CRC for Contamination Assessment and Remediation of the Environment

National Remediation Framework

Technology guide: Soil washing

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National Remediation Framework

The following guideline is one component of the National Remediation Framework (NRF). The NRF was developed by the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) to enable a nationally consistent approach to the remediation and management of contaminated sites. The NRF is compatible with the *National Environment Protection (Assessment of Site Contamination) Measure* (ASC NEPM).

The NRF has been designed to assist the contaminated land practitioner undertaking a remediation project, and assumes the reader has a basic understanding of site contamination assessment and remediation principles. The NRF provides the underlying context, philosophy and principles for the remediation and management of contaminated sites in Australia. Importantly it provides general guidance based on best practice, as well as links to further information to assist with remediation planning, implementation, review, and long-term management.

This guidance is intended to be utilised by stakeholders within the contaminated sites industry, including site owners, proponents of works, contaminated land professionals, local councils, regulators, and the community.

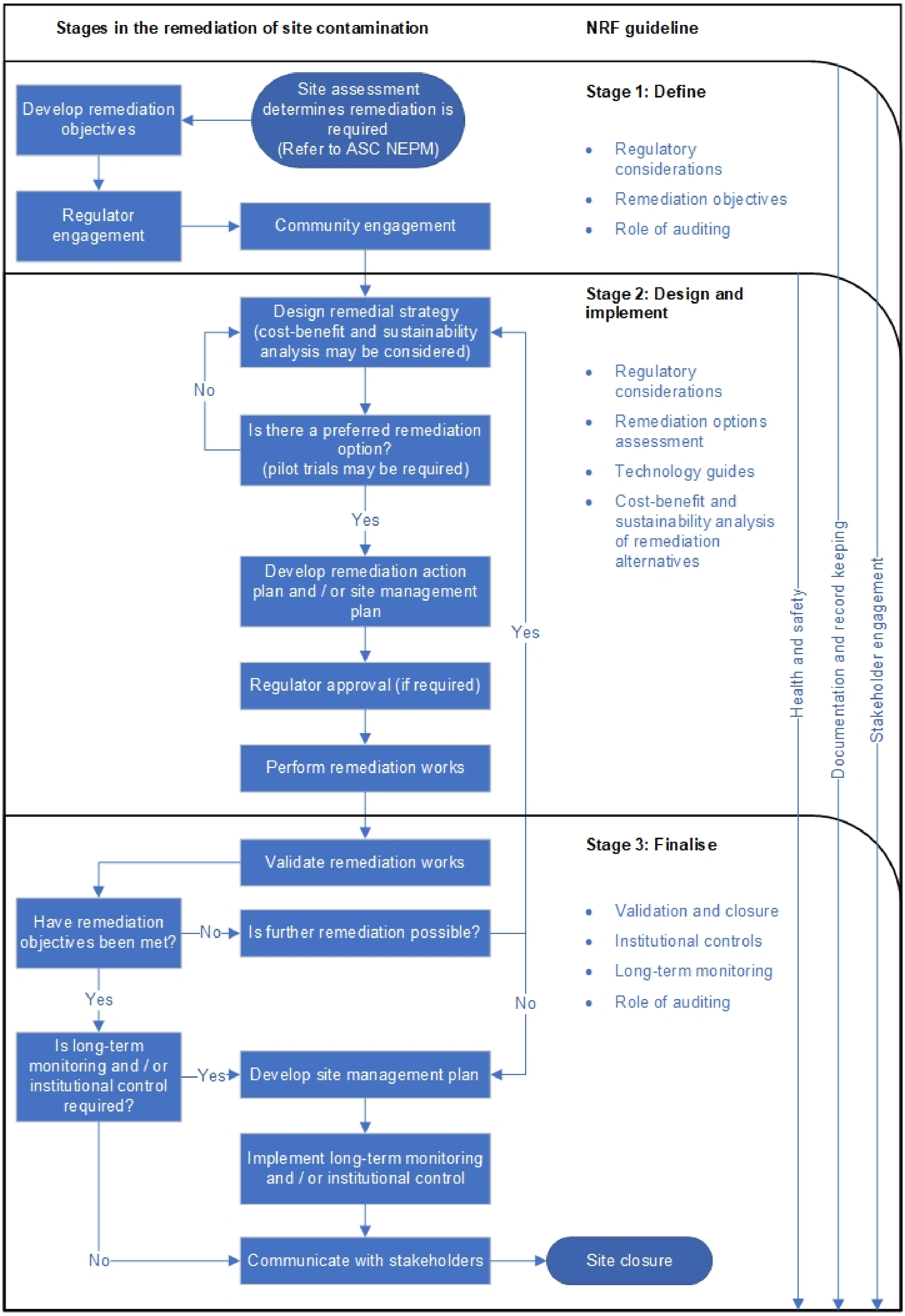
The NRF is intended to be consistent with local jurisdictional requirements, including State, Territory and Commonwealth legislation and existing guidance. To this end, the NRF is not prescriptive. It is important that practitioners are familiar with local legislation and regulations and note that **the NRF does not supersede regulatory requirements**.

