissions (carbon footprint)
- Safety (i.e. risk of remedy causing adverse harm to the environment, health and safety, livelihood etc)

Example environmental metrics for remediation evaluation have been developed by the US EPA in its Green Remediation Framework (Table 3).

Table 3 – Common environmental metrics (US EPA Green Remediation Framework)

Core element	Negatives (Evaluate)	Positives (Evaluate)
Energy	Total energy use – natural gas, electricity, fuel	Renewable energy applied
Air	Total air pollutants, GHG emissions, dust, contaminant emission during treatment	GHG emission reductions, contaminant destruction during implementation
Water	Total water use, contaminant emission during treatment	Water recovery, contaminant emission reductions
Land	Total land disturbed, noise and lighting disturbances	Land reuse, ecosystems enhanced
Material & Waste	Waste generated	Materials reused

The concept of "carbon footprint" is described as *"the total set of GHG (greenhouse gas) emissions caused directly and indirectly by an individual, organisation, event or product"* (Ref. 26). With regard to environmental remediation activities, the vast majority of the associated carbon footprint is directly related to carbon dioxide (CO_2) emissions. These emissions result primarily from the use of fossil fuel- derived energy employed throughout the remediation program life cycle and, to a lesser extent, the CO_2 emissions resulting from the combustion or biological degradation of organic contaminants.

Currently, there is no internationally accepted standard dictating the level of detail required in carbon footprint life-cycle assessments, nor are there any accepted governing bodies regulating calculation methods or validating claims. It is understood that there are standards being used internationally (e.g. British Standards Institute PAS 2050) for various carbon footprint analyses, though the direct applicability of such an approach to land remediation is understood to be un-tested.

Calculating the total carbon footprint of a remediation program at a given site is a demanding and somewhat arbitrary undertaking. Referred to as life-cycle assessment, this process requires that every step in the generation of every product used and every process undertaken in relation to the remediation program be assessed for potential CO_2 emissions. The sum of all the emissions calculations is referred to as the total life-cycle carbon footprint.

However, some quantitative assessment tools are beginning to be developed, for example the Carbon Footprint Calculating Model[6], which has a database of every relevant activity and its production of CO_2-e; from the number of litres of chemicals or biological substrate to the distance that trucks carrying excavated soil have to travel.

A high level assessment of carbon emissions and soil remediation in SA is provided in Section 2.4 with respect to landfill disposal of soils and on site / off site treatment.

[6] http://www.inogenet.com/pressroom/2010/InsightsFeb/Model-for-Carbon-Footprinting-Soil-Remediation-Processes.html

Contaminated soils typically do not result in significant direct emissions of greenhouse gases (although soils contaminated by petroleum waste may result in the emissions of small amounts of volatile organic compounds that have a global warming potential). Nonetheless, the treatment of contaminated soils may involve other activities (extraction, transport and processing) which are likely to result in the emissions of greenhouse gases.

As part of this study, a high level overview of the potential differences in soil treatment (i.e. landfill versus sustainable management) is provided for example purposes.

The analysis is confined to the Adelaide region for the purposes of illustrating the relative greenhouse impacts and associated approximate carbon tax liability of each of the high level main treatment options (landfill disposal versus onsite / offsite treatment), as outlined in Table 4.

Table 4 – Parameters and background for high level assessment of soil treatment carbon liability

	Landfill disposal of soils	Offsite / on site remediation of soils and re-use
Overview	Excavation, transport and internment of soils with or without treatment to lower the concentrations to acceptable waste disposal criteria	Excavation and handling of soils (on site) Excavation, transport, handling of soils, transport for use elsewhere (off site)
Activities	• Excavate soils using plant • Transport of soils approximately 50 km (average distance from City to landfill on outskirts of City) • Internment in engineered facility • Internment in engineered facility following treatment (occurs in open air situation)	• Excavate soils using plant • No transport (on site only) • Transport of soils approximately 10 km (supposing a hub treatment site is available) (offsite) • Potential transport to new site or back to old site (offsite)
Carbon emission origins	• Plant • Truck based transport (50 km) • Plant to move or intern soils • Degassing of carbon from the soils within the landfill (long term)	• Plant • Truck based transport (10 km) • Plant to move soils • Further transport

The relative assessment is based on the following parameters relating to South Australia:

- Around 80,000 tonnes per annum of contaminated soils are transported to and disposed at two landfills. This is also assumed to be the amount treated for remediation.
- Transport to landfill is usually conducted by 20 tonne vehicles. The same type of vehicle is assumed to be used for transport of contaminated soil to treatment facilities and for transport of the cleaned soil.
- Average distance to transport the contaminated soil to landfill is around 50 km.
- Average distance to transport to a hub style (i.e. located close to the target clean-up site) ‘treatment facility’ is around 10 km (assuming establishment of cluster treatment sites in areas of notable development, e.g. TODs).
- A second offsite treatment centre is assessed but at greater distance (i.e. 50 km) – representing a treatment facility that is not a ‘hub’ site (based on current treatment of soils at landfill sites in SA)

- Electricity use at treatment facility is around 50,000 kWh per year. Electricity use for a similar amount of treatment on-site is assumed to be 20% higher – such assumption is based on relative cost per tonne of soil treated, assuming costs for energy input can be partitioned across multiple soils at an off-site facility
- Electricity sourced: 30% renewable energy, 35% natural gas and 35% coal based generation as a relative assessment, noting that SA is likely to be more dependent on gas than coal.
- Rigid trucks fuel use is around 11 MJ/km and emission intensity of 300 grams CO_2-e per km.
- Emissions from manufacture of treatment chemicals are ignored due to the fact that most of these are imported.
- Carbon price of $23/t CO_2-e in 2012/13 – analysis based on flat rate of such pricing.

A summary of the relative emissions and the associated costs is shown in Table 5.

Emissions are jointly highest under the 'business as usual' option of disposing of soils to a landfill (i.e. no soil remediation) and treatment at a non-local facility (ie located at a similar distance from a particular site as a landfill). The lowest level of emissions occurs with the on-site treatment.

Table 5 – Comparative indicative carbon emissions and costs of emissions in SA per annum for remediation purposes based on 80,000 tonnes of contaminated soil to landfill a year

	Transport Emissions	Electricity Emissions	Total Emissions	Cost	Difference (landfill as benchmark)	Cost per tonne of soil
	t CO_2-e	t CO_2-e	t CO_2-e	$	$	$
Landfill disposal	60,000	0	60,000	1,380,000	N/A	17.25
Non-local treatment facility	60,000	52	60,052	1,381,196	+1,196	17.26
Local treatment facility (hub-site) - average	24,000	52	24,052	553,196	- 826,824	6.91
On-site treatment - average	12,000	64	12,064	277,472	-1,102,528	3.47

Based on the high level calculations presented in Table 5, the highest carbon pricing cost per tonne of soil managed is associated with transport and management / disposal of soil to landfill (based on a carbon price of $23/t CO_2-e).

Further high level information concerning the relative carbon price associated with specific soil remediation techniques available (or considered to be feasible based on current market capabilities) in SA is presented in Section 3.4, along with an assessment of feasible remediation technologies likely to be available in SA.

3. Current remediation technologies in South Australia

3.1 Overview

An assessment of available remediation techniques within South Australia has been undertaken and is presented in Section 3.3.

However, a global and national perspective is also provided (Section 3.2) which outlines the known remediation techniques available in other developed economies (the United Kingdom, UK; and the United States of America, USA) and also in Australia nationally. The global and national perspective provides a background of theoretical remediation techniques and provides context for capabilities and technologies available in SA.

3.2 Global and national perspective of on-site remediation techniques

As a broad introduction, a summary of how respective soil remediation techniques are generally grouped is provided in Table 6, along with the predominant advantages and disadvantages of each grouped technique.

A detailed summary matrix of both off-site and on-site remediation techniques is then provided as Table 7. This matrix provides an overview of on-site remediation techniques used globally (i.e. as developed or available in UK and USA) with reference to the availability / development of each technique in Australia. The summary matrix focuses on soil remediation techniques which have aided in the diversion of contaminated soil away from landfill.

Where available the summary matrix also includes a cost assessment for use of each technique normalised to a ‘standard site’ defined as follows:

- Metropolitan location
- Sandy – clay soils
- 1,500 t of contaminated material

Costs of application of each technique will vary significantly depending on (but not limited to) soil type, contamination type, concentrations of contamination and the size of the site (economy of scale).

Approximate costs of each technique are based on the following resources, adjusting for exchange rates, inflation and geographical costs:

- Summersgill, I.D; and Scott, D.W. (2005) Factors affecting remediation technology costs in England and Europe. http://www.eugris.info/newsdownloads/stratford%20paper.pdf
- Federal remediation technologies roundtable screening matrix-http://www.frtr.gov/matrix2/top_page.html

Each technique has been assessed individually; however, in reality contaminated sites often use a variety of remediation techniques. A survey carried out by CL:AIRE in 2007 identified that 75% of remediation projects comprise a number of technology types (Ref. 9). This is because many brownfield sites contain more than one group of contaminants with similar properties and when this is the case the applicability of a technique should be assessed for each contaminant group separately in order to assess which technique might be applicable. However, this does not take into account whether the presence of one type of contaminant influences the degree to which another may be remediated. Even within the same contaminant groups there can be variation in the applicability of a treatment technique. For example, low molecular weight polycyclic aromatic hydrocarbons (PAHs) are more amenable to biodegradation than heavier PAHs, yet both are categorised as non-halogenated SVOCs.

Table 6 – Overview of soil remediation techniques

Soil remediation techniques	Description	Advantages	Disadvantages
In situ biological treatment	Bioremediation techniques are destruction techniques directed toward stimulating microorganisms to use the contaminants as an energy source by creating a favourable environment for the microorganisms. Generally, it requires provision of a combination of oxygen, nutrients, and moisture, and controlling the temperature and pH. Sometimes, microorganisms adapted for degradation of the specific contaminants are applied to enhance the process.	The main advantage of in situ treatment is that it allows soil to be treated without being excavated and transported, resulting in potentially significant cost savings.	In situ treatment generally requires longer time periods, and there is less certainty about the uniformity of treatment because of the variability in soil and aquifer characteristics and because the efficacy of the process is more difficult to verify.
In situ physical / chemical treatment	An example of physical / chemical treatment is oxidation, where oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.		
In situ thermal treatment	This technique uses steam/hot air injection or electrical resistance/electromagnetic/fibre optic/radio frequency heating to increase the volatilization rate of semi-volatiles in the sub-surface and facilitate extraction.		
Containment	Containment treatments are often performed to prevent, or significantly reduce, the migration of contaminants in soils or ground water, and can be developed on the site of interest. It can also be undertaken when it is more cost effective than other techniques.	Containment is necessary whenever contaminated materials are to be buried or left in place at a site. In general, containment is performed when extensive subsurface contamination at a site precludes excavation and removal of wastes because of potential hazards, unrealistic cost, or lack of adequate treatment technologies.	Containment cells (for example) may not be attractive where on-going or future and use cannot safeguard the long term security of the containment, for example a residential land use where future soil disturbance cannot be ruled out.
Ex situ biological treatment	For example, biopiles: Excavated soils are mixed with soil amendments and placed in aboveground enclosures. It is an aerated static pile composting process in which compost is formed into piles and aerated with	The main advantage of ex situ treatment over in situ treatment is that it generally requires shorter time periods than in situ	Ex situ treatment requires excavation of soils, leading to increased costs and engineering for equipment, possible permitting, and

Soil remediation techniques	Description	Advantages	Disadvantages
	blowers or vacuum pumps.	treatment, and there is more certainty about the uniformity of treatment because of the ability to homogenize, screen, and continuously mix the soil.	material handling/worker exposure considerations.
Ex situ physical / chemical treatment -	For example: Stabilisation - Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilising agent and contaminants to reduce their mobility (stabilisation).		
Ex situ thermal treatment -	For example thermal desorption: Soils are heated to volatilise water and organic contaminants. A carrier gas or vacuum system transports volatilised water and organics to a gas treatment system.		

Appendix D provides a concise overview of each technology based on readily available UK data and experience and available US data, including a description of the technology / technique, applicability, approximate costs in UK for comparison against those presented discussed in this Section and also the timescale required.

Currently, it is noted that there is no appropriate national requirement for undertaking a detailed options appraisal with respect to remediation / site management. However, the requirement for a detailed options assessment is likely to be a component of the forthcoming national remediation framework developed by the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE).

Should the national remediation framework have suitable carriage in SA, then practitioners should be expected to follow the guidance and undertake a detailed options appraisal as part of the remediation planning stage. It is noted that current SA EPA guidance relating to groundwater risk assessment and remediation stipulates the requirement for options appraisal prior to remediation of groundwater.

The soil remediation techniques were rated in Table 7 using the following criteria:

Factor	Rating A	Rating B	Rating C	Blank Cells
Development Status	Technology widely available	Technology has been used but not widely	Technique in pilot phase or not in use	Insufficient data
Operation & Maintenance (O&M) Intensity	Low degree of intensity	Average degree of intensity	High degree of capital investment required for O & M based on junior nature of technique	
System Reliability & Maintenance	High reliability low maintenance	Average reliability average maintenance	Low reliability and high maintenance	
Relative cost based on a 'standard site' located in metropolitan area comprising sandy-clay with a contaminated soil volume of 1,500 t	<$100 t	>$100 t - $400 t	>$400 t	
Time scale (Time required to clean up a 'standard'	In situ: less than 1 year	In situ: 1 to 3 years	In situ: in excess of 3 years	

Factor	Rating A	Rating B	Rating C	Blank Cells
site using the technology	Ex situ: less than 0.5 years	Ex situ: 0.5 to 1 year	Ex situ: in excess of 1 year	
Contaminant Group	Effectively demonstrated at pilot or full scale.	Limited effectiveness demonstrated at pilot or full scale	No demonstrated effectiveness at pilot or full scale	

Table 7 – Summary matrix of remediation technologies: UK, USA and Australia

								Contaminant Group									
Soil remediation techniques	**Development Status – Australia**	**Development Status – U.K.**	**Development Status – U.S.A.**	**O&M**	**System Reliability & Maintainability**	**Relative Costs**	**Time Scale**	**Halogenated VOCs**	**Halogenated SVOCs**	**Non-halogenated VOCs**	**Non-halogenated SVOCs**	**PCBs**	**Liquid free phase**	**Metals**	**Cyanide**	**Asbestos**	**Explosives**
In Situ Biological Treatment																	
Enhanced Bioremediation	B	A	A	C	B	A	B	A	A	A	A		C			C	
Phytoremediation	C	B	A	A	C	A	C	A	A	A	A	A	C	A	A	C	A
Monitored Natural Attenuation	A	A	A	C	B	A	C	A	A	A	B		C	C	C	C	C
In Situ Physical / Chemical Treatment																	
Chemical Oxidation / Reduction	B	A	A	C	B	B	A	A	A	A	A	A	C			C	B
Electrokinetic Separation	B	C	A	C	B	B	B	B	B	B	B		C	A	A	C	C
Fracturing	C	C	A	B	B	C	B	B	B	B	B		B	C	C	C	C
Soil Flushing	B	B	A	C	B	B	B	A	A	A	A	C		A	B	C	
Venting	A	A	A	C	A	B	B	A	B	A	A	C	A	C	C	C	C
Solidification / Stabilisation	B	A	A	B	A	B	A	C	C	C			C	A	A	A	B
In Situ Thermal Treatment																	
Thermal Treatment	B	B	A	C	A	C	A	B	A	B	A	B	B	B	C	C	B
Vitrification	C	B	A	C	B	C	B					A	C	A	A	A	
Containment																	
Cover and capping systems	A	A	A	A	C	A	A	B	B	B	B	B	C	B	B	A	C

								Contaminant Group									
Soil remediation techniques	**Development Status – Australia**	**Development Status – U.K.**	**Development Status – U.S.A.**	**O&M**	**System Reliability & Maintainability**	**Relative Costs**	**Time Scale**	**Halogenated VOCs**	**Halogenated SVOCs**	**Non-halogenated VOCs**	**Non-halogenated SVOCs**	**PCBs**	**Liquid free phase**	**Metals**	**Cyanide**	**Asbestos**	**Explosives**
Ex Situ Biological Treatment (assuming excavation)																	
Biological Treatment (Biopiles, Composting, Landfarming)	A	A	A	A	A	A	B	A	A	A	A	B	C	C	B	C	C
Ex Situ Physical / Chemical Treatment (assuming excavation)																	
Chemical Reduction / Oxidation	A	A	A	B	A	A	A	A	A	A	A	A	C			C	B
Dehalogenation	B	C	A	C	C	C	B	A	A	C	C		C	C	C	C	B
Separation	B	C	A	C	A	B	A	B	B	B	B		C	B	B	C	C
Soil Washing	B	A	A	C	A	B	A	A	A	A	A	A	A	A	B	B	B
Solidification / Stabilisation	B	A	A	B	A	B	A	C	C	C			C	A	A	A	B
Ex Situ Thermal Treatment (assuming excavation)																	
Hot Gas Decontamination	C	C	C	C	A	A	A	C	C	C	C		C	C	C	C	C
Open Burn / Open Detonation	C	C	A	C	A	A	A	C	C	C	C		C	C	C	C	A
Pyrolysis	C	C	A	C	C	C	A	B	A	B	A		B	C	C	C	C
Thermal Desorption	B	B	A	C	B	B	A	A	A	A	A		A	C	C	C	A
Vitrification	C	B	A	C	B	C	B					A	C	A	A	A	

3.3 Soil remediation techniques available in South Australia

Generally, it is considered that the provided national capabilities as summarised in Table 7 would be available in SA, with the cost of the mobilisation of specific equipment inter-state likely to be the key cost factor.

This section aims to highlight those technologies that have been applied in SA, or could feasibly be applied in SA if sufficient opportunity were created.

As with the global and national perspective on remediation techniques, the relative high level costs of each technique are shown based on normalisation to a ‘standard site’ as denoted earlier.

The summary of soil remediation techniques as relates to SA is presented in Table 8, and was ranked using the following criteria:

Factor	A	B	C	Blank Cells
Development Status	Technology widely available	Technology has been used but not widely.	Technique in pilot phase or not in use	Insufficient data.
Carbon pricing (on-site remediation on a ‘standard site’ located in metropolitan area comprising sandy-clay with a contaminated soil volume of 1,500 t compared to landfill disposal equivalent of $17.25 per tonne of soil). Please refer to Section 4.2.1 for a calculation of carbon emissions per annum in SA and approximate price of carbon per tonne of managed soil.	Low ~$0 - $10 per tonne of soil managed	Average ~$10 - $17.25 per tonne of soil managed	>$17.25 Exceeds approximate landfill disposal price of carbon in SA based on 2012 information	
Relative cost based on a ‘standard site’ located in metropolitan area comprising sandy-clay with a contaminated soil volume of 1,500 t	<$100 t	>$100 t - $400 t	>$400 t	
Time scale (Time required to clean up a ‘standard’ site located in metropolitan area comprising of sandy-clay with a contaminated soil volume of 1,500 t using the technology)	In situ: less than 1 year	In situ: 1 to 3 years	In situ: in excess of 3 years	
	Ex situ: less than 0.5 years	Ex situ: 0.5 to 1 year	Ex situ: in excess of 1 year	
Contaminant Group	Effectively demonstrated at pilot or full scale.	Limited effectiveness demonstrated at pilot or full scale	No demonstrated effectiveness at pilot or full scale	

Table 8 – Summary of techniques relevant to SA / Australia

	Development Status in SA	Carbon Pricing	Relative Costs (including Carbon Pricing)	Key cost driver	Time Scale	SA and Australian Case Studies
In Situ Biological Treatment						
Enhanced Bioremediation	A	A	A	• Soil type and chemistry • Type and quantity of amendments used • Type and extent of contamination.	B	The Penrice Soda Products main factory site, located at Osborne, provides an example of the successful remediation of a large contaminated site due to an historic fuel oil spill. In the early 1970s a major leak occurred from a 5000 KL above-ground storage tank previously used to store fuel for the now decommissioned Penrice boilers. An environmental assessment was undertaken to determine the impact of the spill on the environment which was unknown and to investigate options for remediation. It was found that a distinct stratum of fuel oil had become trapped in the soil below the groundwater level, however there was no impact via groundwater on the Port Adelaide River, and phase separated hydrocarbons had not migrated off site. Approximately 3000 m3 of soil affected by total petroleum hydrocarbon (TPH) was bio-remediated into a 'fit for purpose' landscaping product. The remediation was the final stage in a series of environmental investigations and cleanups of three sites at Penrice Soda Products that also included removal of a number of underground fuel tanks and remediation of the localised soil. (Source: http://www.epa.sa.gov.au/penrice.html). Ziltek (SA) have developed RemActiv™ which is a liquid additive that enhances the bioremediation process. It contains selected micro-organisms and a specially formulated nutrient mix that result in faster remediation times and cheaper processing costs.
Phyto-remediation	C	A	B	• Scale of effort • Density of sampling	C	N/A – No examples for full scale site remdiation. CSIRO is undertaking long term pilot trials and much research has been undertaken in SA (refer Section 4). It is also understood that phytoremediation case studies have been undertaken by CRC CARE and Flinders University.

	Development Status in SA	Carbon Pricing	Relative Costs (including Carbon Pricing)	Key cost driver	Time Scale	SA and Australian Case Studies
Monitored Natural Attenuation	A	A	A	•	C	N/A – No examples for full scale sites for soils – source is generally removed / treated.
In Situ Physical / Chemical Treatment						
Chemical Oxidation / Reduction	B	B	B	•	A	A range of proprietary agents are available for oxidation / reduction treatment, such as the VeruTEK range marketed by Environmental Remediation Resources of Victoria. Ziltek also offer RemBind which acts as a 'binding up' agent for chemicals in soil.
Electro-kinetic Separation	C	C	B	• Amount of soil to be treated • The conductivity of the soil • The type of contaminant • The spacing of electrodes • Type of process design employed	B	N/A – No examples for full scale sites.
Fracturing	C	B	C	• Only available from one vendor in the US	B	Not considered suitable or relevant to SA based on vendor situation. CSIRO has undertaken pilot research and development on the technique.
Soil Flushing	C	B	A	• Soil permeability • Depth to groundwater	B	N/A – No examples for full scale sites.
Venting (Vapour extraction)	A	B	C	• Economy of scale • Soil type	B	Several contractors including Enviropacific (SA) and OTEK (SA) have capability to undertake soil vapour extraction. It is regularly applied on hydrocarbon spills in SA.
Solidification / Stabilisation	B	C	B	• Varies according to materials or reagents used, their availability, project size, and chemical nature of contaminants • Depth of contaminants	A	Contaminated soil from a former gas works site containing 5,500 mg/kg total PAHs and 214 mg/kg benzo-(a)-pyrene (B(a)P), with leachabilities of 4.435 mg/L and 0.0083 mg/L, respectively, was treated by SA company Ziltek using the chemical fixation reagent RemBind® F at an addition rate of 5% by weight.

	Development Status in SA	Carbon Pricing	Relative Costs (including Carbon Pricing)	Key cost driver	Time Scale	SA and Australian Case Studies
In Situ Thermal Treatment						
Thermal Treatment	C	C	A	• Soil type • Depth to contamination	A	In situ thermal treatment is available interstate, such as The Electro-Thermal Dynamic Stripping Process, or ET-DSP™, in-situ thermal soil decontamination method marketed by Environmental Remediation Resources of Victoria.
Vitrification	B	B	C	•	B	In Situ Vitrification (ISV) is a commercially available mobile, thermal treatment process that involves the electric melting of contaminated soils, sludges, or other earthen materials, wastes and debris for the purposes of permanently destroying, removing, and/or immobilising hazardous and radioactive contaminants. The ISV process is available in Australia through Geosafe Australia Pty. Ltd. The ISV process has been selected for use at the Maralinga site in South Australia to treat burial pits containing soil and debris contaminated with plutonium and uranium as well as lead, barium, and beryllium.
Containment						
Cover and capping systems	A	B	A	• Higher carbon cost awarded based on requirement for transport of capping materials	A	Containment and capping of metals and organics has been used in South Australia on at least two sites located on the periphery of the CBD within the last two years. An estimated 5,000 t has been diverted from landfill with a commensurate reduction in carbon footprint associated with haulage. An example of such cover / containment is the approach undertaken at the ex SA Water depot at Thebarton, where a human health risk assessment was developed to underpin the required thickness of cover material.
Ex Situ Biological Treatment (assuming excavation)						
Biological Treatment (Biopiles, Composting, Land-farming)	A	A	B	• Costs are dependent on the contaminant procedure to be used • Need for additional pre- and post-	B	Enviropacific was engaged by AGL Torrens Island (SA) to bioremediate and dispose of approximately 400 tonne of TPH impacted soils which had been stored in a bunded area onsite at Torrens Island. Concentrations of TPH in the soils exceeded the Low Level Contaminated Waste Criteria (LLCW) which precluded direct disposed to landfill. The works

	Development Status in SA	Carbon Pricing	Relative Costs (including Carbon Pricing)	Key cost driver	Time Scale	SA and Australian Case Studies
				treatment • Need for air emission control equipment. • Biopiles are relatively simple and require few personnel for operation and maintenance		included excavation and cartage of the soils to Southern Waste Depot (SWD) for further chemical characterisation and subsequent bioremediation in the purpose built bioremediation facility. Enviropacific bioremediated the soils to meet the LLCW criteria and the soils were subsequently disposed at SWD. An innovative biopile facility was successfully used to remediate 2000 m^3 of hydrocarbon contaminated soil at a former locomotive fuelling facility in South Australia (SKM).Laboratory scale studies were undertaken to determine the remediation end points and the most effective nutrient supplementation using an ex situ biopile process (Flinders University). Commercial facilities exist at Integrated Waste Services and Southern Resources Co.
Ex Situ Physical / Chemical Treatment (assuming excavation)						
Chemical Reduction / Oxidation	C	A	B	•	A	A range of proprietary agents are available for oxidation / reduction treatment, such as the VeruTEK range marketed by Environmental Remediation Resources of Victoria.
Dehalogenation	C	C	C	•	B	No case studies identified
Separation	C	B	B		A	No case studies identified
Soil Washing	B	C	B	• Economy of scale • Processing speed • Size of machine	A	No case studies identified
Solidification / Stabilisation	B	A	B	• Type of Waste • Moisture content in the sludge drives up costs compared to solid • Contaminant concentration and type determine the amount of reagents added to the waste to attain the required	A	Nyrstar Port Pirie had a 2000T stockpile of material which contained heavy metals (As, Cd, Pb and Zn) exceeding the Low Level Contaminated Waste (LLCW) maximum leachate concentrations. The stockpile consisted of crushed roaster bricks that once lined the roaster at Nyrstar Hobart. The material required immobilisation to prevent the metals leaching such that the material could be disposed of as treated LLCW. Enviropacific were engaged by Nyrstar Hobart to undertake the full scale treatment. The

	Development Status in SA	Carbon Pricing	Relative Costs (including Carbon Pricing)	Key cost driver	Time Scale	SA and Australian Case Studies
				treatment standards • Size of the mobile system		works were undertaken on the Nyrstar Port Pirie site which involved mixing the contaminated crushed bricks using a Hitachi Soil Recycler. The Soil Recycler was imperative for the smooth running of this project as they were able to treat in excess of 120m3 per hour. Leachable post treatment results were all below the laboratory limit of detection or well below the LLCW criteria.
Ex Situ Thermal Treatment (assuming excavation)						
Hot Gas Decontamination	C	C	C		A	No case studies identified
Open Burn / Open Detonation	C	A	B	• Site and material specific	A	Generally only used for munitions / unexploded ordnance - No case studies identified
Pyrolysis	C	C	C	• There are specific feed size and materials handling requirements that impact applicability or cost at specific sites. • The technology requires drying of the soil to achieve low soil moisture content (< 1%). • Highly abrasive feed can potentially damage the processor unit. • High moisture content increases treatment costs. • Treated media containing heavy metals may require stabilization	A	No case studies identified
Thermal Desorption	B	C	A	• Economy of Scale - Quantity of material treated has a large impact	A	Theiss services undertook a large scale remediation project at the former Union Carbide plan t in NSW. The toxic contaminants were a legacy of Union Carbide's operations for nearly half a century. Contaminated soil and sediment was excavated from the land and

	Development Status in SA	Carbon Pricing	Relative Costs (including Carbon Pricing)	Key cost driver	Time Scale	**SA and Australian Case Studies**
				• Moisture content - Increases required heat input (increasing fuel costs)		dredged from the bay, classified to determine how much contamination was present, and the most contaminated materials with high levels of dioxin and other chemicals were thermally treated. The excavated and dredged materials were then reinstated on land according to the residual contamination profile and the relevant land use, ensuring the land was made safe.
Vitrification	B	B	C		B	See earlier entry for in situ vitrification. Ex-situ likely to be less complex.

It is understood that some consultants have been involved in using a number of remediation system. All members of Association of contaminated land consultants Australia (ACLCA) were requested for information of projects they have been involved. There was no information received from any consultant during the study.

3.4 Carbon pricing estimate for SA remediation techniques

Note that Table 8 also provides an approximation of carbon pricing for each remediation technique. The application of CO_2 equivalent (CO_2-e) per technique is an inexact science and various international researchers have undertaken ‘footprint assessment’ for various techniques. However, such assessments are rarely normalised homogeneously across all studies. Further, assessments undertaken in other countries are likely to use a differing electricity generation source distribution to that in SA. Thus carbon pricing per technique as applied here is high level and is based on available values found in literature and considered in line with National Greenhouse Accounting Factors. The approximations are based on a calculation of carbon pricing per tonne of soil and are for relative comparison only.

3.4.1 Basis of the carbon assessment

Previous work undertaken in 2006 by researchers at Cambridge University reviewed five remediation techniques – capping, stabilisation, soil washing, ex-situ bioremediation and landfilling – to assess which were the most sustainable (Ref. 29). Multi-criteria analysis (MCA) was used to assess one project that used each technology for their impacts on human health and safety, local environment, stakeholder concern, site use and the global environment, then normalised the impacts against the remediated soil volume to allow comparison.

In 2008, SKM took such information and further data to create a simple screening tool that allowed a rapid assessment at the design stage of the greenhouse emissions of each remediation technique for a given site in Australia and specified volume of hydrocarbon contaminated material.

The assessment used a detailed lifecycle assessment (LCA), which fed into a more detailed MCA to determine stakeholder priorities before selecting the remediation process. Each technique was broken down into individual steps and each step assessed on three key components:

- Fuel consumption (remediation processes, plant and transport)
- Energy usage (electricity used by the remediation plant)
- Natural resources used (fill material, cement, capping layer construction material)

In addition, where available, the direct emission data of each remediation plant was reviewed to assess the local impacts.

For each of the five techniques the fuel consumption, emissions and general number of off-site and on-site vehicle movements were calculated, based on 8,500 tonnes of contaminated material.

Taking into account only total greenhouse emissions, the preliminary screening indicated thermal desorption and solidification is the least sustainable of the techniques. The significant volume of diesel required to reach the 550-650°C temperatures needed to release and destroy the contaminants during thermal desorption produced as much if not more than the greenhouse emissions required to transport the material to landfill.

Capping, on the other hand, produced the least greenhouse emissions. However, the calculation of emissions undertaken by SKM in 2008 is likely to result in an overestimate, with the assumption that the reduction of contaminant concentrations was solely due to the breakdown of contaminants into CO_2 and H_2O. In reality, a significant proportion of the contaminant concentrations would be due to volatilisation, rather than degradation. It should also be noted that degradation of contamination – and methane generation – within landfilled material was not considered within the screening tool.

Using this data, an assessment of carbon pricing (at 2012 fixed rates) was undertaken for listed techniques in comparison to landfill disposal (Figure 2) supplemented with data from an assessment of energy consumption and carbon dioxide emissions at superfund clean-ups in the USA (Ref 25.). Landfill disposal CO_2e was calculated as discussed in Section 2.4.

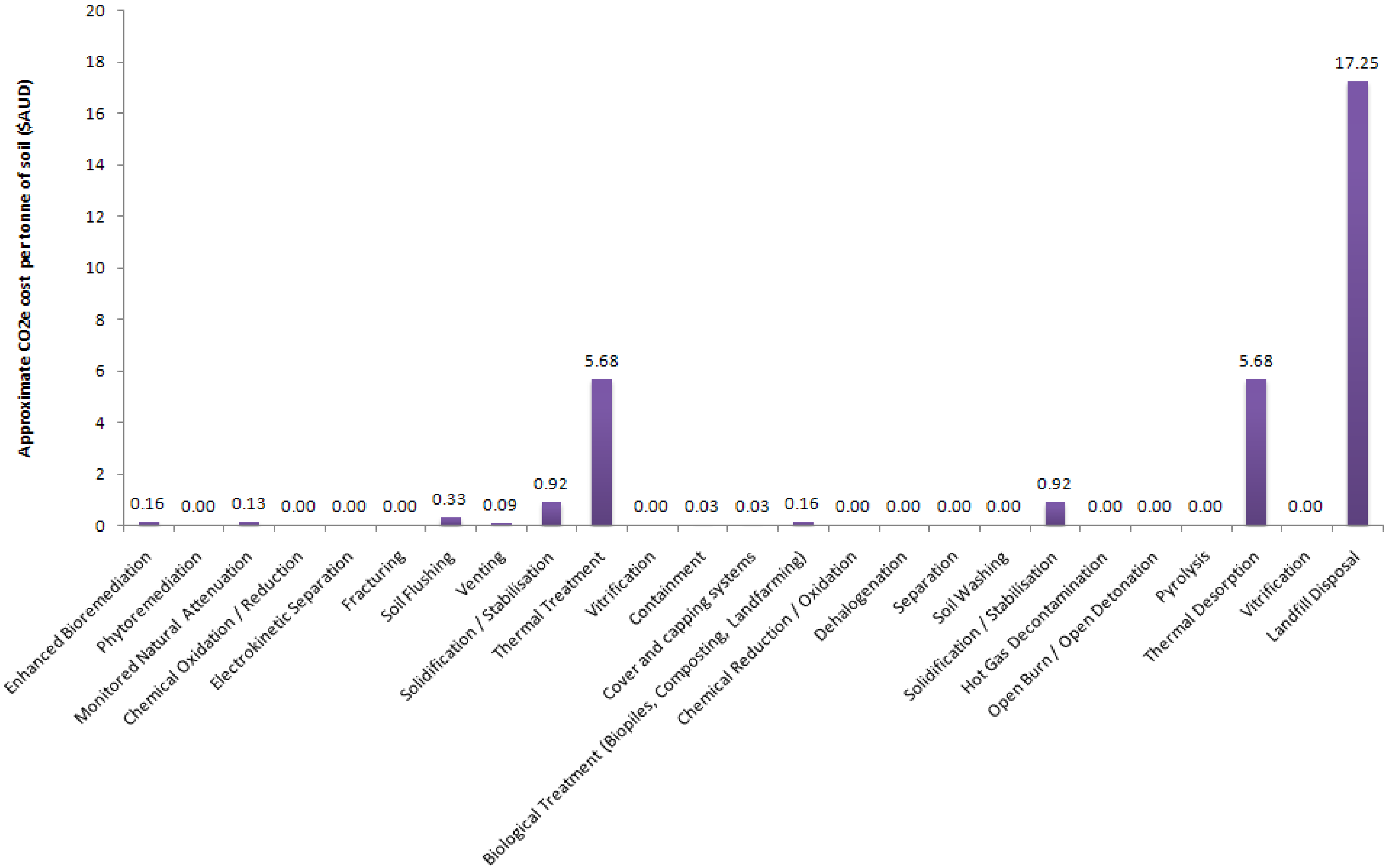
No transparent data was recovered for a considerable number of the techniques, thus such techniques are listed as “0.00” with respect to cost ($AUD).

3.4.2 Summary of high level carbon assessment

Based on the assumptions made, the high level assessment of carbon liability per tonne of soil remediated indicates that landfilling of soils and thermal desorption treatment are (comparatively) the highest in terms of carbon emissions.

The high level assessment as indicated in Figure 4 provides input to the assessment of optimal soil remediation techniques in SA.

Figure 4 – Approximate CO_2e cost per tonne of soil managed by technique (0.00 = no data)



3.5 Suitability of alternative soil remediation techniques in South Australia

Based on the techniques relevant to SA as presented in Table 8, a summary of those techniques ranked as either 'A' (widely available) or 'B' (used but not widely) or 'C' (not used at all) is presented in Table 9 against relevant contaminants.

Table 9 - Summary of techniques available or used in SA in relation to contaminants (blank cell = no assessment made) – based on data availability

Technique	Halogenated VOCs	Halogenated SVOCs	Non-halogenated VOCs	Non-halogenated SVOCs	PCBs	Liquid free phase	Metals	Cyanide	Asbestos	Relative Costs (including Carbon Pricing)	Time Scale
Enhanced Bioremediation	A	A	A	A		C			C	A	B
Monitored Natural Attenuation	A	A	A	B		C	C	C	C	A	C
Chemical Oxidation / Reduction	A	A	A	A	A	C			C	B	A
Venting	A	B	A	A	C	A	C	C	C	C	B
Solidification / Stabilisation	C	C	C			C	A	A	A	B	A
Vitrification					A	C	A	A	A	C	B
Cover and capping systems	B	B	B	B	B	C	B	B	A	A	A
Biological Treatment (Biopiles, Composting, Landfarming)	A	A	A	A	B	C	C	B	C	B	B
Chemical Reduction / Oxidation	A	A	A	A	A	C			C	B	A
Soil Washing	A	A	A	A	A	A	A	B	B	B	A
Solidification / Stabilisation	C	C	C			C	A	A	A	B	A
Thermal Desorption	A	A	A	A		A	C	C	C	A	A
Vitrification					A	C	A	A	A	C	B

The summary of SA relevant techniques indicates that each contaminant is covered by one or more alternative techniques. The choice of techniques would then be subject to an options appraisal (including site / project specific parameters and sustainability parameters). The South Australian environment (climate, geology, soils) is not considered to present an undue hindrance or impediment to application of such techniques, however there may be limitations to some in situ techniques in certain areas where soils are dominated by stiff clays.

In summary, the most common potentially contaminating activities and contaminants in SA (as listed in Table 2) are considered manageable by soil remediation techniques likely to be available in SA, and the local environment would not represent a significant impediment. South Australia therefore has the capabilities to undertake sustainable soil management and remediation.

4. Remediation research & development capabilities in SA

An assessment of South Australian in situ and on-site remediation research and development (R&D) was undertaken as part of this study. A summary matrix is presented in Table 10.

The table details treatment technologies and contaminant classifications as described by the United States Environmental Protection Agency (USEPA) treatment technology screening matrix as presented in previous summary tables, for continuity.

Following the identification of research organisations in South Australia who undertake remediation R&D, the research activities undertaken within each treatment area / technology was qualitatively assessed.

Most R&D activity was associated with the bioremediation of petroleum hydrocarbons (in situ and ex situ) or phyto-remediation of inorganic contaminants. However, research on physical and chemical treatment technologies have also been undertaken albeit to a lesser extent.

It was identified that R&D is not being undertaken on thermal remediation processes in South Australia presumably due to the maturity of the technology (for some contaminant types) and / or cost limitations of the technology.

In South Australia, the majority of in situ and on-site remediation R&D is being undertaken through the CRC CARE (see http://www.crccare.com/) and the University of South Australia (one of CRC CAREs research providers, specifically the Centre for Environmental Risk Assessment and Remediation, CERAR) located at the Mawson Lakes campus. However, other research is being performed at Flinders University (bioremediation, phytoremediation), University of Adelaide and CSIRO (phytoremediation) and the South Australian Research and Development Institute (phyto-remediation, industrial ecology) in addition to Environmental Small and Medium Enterprises (SMEs).

Within CRC CARE, a major program focusing on ‘Cleaning Up’ aims to develop the necessary technologies, indicators and strategies for in situ management of contaminated sites, taking into consideration triple bottom line principles for the remediation and management of contaminated sites. It also addresses the limitations of existing assessment and remediation technologies by establishing parameters for effective risk reduction in remediating unique Australian soils and aquifers.

SA has notable research and development capacity in the private sector with SME’s such as Ziltek, which undertake research and development (and commercialisation) of soil contamination monitoring equipment (e.g. RemScan) and remediation techniques (eg the chemical fixative RemBind).

Table 10 – South Australian research activities and case studies: in situ and ex situ treatment technologies (blank spaces = no research)

Treatment technology	Non-halogenated VOCs	Halogenated VOCs	Non-halogenated SVOCs	Halogenated SVOCs	Fuels	Inorganics	Radionuclides	Explosives	Case Studies
In situ biological treatment									
Bioventing									N/A in SA. CSIRO is understood to have undertaken some managed bio-venting trials in Western Australia (note though that some of the researchers were based in SA). CSIRO evaluated bio-venting as a cleanup technique for diesel fuel contamination. Refer http://www.clw.csiro.au/research/urban/protection/remediation/projects_2.html#04 for further information.
Enhanced bioremediation		✓			✓				The Centre for Environmental Risk Assessment and Remediation (CERAR) aims to develop and validate a bioremediation screening tool to be able to rapidly predict the endpoint of bioremediation and assist determination of whether bioremediation is a suitable technology of remediation. CERAR is based at the University of South Australia. Refer http://www.unisa.edu.au/Research/Centre-for-Environmental-Risk-Assessment-and-Remediation-/Research/
Monitored Natural Attenuation					✓				Monitored Natural Attenuation (MNA) is practised widely in Australia and is accepted in South Australia as a treatment method for soils remediation in certain circumstances (note that MNA is generally more applied to groundwater contamination following treatment or removal of the source 'hot spot').
Phytoremediation					✓	✓			CERAR currently undertakes research into the application of phytoremediation on contaminated sites. Refer http://www.unisa.edu.au/Research/Centre-for-Environmental-Risk-Assessment-and-Remediation-/Research/
In situ physical / chemical treatment									
Chemical oxidation		✓							Chemical oxidation is a relatively established technique and is employed by industry / remediation professionals (for example Ziltek – refer http://www.ziltek.com.au/)

Treatment technology	Non-halogenated VOCs	Halogenated VOCs	Non-halogenated SVOCs	Halogenated SVOCs	Fuels	Inorganics	Radionuclides	Explosives	Case Studies
Electro-kinetic separation	✓								CRC CARE have published research into use of ultrasonic treatment of soils for desorption of DDT.
Fracturing									N/A
Soil flushing				✓					Researchers at the University of South Australia have previously trialled the effectiveness of co solvent soil flushing and fungal biosorption for the remediation of p, p-DDT-contaminated soil. Simulating an in-situ soil flushing technique. Using this technique, p, p-DDT concentrations were reduced from 990 mg kg^{-1} to below Australian and New Zealand Environmental and Conservation Council (ANZECC) guidelines (50 mg kg^{-1}). Reference: Juhasz, A. L.; Smith, E.; Smith, J.; Naidu, R., In situ remediation of DDT-contaminated soil using a two-phase co solvent flushing-fungal biosorption process. Water, Air, and Soil Pollution 2003, 147, (1-4), 263-274.
Soil vapour extraction					✓				Research (overview) of such techniques has been undertaken under the CRC CARE umbrella. Reference: Lam, D; Moritz P. 2007. Technical impractibility for further remediation of LNAPL impacted soils and aquifers. Technical Report 6 CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.
Solidification / stabilisation						✓			Researchers at the University of South Australia have undertaken research into the use of phyto-stabilisation on metal concentrations (refer Appendix E). Reference: Bolan, N. S.; Park, J. H.; Robinson, B.; Naidu, R.; Huh, K. Y., Phytostabilization. A green approach to contaminant containment. In 2011; Vol. 112, pp 145-204.
In situ thermal treatment									
Thermal treatment									N/A
Ex situ biological treatment (assuming excavation)									

Treatment technology	Non-halogenated VOCs	Halogenated VOCs	Non-halogenated SVOCs	Halogenated SVOCs	Fuels	Inorganics	Radionuclides	Explosives	Case Studies
Biopiles			✓		✓			✓	Biopiles are a variation of bioremediation whereby the soil is excavated, mounded and certain parameters are measured and controlled to provide an optimum biodegradation environment. Biopiles are an established technology. They are often used in SA.
Composting					✓				Composting is a variation to the use of biopiles.
Landfarming									N/A
Slurry phase biological treatment					✓				Researchers at the University of South Australia have trialled such technology for treatment of petroleum hydrocarbon in soil. Reference: Aburto-Medina, A.; Adetutu, E. M.; Aleer, S.; Weber, L.; Patil, S. S.; Sheppard, P. J.; Ball, A. S.; Juhasz, A. L., Comparison of indigenous and exogenous microbial populations during slurry phase biodegradation of long-term hydrocarbon-contaminated soil. Biodegradation Doi: 10.1007/s10532-012-9563-8.
Ex situ physical / chemical treatment (assuming excavation)									
Chemical extraction									N/A
Chemical reduction / oxidation			✓		✓				Chemical oxidation is a relatively established technique and is employed by industry / remediation professionals.
Dehalogenation									N/A
Separation									N/A
Soil washing				✓		✓			Soil washing is an established soil treatment technique and is thus unlikely to be the subject of significant research.
Solidification / stabilisation						✓			Solidification and stabilisation is an established soil treatment technique (nationally) and is thus unlikely to be the subject of significant research.

Treatment technology	Non-halogenated VOCs	Halogenated VOCs	Non-halogenated SVOCs	Halogenated SVOCs	Fuels	Inorganics	Radionuclides	Explosives	Case Studies
Ex situ thermal treatment (assuming excavation)									
Hot gas decontamination									N/A – No research case studies encountered
Incineration									N/A – No research case studies encountered
Open burn / open detonation									N/A – No research case studies encountered
Pyrolysis									N/A – No research case studies encountered
Thermal desorption									N/A – No research case studies encountered
Containment									
Cap / cover system / containment						✓			Note that CRC CARE is understood to be undertaking a project involving the development of guidance on safe containment of contamination, and the guidance is aligned to AS/NZS 31000:2009 (Risk Management – Principles and guidelines).
Landfill cap enhancements / alternatives									CERAR undertake notable work in this area – in conjunction with phytoremediation. Refer http://www.unisa.edu.au/Research/Centre-for-Environmental-Risk-Assessment-and-Remediation-/Research/

As a measure of R&D activity in SA, Appendix E summarises the number of publications on in situ and ex situ treatment technologies during the past 10 years. The number of publications in each remediation category was determined using Scopus Search which has coverage of over 23,000 publications. Searches were limited to a date range from 2002 to present including all document types (journals, books, conference proceedings) (i.e. 'Global Publications'). Results were refined by limiting documents to Australian affiliations ('Australian Publications'). Australian publications were viewed to determine their relevance to the keyword query ('Relevant Australian Publications') with South Australian affiliations noted ('SA Publications').

Keywords were identified in article title, abstract and article keywords. Remediation technology keywords (as listed in Table 10) were utilised for Scopus searches; in some cases 'soil' or 'remediation' were included where the treatment technology keyword was too generic. The number of relevant publications may not be exhaustive as alternative keywords may have been utilised (by the respective authors) for referencing purposes. It should also be noted that some research may not yet be published, may not be published in the future or may remain commercial in confidence.

In addition, research publications listed in Appendix E (Australian publications since 2002 detailing in situ and onsite remediation) highlight the majority of activities being undertaken at laboratory scale with few reports of pilot or field scale remediation applications. This is echoed in the South Australian publication data (refer Appendix E).

4.1 Limitations to South Australian remediation research

As discussed previously the majority of in situ and on-site remediation research has been carried out through the CRC CARE, CERAR (University of South Australia) and at Flinders University. Such research is highly regarded as evidenced by the number of publications associated with these researchers.

However much of this research has been performed either at the laboratory scale or on a relatively small field scale. Far less R&D has been carried out at the field level or with industrial partners. The main reason for this is the difficulty and costs associated with running such large trials. This is a current limitation of the research being carried out in South Australia as there are significant differences in the efficacy of a remediation technique in laboratories compared with those carried out at full scale and with additional project factors to contend with (financial and time factors).

A review of the capabilities/ outputs presented in Table 10 indicates that there are both several contaminants and technologies where research has not been undertaken. One potential reason for these shortfalls is indicated by the fact that the research that has been undertaken is predominantly bioremediation based. Bioremediation can be more easily studied in a standard laboratory environment than physical / chemical or thermal techniques, which require larger inputs of resources and also appropriate test sites for development.

4.2 Opportunities for research

A continuing collaboration of research centres with industrial partners (field sites), consultants (site assessment and monitoring) and remediation contractors (resources and equipment) would hopefully extend the research and development area in SA into studying other contaminants / technologies, with subsequent increased opportunity for commercialisation of techniques based on full scale pilot trials (i.e. similar to CL:AIRE[7] in the UK).