The NRF has three main components that represent the general stages of a remediation project, noting that the remediation steps may often require an iterative approach. The stages are:

- Define;
- Design and implement; and
- Finalise.

The flowchart overleaf provides an indication of how the various NRF guidelines fit within the stages outlined above, and also indicates that some guidelines are relevant throughout the remediation and management process.

It is assumed that the reader is familiar with the ASC NEPM and will consult other CRC CARE guidelines included within the NRF. This guideline is not intended to provide the sole or primary source of information.


Stages in the remediation of site contamination
NRF guideline
Site assessment determines remediation is required (Refer to ASC NEPM)
Develop remediation objectives
Regulator engagement
Community engagement
Stage 1: Define
Regulatory considerations
Remediation objectives
Role of auditing
Design remedial strategy (cost-benefit and sustainability analysis may be considered)
No
Is there a preferred remediation option? (pilot trials may be required)
Yes
Develop remediation action plan and / or site management plan
Regulator approval (if required)
Perform remediation works
Stage 2: Design and implement
Regulatory considerations
Remediation options assessment
Technology guides
Cost-benefit and sustainability analysis of remediation alternatives
Yes
Health and safety
Documentation and record keeping
Stakeholder engagement
Validate remediation works
Have remediation objectives been met?
No
Is further remediation possible?
No
Yes
Is long-term monitoring and / or institutional control required?
Yes
Develop site management plan
Implement long-term monitoring and / or institutional control
No
Communicate with stakeholders
Site closure
Stage 3: Finalise
Validation and closure
Institutional controls
Long-term monitoring
Role of auditing

Executive summary

Soil washing is a physical or chemical technology that separates contaminated and non-contaminated soil components by exploiting physical differences between them, such as particle size, shape, density and / or surface properties. Following soil washing, the contamination is concentrated into a smaller fraction of the total volume of impacted soil or sediment (generally in the fine fraction) which can be more easily disposed of or treated further (e.g. by solidification or stabilisation). The 'clean' fraction of the treated soil, comprising larger particles such as sand and gravel, is then able to be re-used separately, such as on-site (providing the concentrations meet the remediation criteria).

Soil washing falls into the 'separation' category of remediation technologies – it does not destroy contaminants, but rather separates them from most of the soil particles to reduce the volume of soil that requires further treatment

During soil washing, the remediation of the contaminated soil occurs in one of two ways:

- Dissolving or suspending contaminants in water:
- Concentrating contaminants into a smaller volume of soil:

Wash water can be supplemented with several substances to help remove contaminants, such as basic leaching agents, surfactants, acids or chelating agent

There are four main stages in applying soil washing as a treatment technology:

- Soil preparation and screening;
- Physical separation;
- Chemical extraction; and
- Waste water treatment.