Notably, where private sector remediation research and development companies have been funded to undertake specific research and development, commercialisation of the product has occurred[8], on what would appear to be a modest level of investment.

[7] Contaminated Land: Applications in Real Environments (http://www.claire.co.uk/)

[8] For example, the SA based research and development company Ziltek have recently developed and marketed the RemScan unit for real time detection and quantification of petrol hydrocarbon concentrations in soils, which is likely to have significant benefits for site clean-up. The development was funded by Victoria's Hazwaste Fund (refer Section 7).

A summary is provided below in terms of shortfalls and associated opportunities in current research associated with the various remediation technologies shown in Table 10:

In situ bio-venting is one of the most cost-effective in situ technologies currently available, particularly for the remediation of petroleum hydrocarbon contaminated sites. However, sub-optimal bioventing may result in greater residual concentrations in the soil and consequently longer clean up times and higher costs. Improved understanding in terms of the impact of bioventing is generally considered an important research aim, however, within the South Australian context, there appears to be a lack of research in this area (and with the exception of some limited trials undertaken by CSIRO, does not appear to be well researched in Australia in general). Future research in this area will result in improved performance, reduced costs and better predictive models for reaching site closure.

In situ enhanced bioremediation research within South Australia research has been relatively strong in terms of volatile organic compounds, both halogenated and non-halogenated. However, there is little evidence of research in this area for semi-volatile organic compounds such as plasticizers and high molecular weight polycyclic aromatic hydrocarbons (e.g. benzo(a)pyrene). Given the potential health effects associated with some of these compounds, further research in this area is recommended.

Phytoremediation of inorganic compounds (e.g. metals) and petrogenic hydrocarbons is a well-researched area both globally and locally within South Australia. The limitations of phytoremediation for other pollutants have been well documented and are based around the toxicity to plants of other pollutants. However, a shortfall in South Australian phytoremediation research is the lack of data demonstrating the effectiveness of this technology at pilot and field scale.

In situ chemical/physical treatments are time effective in comparison to biological technologies; however, engineering considerations may limit their application. For the application of chemical oxidation technologies in situ, off-site movement and ecological impact of oxidants is a concern. Given their global application, the fact that these technologies have not been further researched for the South Australian environment represents a shortfall.

In situ thermal treatment (e.g. steam injection) has been widely used to enhance in situ diesel and solvent recovery (including chlorinated solvents) from contaminated soils together with other heating technologies such as electrical heating, and electrical resistance tomography. Due to the expense of equipment and operation, application and research has been limited to the US and in Europe (over 200 projects completed to date). It is difficult to envisage significant South Australia-based research in the future, given the limited opportunities (and often, resources) required to carry out thermal technologies. However, economically this treatment compares generally well with other technologies and has been observed to have a relatively low environmental impact (except for greenhouse gas emissions). Field scale demonstration of such technology in SA may lead to better uptake.

Ex situ biological treatment research in South Australia has been extensive, especially in the area of petrogenic hydrocarbon. As a mature technology it has proved successful for the degradation of a wide range of non-halogenated compounds. Further site specific research is required prior to full scale implementation of bioremediation strategies to ensure specific site conditions are considered in the design of the technology.

Ex situ Physical/chemical treatment uses the physical and/or chemical properties of the contaminants or of the contaminated medium to destroy (i.e., chemically convert), separate, or contain the contamination. Techniques such as chemical oxidation are widely practiced and numerous research articles have been published by overseas investigators. Given the widespread use of these technologies the fact that only limited publications from South Australian researchers were found (and limited to soil washing), this area of research represents a significant shortfall. However, research is currently being conducted in South Australia with a focus on chemical oxidation, soil washing and stabilization of non-halogenated compounds. It is likely that this will result in increased research output in the coming years.

Ex situ thermal treatments have not been researched in South Australia. As detailed earlier, this is likely to be associated with the maturity of the technology in addition to the high costs associated with its operation. This suggests that it is unlikely that such research will be performed in the future within South Australia.

Containment of contaminated material on site, sometimes following primary treatment, remains an important part of the South Australian Remediation Industry. Where significant volumes of low solubility and low vapour producing contaminated material are present, the use of onsite containment (i.e. within a cell) can be an attractive option (subject to final land use – e.g. if residential then the attractiveness of such an option tends to diminish due to the long term management or avoidance of disturbance required). On a global scale, research in this area is extensive; on a South Australian scale, research is limited to the fate of inorganic materials in landfills. This is surprising given that for some time there has been widespread containment of a range of organic and inorganic contaminants. Further, this legacy issue will require monitoring over time while research in this area may lead to a greater understanding of the fate and effect of these contaminants in landfills. However it is noted that CRC CARE is undertaking a project involving the development of guidance on safe containment of contamination.

5. Drivers for soil remediation in SA

There are several drivers for contaminated soil remediation / re-use:

- Remediation may be necessary for land posing significant risks to human health or other receptors in the environment such as groundwater or surface water. The remediation may be enforced or voluntary.
- Remediation may be required to facilitate redevelopment of formerly used land, which may take place for commercial reasons, or because economic instruments have been put in place to support this process.
- Repairs to previous remediation work may be necessary where a past remediation project has failed, or a redevelopment has been carried out without adequate risk assessment and management. These situations are often due to inadequate site investigation in the first instance.
- Remediation may also take place on a voluntary basis without any regulatory requirement to control liabilities or as an investment to realise a gain in land value. Two specific commercial activities are important drivers for such remediation projects:
  - Divestment of industrial sites where a potential purchaser requires environmental liabilities to be defined or removed prior to purchase
  - Acquisition / take-over, where a site has to satisfy the environmental policy of a new controlling company.

In SA, a predominant driver for the sustainable remediation / management of contaminated soils is the Strategic Plan (and associated strategies/policies), which identifies population growth as a key driver in the on-going economic development and sustainability of the State. The majority of growth is expected within 800 metres of existing or extended transport corridors and the associated 14 TODs identified across the metropolitan area. As many of the areas that are proposed for growth in the 30 year Plan are former or existing industrial or brownfield sites a significant increase in remediation of contaminated land (and associated need to deal with significant volumes of contaminated soil) is likely to be required.

Key drivers are discussed further below.

5.1 Policy drivers

5.1.1 SA Strategic Plan 2011

As highlighted in Section 1.4, the SA Strategic Plan is a driver for increasing the remediation and reuse of contaminated soil. Relevant targets include:

- Population target of 2 million persons by 2027 (Target 45)
- Exceeding the national economic growth rate over the period to 2020 (Target 35)
- Reduction in waste to landfill of 35% by 2020 with a milestone target of 25% by 2014 (Target 67)

The Progress Report on the SA Strategic Plan released in 2010 reported that the milestone target of 25% reduction of waste to landfill by 2014 is on track to be met. It was reported that waste to landfill has been reduced every year since 2003-04, to 1.072 megatonnes in 2008-09.

The Plan aims to reduce the amount of waste (which includes contaminated soil) to landfill while at the same time increasing population and economic growth. To achieve these targets there is a need to remediate contaminated land (e.g. as part of re-development of industrial sites) while minimising the amount of contaminated soil disposed of to landfill.

5.1.2 30 Year Plan for Greater Adelaide 2010

As highlighted in Section 1.4, the 30 Year Plan for Greater Adelaide is a driver for increasing the reuse of contaminated soil.

During the 30 year timeframe the State Government is planning for an increase in population by 560,000 people, the construction of additional 258,000 homes, economic growth of $127.7 billion and the creation of 282,000 additional jobs.

Relevant targets from the 30 year plan include:

- 60% of all growth within 800 metres of existing or extended transit corridors (Target C).
- 14 Transit Oriented Developments (TODs) across the metropolitan area to accommodate 60,000 new dwellings (Target M).
- Provide net land supply of 10,650 hectares in 14 designated growth areas in Greater Adelaide region (Target P).

TODs are proposed to be located at Elizabeth, Salisbury, Mawson Lakes, Modbury, Port Adelaide, West Lakes, Woodville, Bowden, Adelaide City, Keswick, Glenelg, Oaklands, Bedford Park and Noarlunga.

TOD's are predominately concentrated on remnant industrial and brownfield sites. Growth along transit corridors may require change of use of former or current industrial sites. Infrastructure development (social and physical infrastructure) will also be required to support growth targets.

As many of the areas that are proposed for growth in the 30 year Plan are former or existing industrial sites a significant increase in remediation of contaminated land (and associated need to deal with significant volumes of contaminated soil) is likely to be required.

5.1.3 Housing and Employment Land Supply Program

Within the Metropolitan area, the Housing and Employment Land Supply Program (HELSP) seeks to support the residential growth targets outlined in the 30 Year Plan and identifies the requirements for large re-zoning of land to support greenfield development in Northern and Southern Adelaide, in addition to policy changes to support high density, infill development in Western and Eastern Adelaide.

HELSP notes there is contamination which may require remediation at key current and future residential development sites including at Highbury, St Clair, Bowden Village and a Victor Harbor site.

From an employment lands perspective, the HELSP identifies the completion of rezoning at the Gillman Eco-Industrial Precinct, maximising land supply at Tonsley Park and Port Stanvac and structure planning the Greater Edinburgh Parks as a priority. Contamination is identified as a risk to industrial land supply in the future.

5.1.4 SA Waste Strategy 2011-2015

As highlighted in Section 1.4, the SA Waste Strategy is a driver for increasing the reuse of contaminated soil.

The two core objectives of the Strategy are:

- To maximise the useful life of materials through reuse and recycling; and
- To avoid and reduce waste.

The Waste Strategy 2011–2015 identifies the need to encourage remediation of low level and high level contaminated soils for reuse as a priority for action.

The Strategy anticipates that the private sector will expand recycling services to business and industry which should further reduce landfill material and improve resource efficiency, however notes that important areas for future intervention are contaminated soils, food, cardboard and timber.

The Strategy recognises the opportunity to further reduce waste to landfill by encouraging remediation of low level and high level contaminated soils for reuse. The recognition of this issue and inclusion of a priority action to address the issue provides a driver for increased reuse of contaminated soil.

5.1.5 Zero Waste SA Annual Report 2010-11

The Annual Report states:

> *While it is important to recognise the achievements of 2009–10, landfill data shows that waste to landfill increased by approximately 48,900 tonnes in 2010–11 bringing the State's total reduction of waste to landfill since 2003 to approximately 13.5% (compared with 17.32% in 2009–10 and 14.4% in 2008–09). The increase is attributed to approximately 84,600 tonnes of contaminated soil disposed to landfill from infrastructure developments and sites across metropolitan Adelaide.*
>
> *Contaminated soil is frequently a legacy issue arising from past land use, and industrial or commercial business practices, and is often detected only when changes in land use are proposed.*
>
> *Increased disposal of contaminated soil to landfill has the potential to skew South Australia's waste diversion achievements and may need to be accounted for separately from other solid waste streams disposed to landfill.*
>
> *Zero Waste SA will work collaboratively with relevant organisations to reduce the quantity of contaminated soil being disposed to landfill from major infrastructure projects where this is technically and economically feasible.*

The Annual Report recognises the potential future impact of significant quantities of contaminated soil being disposed of to landfill and potential for this waste stream to jeopardise the continued reduction of waste to landfill statistics. The recognition of this issue is a driver for increasing the reuse of contaminated soil.

5.2 Risk and regulation drivers

Remediation will be necessary for land posing risks to human health or other receptors in the environment such as groundwater or surface water. The remediation may be enforced or voluntary. The EPA has the powers to issue assessment and remediation orders (sections 103H and 103J) to appropriate persons under the *Environment Protection Act 1993.*

Regulatory drivers for increased reuse of contaminated soil are discussed further in Appendix B. A summary of the key regulation is provided below:

Environment Protection Act 1993 and Environment Protection Regulations 2009
Environment Protection (Waste to Resources) Policy 2010
National Environment Protection (Assessment of Site Contamination) Measure 1999
EPA Standard for the Production and Use of Waste Derived Fill, January 2010
EPA Draft Guidelines for Solid Waste - Criteria for assessment, classification and disposal of waste, September 2009
EPA Guidelines for Environmental Management of on-site remediation, November 2008
EPA Guideline for stockpile management: Waste and waste derived products for recycling and reuse, September 2010
EPA Waste Information Sheet - Undercover storage requirements for waste/recycling depots, September 2010

5.3 Land requirements

Remediation may be required to facilitate redevelopment of formerly used land, which may take place for commercial reasons, or because economic instruments have been put in place to support this process.

Where land availability is at a premium (e.g. city centre), remediation may be required to make the land suitable for a new and more sensitive end use.

5.4 Insurance / regulatory liabilities as drivers for remediation

Repairs to previous remediation work may be necessary where a past remediation project has failed, or redevelopment has been carried out without adequate risk assessment and management. These situations are often due to inadequate site investigation.

Such situations are considered rare but where no or inadequate site assessment was undertaken or where prescribed remedial measures were insufficient, then corrective remediation can be required.

There can also be a requirement to undertake prescribed / enforced clean up on a site under regulatory powers.

These drivers are not necessarily a driver for re-use of contaminated soils as such (i.e. they are more a driver for remediation) but they can be a reason to undertake cost effective and sustainable remediation. The EP Act requires the EPA to consider s10 (i.e principles of ecological sustainable development) when exercising its regulatory powers. The Act is risk based and includes a definition of remediation (s3).

5.5 Corporate liability as a driver for remediation

Remediation may occur on a voluntary basis without any regulatory requirement to control liabilities or as an investment to realise a gain in land value.

Similar to the insurance / regulatory driver discussed above, corporate liability around site clean-up is not necessarily a driver for re-use of contaminated soils as such (i.e. they are more a driver for remediation by any means) can be a reason(opportunity) to undertake cost effective and sustainable remediation.

Such remediation may occur when a corporate entity or government agency wishes to divest a commercial or industrial site where a potential purchaser requires environmental liabilities to be defined or removed prior to purchase, or where a higher sale value could be realised if the site is sold with known or removed liabilities.

Also, where a company is acquired or merged then sites within the portfolio may need to satisfy the environmental policy of a new controlling company.

The legislation makes provision for total or partial transfer of liability for site contamination in certain circumstances (section 103E). These circumstances include a requirement for full disclosure/arms length transaction agreements to be in writing. For agreements after the commencement of the legislation there is a requirement that any agreement be accompanied by a notice in a form approved by the EPA that outlines the legal effect of such an agreement. Agreements entered into after the commencement of the legislation may also be required to be lodged with the EPA with a specific form before they can take effect.

6. Impediments to soil remediation in SA

6.1 Overview

This study has encountered consistent impediments to increased soil remediation in SA from the broad spectrum of consulted stakeholders. The outdated dig and dump approach to contaminated soils will continue to prevail unless:

- landfill levies are adjusted to deter disposal of contaminated soils and really enable sustainable remediation / take up of alternate remediation technologies (with feedback of increased levies directly into the clean up market).
- open forum discussion is undertaken with site contamination auditors to discuss the occurrence and limitations of alternatives to dig and dump with respect to the inherent conservatism of the audit process
- the development and land management market is given more incentive to develop contaminated sites (e.g. tax relief)
- Regulators are encouraged to implement a risk based guidance procedure for the classification of soils on sites which are shown to be contaminated. A risk based approach will reduce the instances of 'over-classification' of soil
- an increase in soil treatment and recycling sites ('hubs') that are located in a manner optimum for minimisation of carbon footprint associated with soil transport in support and in accordance with future urban regeneration.

It is also important to consider that project based constraints can apply and govern the nature of any soil remediation implemented. This might include constraints regarding timescale, financial implications, site access, working time constraints due to site location and master planning.

Notwithstanding the site constraints, detailed discussion of impediments is provided below.

6.2 Landfill disposal costs

In SA, the relative cost of treatment and long term management of soils versus dig and dump is still prohibitively high and unattractive to land managers, as disposal costs and landfill levies are relatively low compared to some other jurisdictions (refer to Figure 5). It is also important to note that appropriately treated contaminated soil may be used as waste fill in landfill (daily cover material in landfill) which is exempt from the waste levy.

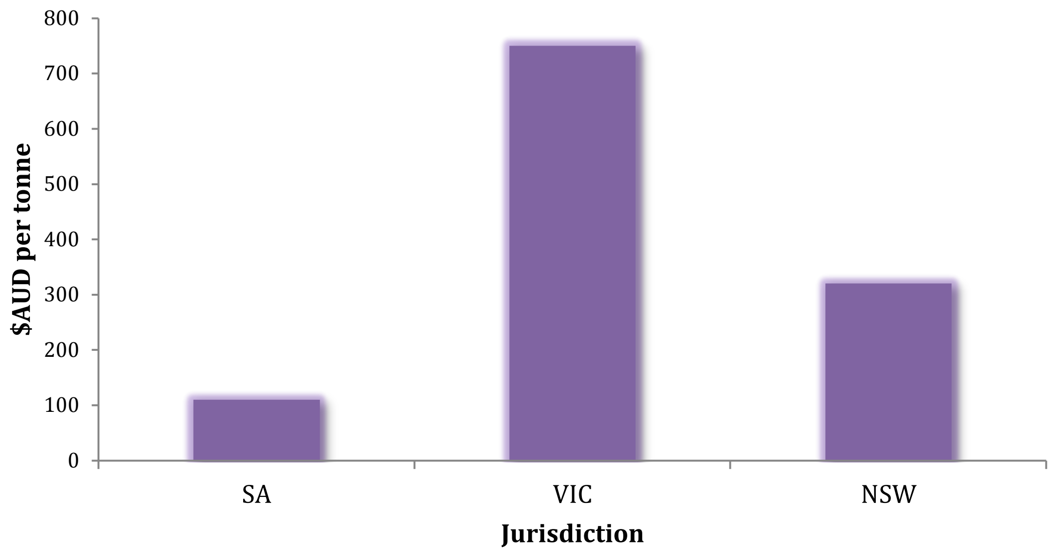
Across Australia, SA has one of the lowest costs for disposal of contaminated soil to landfill, ranging from approximately $25 per tonne gate fee for waste derived fill ('clean' material) to $160 per tonne for low level contaminated soil (bulk). The intermediate level classification approximates $70 - $100 per tonne gate fees (depending on receiving site and agreements).

Victoria in comparison approximates $17.50 per tonne for waste fill, with contaminated soils ranging from $118 per tonne (Category C) to $1,080 per tonne (Category A). Thus the equivalent low level waste disposed of in SA for $160 per tonne may cost up to $1,080 per tonne in Victoria.

In New South Wales, disposal of virgin excavated natural (clean) material (VENM) to landfill can cost approximately $204 per tonne, rising to $320 for 'special' wastes including contaminated soils and asbestos[9].

[9] http://www.newcastle.nsw.gov.au/services/waste_and_recycling/summerhill

Figure 5 – Approximate Average Costs of Intermediate Soil to Landfill



Note that the figures quoted here regarding SA are often open to some fluctuation due to bulk disposals - further, there are three facilities licensed to accept high level contaminated soils in SA. Competition between the three facilities may present transient downward pressure on disposal prices.

It is also worth noting that the costs may be more reflective of the waste classification system used in each state. For example, where the classification is considered flexible or more workable, such as in Victoria, it is often possible to treat soils so that they meet lesser disposal criteria and therefore the associated disposal costs are lower. [10]

In comparison to the low landfill disposal rates, the treatment and long term management of contaminated soils represents a significant up-front R&D cost, scientific, regulatory and stakeholder uncertainty, and long term engineering commitments and associated costs.

In the current economic climate, developers tend to fund future development phases from revenue derived from earlier sales. The introduction of large up-front and on-going costs interferes with this delicate financial balance, where disposal of contaminated soils to landfill provides a relatively guaranteed fixed price.

6.3 Site contamination auditor conservatism

Dig and dump currently would appear to have some benefits over other measures with respect to the site contamination audit system.

Excavation and removal of contamination presents a low risk outcome which is on face value perhaps more considerate of an Auditor's professional indemnity insurance, and also client expectations around costs and timing of site clean-up, than more intricate and less proven techniques.

Legacy issues (i.e. application of on-site long term management techniques such as containment) may also be a factor of concern when a site is audited under the site contamination audit system. The stipulation on Interim

[10] A detailed review of the policy and practise in NSW and Victoria is beyond the scope of this study however additional information can be found on line: http://epanote2.epa.vic.gov.au/EPA/publications.nsf/d85500a0d7f5f07b4a2565d1002268f3/ac87ef8b036fb755ca256c6000784c11/$FILE/878.pdf, and http://www.environment.nsw.gov.au/waste/classification.htm

or Audit Advice of registration, memorials on title, land use restrictions may be unattractive to an Auditor due to the dilution and increased ambiguity of an immediate end point to management.

Further, client pressure may dictate that long term on-site soil management solutions such as cover systems containment, physical and chemical encapsulation, vitrification which require the attachment of institutional controls such as registration, memorials on title, land use restrictions etc, denude land value, particularly where the availability of alternate "greenfield" development land is high, or where disposal to landfill is economically more beneficial.

It is also important to note that the South Australian site contamination audit system is a risk based decision making process and there is inherent conservatism associated with any risk based assessment. Risk assessments incorporate a large number of professional judgements, assumptions and compromises resulting from limited data. This presents many uncertainties for risk assessors which can contribute to over-conservatism.

The conservatism of risk assessment might be better addressed under a national remediation framework / guideline that outlines remediation options appraisal as a necessary step.

6.4 Remediation framework / guidelines

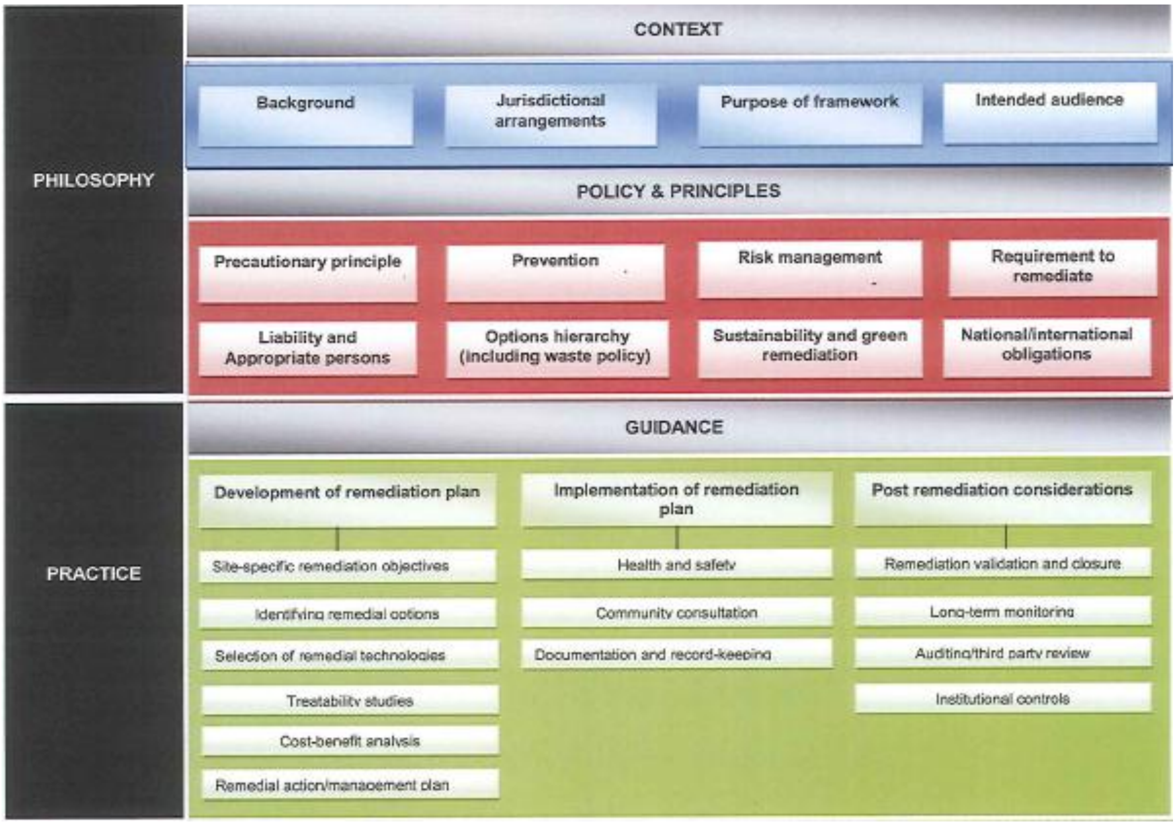
Historically, there has been a lack of national guidance in Australia for the development industry with respect to contaminated site remediation.

The pending revision of the NEPM currently remains in draft format, although is understood to now incorporate risk based remediation strategies as part of the contaminated site management process. However, there is a jump to the Remediation Action Plan (RAP) without consideration of development of a remediation strategy and options appraisal (i.e. outline and detailed with option appraisals) document. Currently the actual remediation planning and implementation strategies appear to have been overlooked in Australia, with the exception of some dated national documents.

To remedy this, CRC CARE is currently developing a national remediation framework to provide a consistent national approach to contaminated site remediation and management, noting that guidance issued by some States is of high quality but not contingent across jurisdictions. An objective of the national remediation framework will be to provide practical guidance within an overall framework which establishes the context of remediation in Australia.

The draft framework comprises two components: Philosophy and Practice (Figure 6).

Figure 6 – National Remediation Framework (Draft – Courtesy CRC CARE)



In addition to the national remediation framework, a sustainable remediation framework is currently being developed by Sustainable Remediation Forum ANZ (SuRF ANZ).

The sustainable remediation framework presents sustainable development criteria for soil and groundwater remediation decisions that can be applied in Australia. The formulation of this Framework has drawn heavily from a similar document prepared recently by the Sustainable Remediation Forum (SuRF) UK and CL:AIRE, and its initial preparation has been supported by CRC CARE and the Australasian Land and Groundwater Association (ALGA).

In essence, sustainable remediation is defined in the document as:

> *"a remediation solution selected through the use of a balanced decision making process that demonstrates, in terms of environmental, economic and social indicators, that the benefit of undertaking remediation is greater than any adverse effects".*

It is envisaged that the SuRF framework would complement the national remediation framework to provide metrics with respect to options analysis to sustainable aspects of remediation options.

However, any change in the remediation paradigm will be driven by market conditions and that is where industry and government needs to focus.

6.5 Regulatory direction

Despite regulator and industry enthusiasm for alternate remediation technologies, the land development market still prefers dig and dump as it is relatively low cost, enjoys regulator and market confidence and an un-encumbered property title.

In SA, advancements have been made with respect to identification and reuse of soils as waste derived fill, and guidelines are available for the environmental management of remediation activities.

The waste derived fill guidance and approach has been generally successful with respect to reuse of waste derived fill. However the guidance is restricted to providing guidelines on classification of soil, and not on remediation of contaminated soil. It is noted that the forthcoming CRC CARE national remediation framework should offset this.

However, this study has encountered several examples where the waste derived fill guidelines have hindered land and material management with respect to sustainable soils reuse due to exceedance of a single soil guidelines criterion where the exceedance is usually representative of background concentrations.

For example, in central Adelaide and across the Adelaide plains, it is not uncommon to encounter soils that are naturally elevated in manganese or vanadium. These elements have generally low, conservative criteria within the waste fill guidelines. Such criteria appear to be based on ecological protection values (Ecological Investigation Levels, EILs) established within the NEPM. Therefore it is common to find that natural soils from across the Adelaide plains from sites without a potentially contaminating activity are classed as intermediate soils (rather than waste 'clean' fill) due to a mean concentration of manganese which exceeds the conservative criterion. As the NEPM EIL values were established as investigation limits and not clean-up criteria, risk based assessment of such exceedances should be undertaken to avoid unduly writing off soils based on exceedance of potentially overly conservative criterion.

In practise, this can be occasionally circumvented by reusing the soil at site with similar background levels.

It is noted however, that analysis undertaken by SuRF ANZ indicates that the Australian regulatory system does allow for outcomes that are in accord with the concepts of sustainable remediation. Further, it was concluded that the current approach in Australia can provide for solutions to soil contamination issues in a balanced sustainable manner although this is not formally represented through assessing options against a set of environmental economic and social metrics. Note that the development and adoption of both the national remediation framework and the sustainable remediation framework will address this gap.

6.6 Suitable facilities for treatment / recycling off site

Most contaminated soil in SA is treated (stabilised) at one of two facilities, either to the north or south of the metropolitan area. These facilities are licensed by the EPA for such storage and treatment of contaminated soils. As discussed above, individual sites can be licensed for such operations, but this may be unattractive to developers. This often currently results in soil being transported to one of the two licensed facilities for stabilisation / treatment and ultimately disposal.

This has obvious sustainability repercussions with respect to the carbon footprint when considering transport of soils to these facilities. Further, where soils are surplus to requirements at any particular site, soils are likely to be disposed of.

An increase in localised soil treatment centres within or associated with areas of urban regeneration would create space and expertise to undertake soil treatment (i.e. if the site is too small to cope with soil treatment processes) and receive surplus soils failing the WDF criteria. These 'hub' sites could use the latest soil treatment technologies on site, with an aim of 100% of contaminated soils are re-used and retained on the linked sites. Treated surplus soils could then be exchanged for contaminated soils.

It is noted that these ideas have been discussed in SA previously, however there would appear to be concern that there must be a legal agreement and absolute requirement with respect to end use of such soils deposited to a local treatment centre, to avoid the centre becoming a landfill (i.e. due to orphan soils). It is considered that such an arrangement may work in metropolitan areas undergoing significant regeneration, but is dependent on locations, geography, surrounding land use, end use agreements, soil contaminants and contaminant concentrations.

Any on-site remediation or soil treatment centre will require appropriate environmental management to protect potential environmental receptor and community. This is undertaken through implementation of the EPA Guidelines for Environmental Management of On-Site remediation (EPA 623/06). The requirements of this document are consistent with ensuring receptors are protected and could be seen by some contractors as an impediment to implementation of no-site treatment. Off-site remediation also requires the production of Environmental Management Plans which will place requirements for environmental and community protection during the remediation. Such plans have to cover the same requirements as EPA 623/06 and will include assessment and mitigation of:

Project Roles and Responsibilities
Relevant Management Plans
Air Quality (volatiles, particulate, asbestos)
Noise
Surface Water
Soil Quality
Groundwater management
Flora and fauna
Heritage
Social consultation and involvement

It is understood from the consultation process in producing this document that the Gillman site in Adelaide is due for remediation of the soils. As part of the options appraisal process it is believed the concept of a Hub site is being considered. This is understood to be related to nature of the soil contamination and the requirement for inert fill material to be used in the development. The Hub site concept will produce treated soil which, in theory, can be reused at the site. However such reuse would require consideration of a risk based reuse strategy.

7. Opportunities for soil remediation in SA

7.1 Overview

Principally, there are tried and tested mechanisms available both nationally and globally for diverting soils from landfill, which could be reviewed in greater detail to find the best fit for SA.

The approaches required are based on a two pronged approach to firstly provide methods and incentives to discourage disposal of soils to landfill, and secondly, to encourage treatment and alternative material reuse of contaminated materials rather than disposal to landfill. These two approaches need to happen in parallel as part of any effective programme of landfill diversion.

The predominant impediment to soil remediation in SA is considered to be the low costs of contaminated soil to landfill disposal. Funds recovered from an increase in the levy could be directed into a fund established for the purposes of investing in infrastructure and implementation projects, R & D and demonstration projects, and knowledge and capacity building projects in the contaminated site remediation / brownfield regeneration area.

Coupled to this, more flexibility with respect to selection and implementation of onsite remediation could be delivered by a national framework or code of practise, managed and administered by a non-profit organisation (i.e. CRC CARE).

Tax breaks for site remediation projects would also encourage lateral thinking on undertaking site redevelopment in a sustainable manner, and further encourage brownfield regeneration, although leadership and framework for such would likely have to originate at Federal Government level.

Based on consultations and assessment of the contaminated land industries in other economies (and considering current impediments), the key opportunities to encourage diversion of contaminated soils from landfill in South Australia are:

1. Increase in Landfill Levy for disposal of contaminated soils (in conjunction with item 6, below)
2. Land remediation tax relief
3. Strengthening of risk based approaches with respect of soil classification and reuse as WDF
4. National remediation framework encouraging options appraisal and sustainability
5. Soil treatment centres for treatment of required or surplus soils and exchange of ‘old’ for ‘new’ soils
6. Funding the development and application of onsite and offsite remediation technologies

Several of these mechanisms are tried and tested, having already been implemented in other countries, particularly the UK.

Historically in the UK there had been sufficient landfill capacity such that “dig and dump” was the preferred option for dealing with contaminated soils at development sites, with the long timescale needed for remediation often being cited by developers as a reason for not adopting other approaches. With the decline in available landfill capacity and the need to meet various European Waste Disposal Directives, a number of methods have been adopted in the UK to help to facilitate the move away from landfill.

A summary of the identified mechanisms (opportunities) with respect to the two aspects of discourage and encourage are presented in Figure 7.

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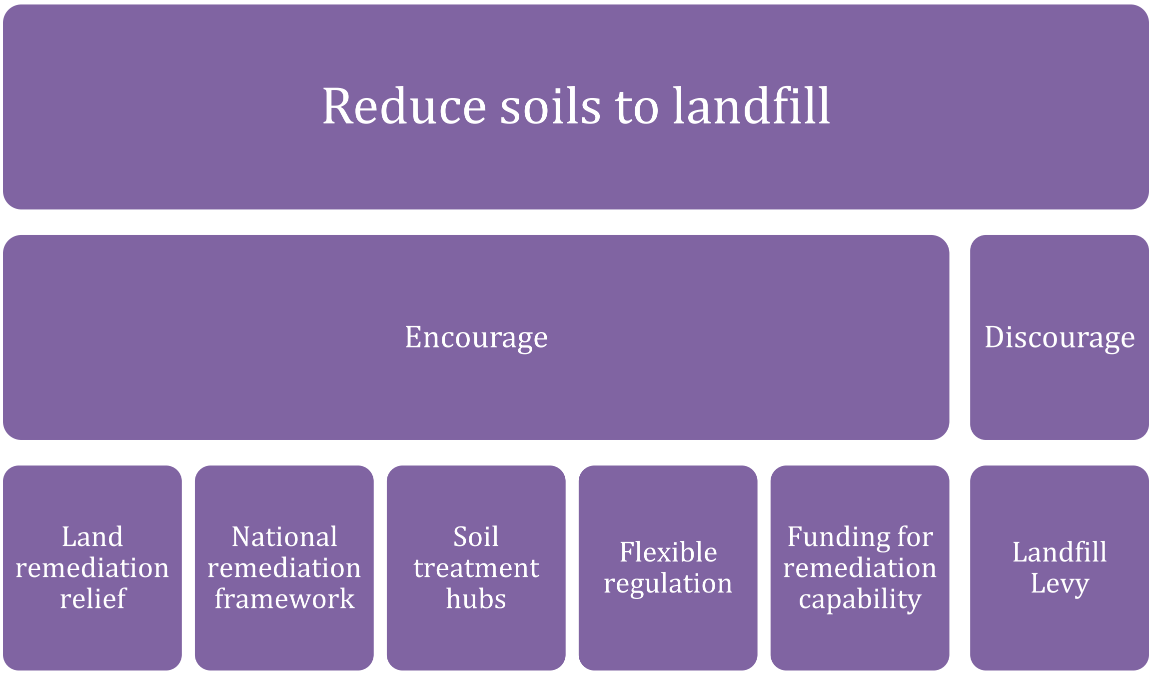
Figure 7 – Summary of mechanisms (opportunities) relating to encourage / discourage



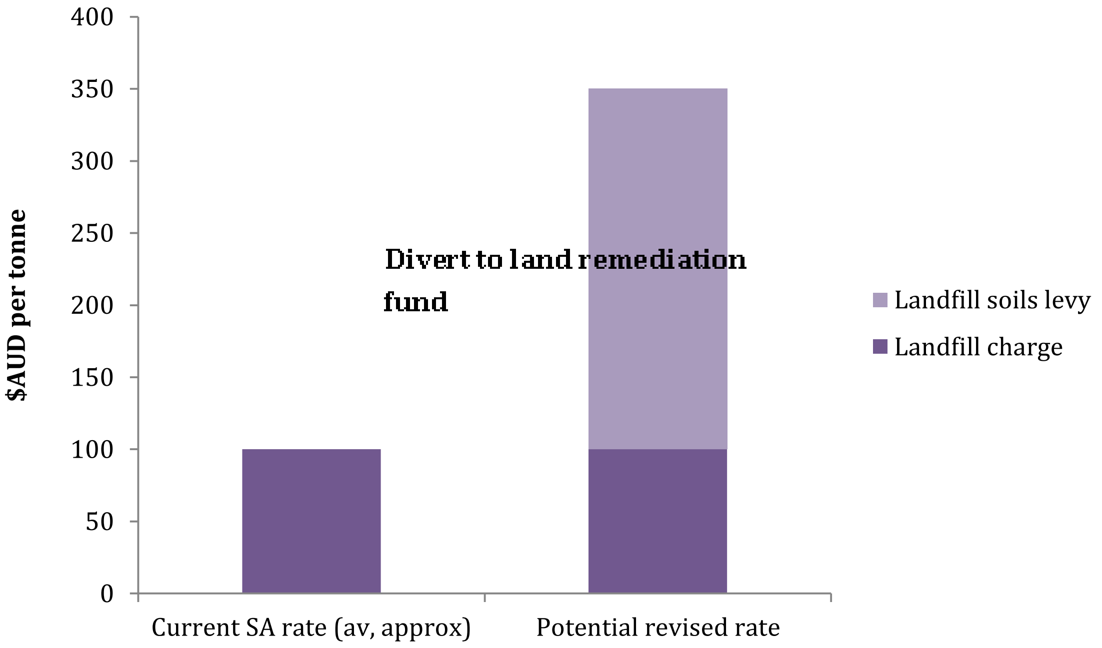
7.2 Landfill levy

An increase in landfill levy (specifically on soils only) could be considered to discourage overt disposal of contaminated soils to landfill and make on site (or hub located) remediation of soils more attractive.

Currently, the average cost (per tonne) of remediation of contaminated soil in Australia and in SA may equate to $400, depending on the contaminant and the chosen technique.

Clearly the low (circa $100 - $160 per tonne) rates of soil disposal to landfill makes remediation an expensive option. An increase in the landfill levy (or application of landfill levy with respect to waste fill) without increase in actual landfill charges would actively discourage disposal of such soils, while providing a potential funding source for the land remediation industry (Figure 8).

Figure 8 – Example increase / application of $250 levy on soils to landfill



Using an example major development project where 50,000 tonnes of soil is excavated and disposed of to landfill, a levy of $100 to $250 per tonne (in addition to landfill charge - arbitrary figure for example purposes, but would bring in line with very approximate remediation costs per tonne – not suggestive) would generate between $5 million and $ 12.5 million.

A summary of how a landfill tax arrangement can work is provided in Appendix F.

It is also noted that Victoria employs a much lower disposal rate for asbestos ($30 compared to SA's $200 per tonne) which is kept low to encourage responsible management of asbestos. Given recent media reporting of large scale illegal dumping of asbestos in SA, it is proposed that asbestos disposal rates are also reviewed, in order to encourage responsible disposal of asbestos.

There may always be some contaminated soil / residue that has to be disposed due to inherent un-treatability. A case by case consideration of soil disposal could be established where soils are un-manageable. Such case by case assessment could determine if the soils levy may be waived on the grounds that the soil is simply too much of a risk and is untreatable.

It is noted that such an increase in levy with respect to soils may increase the risk of fraud (i.e. illegal disposal / dumping), which if not appropriately managed may have a greater cost to the community in general by way of a requirement for increased monitoring and inspection of waste disposal and increased environmental and public health risks resulting from such dumping. The higher the levy, the higher the incentive for fraud, and thus a fine balance must be struck.

The impact of any levy could be assessed by considering the volumes of landfilled soils in each of the States. It will be interesting to establish if the higher levy has driven down landfill and encouraged onsite treatment. Discussions with contractors in Victoria (EESI and Enviropacific) has revealed that onsite remediation of soils is more prevalent in Victoria than compared to South Australia. Indeed SKM has been involved in a number of projects where the onsite remediation of soils has been successfully used to reduce the classification of the soil for disposal and thereby reduce the levy attracted by that disposal.

7.3 Funding the development and application of onsite remediation technologies

The funding of R & D of on-site and off-site remediation technologies and education of the land management industry with respect to application of such technologies is a key factor in offering alternatives to dig and dump.

This study has identified two key example approaches for the funding of such R&D:

1. The Victorian 'HAZWaste Fund'
2. The US 'Superfund'

7.3.1 HAZwaste fund (Victoria)

The HazWaste Fund (the Fund) is designed to support industry to accelerate reductions in the volume and hazard of hazardous waste (or prescribed industrial waste) generated in Victoria, and to increase remediation of contaminated soils, which began in 2008. An estimated $30 million was available over 4 years. The current Fund is due to end June 2012. There would not appear to be any established plans to continue the fund beyond this date.

The three primary objectives of the fund are:

- Reduce hazardous waste to landfill
- Reduce the hazard category of hazardous waste disposed to landfill
- Increase remediation of contaminated soil

The Fund is primarily funded via the landfill levies applied to hazardous / contaminated soil disposal, such that the higher levies are re-invested into development of more sustainable approaches (via investment) in three key areas:

1. Infrastructure and implementation projects
2. R & D and demonstration projects
3. Knowledge and capacity building projects

In achieving its objectives the Fund aimed to:

- Ensure simple effective transparent and value for money reinvestment of hazardous waste landfill levy revenue
- Deliver reinvestment and beneficial distribution of funds, with consideration given to the contributing source sectors
- Deliver effectively and achieve the desired waste reductions of the strategy
- Ensure sound marketplace communication of the opportunities for accessing the fund.

The benefits of such an approach are obvious, and such a framework in SA could be co-administered by a panel comprising industry and government experts.

7.3.2 US Superfund approach

On-site remediation technologies in the USA are perhaps the most advanced and diverse in the world. One of the key drivers of remediation and remedial technologies is the 'Superfund', which was set up in 1980 in the wake of the discovery of toxic waste dumps in the 1970s which put public health at risk. The money within the fund is obtained by taxing polluting industries to form the Superfund, implementing the 'polluter pays principal', to remediate abandoned sites, or to litigate to force corporations to remediate their contaminated sites. The US Environmental Protection Agency (USEPA) seeks to identify parties responsible for contamination of sites and compel them to clean up the sites. Where responsible parties cannot be found, the USEPA is authorised to clean up sites itself, using the Superfund. The USEPA state that the Superfund has been a success to date, with nearly 1.3 million acres of land returned to productive use (Ref.11).

As the Superfund programme has matured the USEPA recognised that the process of cleaning up a hazardous waste site can use a substantial amount of resources and consequently create its own environmental 'footprint'. The USEPA's 'Superfund Green Remediation Strategy' sets out current plans for the Superfund Remediation Programme to reduce the demand placed on the environment during cleanup actions and to conserve natural resources, however comments referring to diverting waste away from landfill are not cited specifically (Ref. 11).

Numerous initiatives are currently taking place in the field of green and sustainable remediation (GSR) in the US, driven by a global focus on assessing the causes of climate change and a collective growing awareness of the potential adverse impacts of energy-intensive remediation systems (Ref. 19). Many federal and state-lead cleanup programmes have begun to consider how remedial actions could lower their environmental footprint. This is considered "greening" the cleanup or a green remediation, whereas a sustainable cleanup would go further to consider economic and social aspects. Most practitioners understand that sustainability involves three basic aspects, including environmental, economic, and social considerations. Sustainability may be considered on a scale from local to global effects of the remedy, depending on the boundaries identified during the GSR planning process (Ref. 19).

The US Sustainable Remediation Forum (SURF) published three key documents around this subject in the summer of 2011. The first publication is a Framework for Integrating Sustainability into Remediation Projects, which describes how to integrate sustainability concepts into remediation projects and outlines a process that can be integrated with traditional goal-based regulatory criteria (Ref. 20). The second publication is a matrix for Integrating Sustainability Evaluations into Remedial Projects which provides extensive quantitative and qualitative parameters that can match the size and scope of any given project. Metrics consist of key impacts, outcomes, or burdens that will be assessed or balanced to determine the influences and impacts of a remedial action. Examples include mass of waste disposed, quantity of recycled/reused material, energy use and cost, GHG emissions, jobs generated, functional acreage restored and regulatory and stakeholder satisfaction. A companion "toolbox" – a series of tables organised by project phases, including remedial investigation, remedy selection, remedial design, remedial construction, operation and maintenance, and closure – has been published simultaneously on the SURF website (Ref 21). The matrices can be utilised as a useful tool when assessing which remedial option to include in the context of sustainability. The GSR Metrics have been co-adopted by SuRF ANZ who is looking to adapt the metrics for Australian use.

The third publication is Guidance for Performing Footprint Analysis & Life Cycle assessment or the Remediation Industry which lays out a nine-step process for conducting environmental footprint analysis.

The fact that the US has had to implement such a programme demonstrates one of the potential pitfalls of high value remediation funds – that of not considering the lifecycle impact of remediation on the environment. In some cases there is potential for the remediation activities themselves, particularly those with a high energy demand, to have a greater environmental impact than the original contamination. Clearly, implementation of any similar programmes in South Australia will require a balance to be maintained between the environmental footprint of the techniques being used and what they are set to achieve by way of remediation.

To further support the cleanup of contaminated land the US government has also implemented Brownfield Tax Incentives, similar in concept to those adopted by the UK Land Remediation Relief (LRR). US Brownfield Tax Incentives were originally signed into law in 1997 and extended through to December 31, 2011. The objective of the Brownfield Tax Incentive was to encourage the cleanup and reuse of contaminated land. Under the Brownfield Tax Incentive, environmental cleanup costs were fully deductible in the year incurred, rather than capitalised and spread over time. Previously filed tax returns could be amended to include deductions for past cleanup expenditures. The incentive is applicable to properties that meet specific land use and contamination requirements and does not include those on the proposed EPA's National Priorities List which the money from the Superfund is allocated to.

Since its implementation the Brownfield Tax Incentive has not been utilised as frequently as anticipated, despite its great potential to support contaminated land cleanup and reuse. A key reason for the limited use of the incentive may be uncertainty over its availability over an extended period of time, as the tax provision has never had long-term authorisation and the US Congress has allowed the provision to lapse five times since it was introduced in 1997 (Ref.11). It is understood that currently the incentive has once again lapsed in December 2011; however, it may be reintroduced in the future.

Both the early implementation of the Superfund and the Brownfield Tax Incentives in a country the size of the USA, with its advanced large economy, have led to the application of a broader spectrum of onsite treatment technologies when compared to the those implemented within the UK, demonstrating that the implementation of such funding mechanisms can stimulate the development of soil treatment technologies that reduce soil disposal to landfill.

7.4 Land remediation relief / fund

A land remediation tax relief would likely attract more development on brownfield sites and provide more liquidity into the remediation market, amongst other more obvious benefits on local and state economy.

It is noted that company tax relief falls within the Commonwealth (Federal) tax regime, and thus any introduction of land remediation tax or similar would have to be affected at the Federal level. However, diversion of some funds from an increased waste levy to a land assessment fund (in addition to R&D) may provide some stimulus to developers / companies.

The State is likely to have a notable industrial (brownfield) legacy. A large proportion of this legacy is likely managed by Local Government who would not have sufficient funds to assess or adequately identify such land.

Following from the potential creation of a fund for investment in research and development, monies might also be invested from an increase in the landfill levy into a land assessment fund, similar to the Part 2A process in the UK, and the superfund in the US.

By creating a centralised fund, Local Government might then be able to apply to the managing body to begin to identify brownfield land within their land that could be suitable for cost effective regeneration or divestment (i.e. some basic assessment by Local Government may encourage uptake by the private sector).

A summary of how a land remediation tax relief arrangement can work is provided in Appendix G.

7.5 Flexible regulation

Consideration could be given to the adoption of more risk based interaction with respect to soil classification to avoid unduly over classifying soils.

For example, the WDF standard is naturally prescriptive in relation to source of soil, and the physical and chemical criteria. There is an opportunity for the standard to cross reference to guidance on treatment/remediation options for waste soil classified as Intermediate Waste Soil or Level 1 Waste and encourage consideration of these options to treat / manage the waste soil to be used as WDF.

In other countries (such as UK) the reuse criteria are risk based and concentrations such as those in the waste fill guidance are generic. Such generic criteria (usually established through the contaminated land assessment phase) are allowed to be exceeded for certain uses onsite provided it is safe from an environmental and human health perspective.

It is suggested that a broader definition, increased flexibility of approach and increased focus on risk assessment in classifying waste fill would widen the scope of reuse of contaminated soil.

A review and highlight of desire for sustainable remediation to be applied on development projects could be made by the EPA via the development planning approval process during statutory consultation.

7.6 National remediation framework and management

A national remediation framework is pending and should be encouraged, endorsed and adopted throughout Australia. However ongoing management of the technical direction of land remediation could be further managed by a non-profit organisation such as CRC CARE.