Soil washing is rarely a stand-alone treatment technology, as the fine soils and waste water will generally require additional treatment following completion of the washing process. While the waste water is generally treated using standard industry practices, the sludge generated during the waste water treatment may require treatment by an alternative remediation technology such as solidification/stabilisation, bioremediation, chemical treatment (e.g. the base catalysed decomposition process) or thermal treatment.

Key considerations that will often determine the feasibility of applying soil washing systems as a potential remediation option include:

- Whether the contaminated material has a significant percentage of coarse material that can be separated as a clean fraction suitable for reuse or lower cost disposal;
- Whether the separated fine contaminated material (slurry) can be dewatered and disposed of;
- Whether the relative volumes and costs for disposal of the resulting coarse or clean fraction and the fine or contaminated fraction makes the process economic.

- Will the relevant regulatory agencies accept soil washing as a viable means of remediation?
- Can the treated material be reused? Will the concentrations of inorganics and residual organics allow the treated material to be reused as backfill on the site or as clean fill elsewhere, or will subsequent treatment (e.g. stabilisation) or landfill disposal be required?
- Is it likely that other stakeholders (such as local government or members of the public) will accept the use of the technology, particularly those stakeholders that can have a significant bearing on whether the technology is applied at the site? Are there sensitive sites nearby that would not be compatible with the proposed operation?
- Is there a time constraint, and can the application of soil washing meet this constraint?
- Is the expected order of cost of treatment acceptable?

Abbreviations

CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
NRF	National Remediation Framework
PPE	Personal Protective Equipment
RAP	Remediation Action Plan

Glossary

Bench test	Remedial activity carried out as part of a treatability study on a small scale to assess the feasibility, efficacy, inputs, costs, time and risk of the planned remedial action. Normally conducted in an ex-situ laboratory with contaminated material collected from the site. May preceed a pilot test.
Concentration	The amount of material or agent dissolved or contained in unit quantity in a given medium or system.
Conceptual site model	A representation of site-related information including the environmental setting, geological, hydrogeological and soil characteristics together with the nature and distribution of contaminants. Contamination sources, exposure pathways and potentially affected receptors are identified. Presentation is usually graphical or tabular with accompanying explanatory text.
Contaminant	Any chemical existing in the environment above background levels and representing, or potentially representing, an adverse health or environment risk.
Contaminated site	A site that is affected by substances that occur at concentrations above background or local levels and which are likely to pose an immediate or long-term risk to human health and/or the environment. It is not necessary for the boundaries of the contaminated site to correspond to the legal ownership boundaries.
Contamination	The presence of a substance at a concentration above background or local levels that represents, or potentially represents, a risk to human health and/or the environment.
Environment(al) protection authority / agency	The government agency in each state or territory that has responsibility for the enforcement of various jurisdictional environmental legislation, including some regulation of contaminated land.
Pilot trial	Remedial activity carried out as part of a treatability study on a small scale to assess the feasibility, efficacy, inputs, costs, time and risk of the planned remedial action. Normally conducted in-situ on a restricted scale. May follow a bench test.
Practitioner	Those in the private sector professionally engaged in the assessment, remediation or management of site contamination.

Proponent	A person who is legally authorised to make decisions about a site. The proponent may be a site owner or occupier or their representative.
Remediation	An action designed to deliberately break the source-pathway-receptor linkage in order to reduce the risk to human health and/or the environment to an acceptable level.
Risk	The probability that in a certain timeframe an adverse outcome will occur in a person, a group of people, plants, animals and/or the ecology of a specified area that is exposed to a particular dose or concentration of a specified substance, i.e. it depends on both the level of toxicity of the substance and the level of exposure. 'Risk' differs from 'hazard' primarily because risk considers probability.
Site	A parcel of land (including ground and surface water) being assessed for contamination, as identified on a map by parameters including Lot and Plan number(s) and street address. It is not necessary for the site boundary to correspond to the Lot and Plan boundary, however it commonly does.
Soil washing	A remediation method where contaminants in the soil are separated from the non-contaminated soil particles by physical separation or chemical extraction techniques or a combination of the two. Also referred to as soil separation or physical separation.
Sorbed	The process by which one substance becomes attached to another substance. This may occur through adsorption or absorption.
Treatability studies	A series of tests designed to ascertain the suitability of the treatment for the contaminants under the site conditions