A summary of how a national remediation framework and management can work is provided in Appendix H.

7.7 Soil treatment centres

Localised soil treatment centres may offer an additional clean up option to developers and contractors where on-site treatment is impractical or not financially viable due to the volume of material arising. In addition, the treatment centres may offer benefits including:

- Close to 100% of the soil can be re-used following treatment;
- Disposal to landfill is largely eliminated;
- Large volumes of soil can be treated (which may include low volumes of material from a number of individual sites) which makes treatment more cost effective;
- A range of contaminants can be treated with a variety of remedial techniques; and
- Rapid turnaround times can be offered, all of which make the treatment centres a feasible alternative to landfilling.

The disadvantages of such sites are the capital investments costs, the need for numerous sites across the metro area to avoid high transport costs and the fact that there is no guarantee that the stockpiled soil, once treated, will actually be used. This lack of end use agreement would likely not be acceptable to regulators, as orphan soil would result in either transportation to a licensed facility or legacy stockpiling of residual soils. Such a scheme however may provide benefits if properly organised (i.e. potentially state sponsored – note in 2012 the development or redevelopment of several key Government facilities within 500 m of each other in central Adelaide).

A Soil Recycling Facility is currently being developed in Cootamundra, NSW by EESI Contracting[11]. The facility received its first soil for recycling in November 1012. The objective of the Soil Recycling Facility is to be a commercially viable solution to either completely remediate contaminated soil for reuse, or reduce the level of contamination to minimise landfill costs. The Soil Recycling Facility has the capacity to accept 30,000 tonnes per annum and store 15,000 tonnes of contaminated soil at any one time. The Soil Recycling Facility is licensed to receive and treat contaminated soil that is classified in accordance with the relevant NSW regulations, up to and including the hazardous waste category.

There are no restrictions around the remediation technologies that the Soil Recycling Facility can employ onsite. EESI Contracting's main focus is to utilise more sustainable technologies, such as its patented Dynamic Biopiles bioremediation process. However, where appropriate and depending on the contaminant, techniques such as chemical immobilisation and cement stabilization will be used.

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[11] http://eesicontracting.com/our-services/soil-recycling/

8. Conclusions and recommendations

Currently, the preferred method of contaminated soils management in SA appears to be ‘dig and dump’ of soils to landfill. This approach is unsustainable, both in terms of waste to landfill, the carbon footprint associated with such practise and use of non-remediated materials in lieu of remediated materials. The tonnage of contaminated soils to landfill is annually distorted by any particular major development occurring in that given year.

Based on a high level review of contaminated sites and potentially contaminating activities and contaminants likely to be present in SA, it is considered that there is sufficient market capacity to provide alternative remediation techniques to remediation of such sites (noting that the general SA environment is amenable to all identified methods of alternative remediation). Further, there is an established and relatively strong research base in SA which given the appropriate opportunities to undertake field scale trials of technologies with subsequent commercialisation has the potential to be a global leader in remediation technologies.

Given the market and research capabilities in SA, there is an imbalance towards reliance on ‘dig and dump’ rather than uptake of alternative (and sustainable) remediation.

The study has identified that there are several impediments to soil remediation and divergence of soils from landfill, although the cost of disposing soil to landfill in SA is widely considered to be the predominant impediment to remediation of soils. In addition to costs, dig and dump appears to be the safe option, and may provide comfort to site developers and site contamination auditors alike.

The prevalence of dig and dump is compounded by the absence of any acknowledged national remediation framework, and therefore there is no requirement for a detailed options analysis when undertaking site development. A national remediation framework will hopefully soon be delivered by CRC CARE, supplemented by a sustainable remediation framework developed by SuRF ANZ. Any development of policy in SA should be cognisant of such frameworks, and dovetail into such frameworks.

The current guidelines available in SA focus on classification of soils for reuse, and not on providing a soils remediation framework. In addition, the soil classification guidelines occasionally hinder organisations, due to the restrictive nature of certain criteria. Further, the research, development and application of alternative site remediation technologies in SA require strengthening in certain areas (i.e. education as much as development). Investment in such research and development of technologies may be possible from a fund / framework financed by an increase in landfill levy, as employed in Victoria. Such a fund may also partly or wholly fund land development / regeneration stimulus grants, administered by an appropriate organisation.

Considering the findings of this study, we present the following recommendations:

1. Consideration of an increase in landfill levy (or a differential landfill levy on contaminated soils or hazardous substances) to create financial disincentive for “dig and dump”. In addition, the increase can be used to create a dedicated fund to support research and development of on-site and off-site remediation technologies and education of the land management industry with respect to their application.
2. Consideration of land remediation tax relief or ring fenced assessment fund (e.g. potentially funded through an increase in landfill levy) for site assessment and remediation (accessible by Local Authorities) to facilitate brownfield regeneration.
3. Further strengthening of risk based approaches with respect to soil classification and reuse as waste derived fill.
4. Adoption and promotion of both the upcoming national remediation framework and sustainable remediation framework
5. Investigation and consultation of development of soil treatment centres for treatment of required or surplus soils and exchange of ‘old’ for ‘new’ soils should notable cluster development be planned.

9. References

1. http://www.politics.co.uk/reference/landfill-tax
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10. Statement of limitations

The purpose of this report and the associated services performed by Sinclair Knight Merz ("SKM") is to review current available soil remediation techniques and the associated costs and benefits as well as to identify potential drivers, impediments and opportunities for reuse / remediation of contaminated soils in South Australia in accordance with the scope of services set out in the contract between SKM and the Client. That scope of services, as described in this report, was developed with the Client.

In preparing this report, SKM has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, SKM has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

SKM derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. SKM has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by SKM for use of any part of this report in any other context.

Where possible, relevant stakeholders with respect to soil management in South Australia have been contacted and consulted. Some stakeholders were unable to meet the project timelines and therefore their direct consultation was not possible.

This report has been prepared on behalf of, and for the exclusive use of, SKM's Client, and is subject to, and issued in accordance with, the provisions of the contract between SKM and the Client. SKM accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

Appendix A. List of stakeholders consulted

- Association of contaminated land consultants Australia (ACLCA) and consultants therein.
- CRC CARE
- Department of Planning, Transport and Infrastructure
- EESI Consulting
- Environment Protection Authority
- Enviropacific
- McMahons Services
- SuRF ANZ
- Urban Renewal Authority
- Ziltek

Appendix B. Contaminated soil regulatory framework (SA)

B.1 Environment Protection Act 1993 and Environment Protection Regulations 2009

The *Environment Protection Act 1993* (EP Act) provides the regulatory framework for the protection of the environment and establishes the Environment Protection Authority. The objects of the EP Act include promoting the principles of ecologically sustainable development.

The management of site contamination and use of 'contaminated soil' is regulated by the EP Act and associated regulations, policies, guidelines and standards.

The EP Act regulates the site contamination management system, ensuring responsible parties meet their obligations. The EPA is also responsible for administering the site contamination audit system which accredits expert and independent professionals under the Act as site contamination auditors.

A site auditor may be subject to penalties (including fines and imprisonment) if they do not fulfil their role in carrying out an audit in compliance with the EP Act, EP Regulations and relevant guidelines issued by the EPA. In addition, when auditing a site, a site contamination auditor is presenting a professional opinion that the site is fit for purpose. If a site should then subsequently be found to be not fit for purpose, either through negligence or wilful misleading actions, the appointed auditor, in their capacity as stating the site is fit for purpose, would be held liable in civil claims courts.

Environment Protection Regulations 2009 (EP Regulations), clause 3(1) defines *waste fill* as: waste consisting of clay, concrete, rock, sand, soil or other inert mineralogical matter in pieces not exceeding 100 millimetres in length and containing chemical substances in concentrations (calculated in a manner determined by the Authority) less than the concentrations for those substances set out in the chemical substance table (but does not include waste consisting of or containing asbestos or bitumen). Refer to clause 3(1) of the Regulations for the chemical substance table.

Overall the Object of the EP Act is a **driver** for increasing the reuse of contaminated soil, because increasing the reuse of contaminated soil is a more sustainable approach to remediation.

B.2 Environment Protection (Waste to Resources) Policy 2010

The stated objective of the *Environment Protection (Waste to Resources) Policy* (W2R EPP) is to achieve sustainable waste management by applying the waste management hierarchy consistently with the principles of ecologically sustainable development set out in section 10 of the EP Act.

The W2R EPP states that in order to meet the this objective, waste management should also—

(a) promote best practice and accountable waste management, taking into account regional differences within the State; and

(b) include effective recording, monitoring and reporting systems with respect to waste transport, resource recovery and waste disposal; and

(c) promote environmental responsibility and involvement in waste avoidance, waste minimisation and waste management within the community.

The W2R EPP establishes waste management obligations and penalties for unlawful disposal of waste[12]. Waste must be disposed of lawfully, for example at a licensed or approved depot or via a kerbside waste collection service, otherwise penalties apply.

[12] The EP Act defines *waste* as:
(a) any discarded, rejected, abandoned, unwanted or surplus matter, whether or not intended for sale or for recycling, reprocessing, recovery or purification by a separate operation from that which produced the matter; or

The W2R EPP provides a mechanism by which waste that meets specifications or standards published or approved in writing by the EPA will be considered a product instead of a waste (see clause 4(a) of the W2R EPP).

The W2R EPP is a **driver** for increasing the reuse of contaminated soil as it promotes sustainable waste management and provides a mechanism for development of specification/standard to define circumstance when waste should be considered a product for use. Such a standard has been developed to guide classification and use of *waste derived fill*.

B.3 National Environment Protection (Assessment of Site Contamination) Measure 1999

The Site Contamination NEPM operates as an environment protection policy under the *Environment Protection Act 1993*.

The NEPM is designed to determine whether site contamination poses an actual or potential risk to human health and the environment, either on-site or off-site, of sufficient magnitude to warrant remediation appropriate to the current or proposed land use to manage legacy contamination.

A variation to the NEPM was initiated in June 2007 including consultation on a revised version in 2010. However the release of the final revision is still pending.

The pending revision of the NEPM incorporates risk based remediation strategies as part of the contaminated site management process. However, there is a jump to the Remediation Action Plan (RAP) without consideration of development of a remediation strategy or options appraisal (i.e. outline and detailed with option appraisals) document.

The Site Contamination NEPM is not seen as a driver for increased reuse of contaminated soil. It may be a **minor impediment** as it does not require demonstration of options assessment based on a triple bottom line approach, prior to a RAP being prepared and implemented. Options assessment using a TBL approach would assist to demonstrate that reusing contaminated soil is a more sustainable approach.

In many cases, contrary to statements within NEPM, the Health Investigation Levels (HILs) and Ecological Investigation Levels (EILs) published are used as remediation action values. This degree of conservatism can generate substantial volumes of soil material. Appropriate risk assessment can optimise the amount of soil requiring treatment and the revised NEPM goes some way to reinforce this approach.

B.4 EPA Standard for the Production and Use of Waste Derived Fill, January 2010

The Standard for the Production and Use of Waste Derived Fill (WDF) has been developed in accordance with clause 4(a) of the W2R EPP to guide the EPA's decisions on whether a material is a WDF product or a waste. The Standard provides a classification of waste that can potentially be used as WDF and establishes a process for assessment of suitability of material as WDF for approval by the EPA.

Three sources of waste material are described as being potentially suitable for use as a waste derived fill (WDF): waste soil proposed for direct reuse, processed Construction and Demolition Waste (C&D Waste), and a homogenous mineral-based industrial residue (noting some limitations to end use).

If a soil is excavated for removal from a site, then this becomes a waste and therefore the waste soil requires management in accordance with this standard.

Default chemical criteria for reuse of these wastes as WDF are provided. The three levels of chemical criteria are:

(b) anything declared by regulation (after consultation under section 5A) or by an environment protection policy to be waste, whether of value or not.

1. WDF that does not exceed the chemical criteria for Waste Fill, as specified in clause 3(1) of the EP Regulations. This WDF is indicative of a low-risk material for use as fill.
2. WDF that exceeds these low-risk criteria, but does not exceed upper level criteria (i.e. Intermediate Waste Soil or Level 1 Waste criteria). For this WDF, the standard provides a mechanism for a site-specific risk-based approach for the proponent to employ to assess the potential to allow the use waste as a fill product. [Refer to Appendix 2 of Standard for criteria for Intermediate Waste Soil and Level 1 Waste]
3. Finally, waste materials that exceed the criteria for Intermediate Waste Soil or Level 1 Waste are not permitted to be used as WDF. This is to ensure these higher-risk waste materials are disposed to a specifically authorised and secure landfill, noting that the bulk of soil disposed of to landfill is likely to be Level 1 / High level waste .

When the WDF is waste soil sourced from a site where a potentially contaminating activity (as defined in regulation 50 and schedule 3 of the *Environment Protection Regulations 2009*) has or is occurring, only a site contamination auditor (auditor) accredited under Division 4 of Part 10A of the EP Act is permitted to certify its use at a sensitive site. A site contamination consultant can only certify its use at a non sensitive site. This is consistent with the requirements that only an auditor can certify a change in land use to a more sensitive use.

This standard is a **driver** to increasing reuse of contaminated soil as it provides guidance on classification of waste soil and establishes a process for assessment and approval of waste soil as WDF. However the standard does not provide direction on the treatment of waste soil that exceeds the criteria for Intermediate Waste Soil or Level 1 Waste to allow it to be used as WDF.

Also the approval process requires each WDF proposal to be considered on a case by case basis. If remediation operators had approved operating procedures or an on-going licence the WDF process may be more efficient and more attractive.

The standard is naturally prescriptive in relation to source of soil, and the physical and chemical criteria. There is an **opportunity** for the standard to cross reference to guidance on treatment/remediation options for waste soil classified as Intermediate Waste Soil or Level 1 Waste and encourage consideration of these options to treat / manage the waste soil to be used as WDF.

In other countries (such as UK) the reuse criteria are risk based and concentrations such as those in the waste fill guidance are generic. Such generic criteria (usually established through the contaminated land assessment phase) are allowed to be exceeded for certain uses onsite provided it is safe from an environmental and human health perspective.

It is suggested that a broader definition, increased flexibility of approach and increased focus on risk assessment in classifying waste fill would widen the scope of reuse of contaminated soil.

B.5 EPA Draft Guidelines for Solid Waste - Criteria for assessment, classification and disposal of waste, September 2009

This guideline outlines the process for determining the waste classification and relevant disposal requirements based on risk. The waste classification is based on first determining the category of waste and whether there is a need for further assessment or treatment prior to disposal. The waste classification is related to the landfill classification/s that is suitable for receiving the waste.

Waste soil is defined as all soil removed or excavated for removal from any site which is classified according to its source, physical criteria and the chemical substances it contains. Waste soil therefore includes contaminated soil.

The guideline classifies waste soil as either Category A - General Waste, Category B – Level 2 Waste or Category C - High Level Contaminated Soil based on source, chemical and physical criteria. Each class of waste soil must be disposed of (or treated prior to disposal as is the case for High Level Contaminated Soil) at facilities authorised to receive the specifically classified waste. Refer to Table 1 for a summary of the waste soil classification and disposal requirements.

This guideline provides **neither a driver nor impediment** to increasing the reuse of contaminated soil. There is an **opportunity** for this guideline to cross reference to the WDF standard and encourage consideration of the option of using suitable waste soil as WDF.

B.6 EPA Guidelines for Environmental Management of on-site remediation, November 2008

This guideline describes the EPA's environmental management expectations on a site where site contamination has occurred and remediation is planned.

Methods and processes used in remediation, which can range from relatively straightforward earthmoving operations to complex technological treatment processes, may cause adverse impacts if not properly managed. The majority of remediation methods involve some on-site activities, even when the treatment and disposal of materials may occur elsewhere.

The guideline describes the environmental aspects that must be considered, and planned for, before starting a remediation project. It is anticipated that careful planning, prior to remediation, will result in the control of both predictable and preventable environmental impacts.

This guideline provides neither a **driver nor impediment** to increasing the reuse of contaminated soil.

B.7 EPA Guideline for stockpile management: Waste and waste derived products for recycling and reuse, September 2010

This guideline outlines the potential risks associated with the stockpiling of wastes and waste derived products and provides guidance on the appropriate and relevant controls to reduce those risks. It applies to a range of waste materials, including waste soil, and also contains guidance for other wastes such as organic wastes and wastes temporarily stored at authorised transfer or sorting facilities.

This guideline provides **neither a driver nor impediment** to increasing the reuse of contaminated soil.

B.8 EPA Waste Information Sheet - Undercover storage requirements for waste/recycling depots, September 2010

This information sheet advises that the EPA requires all non-inert waste streams to be stored and processed in an enclosed undercover facility, stating that this helps to maximise resource recovery and act as a mitigation measure against leachate and potential contamination of surface and groundwater. Waste types not requiring undercover facilities include waste fill, Inert Waste, Construction and Demolition Waste (Inert), Ferrous and Non-ferrous Metals, Green Waste and Waste Tyres. The Information Sheet states that the EPA is progressively amending licence conditions for existing licensed facilities upon renewal and will incorporate an implementation timeframe to comply with the undercover storage requirement.

This information sheet provides **neither a driver nor impediment** to increasing the reuse of contaminated soil.

Appendix C. Survey on sustainable remediation (Conroy, 2010)

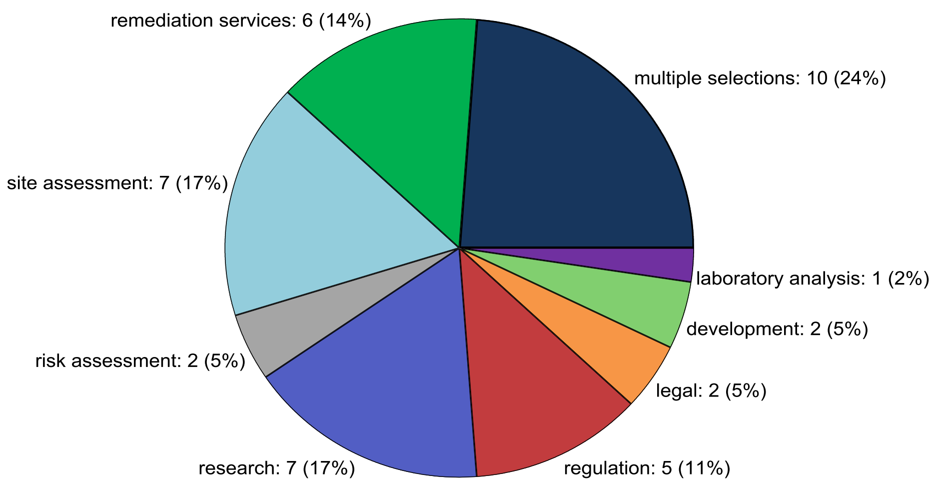
C.1 Background

As part of a Masters research project, a questionnaire was issued to respondents to gauge the role of sustainable remediation in the South Australian remediation industry. Scoping revealed that the industry contained approximately 250 surveyable stakeholders across several professional disciplines, including remediators, auditors, contractors, regulators, lawyers, and scientists/researchers. Sampling adequacy was achieved by implementing the quota sampling methodology to specifically target a range of stakeholder representatives of the whole population, on a professional basis. Similarly, pre-testing during the scoping phase showed the reliability of the questionnaire items to measure target parameters. Based on the knowledge gained through scoping, the response rate of 48.8% (42/86) was considered adequate to extrapolate population trends given the high level of representativeness and response measurement adequacy.

C.2 Demographics

Since the SA remediation industry was largely uncharacterised prior to this survey, one of the primary research objectives involved the collection and collation of demographic data. This enabled the profiling of the industry in its present state and provided a basis for characterising stakeholder feedback. Figure 9 highlights the range of professional associations of respondents.

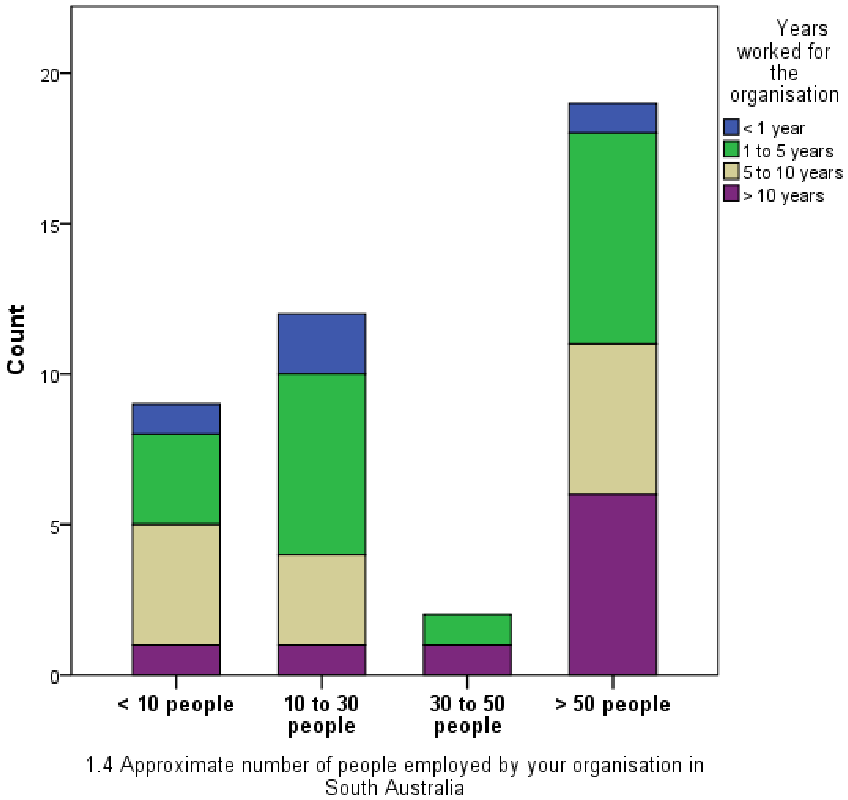
Figure 9 – Range of professional associations of respondents to remediation survey



C.3 Experience

In spite of the lack of data for respondents in the '30 to 50 people' category (organisation size), Figure 10 below emphasises the significant increase in experienced staff present in larger organisations (> 50 people).

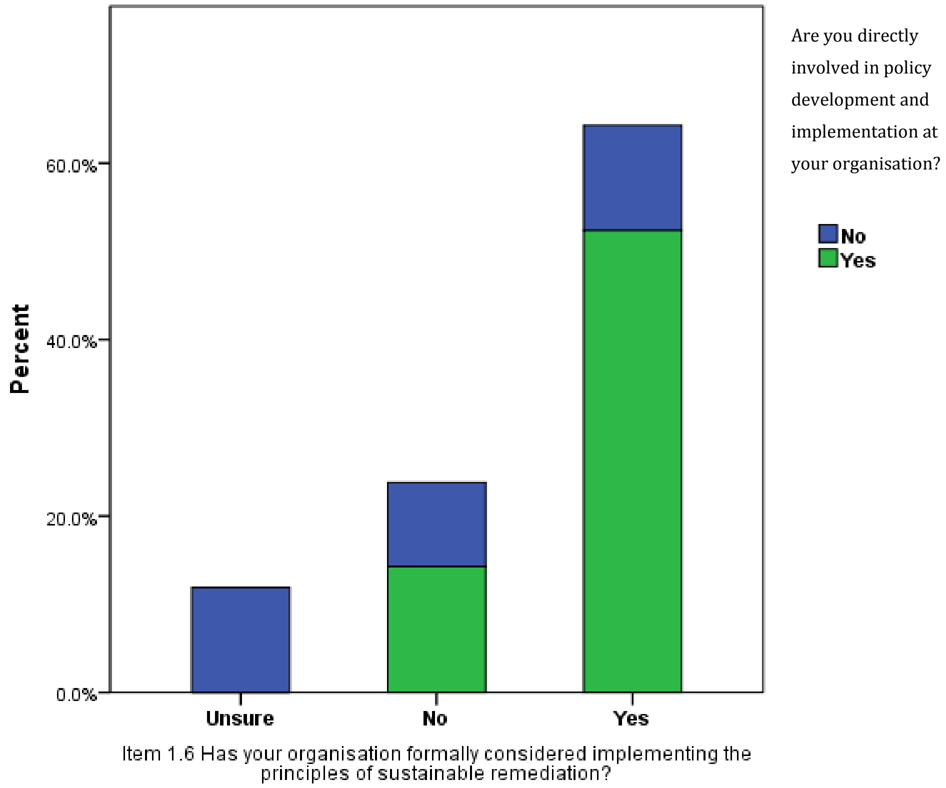
Figure 10 – Experienced staff (larger organisations)



C.4 Respondents' policy influence

Approximately half of respondents indicated that they were involved in policy development at their organisation and that they had considered implementing sustainable remediation (Figure 11).

Figure 11 – Consideration of implementing sustainable remediation



C.5 Sustainable remediation awareness and implementation

The mean period of awareness of sustainable remediation (n = 38) was 27 months. Most respondents reported an 'informal' introduction to the concept, such as a conversation with a colleague. Implementation of sustainable remediation was mostly predominant in consultancy (Figure 11).

Figure 12 – Awareness of sustainable remediation

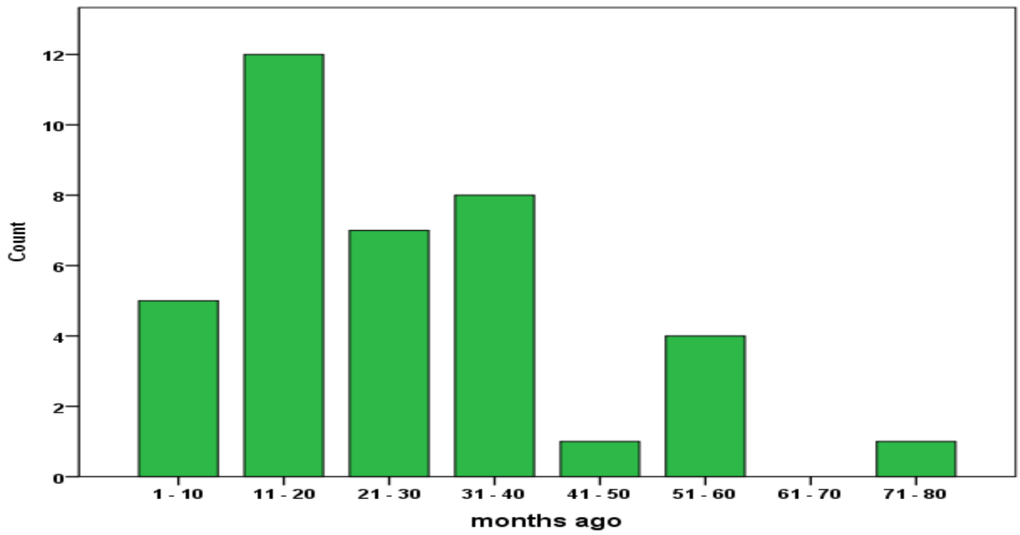
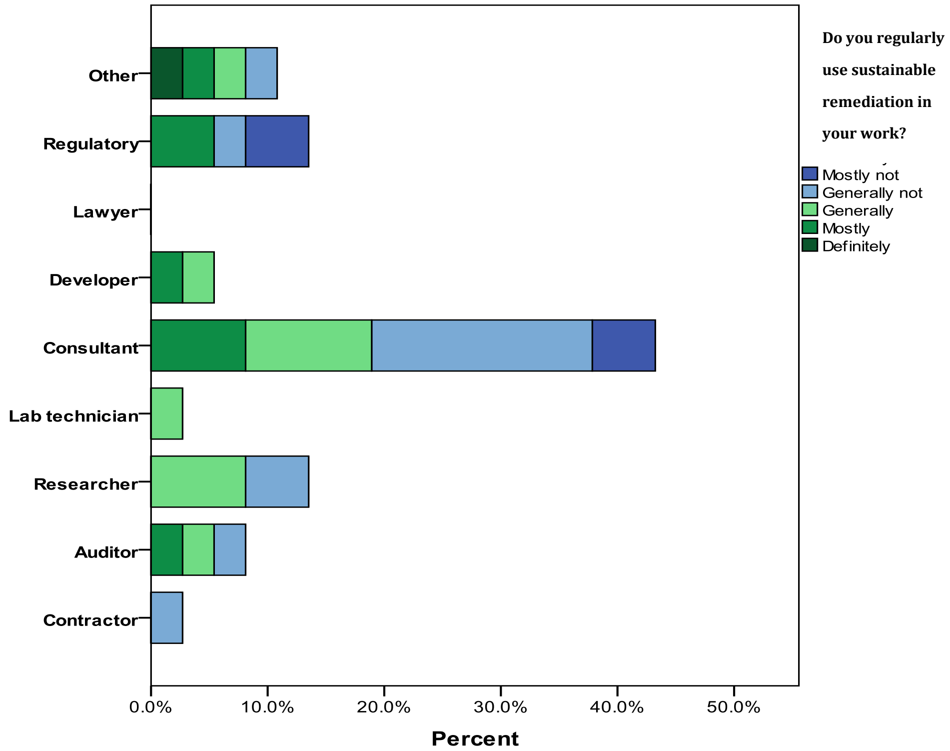


Figure 13 – Implementation of sustainable remediation



Appendix D. Overview of on-site remediation technologies

D.1 Enhanced bioremediation

Enhanced Bioremediation

Description

In situ biological method which uses reagents to enhance aerobic or anaerobic biodegradation of organic contaminants or the transformation of inorganic contaminants into less mobile or less toxic forms.

Potential Advantages

- can be used to treat soil and groundwater;
- minimal site disturbance;
- lower monitoring costs in comparison with monitored natural attenuation due to accelerated remediation;
- relatively simple technique;
- Plant/mobilisation & installation costs are low to moderate.

Limitations

- difficult to apply to a heterogeneous subsurface;
- uncertain supply of quantity of amendments;
- toxic intermediate breakdown products may be formed;
- Timescale strongly dependent on in-situ application success. Can be difficult to set into a definite project plan.

Applicability to Contaminants and Ground Material

Organic		**Inorganic**		**Materials**	
Halogenated VOCs	✓	Metals	I/D	Gravel >2mm	✓
Halogenated SVOCs	✓	Radionuclide	I/D	Sand 0.06-2mm	✓
Non-halogenated VOCs	✓	Corrosive	I/D	Silt 2-60m	✓
Non-halogenated SVOCs	✓	Cyanide	I/D	Clay <2um	I/D
Organic corrosive	I/D	Asbestos	×	Peat	I/D
Organic cyanides	I/D	Explosives	I/D	***Key***	
PCBs	I/D			Not applicable	×
Pesticides/herbicides	I/D			Insufficient data	I/D
Dioxins/furans	I/D			Potentially applicable	✓
Liquid free phase	×*				

Notes: *Not suitable for plumes with free phase contaminants unless combined with other forms of treatment. Limited to saturated contamination zone. Less suitable to low permeability soils.

Development Status in the UK

Widely available technique used in the UK

Case Study - Anaerobic Bioremediation

In 2009 during the remediation of a former tar and chemical works a 50 well in-situ biological treatment plant was installed to degrade a general hydrocarbon and phenol plume. The system utilised warm air blowers to provide sparged air to provide oxygen into the system. Respiration product and volatiles (xylene and toluene) were removed by a soil vapour extraction system. An overall increase of circa 10 degrees centigrade was seen with degradation of phenols to around detection limits and general hydrocarbons to below the remedial target of 1mg/l. The treatment was completed within 12 months with over the degradation of over 1 tonne of contaminant achieved. The remediation was successful and significant reductions in contaminant concentrations recorded to below the risk assessed targets which diverted waste away from landfill.

<table>
<tr><th colspan="3">Enhanced Bioremediation</th></tr>
<tr><td colspan="2">Relative Costs & Timescale
Relative Technology Cost: Low to Moderate
Average UK Cost : <5,000/m^3 = £37.5/m^3; >5,000/m^3 = £23.5/m^3
Average Timescale: 1 to 3 years.</td><td>Landfill disposal cost comparison:
<5,000/m^3 = £30 - £400
>5,000/m^3 =£30 - £300
Cost range dependant on type of waste, transport costs and regional variation.</td></tr>
<tr><td>References</td><td colspan="2">CL:AIRE 2010 SP1001 (Ref.13). USEPA (Ref. 11) Vertase F.L.I (Ref 14).</td></tr>
</table>

D.2 Phytoremediation

Phytoremediation	
Description *In situ* biological method which uses living plants to contain, disperse, stabilise, extract and/or destroy contaminants.	
Potential Advantages ▪ low cost; ▪ may enhance biodiversity; ▪ provides vegetative cover; ▪ Low mobilisation and installation cost relating to plant management and cultivation.	***Limitations*** ▪ extraction moves the contaminants to biomass which may create a hazardous waste, which may be expensive to dispose; ▪ depth of treatment limited; ▪ high concentrations of contaminants can be toxic to plants; ▪ may require a further waste reduction process to concentrate contaminants in harvested biomass (e.g. incineration). ▪ contaminants can be moved from depth to the surface which may expose surface receptors to them; ▪ transfer of contamination across media, e.g., from soil to air; ▪ products may be mobilised into groundwater or bioaccumulated in animals.

Applicability to Contaminants and Ground Material

Organic		**Inorganic**		**Materials**	
Halogenated VOCs	✓	Metals	✓	Gravel >2mm	✓
Halogenated SVOCs	✓	Radionuclide	✓	Sand 0.06-2mm	✓
Non-halogenated VOCs	✓	Corrosive	✓	Silt 2-60m	✓
Non-halogenated SVOCs	✓	Cyanide	✓	Clay <2um	✓
Organic corrosive	×	Asbestos	✓	Peat	✓
Organic cyanides	×	Explosives	✓	***Key***	
PCBs	✓			Not applicable	×
Pesticides/herbicides	✓			Insufficient data	I/D
Dioxins/furans	✓			Potentially applicable	✓
Liquid free phase	×				

Phytoremediation		
Development Status in the UK An emerging technique within the UK. ***Case Study*** Harrison Group Environmental undertook a remediation options appraisal to remediate heavily contaminated with chlorinated solvents in soil and groundwater in Lincolnshire. The strategy compared two options: **Alternative 1: Large Scale Soil Excavation and Removal:** Excavation and off-site disposal of soil exceeding thresholds across the site. Groundwater remediation following active soil remediation activities would occur through monitored natural attenuation. Costs for implementation of this alternative would be exceedingly high, estimated at £684,000 to £927,000 with contingencies. Therefore, this option was not considered viable on a commercial basis. **Alternative 2: Phytoremediation of Soil and Groundwater:** Soil and groundwater remediation through phytoremediation (trees) to achieve compliance with standards for contaminants in groundwater. This alternative would rely on the transfer of contamination from the soil to the groundwater matrix and phytoremediation to ultimately mitigate the soils as an ongoing source of contamination. Although innovative, this technology appeared likely to represent an effective technology for remediating the contamination in soil and groundwater such that they no longer represent a risk to future on-site residents in the long term. However, this option would not effectively result in short term reduction of source concentrations. Therefore, it is likely that phytoremediation coupled with focussed source removal would be a more effective measure, which was recommended. Costs for this alternative were estimated as ranging from £126,000 to £200,000.		
Relative Costs & Timescale Relative Technology Cost: Low. No data available on average UK cost. Average Timescale: in excess of 3 years		Landfill disposal cost comparison: <5,000/m^3 = £30 - £400 >5,000/m^3 =£30 - £300 Cost range dependant on type of waste, transport costs and regional variation
References	CL:AIRE 2010 SP1001 (Ref. 13). Harrison Group (Ref. 17)	

D.3 Monitored Natural Attenuation

Monitored Natural Attenuation

Description

In situ risk management method to confirm that natural processes are reducing the load, concentration, flux or toxicity of contaminants within a specified timescale. This is included as it relates to natural attenuation of the vadose zone associated with groundwater.

Potential Advantages

- less generation or transfer of remediation wastes;
- less intrusive as few surface structures are required;
- can be used in conjunction with, or after, other remediation methods;
- overall cost likely to be lower than many active remediation technologies.

Limitations

- requires extensive site investigation;
- requires a long term commitment to monitoring and a contingency plan (and funds) if the contaminants or groundwater do not behave as predicted;
- requires significant depth of understanding of local geology and hydrogeology;
- subsurface conditions may change over time and may result in renewed mobility of previously stabilised contaminants.
- Only generally applicable where soil contamination is resulting in the ongoing pollution of controlled waters and treatment of vadose zone is required.

Applicability to Contaminants and Ground Material

Organic		**Inorganic**		**Materials**	
Halogenated VOCs	✓	Metals	I/D	Gravel >2mm	✓
Halogenated SVOCs	✓	Radionuclide	I/D	Sand 0.06-2mm	✓
Non-halogenated VOCs	✓	Corrosive	I/D	Silt 2-60m	I/D
Non-halogenated SVOCs	I/D	Cyanide	I/D	Clay <2um	I/D
Organic corrosive	I/D	Asbestos	×	Peat	I/D
Organic cyanides	I/D	Explosives	✓	***Key***	
PCBs	I/D			Not applicable	×
Pesticides/herbicides	I/D			Insufficient data	I/D
Dioxins/furans	×			Potentially applicable	✓
Liquid free phase	×				

Development Status in the UK

The technique has been widely uses in the field in the UK and has a proven track record.

Case Study

In 1996 nitrobenzene contamination was detected in soil and groundwater at a chemical manufacturing facility in southern England. A six month monitoring groundwater, vadose zone and surface water was initiated. The results delineated a nitrobenzene plume and identified it was not impacting a local surface water course. By calculating the potential diluting effect of surface water on contaminants, it was shown that the absence of any noticeable deterioration in river water quality could not have been due to dilution alone, but was instead evidence of natural processes attenuating contaminants within the ground/vadose zone or river sediments. Of the remediation options that were considered, monitoring the natural attenuation (MNA) processes was considered to be most cost effective and least disruptive to the manufacturing operations. MNA cost were £240,000 compared to £1.1million for source removal and £2.4 million for pump and treat remedial option, all based on a six year period.

Relative Costs & Timescale

Technology Cost: Low.

Landfill disposal cost comparison:

<5,000/m^3 = £30 - £400

Monitored Natural Attenuation		
Average UK Cost : <5,000/m^3 = £11.5/m^3; >5,000m^3 = £10/m^3 Average Timescale: 1 to 3 years.		>5,000/m^3 =£30 - £300 Cost range dependant on type of waste, transport costs and regional variation.
References	CL:AIRE 2010 SP1001 (Ref. 1). Harrison Group UK (Ref. 17).	

D.4 Chemical oxidation and reduction

Chemical Oxidation and Reduction

Description

The technology is an In situ or ex situ chemical method involving addition of chemicals to soil or groundwater to oxidise or reduce the contaminants thereby degrading them, reducing their toxicity, changing their solubility, or increasing their susceptibility to other forms of treatment. For example in the case of organic compounds such as petroleum, they are converted into carbon dioxide and water.

Potential Advantages

- Reactions are fast and can result in complete degradation;
- applicable to a wide range of organic contaminants;
- uses reagents that are considered low cost and easily delivered to the subsurface.
- plant/mobilisation and instillation costs are relatively low.

Limitations

- May require large volumes of reagent;
- environmental impact needs consideration as the technique uses aggressive reagents;
- toxic intermediate breakdown products may be formed;
- groundwater may be coloured by reagents (e.g. permanganate is purple in solution);
- precipitation reactions may be reversible with changes in redox conditions over time;
- may be difficult to facilitate contact between contaminants and reagents in the treatment zone.

Applicability to Contaminants and Ground Material

Organic	In-situ	Ex-situ	Inorganic	In-situ	Ex-situ	Materials	In-situ	Ex-situ
Halogenated VOCs	✓	✓	Metals	I/D	✓	Gravel >2mm	✓	✓
Halogenated SVOCs	✓	✓	Radionuclide	×	×	Sand 0.06-2mm	✓	✓
Non-halogenated VOCs	✓	✓	Corrosive	I/D	I/D	Silt 2-60µm	✓	✓
Non-halogenated SVOCs	✓	✓	Cyanide	I/D	I/D	Clay <2µm	I/D	✓
Organic corrosive	×	×	Asbestos	×	×	Peat	×	×
Organic cyanides	×	×	Explosives	I/D	I/D	***Key***		
PCBs	✓	✓				Not applicable	×	
Pesticides/herbicides	I/D	I/D				Insufficient data	I/D	
Dioxins/furans	×	×				Potentially applicable	✓	
Liquid free phase	×	×						

Notes: Chemical oxidation is only applicable to contaminants that can be oxidised but is not generally suitable for free product or highly elevated concentrations. It is easier to facilitate contaminants and reagents in excavated soil.

Development Status in the UK

The technique has been widely uses in the field in the UK and has a proven track record.

Case Study

In 2010 Vertase FLI conducted an ex-situ chemical oxidation of medium chain hydrocarbons that were not amenable to bio-remediation, with hydrogen peroxide. Contaminated material was mixed with a specialised excavator while hydrogen peroxide was injected into the mixing chamber. Approximately 1,500m^3 of contaminated soils was successfully remediated to below the site specific target levels (SSTLs) and diverted away from landfill.

Relative Costs & Timescale	Landfill disposal cost

Chemical Oxidation and Reduction		
Relative Technology Cost: Low. Average UK Cost Ex situ : <5,000m^3 = £45/m^3; >5,000m^3 = £43.5/m^3 In situ: <5,000m^3 = £50/m^3; >5,000m^3 = £40/m^3 Average Timescale: In-situ <1 year. Ex-situ <0.5 years.		comparison: <5,000/m^3 = £30 - £400 >5,000/m^3 =£30 - £300 Cost range dependant on type of waste, transport costs and regional variation
References	CL:AIRE 2010 SP1001 (Ref.13). USEPA (Ref. 11) Vertase F.L.I (Ref .14).	

D.5 Soil flushing

Soil Flushing

Description

In situ physical/biological/chemical method that uses aqueous solutions to dissolve and recover contamination from the ground. Once above ground the recovered solution is treated and reused if appropriate.

Potential Advantages

- process can be designed to treat specific contaminants,
- including both organic and inorganic compounds;
- can be used in both pathway management and source control;
- may prevent the need for excavation.
- Low mobilisation and installation cost as comprises site investigation followed by monitoring only.

Limitations

- low permeability or heterogeneous soils are difficult to treat;
- risk of worsening situation by producing more toxic or mobile compounds;
- effectiveness can be hindered by a shallow water table;
- good understanding of site geology and hydrogeology is required to prevent loss of contaminant and soil flushing solution beyond the capture zone and allay regulatory concerns;
- above ground separation and treatment can be expensive.
- Plant mobilisation and installation costs low to moderate, plant headwork required.

Applicability to Contaminants and Ground Material

Organic		**Inorganic**		**Materials**	
Halogenated VOCs	✓	Metals	✓	Gravel >2mm	✓
Halogenated SVOCs	✓	Radionuclide	I/D	Sand 0.06-2mm	✓
Non-halogenated VOCs	✓	Corrosive	I/D	Silt 2-60m	I/D
Non-halogenated SVOCs	✓	Cyanide	I/D	Clay <2um	×
Organic corrosive	I/D	Asbestos	×	Peat	×
Organic cyanides	I/D	Explosives	I/D	***Key***	
PCBs	×			Not applicable	×
Pesticides/herbicides	×			Insufficient data	I/D
Dioxins/furans	×			Potentially applicable	✓
Liquid free phase	I/D				

Development Status in the UK

Widely available technique used in the UK

Case Study

In 2011 Regenesis undertook remedial works at a dry cleaner site in north west England. An active dry cleaner site had a large spill of PCE and TCE. It was thought that as natural attenuation was not occurring, the whole impacted area needed to be excavated, with further processing and treatment being completed. This would have involved sheet piling, deep excavation and under-pinning – plus increase H&S risk and disruption to the site activities. The alternative solution implanted by the remediation contractor was in situ solution which adjusted the redox conditions in the ground for an extended period after a single injection, which created the right conditions for enhanced attenuation through reductive dechlorination and the contaminants, were flushed out of the soil. The works took about 2 weeks with no disruption of the works and were completed at a fraction of the previous estimated cost. 5000m^3 of soil was treated saving In excess of £1M of landfilling costs.

Relative Costs & Timescale	Landfill disposal cost comparison:

Soil Flushing		
Relative Technology Cost: Low to Moderate. Average UK Cost : <5,000/m^3 = £44m^3; >5,000/m^3 = £45.5/m^3 Average Timescale: 1 to 3 years.		<5,000/m^3 = £30 - £400 >5,000/m^3 =£30 - £300 Cost range dependant on type of waste, transport costs and regional variation.
References	CL:AIRE 2010 SP1001 (Ref. 13).	

D.6 Venting

Venting (bioventing, bioslurping, soil vapour extraction, dual phase extraction (DPE))

Description

In situ physical/biological method involving the movement of air through the unsaturated zone to promote volatilisation and/or biodegradation of contaminants from soil and the vapour phase.

In situ

Potential Advantages	***Limitations***
▪ can be cost-effective; ▪ can treat many organic compounds, free product and dissolved phase; ▪ can induce physical and biological processes; ▪ minimal site disturbance; ▪ Relatively low plant installation costs.	▪ limited by the structure of the soil, degree of saturation, pore connectivity and porosity; ▪ effectiveness can be hindered by a shallow water table unless water is pumped out; ▪ limited by the depth of contamination; ▪ verification of treatment can be difficult; ▪ not applicable to inorganic compounds due to their low volatility.

Ex situ

Potential Advantages	***Limitations***
▪ soil can be engineered to suit contaminant properties and remediation requirements; ▪ not limited by the heterogeneity of the subsurface (c.f. *in situ* venting).	▪ potential for loss of volatile contaminants over permitted emission levels during excavation, unless properly managed; ▪ health and safety concerns at all stages.

Applicability to Contaminants and Ground Material

Organic	**In-situ**	**Ex-situ**	**Inorganic**	**In-situ**	**Ex-situ**	**Materials**	**In-situ**	**Ex-situ**
Halogenated VOCs	✓	✓	Metals	×	×	Gravel >2mm	✓	✓
Halogenated SVOCs	I/D	I/D	Radionuclide	×	×	Sand 0.06-2mm	✓	✓
Non-halogenated VOCs	✓	✓	Corrosive	×	×	Silt 2-60µm	I/D	I/D
Non-halogenated SVOCs	✓	✓	Cyanide	×	×	Clay <2µm	I/D	I/D
Organic corrosive	×	×	Asbestos	×	×	Peat	×	×
Organic cyanides	×	×	Explosives	×	×	***Key***		
PCBs	×	×				Not applicable	×	
Pesticides/herbicides	×	×				Insufficient data	I/D	
Dioxins/furans	×	×				Potentially applicable	✓	
Liquid free phase	✓	✓						

Notes: Environmental impact of petrol/diesel generator powering plant to be considered.

Development Status in the UK

Widely available technique used in the UK

Case Study

A high vacuum extraction unit was designed and constructed by Vertase FLI in 2011 to provide a multi phase solution to a former manufacturing site that was undergoing re-construction. Approximately 70 wells were installed around the groundworks contractor as contamination was discovered during the construction phase. All wells and pipework were then buried and a system mobilised to site. All pipework was incorporated into the construction allowing the project to continue whilst the treatment was undertaken. The

Venting (bioventing, bioslurping, soil vapour extraction, dual phase extraction (DPE))		
plant was located remotely to the construction area and monitored via telemetry. An online FID (flame ionisation detector) and free product flow meter was used to monitor the abstracted vapour and free product enabling a robust examination of the remediation and effective regulatory sign off. Another simpler system comprised of 15No. transferable, top-loading submersible pneumatic pumps which were used to abstract water and free phase product into an oil water separator. The product was separated and collected ready for off-site recycling, water was stored in a separate tank and pumped through a GAC filter and into a cleaned water drainage under a trade effluent licence. A vacuum pump and air-water knockout pot system was used to abstract vapours from abstraction wells simultaneously with the submersible water-free phase abstraction. Vapours were treated with a granular activated carbon and liquids from the knockout pot were treated with the abstracted free phase liquids. The system operated for approximately 30 weeks, 26 wells were treated and over 6000 litres of free product was removed the majority during the first 18 weeks of operation. Levels of free product in the wells were reduced from over 600mm to effectively zero during the works.		
Relative Costs & Timescale Relative Technology Cost: Low to Moderate Average UK Cost : In situ: <5,000m^3 = £40m^3; >5,000/m^3 = £30.5/m^3 Ex Situ*:* <5,000m^3 = £35m^3; >5,000/m^3 = £22/m^3 Average Timescale: In situ: 1 to 3 years Ex situ: 0.5 to1year		Landfill disposal cost comparison: <5,000/m^3 = £30 - £400 >5,000/m^3 =£30 - £300 Cost range dependant on type of waste, transport costs and regional variation
References	CL:AIRE 2010 SP1001 (Ref. 13). Vertase FLI (Ref. 14).	