Measurements

Unit or symbol	Expansion
%	Percent
mm	Millimetre

Table of contents

1. Introduction

The purpose of this guideline is to provide information on soil washing as a treatment technology for the remediation of contaminated sites to assist with selection of remediation options. The document contains information to inform remediation planning and aid compilation of a remediation action plan (RAP).

This guidance is primarily intended to be utilised by remediation practitioners and those reviewing practitioner's work, however it can be utilised by other stakeholders within the contaminated sites industry, including site owners, proponents of works, and the community.

Soil washing is one of many technologies available for contamination remediation, and other technologies may be more appropriate. It is assumed that the information presented within will be used in a remediation options assessment to identify and select the preferred technologies for more detailed evaluation. This guideline provides information for both initial options screening and more detailed technology evaluation. This guideline does not provide detailed information on the design of soil washing systems as this is a complex undertaking and should be carried out by appropriately qualified and experienced practitioners. Readers are directed to the NRF *Guideline on performing remediation options assessment* for detailed advice on assessing remediation options. In addition, the remediation objectives, particularly the required quality of the soil after treatment, are a critical matter and it is assumed that these have been determined and considered in the remediation options assessment and selection process. Readers are directed to the NRF *Guideline on establishing remediation objectives* for more detailed advice.

References to case studies are presented in **Appendix A.**

A number of sources of information were reviewed during the formulation of this document to compile information on potential technologies. These are listed in references, and provide an important resource to readers.

2. Technology description

Soil washing is a physical or chemical technology that separates contaminated and non-contaminated soil components by exploiting physical differences between them, such as particle size, shape, density and / or surface properties. Following soil washing, the contamination is concentrated into a smaller fraction of the total volume of impacted soil or sediment (generally in the fine fraction) which can be more easily disposed of or treated further (e.g. by solidification or stabilisation). The 'clean' fraction of the treated soil, comprising larger particles such as sand and gravel, is then able to be re-used separately, such as on-site (providing the concentrations meet the remediation criteria).

Soil washing falls into the 'separation' category of remediation technologies – it does not destroy contaminants, but rather separates them from most of the soil particles to reduce the volume of soil that requires further treatment.

Soil washing is also be referred to as 'soil separation' or 'physical separation'. Soil washing systems can include only physical separation or chemical extraction or a combination of the two techniques.

During soil washing, the remediation of the contaminated soil occurs in one of the following ways:

- Dissolving or suspending contaminants in water:
  - This can be expedited via the addition of chemicals such as solvents and surfactants to the wash water.
- Concentrating contaminants into a smaller volume of soil:
  - Particle size separation: This process is based on the knowledge that contaminants, both organic and inorganic, usually bind to silt, clay or organic soil particles. These particles are in turn bound to larger sand and gravel particles in the matrix through sedimentation or other processes. The washing process acts to separate the soil components by particle size, removing the smaller particles and contaminants from the larger particles of the soil. This has the effect of concentrating the contaminants into a much smaller volume which can effectively be removed or further treated.
  - Gravity separation: Useful where contaminants have a particularly high or low specific gravity, such as heavy metals and metal compounds (e.g. lead, radium oxide).
  - Attrition scrubbing – strips contaminants adhering as coatings to coarser particles. Attrition washing can increase the fines in soils processed with the aim of returning the clean, coarser fraction to the site for continued use if the remediation criteria are met.

Wash water can be supplemented with several substances to help remove contaminants, such as basic leaching agents, surfactants, acids or chelating agent

Different methods (different wash fluids, soil to water ratios, solvents, surfactants and other additives) are used for different combinations. Complex combinations of contaminant types (such as a mixture of metals, non-volatile organics and semi-volatile organics) and non-uniform distribution of contaminants in the soil body can make prescription of a soil washing method difficult. In these cases, the best approach may be conduct successive rounds of treatment using different soil wash variables to target different contaminants.