D.7 Stabilisation / solidification

Stabilisation and Solidification
Description *In situ* and *Ex situ* physical/chemical method involving a reaction between a binder and soil to reduce the mobility of contaminants by physical encapsulation or chemical immobilisation.

Potential Advantages	***Limitations***
▪ can be used to treat recalcitrant contaminants (e.g. metals, PCBs, dioxins); ▪ process equipment occupies a relatively small footprint; ▪ the physical properties of the soil are often improved by treatment (e.g. increased strength, lower permeability). ▪ treated material can be reused on site or be re-classified for less expensive disposal, both subject to regulatory approval.	▪ does not destroy or remove the contaminants; ▪ may be difficult to predict long-term behaviour; ▪ may result in an overall increase in volume of material; ▪ may require long-term maintenance of protection systems and/or long-term monitoring; ▪ reagent delivery and effective mixing can be difficult to achieve; ▪ Plant/mobilisation & installation cost relatively high due to the installation of the batching plant.

Applicability to Contaminants and Ground Material

Organic	**In-situ**	**Ex-situ**	**Inorganic**	**In-situ**	**Ex-situ**	**Materials**	**In-situ**	**Ex-situ**
Halogenated VOCs	×	×	Metals	✓	✓	Gravel >2mm	✓	✓
Halogenated SVOCs	I/D	I/D	Radionuclide	✓	✓	Sand 0.06-2mm	✓	✓
Non-halogenated VOCs	×	×	Corrosive	✓	✓	Silt 2-60µm	✓	✓
Non-halogenated SVOCs	I/D	I/D	Cyanide	✓	✓	Clay <2µm	✓	✓
Organic corrosive	I/D	I/D	Asbestos	✓	✓	Peat	×	×
Organic cyanides	I/D	I/D	Explosives	I/D	I/D	***Key***		
PCBs	I/D	I/D				Not applicable	×	
Pesticides/herbicides	I/D	I/D				Insufficient data	I/D	
Dioxins/furans	I/D	I/D				Potentially applicable	✓	
Liquid free phase	×	×						

Development Status in the UK

The technique has been widely uses in the field in the UK and has a proven track record.

Case Study

In 2007 Celtic undertook stabilisation treatment of a former rubber manufacturing waste site in Leyland, which was contaminated with a mix of hydrocarbons, rubber cut offs, and boiler ash. 21,000m^3 of contaminated soil was treated on site, creating a stable development landform. The project diverted 37,000 tonnes of waste from landfill with a cost saving of £2,000,000 against off-site disposal.

Relative Costs & Timescale			Landfill disposal cost comparison:
Relative Technology Cost:	Moderate in situ, Low to Moderate ex situ		
Average UK Cost:	In situ: Ex situ:	<5,000/m^3 = £69m^3; >5,000/m^3 = £49/m^3 <5,000/m^3 = £40m^3; >5,000/m^3 = £32/m^3	<5,000/m^3 = £30 - £400 >5,000/m^3 =£30 - £300
Average Timescale:	In situ: Ex situ:	<1 year <0.5 years	Cost range dependant on type of waste, transport costs and regional variation

Stabilisation and Solidification	
References	CL:AIRE 2010 SP1001 (Ref. 13). Celtic (Ref.15).

D.8 Thermal treatment

Thermal Treatment	
Description *In situ* thermal method involving the use of electrical energy or radiation to enhance the mobility of organic contaminants in both the saturated and unsaturated zones which can facilitate their recovery and treatment. *Ex situ* thermal method involving the use of heat to destroy organic contaminants or enhance their mobility and facilitate their recovery and treatment. Some inorganic contaminants may also be treated (inc incineration).	
In situ	
Potential Advantages ▪ applicable to a wide range of soil types; ▪ applicable to difficult dense non-aqueous phase (DNAPL) contaminants; ▪ minimal site disturbance.	***Limitations*** ▪ buried objects or utilities may cause operating problems; ▪ limited to enhancement of VOC/SVOC recovery; ▪ potential for damage to soil structure, fauna and flora and impacts on groundwater quality; ▪ enhanced mobility of contaminants might lead to migration outside the treatment zone; ▪ Plant mobilisation/installation costs relatively high.
Ex situ	
Potential Advantages ▪ applicable to a wide range of organic and some inorganic contaminants; ▪ potential for high contaminant removals.	***Limitations*** ▪ incineration can be expensive with high energy costs; ▪ material may need screening and pre-treatment; ▪ may result in loss of organic matter in the soil which restricts its use post-treatment; ▪ emissions must be carefully controlled in case incomplete combustion products (e.g. dioxins and ▪ furans) are formed, particularly for thermal desorption

Applicability to Contaminants and Ground Material

Organic	**In-situ**	**Ex-situ**	**Inorganic**	**In-situ**	**Ex-situ**	**Materials**	**In-situ**	**Ex-situ**
Halogenated VOCs	I/D	✓	Metals	I/D	I/D	Gravel >2mm	✓	×
Halogenated SVOCs	✓	✓	Radionuclide	×	×	Sand 0.06-2mm	✓	✓
Non-halogenated VOCs	I/D	✓	Corrosive	×	I/D	Silt 2-60µm	✓	✓
Non-halogenated SVOCs	✓	✓	Cyanide	×	I/D	Clay <2µm	✓	I/D
Organic corrosive	×	I/D	Asbestos	×	I/D	Peat	I/D	I/D
Organic cyanides	×	I/D	Explosives	I/D	I/D	***Key***		
PCBs	I/D	✓				Not applicable	×	
Pesticides/herbicides	I/D	✓				Insufficient data	I/D	
Dioxins/furans	I/D	✓				Potentially	✓	

Thermal Treatment							
Liquid free phase	I/D	✓				applicable	

Development Status in the UK

Available from several suppliers in the UK

Case Study

CL:AIRE sponsored remedial trial at former coking works in Chesterfield. The trial involved MEL Limited in conjunction with United Soils Recycling from the USA, using heat provided by diesel fuel burners to heat contaminated waste material and desorbs contaminates into a gaseous phase which was then extracted and treated. The contaminated material responded well to the thermal treatment with contaminant reductions of up to 99% being achieved. However, where areas did not receive sufficient air only 20% reductions were observed, this lead to a mean reduction in both total PAHs and DRO in waste tip material being approximately 70%. Based on treating 50,000m^3 the approximate cost of treatment equated to 100m^3. However, it was noted on a larger scale the cost are likely to equate to approximately between 63 to 68m^3.

Relative Costs & Timescale	Landfill disposal cost comparison:
Relative Technology Cost: Moderate to High Average UK Cost : In Situ: <5,000/m^3 = £66/m^3; >5,000/m^3 = £27/m^3 Ex Situ: <5,000/m^3 = £133m^3; >5,000/m^3 = £56.5/m^3 Average Timescale: In situ: <1 year Ex situ: <0.5 years	<5,000/m^3 = £30 - £400 >5,000/m^3 =£30 - £300 Cost range dependant on type of waste, transport costs and regional variation

References	CL:AIRE 2010 SP1001 (Ref. 13). CL:AIRE (Ref. 9).

D.9 Civil engineering

Civil Engineering based methods	
Description Ex situ or in situ methods to manage contaminated soil and groundwater using established engineering approaches. Civil engineering approaches are commonly used in the UK and can be grouped into containment measures and excavation/abstraction measures (containment, barriers, cover systems, excavation, landfill disposal, abstraction).	
Potential Advantages ▪ Applicable to a range ground conditions and contaminant types ▪ Rapid deployment. ▪ Containment measures may be economic where large volumes of contaminated material prevent the cost effective use of excavation.	***Limitations*** ▪ Contaminated matrix is isolated through the use of barriers or cover systems which prevent exposure to the surrounding environment. ▪ Contaminants remain in-situ and require long term monitoring. ▪ High cost associated with handling and transportation large volumes of material

Applicability to Contaminants and Ground Material

Organic		Inorganic		Materials	
Halogenated VOCs	✓*	Metals	✓	Gravel >2mm	✓
Halogenated SVOCs	✓*	Radionuclide	✓*	Sand 0.06-2mm	✓
Non-halogenated VOCs	✓*	Corrosive	✓*	Silt 2-60µm	✓
Non-halogenated SVOCs	✓*	Cyanide	✓*	Clay <2µm	✓
Organic corrosive	✓*	Asbestos	✓	Peat	✓
Organic cyanides	✓*	Explosives	×	***Key***	
PCBs	✓*			Not applicable	×
Pesticides/herbicides	✓*			Insufficient data	I/D
Dioxins/furans	✓*			Potentially applicable	✓
Liquid free phase	✓*				

Development Status in the UK

Widely available technique used in the UK

Case Study

Following closure of the Chemical Defence Establishment Nancekuke in the 1970s the facility was decontaminated, dismantled and the wastes deposited in a series of on site dump sites. In 2000 concerns were raised regarding the contents of the dumps which were located in a sensitive area, excluded engineered caps / liners and the contents of which were not completely known. Proposals were therefore made to excavate the dump areas and deposit the material in a new, purpose designed on site landfill. Once the high cost of this work was established an alternative approach was formulated which involved detailed investigation of the dumps and design of an appropriate cap for each dump, and in the case of one dump, design of a water management system. The capping systems negated the need for excavation and disposal to a new landfill of 50,000 m^3 of waste and, due to the nature of the wastes, saved many £millions.

Relative Costs & Timescale	Landfill disposal cost comparison:

Civil Engineering based methods		
Relative Technology Cost: low to high (depending upon the nature of the technique) Timescale – can be <6months, depending upon the technique		<5,000/m^3 = £30 - £400 >5,000/m^3 =£30 - £300 Cost range dependant on type of waste, transport costs and regional variation
References	CL:AIRE 2010 SP1001 (Ref. 1).	

✓* = Limited effectiveness demonstrated.

D.10 Biological treatment

Biological treatment (Biopiles, windrow turning, landfarming, composting)
Description   *Ex situ* biological method which exploits existing microbial processes to degrade, or reduce the toxicity of, contaminants in soil.

Potential Advantages	***Limitations***
▪ can result in complete contaminant degradation; ▪ soils can often be reused on site; ▪ preservation or enhancement of soil structure (except for slurry phase bioreactor).	▪ heavier organic contaminants are difficult to degrade; ▪ potential for formation of toxic intermediate breakdown products; ▪ conditions must be carefully controlled to ensure complete and consistent treatment.

Applicability to Contaminates and Ground Material

Organic		Inorganic		Materials	
Halogenated VOCs	✓	Metals	×	Gravel >2mm	✓
Halogenated SVOCs	✓	Radionuclide	×	Sand 0.06-2mm	✓
Non-halogenated VOCs	✓	Corrosive	×	Silt 2-60µm	✓
Non-halogenated SVOCs	✓	Cyanide	I/D	Clay <2µm	I/D
Organic corrosive	I/D	Asbestos	×	Peat	I/D
Organic cyanides	I/D	Explosives	×	***Key***	
PCBs	I/D			Not applicable	×
Pesticides/herbicides	I/D			Insufficient data	I/D
Dioxins/furans	×			Potentially applicable	✓
Liquid free phase	×				

Development Status in the UK

Widely available technique used in the UK

Case Study

In 2008 VertaseFLI Ltd were engaged to treat coke works wastes at the Former Lambton Coke Works site which was to be redeveloped for residential housing and public open space. The waste types included spent oxides, tar and hydrocarbon impacted soils. Waste materials selected for bioremediation comprised light and heavy oil impacted soils. VertaseFLI designed a comprehensive pre-treatment process involving selective excavation and screening to remove oversized and deleterious material. In the first phase of the project, approximately 30,000 m3 of hydrocarbon impacted soils were bioremediated suing windrows to levels below the site specific target levels over a 20 week treatment period.

Relative Costs & Timescale	Landfill disposal cost comparison:
Relative Technology Cost: Low to Moderate	$<5,000/m^3$ = £30 - £400
Average UK Cost: $<5,000/m^3$ = £32.5/m^3; $>5,000/m^3$ = £25/m^3	$>5,000/m^3$ =£30 - £300
Average Timescale: 0.5 to 1 year	Dependant on type of waste, transport costs and regional

Biological treatment (Biopiles, windrow turning, landfarming, composting)	
	variation.
References	CL:AIRE 2010 SP1001 (Ref. 13). Vertase FLI (Ref. 14).

D.11 Soil washing

Soil washing and separation processes

Description

Ex situ physical/chemical method using an aqueous solution (typically water) to separate contaminants and/or contaminated soil particles from uncontaminated material.

Potential Advantages

- applicable to a wide range of contaminants;
- reduces volume of contaminated material which may reduce the cost of disposal, or treatment by another technology.

Limitations

- may be uneconomic to treat small volumes, due to high plant and installation costs;
- uneconomic to treat material with a high fine content;
- contaminant depleted fractions may not meet the required remediation standard, and therefore require further treatment or disposal;
- a water processing unit is likely to be required, which will add cost.

Applicability to Contaminates and Ground Material

Organic		**Inorganic**		**Materials**	
Halogenated VOCs	✓	Metals	✓	Gravel >2mm	✓
Halogenated SVOCs	✓	Radionuclide	✓	Sand 0.06-2mm	✓
Non-halogenated VOCs	✓	Corrosive	I/D	Silt 2-60µm	I/D
Non-halogenated SVOCs	✓	Cyanide	I/D	Clay <2µm	I/D
Organic corrosive	I/D	Asbestos	I/D	Peat	I/D
Organic cyanides	I/D	Explosives	I/D	***Key***	
PCBs	✓			Not applicable	×
Pesticides/herbicides	✓			Insufficient data	I/D
Dioxins/furans	I/D			Potentially applicable	✓
Liquid free phase	✓				

Development Status in the UK

The technique has been widely uses in the field in the UK and has a proven track record.

Case Study

In 2009 VHE undertook the reclamation of 15ha Woolwich Arsenal site involved the treatment of 240,000m³ of contaminated material by a soil washing plant designed and built in-house by VHE's site team. The client opted for soil washing due to the physical nature of the affected material and the planning requirement to keep lorry movements to a minimum. Following screen testing for explosive residues and the separation of materials of different sizes, soil was washed, crushed and screened to allow as much as possible to be re-used in the subsequent re-engineered ground works operation. Phase 1 involved the treatment by soil washing of 130,000 m³ of material. Phase 2 extended the washing to a further 45,000m³ (amounting to an additional 75,000 tonnes). During Phase 1, daily

<table>
<tr><th colspan="3">Soil washing and separation processes</th></tr>
<tr><td colspan="3">outputs of 1,000 tonnes were not uncommon and between 250 and 500 tonnes were normal. Between 80 and 85% of the input material was re-used, of which 70% was gravel and 30% was sand.</td></tr>
<tr><td colspan="2">Relative Costs & Timescale
Relative Technology Cost: Low to Moderate
Average UK Cost: <5,000/m^3 = £54/m^3; >5,000/m^3 = £28.5/m^3
Average Timescale: <0.5 years</td><td>Landfill disposal cost comparison:
<5,000/m^3 = £30 - £400
>5,000/m^3 =£30 - £300
Cost range dependant on type of waste, transport costs and regional variation .</td></tr>
<tr><td>References</td><td colspan="2">CL:AIRE 2010 SP1001 (Ref. 1). VHE (Ref. 18).</td></tr>
</table>

D.12 Vitrification

Vitrification

Description

In situ thermal or physical/chemical method involving the use of extremely high temperatures to destroy organic contaminants or immobilise inorganic contaminants within a glass-like material.

Ex situ thermal or physical/chemical method involving the use of electrical power to produce high temperatures to destroy organic contaminants or immobilise inorganic contaminants within a glass-like material.

Potential Advantages

- applicable to a wide range of contaminants and contaminated materials;
- able to treat difficult to remediate contaminants.

Limitations

- off-gas needs to be carefully controlled due to volatilisation of organics and some metals;
- volume reduction may lead to risk of subsidence;
- expensive and energy intensive;
- entire soil function is destroyed;
- material with high water content can be problematic.

Applicability to Contaminates and Ground Material

Organic	**In-situ**	**Ex-situ**	**Inorganic**	**In-situ**	**Ex-situ**	**Materials**	**In-situ**	**Ex-situ**
Halogenated VOCs	I/D	I/D	Metals	✓	✓	Gravel >2mm	I/D	I/D
Halogenated SVOCs	I/D	I/D	Radionuclide	✓	✓	Sand 0.06-2mm	✓	✓
Non-halogenated VOCs	I/D	I/D	Corrosive	✓	✓	Silt 2-60µm	✓	✓
Non-halogenated SVOCs	I/D	I/D	Cyanide	✓	✓	Clay <2µm	✓	✓
Organic corrosive	I/D	I/D	Asbestos	✓	✓	Peat	I/D	I/D
Organic cyanides	I/D	I/D	Explosives	I/D	I/D	***Key***		
PCBs	✓	✓				Not applicable	×	
Pesticides/herbicides	✓	✓				Insufficient data	I/D	
Dioxins/furans	✓	✓				Potentially applicable	✓	
Liquid free phase	I/D	I/D						

Development Status in the UK

An emerging technique in the UK

Relative Costs & Timescale

Technology Cost: Moderate to high

No data available on average UK cost.

Average Timescale: up to 1 year.

Landfill disposal cost comparison:

<5,000/m^3 = £30 - £400

>5,000/m^3 =£30 - £300

Cost range dependant on type of waste, transport costs and regional variation

References	CL:AIRE 2010 SP1001 (Ref. 1).

D.13 Additional Techniques Developed in the USA

Techniques that have not been discussed above within a UK context are summarised below with the applicability, relative cost and timescale summarised within the summary matrix within Section 2. These techniques are mostly restricted to the US and little information available.

Technology	Description
Fracturing	These technologies are used for the in-situ treatment of contaminant-impacted sediments. Fracturing techniques can effectively increase the flow of vapours and liquids through low permeable formations and reduce remediation time requirements. This remedial approach can further extend the applicability of in-situ technologies to a low permeable environment and deliver supplements to a fractured formation (e.g., oxygen, organisms, and nutrients).
Electrokinetic separation	The Electrokinetic Remediation (ER) process removes metals and organic contaminants from low permeability soil, mud, sludge, and marine dredging. ER uses electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics. This in situ soil processing technology is primarily a separation and removal technique for extracting contaminants from soils.
Dehalogenation	Reagents are added to soils contaminated with halogenated organics. The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.
Separation	Separation techniques concentrate contaminated solids through physical and chemical means. These processes seek to detach contaminants from their medium (i.e., the soil, sand, and/or binding material that contains them).
Hot Gas Decontamination	The process involves raising the temperature of the contaminated equipment or material for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants.
Open Burn/ open Detonation	In OB operations, explosives or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonatable wave. In OD operations, detonatable explosives and munitions are destroyed by a detonation, which is generally initiated by the detonation of an energetic charge.
Pyrolysis	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.
Thermal desorption	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.

Appendix E. South Australian research

E.1 Summary of research publications

Treatment technology keywords	Global Publications	Australian Publications	Relevant Australian Publications	SA Publications
In situ biological treatment				
In situ bioventing	41	1	1	0
In situ soil bioremediation	972	32	12	2
Soil phytoremediation	3207	92	70	14
In situ physical / chemical treatment				
In situ soil chemical oxidation	380	7	2	0
In situ soil electrokinetic separation	6	0	0	0
In situ soil fracturing	30	0	0	0
In situ soil flushing	95	3	2	2
In situ soil vapour extraction	103	1	1	0
In situ soil solidification	43	1	1	0
In situ soil stabilisation	315	12	3	1
In situ thermal treatment				
In situ thermal treatment	1890	37	0	0
Ex situ biological treatment (assuming excavation)				
Biopiles	66	5	5	3
Soil composting	3071	78	15	5
Landfarming (N/A)				
Slurry biological treatment (biorem.)	296	3	2	1
Ex situ physical / chemical treatment (assuming excavation)				

Treatment technology keywords	Global Publications	Australian Publications	Relevant Australian Publications	SA Publications
Soil chemical extraction (and remediation)	972	39	1	0
Soil chemical reduction	4392	164	2	0
Soil chemical oxidation	2770	116	5	0
Soil dehalogenation	137	2	1	0
Separation (and remediation)	335	17	1	0
Ex situ soil washing	37	2	2	2
Ex situ soil solidification	8	0	0	0
Ex situ soil stabilisation	18	0	0	0
Ex situ thermal treatment (assuming excavation)				
Hot gas decontamination	26	0	0	0
Incineration (and remediation)	390	7	3	0
Open burn / open detonation				
Pyrolysis	299	11	0	0
Thermal desorption	217	8	5	0
Containment				
Landfill cap	130	9	8	1
Landfill cap enhancements / alternatives				

E.2 Australian publications since 2002 detailing in situ and onsite remediation. Contributions from South Australian research are highlighted with asterisks.

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Appendix F. Landfill tax – The UK situation and experience

In response to increasing quantities of waste being deposited into landfill the UK Government introduced Landfill Tax into legislation in 1996. It is a tax on the disposal of waste collected by landfill site operators, with the aim to encourage waste producers to produce less waste, recover more value from waste (e.g. through composting or recycling) and to use more environmentally friendly methods of waste disposal. The tax is charged on a weight basis with two categories: active waste (standard tax rate) and inert/inactive waste, (which has a lower tax rate). When introduced, Landfill Tax was charged at a rate of £7 per tonne at the standard rate and £2 per tonne at the reduced rate by Her Majesties Revenue and Customs (HMRC). At its inception there were some exemptions from Landfill Tax, including waste disposal relating to waste arisings from the clearing of contaminated land. The aim of the exemption served as a method of incentivising the cleanup of contaminated land to ensure that Landfill Tax was not a barrier to the development of brownfield sites. The arrangement represented a market distortion in favour of landfilling contaminated waste soil. However, when the tax exemption was introduced there were few commercially viable alternatives to traditional 'dig & dump' of contaminated arisings.

In 1999 the UK Government published a draft waste strategy ''A Way with Waste'', which updated the 1996 plan. As part of this, the 1999 Budget saw the standard rate of Landfill Tax increased to £10 per tonne and the introduction of a "Landfill Tax Accelerator", under which the standard rate would rise by £1 per tonne each year until 2004 as a means to further deter landfill waste disposal. The exception for contaminated land arisings remained in place.

A number of controversies associated with the 1999 strategy were alleged including that the tax led to an increase in fly-tipping, the use of unlicensed waste disposal sites and created an additional burden on local authorities which could potentially divert money away from other local authority environmental projects (Ref.1).

In April 1999 The Landfill Directive was issued by the European Commission (EC) to its member states, which includes the UK. The objective of the Directive is to prevent or reduce as far as possible negative effects on the environment from the landfilling of waste, by introducing stringent technical requirements for waste and landfill. It defines the different categories of waste (municipal waste, hazardous waste, non-hazardous waste and inert waste) and applies to all landfills, defined as waste disposal sites for the deposit of waste onto or into land. Landfills are divided into three classes within the Directive:

- landfills for hazardous waste;
- landfills for non-hazardous waste;
- landfills for inert waste.

The Directive was transposed into UK legislation in 2002 through the Pollution Prevention and Control Regulations (PPC), and enforced by the regulator in England and Wales - the Environment Agency (EA). This led to a mismatch of waste classification disposed into landfills by the EA, which classifies three types of waste, as stated above, in contrast with the two Landfill Tax rates for active waste and inert/inactive waste, as defined by HMRC. However, the Directive's classification for inert waste broadly corresponds with HMRC's definition of inert/inactive, and both non-hazardous and hazardous waste within the Directive, fall within the standard rate of landfill taxation.

To aid in controlling waste which could potentially cause harm to human health and the environment and to further aid in discouraging waste (with the exception of municipal waste) to be disposed of into landfill, the UK Government implemented the Hazardous Waste Directive in 2005. The Directive set out the regime for the control and tracking of hazardous waste in England and Wales. Under these Regulations, a process of registration of hazardous waste producers and a new system for recording the movement of waste was introduced.

The implementation of the Hazardous Waste Directive led to a fall in the amount of contaminated land arisings qualifying for landfill tax exception with less than half of all contaminated land arisings qualify for exception in 2005-06 (circa 2 million tonnes) when compared to the previous 2004-05 statistics (circa 5 million tonnes) (Ref. 2). An amendment to the EC Landfill Waste Directive published in 2007, which was implemented into legislation within England and Wales through an update to the Pollution Prevention Control Regulations meant all waste had to be treated before it could be sent to landfill and liquid waste was banned from landfill altogether. The consequence of the implementation of the Hazardous Waste Directive 2005 and the update to the EC Landfill Waste Directive led to a sharp increase in the cost of landfilling hazardous waste and Landfill Tax would now only be attributed to a small proportion of the overall cost of landfilling hazardous waste (Ref. 3).

The UK Government considered the contaminated soil landfill tax exemption policy in 2007 and found a mismatch between its policy objectives of sending less waste to landfill and identified a need to reconsider the contaminated soil exemption due to technological improvements which had led to advances in decontaminating waste on site, with the possibility that the resulting material might be put to a practical use. In 2008 the UK Government sent a significant message to the contaminated land industry regarding its desire to reduce dependence on landfill. The March budget of that year announced that new applications for Landfill Tax exemption would not be accepted after December 2008, and any landfill tax exemption certificates would only be valid until 31st March 2012. From the 1st April 2012 therefore, landfill tax exemption has ceased to exist entirely for contaminated soils.

Retrospectively the introduction of Landfill Tax has been deemed a success as the proportion of waste sent to landfill had fallen by around a third by 2009, accompanied by a similar increase in recycling (Ref. 4). In the March 2010 budget the UK Chancellor of the Exchequer announced that the landfill tax escalator would be extended until 2014 and would continue to increase by £8 per tonne in the 2010 budget. The implication of these measures led to landfill tax rising to £64 in 2012, and it will rise further to £72 in 2013, and £80 by 2014, with the aim to reduce the UKs dependence on landfill by encouraging further investment in alternative waste management options to landfill. The Budget 2010 report, published after the Chancellor had spoken, stated: The increase in the standard rate will divert an additional 600,000 tonnes of waste, and result in further carbon savings (Ref 5).

Given the large proportion of waste which has been diverted away from landfill since the inception of Landfill Tax, the policy can be deemed a success as it has met the primary objective to reduce the amount of waste produced by reducing the financial attractiveness of landfill as a means of waste management. Since the application of this tax to contaminated soil arisings, and the year on year escalation of the tax, part of the reason for the reduction in waste to landfill has comprised a reduction in soil from development sites.

Appendix G. Land remediation tax relief

In 2000 a UK Government White Paper recommended that an additional tax relief should be given to help developers decontaminate contaminated land (Ref. 2). Subsequently, land remediation tax relief (LRR) was introduced by the Finance Act 2001 as an incentive for the development of Brownfield sites (Ref. 3). The tax relief gives a financial incentive to developers to bring land back into use that has been contaminated by a previous industrial use. The tax relief provides a deduction of 100% in corporation tax, plus an additional deduction of 50%, for qualifying expenditure incurred by companies in cleaning up land acquired from a third party in a contaminated state. For example, a company incurring £1m of expenditure will get a tax deduction of £1.5m, which will be worth £360,000 at the current 24% corporation tax rate. In addition, loss making companies can claim a payable tax credit of 16% of the losses arising as a result of land remediation relief. Therefore, a loss making company incurring £1 million expenditure can carry forward a £1.5M loss or exchange it for £240,000.

In 2006, HMRC published an early evaluation of the Urban White Paper fiscal measures (Ref 6). This included an evaluation of the land remediation relief. The paper found that awareness of the relief was generally low, but had been increasing. Although finding some evidence that land remediation relief had encouraged companies to take on further schemes on contaminated sites, the research concluded that it was too early to quantify the effects. As development projects typically work to long timescales and it takes time for such tax incentives to be incorporated into investment decisions, the full effects of land remediation relief would only emerge over a longer time period.

In 2009, LRR was extended to address market failure in bringing long term derelict land back into use with LRR extending to incorporate both contaminated land and derelict land. Again an incentive was given where land, whose development has been blighted by various kinds of enduring dereliction, is brought back into productive use.

More recent information contained within a HM Treasury Paper dated December 2011 stated that 1,300 companies claim the land remediation relief each year, which costs the Exchequer around £40 million annually (Ref. 7). The UK Government agreed with the Office of Tax Simplification's view that the relief failed to deliver its policy objective of increasing the supply of brownfield land for development, as a result a consultation was launched which proposed its abolition. The UK Government has more recently announced that it will not remove the relief because it wants to support house-building and regeneration. "The Government has considered the responses and decided that removal of this relief would risk undermining the Government's plans to support the housing and construction sectors through planning reforms and the release of large areas of publicly owned land for development," the report stated, "The Government has therefore decided not to abolish this relief" (Ref. 8).

Although not a technique for diverting waste soil from landfill, the LRR is discussed here as it demonstrates the balance that can be introduced by appropriate taxation to encourage brownfield development, even when methods such as landfill tax are introduced, which if implemented alone could make such development cost prohibitive. It emphasises the need for both encouraging development whilst discouraging disposal to landfill.

Case Study: Commercial and Light Industrial Development, Doncaster (Ref. 9.)

Across the undeveloped site various contaminants in the ground were detected including excessive concentrations of methane, carbon dioxide and sulphates. A high water table and mobile groundwater conditions to some areas of the site were also identified.

Land Remediation Works

- Removal off site of made ground;
- Removal of sulphates where mobile groundwater conditions also present;
- Backfilling excavations with inert materials and vibro compaction;
- Gassing mitigation measures including monitoring, membranes and venting.

In addition, due to the nature of the made ground, high water table and mobile groundwater conditions, shallow or strip and fill foundations were not deemed suitable and piled foundations were recommended to ensure stability of the new buildings.

Land Remediation Relief

In total £4,600,000 of eligible land remediation expenditure was identified comprising the full costs of the excavation works and gassing measures and part of the foundation costs plus professional fees, preliminary items and other associated on-costs. In this case 50% of the eligible expenditure was qualifying for land remediation relief. A total tax/cash saving of £690K was claimed.

Appendix H. Example of a national remediation framework

In 1999, a non-profit organisation by the name of ‘Contaminated Land: Applications in Real Environments’ (CL:AIRE) was formed in the UK with the primary objective to promote sustainable alternatives to disposal of waste into landfill sites by encouraging the use of innovative technologies to clean up contaminated land and groundwater. Part of the organisation includes the Technology and Research Group (TRG), which draws on some of the foremost professionals and academics within the field to provide credible, third party appraisals of remediation technologies and strategies which help to both improve on-site remediation technology development and assist in formulating alternative strategies to landfilling of waste. CL:AIRE has developed a process in which projects are submitted, evaluated by the TRG, and if approved monitored and reported so that the industry as a whole can benefit from the results.

Since its formation CL:AIRE has established itself as a respected independent organisation providing the UK contaminated land industry with a valuable services, including provision of development training courses, distributing information and acting as a credible resource for relevant stakeholders, to ensure up to date best practice and innovative remediation techniques are developed and implemented in the field. CL:AIRE in its own right is now a useful organisation to help encourage diversion from landfill.

Three important aspects of CL:AIRE’s work in diverting soil from landfill are as follows:

1. development and publication of the CL:AIRE Definition of Waste: Development Industry Code of Practice (the Code) which is an initiative to improve the sustainable and cost effective development of land including greenfield, brownfield and contaminated sites;
2. establishing a materials exchange database to support the transfer of materials from sites where there is a surplus to those where there is a materials deficit; and
3. providing a focal point and support for implementing, demonstrating and publishing the findings of soil remediation techniques that may not otherwise be developed. The development of such techniques may avoid material disposal to landfill.

Each of these is discussed in turn below.

H.1 Definition of Waste: Development Industry Code of Practice

H.1.1 Background to the Code of Practice

As part of the UK Government’s sustainable development plans, in 2006 the EA published ‘the Definition of Waste: Developing Greenfield and Brownfield sites’. The document provided clarity on some of the definitions of waste issues that arise during land development. While the guidance was welcomed for the direction it took, it remained a qualified advisory document, leaving practitioners unable to rely on some important aspects with the associated risk from inconsistent application, stalled projects or, at worst, prosecution for failing to comply with waste legislation (Ref.10). At issue was when do soils, both natural and impacted by contamination, become a waste on a development site. Also, at what point do they cease to be a waste during the process of excavation movement, possible treatment on or off site, then final re-use on the same or different site. However, the EA made it clear that if soils excavated on a development site were taken for off-site use they would likely be classified as a waste, even when it may be a useful resource.

Pressed by stakeholders for a resolution of the qualifications within the EA Guidance, the EA arranged a workshop in March 2007. Representatives from the EA, CL:AIRE, and stakeholders from industry and house building representatives collaborated to set out a framework whereby it moved to a more deregulatory approach to this important aspect of development activity. The result of the workshop was for CL:AIRE to produce the Definition of Waste: Development Industries Code of Practice, which was published in 2008, as a voluntary code to build upon the previous EA 2006 documentation.

The Code was launched to provide a pragmatic solution to use excavated material, including soils on development sites, in a sustainable manner without getting embroiled in UK Waste Legislation. The principle aim of the Code was to provide a clear and concise process to determine whether excavated materials on development sites or a cluster of development sites constitute a waste or a material that can be re-used outside of waste management regulation. The Code also helped to identify the point when treated waste need no longer be considered a waste with the anticipated consequence to aid resource efficiency and reduce landfill disposal. This is achieved essentially by ensuring soils remain out of the waste stream and by avoiding otherwise unnecessary transportation of soils off site for treatment or disposal, with the knock on benefit of negating the need to import clean fill back onto site to fulfil a sites earthwork requirement.

H.1.2 Regulation of the Code

The Code changes the way the EA regulates such activities, with the involvement of a significant degree of self-regulation, relying on the professional integrity of the project team. Under the Code there is less need to involve the regulator (the EA), who previously controlled the process under a permit or a permitting exemption. The decision on whether to re-use soil now rests with the developer or the contractor, as long as the Code is carefully followed. Once a number of schemes had successfully proven the self-regulation approach could be implemented correctly, the EA has gradually had less involvement in the process. The process of self regulation is essentially undertaken by the 'Qualified Person', which is a concept similar to that of the self assessment Auditor role commonly used in contaminated land sign off within Australia.

H.1.3 The Qualified Person

The Qualified Person with regards to the Code is required to be chartered in a relevant discipline, have attended a once day CL:AIRE training course and have at least five years relevant experience. They are also required to be totally autonomous from the project but may still work for the company that prepares the audit trail. When a declaration is sent to the EA by the Qualified Person identifying that excavated materials are to be dealt with as set out in the Code, the EA take the view that the materials on site where they are to be used will not be waste.

H.1.4 Benefits of the Code

The risk assessment aspect of the Code is based on a 'suitable for use' approach and does not distinguish between contaminated and uncontaminated soil. This allows for a definitive point to be established for when waste ceases to be waste and is fully recovered which is the primary benefit of the Code. A summary of the key benefits of the Code are:

- it promotes materials for reuse;
- provides greater clarity, consistency and certainty over what is / is not waste;
- supports diversion from landfill;
- reduces transport costs; and,
- sets out good practice for assessing what is waste.

H.1.5 Implementation of the Code

To implement the Code a comprehensive documented audit trial in the form of a Remediation Strategy or a Design Statement, depending on the contaminated status of the materials has to be completed. The documentation must include:

- desk and site investigations;
- conceptual site model;
- risk assessment;
- materials management plan;
- verification plan; and,

- signed declaration from a Qualified Person confirming documentation adheres to the Code.

Upon completion of the work a Validation Report must be prepared and kept by the developer for a minimum of two years.

The Code only applies in the following circumstances and the Remediation Strategy or Design Statement must confirm that these criteria will be met – these are fundamental to the Code and are designed to ensure appropriate material use:

- the material is suitable for use;
- re-use of excavated material is a certainty;
- only the required volume of material will be used; and
- the material will not harm the environment or human health.

Initially the Code of Practice applied only to soil being re-used on the same site or at a predefined cluster of sites. Re-use of soil on other sites was not initially included, nor was soil coming from a fixed treatment facility. These activities were regulated by the environmental permitting regime. However, the Environment Agency audited all of the projects completed under the Code and made a number of revisions to allow more flexibility in the re-use of soils – these were incorporated into Version 2 (see below).

From 2008 to 2011 Version 1 of the Code was used successfully on more than 125 projects ranging from landmark developments through to routine infrastructure and utility works, with the anticipated affect of allowing the regulator to step back from the detailed auditing and quality assurance of many earthworks projects which pose little or no risk to the environment (Ref. 9). An appropriate degree of scrutiny is still applied to higher risk schemes, but the public resources saved by this initiative allow the regulator to focus its limited resources on dealing with more damaging illegal activities. The certainty of the Code also allowed more on site use of material and reduced disposal to landfill.

H.1.6 The Code Updated

In 2011, CL:AIRE, produced an updated version of the Code of Practice to further deliver cost, time, social and environmental benefits to those dealing with excavated site materials. The new updated Code includes the direct off site transfer and re-use of clean naturally occurring soil materials between sites. It also creates the conditions to support the establishment and operation of fixed soil treatment facilities, which have a key role to play in the future of sustainable materials management. As with Version 1 it also enables the reuse of both contaminated and uncontaminated materials on the site of production, and between sites within defined Cluster projects. The record of use for the Code shows that over time it has become a preferred approach to the management of materials on their site of origin and beyond using the Cluster method. Official statistics to assess the overall impact the Code on diverting material away from landfill has as yet not been complied. However, CL:ARE has provided SKM with the following preliminary information:

- to March 2012, 356 declarations have been registered under the scheme;
- information provided on 67 of these sites indicates a volume of 1,420,640m^3 of material was reused, equating to an average of 21,204m^3 per site.

Based on the average volume of reuse per site, the total amount of materials being reused and diverted away from landfill is likely to be of the order of 8.1Mm^3. To generate a conservative approximate cost saving, we have based the potential disposal of the on-site reused material as inert waste, which if currently disposed of to landfill in the UK would incur a £2.50 tax charge and a £5 gate fee, this would equate to a cost saving to developers of circa £61M.

The following case study adopted the CL:AIRE Code of Practice and demonstrate how developers have benefited from substantial reductions on cost, shortened programmes and reduced impact on the local environment.

Case Study: Chinnor Cement Works

The site at Chinnor is a 77ha former cement works comprising a cement kiln dust landfill and series of chalk quarries, with a proportion of the site (7ha) identified as an area for residential redevelopment. The site is located above a Principal chalk aquifer and spring system, with previous site investigations indicating that petroleum hydrocarbons (primarily from leaking fuel tanks, were present within both soils and groundwater. A remedial strategy was developed involving the removal of circa 5,400m^3 of soil for off-site disposal. The solution was rejected as it would require 525 vehicle moments a day in a rural area, would be expensive, and impact heavily on the local community.

The client instructed a specialist remediation contractor to undertake an appraisal of the previous site investigation/risk assessment, remedial strategy and cost. Gaps were identified in the previous risk assessment and noted that the remedial strategy (dig and dump) was both unsustainable and costly. The client, who was aware of the potential to save money, instructed the remedial design team to explore alternative solutions. Additional site investigation works were undertaken followed by detailed hydrogeological assessment, groundwater risk assessment, human health risk assessment and remedial strategy in order to develop and refine the Conceptual Site Model. Careful consideration was then given to the final development plan and cut & fill requirements, which helped the formulation of a viable on site remediation strategy and robust Materials Management Plan. On site remediation techniques (using both bioremediation and soil stabilisation/solidification) were proposed for the impacted soils, as opposed to an excavation and disposal option. Upon further testing, only 3,500m^3 of materials required treatment, with the remainder suitable for reuse without treatment. Once the revised strategy was agreed with the regulators, a Materials Management Plan was developed that took into account the volume of materials produced and identified areas within the site where the soil could be suitably re-used. In addition, all metal from the demolition of the above-ground structures was recycled.

Key Features

- Material requiring remediation or re-use on site - 11,000tonnes
- Cost of site remediation - £206,000
- Soils transported to landfill 0t
- Cost of additional site investigation required to meet the Code £50,000
- Cost saving avoiding dig and dump £89,600
- Cost saving avoided through import of new material £97,777

H.2 CL:AIRE Materials Exchange Programme

As part of the Code CL:AIRE is keeping a register of materials and services which may fall within the Code of Practice, with the aim to link material holders with service providers or organisations requiring materials in order to make the process of finding project partners an easier and quicker process. Organisations involved in the management of development sites are urged to register key information on materials and services which fall within the Code, which are then held in confidence by CL:AIRE. The register is implemented prior to or at the initiation of remediation of brownfield sites. At which point locally available treatment options are evaluated, where are there site imbalances of soils or fill materials. CL:AIRE then reviews the information provided against the Register and contact organisations where possible project partnerships for ‘finding homes’ for materials. The information is submitted to the Register and circulated amongst its members on a regular basis, should an entry be of particular interest to a member they then notify CL:AIRE who then act to make the necessary introductions such that further discussions and information transfer can take place.

Although there is no information available on the success of this system to date, there are clear benefits in such material exchange databases in order to limit the need for disposing of surplus materials to landfill which may have beneficial use elsewhere and limit the need for use of virgin material.

H.3 Soil Treatment – Development of New Technologies

One of the key roles for CL:AIRE is to encourage project partners to undertake technology demonstration and research projects and to ensure that the information is peer reviewed and published such that it raises industry awareness of new techniques that have been applied on “real” sites. The project partnership approach is designed to bring together site owners, consultants, developers, contractors, specialist technology providers and academics. The scope of the projects undertaken includes site investigation techniques, monitoring and remediation solutions and to date 26 technology demonstration projects have been completed and 20 research projects. There are benefits in this approach to all of the parties involved, including profile raising, credibility, material dissemination and in some instances technical support and financial support through third parties. The reports are available through the CL:AIRE website and are largely free. The available publications are listed in Appendix I.

Appendix I. Available relevant CL:AIRE publications of soil remediation / land management

I.1 *Technical Bulletins*

TB 01 - Introduction to an integrated approach to the investigation of *fractured rock aquifers* contaminated with *non-aqueous phase liquids* (2002)

TB 02 - *Multilevel sampling systems* (2002)

TB 03 - Principals & practice for the collection of representative groundwater samples (2008)

TB 04 - Parameterisation of aquifer hydraulic properties: A contaminant hydrogeology perspective (2009)

TB 05 – The use of *geophysical investigation techniques* in the assessment of *contaminated land and groundwater* (2007)

TB 07 - Improving the reliability of *contaminated land assessment* using statistical methods: Part 1 (2004)

TB 09 - *Stabilisation/Solidification Treatment and Remediation*: Part 1: Summary of the *State of Practice Reports I-IV STARNET* (2004)

TB 11 - A practical guide to investigating *DNAPL* releases in the subsurface (2004)

TB 12 - Statistical Assessment of Contaminated Land: Some Implications of the 'Mean Value Test' (2006)

TB 13 - Understanding *Soil Washing* (2007)

TB 14 - Treatment of *Chromium Contamination* and *Chromium Ore Processing Residue* (2007)

TB 15 - Accounting for the groundwater-surface water interface in contaminated land assessments (2011)

I.2 *Case Study Bulletins*

CSB 01 - Site characterisation in support of *monitored natural attenuation* of *fuel hydrocarbons* and *MTBE* in a *chalk aquifer* in Southern England (2002)

CSB 02 - A constructed wetland to treat *acid mine drainage* from colliery spoils at *Quaking Houses, County Durham* (2002)

CSB 03 - Portadown *biological reactive barrier* (2005)

CSB 04 - *Mine water treatment* at *Wheal Jane Tin Mine, Cornwall* (2004)

CSB 05 - Remediation trial at the *Avenue Coking Works* using *stabilisation/solidification* and *accelerated carbonation technology* (2006)

CSB 06 - Remediation Trial at the Avenue Using *Thermal Treatment* (2006)

CSB 07 - Remediation Trial at the Avenue Using Soil Washing (2008)

CSB 08 - *Public affairs and communications on contaminated land projects* (2007)

CSB 09 - Remediation of a Former Landfill in Coventry: A Practical Application of the Definition of Waste: Development Industry Code of Practice in a Cluster Project

CSB10 - The Development of Risk Based Generic Assessment Criteria (GAC) for Assessment of Chronic Human Health Risks from Exposure to Soil Contaminants

I.3 *Research Bulletins*

RB 01 - *Enhanced in situ bioremediation* technique for *manganese removal from mine waters* (2003)

RB 02 - FIRS (*Ferric Iron Remediation and Stabilisation*): a novel *electrokinetic technique for soil remediation and engineering* (2003)

RB 03 - Project SIReN: Research projects (2006)

RB 04 - Project SIReN – Future research needs (2006)

RB 05 - *Remediation of Heavy Metal Pollution* via *Bone Meal Amendments to Soil*: Field and Laboratory Trials (2007)

RB 06 - Results of a laboratory microcosm study to determine the potential for *bioremediation of chlorinated solvent DNAPL* source areas (2006)

RB 7 - Field portable x-ray fluorescence (FPXRF): A rapid and low cost alternative for measuring metals and metalloids in soils (2008)

RB 8 - Modelling approaches for assessing risks associated with petroleum hydrocarbon spills in the UK Chalk aquifer (2009)

RB 9 - Electrokinetic Ferric Iron Remediation and Stabilisation (FIRS) of Hexavalent Chromium Contaminated Soils: An *Ex Situ* Field Scale Demonstration (2009)

RB 10 - Bioremediation of heavy hydrocarbons –reducing uncertainty in meeting risk-based targets: laboratory to field scale (PROMISE Project) (2010)

RB 11 - Streamtube project overview: Longitudinal transect assessment of the SABRE site DNAPL source zone (2010)

RB 12 - Modelling Food-Chain Transfer of Contaminants in Soil to Terrestrial Ecological Receptors (2010)

RB 13 - The utility of continuous monitoring in detection and prediction of “worst case” ground-gas concentration

RB 14 - Generic Human-Health Assessment Criteria for Arsenic at Former Coking Works Sites

RB15 - Generic Human-Health Assessment Criteria for Benzo[a]pyrene at Former Coking Works Sites

RB16 - Generic Human-Health Assessment Criteria for Benzene at Former Coking Works Sites

I.4 SUBR:IM (*Sustainable Urban Brownfield Management: Integrated Management*) **Bulletins**

SUB 01 - The role of the development industry in *brownfield regeneration* (2006)

SUB 02 - Uncovering the True Impacts of *Remediation* (2007)

SUB 03 - *Climate Change, Pollutant Linkage and Brownfield Regeneration* (2007)

SUB 04 - *Measuring Sustainability*: Whats in a number? (2007)

SUB 05 - *Avoiding Future Brownfield Sites through Design for Deconstruction and the Reuse of Building Components* (2007)

SUB 06 - *Communicating Risk on Contaminated Sites*: How Best to Engage with Local Residents (2007)

SUB 07 - Acid Tar Lagoons (2008)

SUB 08 - Community Engagement, Urban Regeneration and Sustainability (2008)

SUB 9 - Quality in land remediation: Indicators and protocols for brownfield land (2008)

SUB 10 - The use of compost in the regeneration of brownfield land (2008)

SUB 11 - Integrated Remediation, Reclamation and Greenspace Creation on Brownfield Land (2009)

SUB 12 - SUBR:IM (Sustainable Urban Brownfield Regeneration: Integrated Management) - An Overview (2009)

I.5 *Site Bulletins*

SB 01 - *MNA Bulletin* (2005)

SB 02 - SIReN (*MNA*) overview and description of projects (2005)

SB 03 - *Coal Mine Sites for Targeted Remediation Research:- The CoSTaR Initiative* (2006)

I.6 *Guidance Bulletins*

GB 01 - *Stabilisation/solidification for the treatment of contaminated soil* (2005)

GB 02 - Managing Japanese knotweed on development sites: Code of Practice (2008)

GB 03 - The Definition of Waste: Development Industry Code of Practice

I.7 *SABRE Bulletins*

SAB 01 - Project SABRE (Source Area BioRemediation) – an overview (2010)

SAB 02 - Site investigation techniques for DNAPL source and plume zone characterisation (2010)

SAB 03 - Results of laboratory column studies to determine the potential for bioremediation of chlorinated solvent DNAPL source areas (2010)

SAB 04 - Insights and modelling tools for designing and improving chlorinated solvent bioremediation applications (2010)

SAB 05 - Overview of the SABRE field tests (2010)

I.8 *Other CL:AIRE publications*

CL:AIRE Policy Paper (2010)

Definition of Waste: Development Industry Code of Practice (2008)

Generic Assessment Criteria (GAC) Report (2010)

Guidance on Comparing Soil Contamination Data with a Critical Concentration

SuRF-UK: A Framework for Assessing the Sustainability of Soil and Groundwater Remediation (2010)

UK Trade & Investment & CL:AIRE - Contaminated Land and Remediation: A guide to technologies and services from the UK (2006)