The resultant contaminated water (and/or silt) must then be treated with appropriate methods, and / or appropriately disposed of.

There are four main stages in applying soil washing as a treatment technology:

- Soil preparation and screening;
- Physical separation;
- Chemical extraction; and
- Waste water treatment.

Figure 1 below provides a flow diagram of the soil washing process.

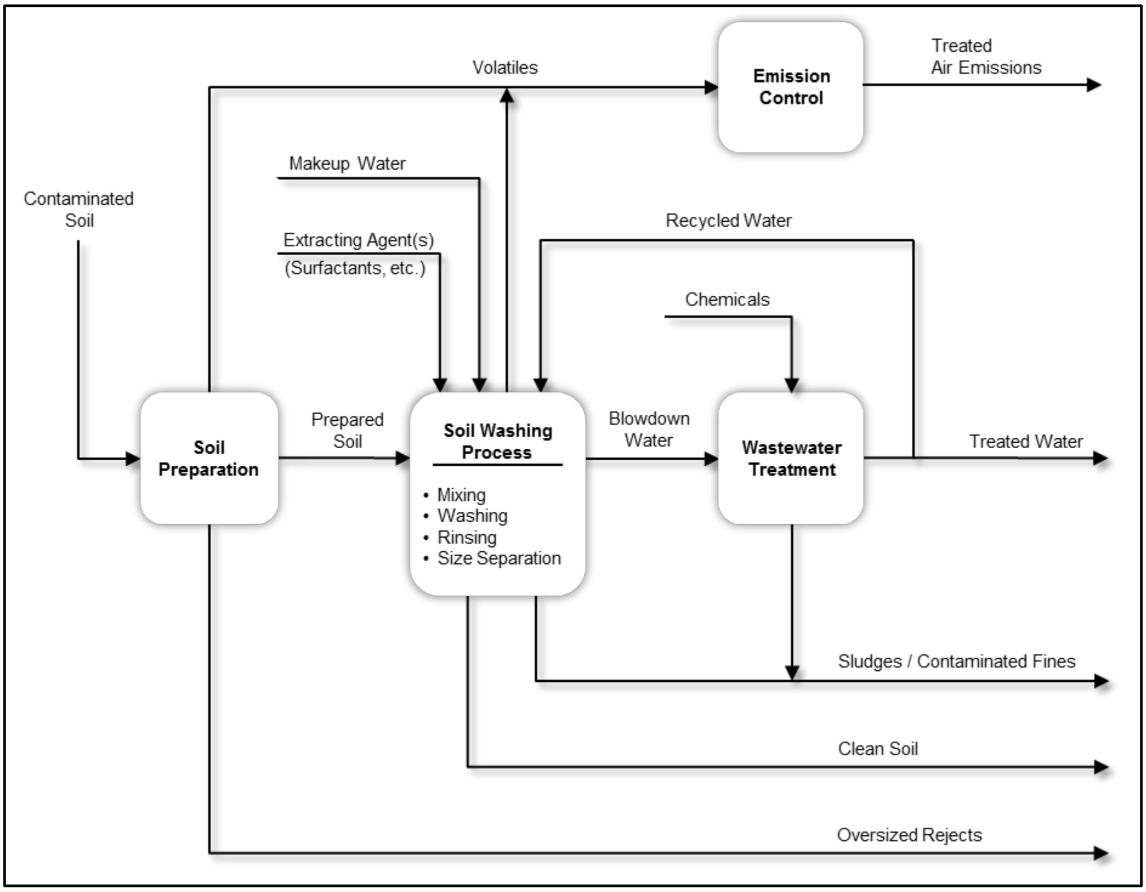


Figure 1: Soil washing process diagram

2.1.1 *Soil preparation and screening*

Soil preparation and screening comprises mechanical screening to remove oversize particles from the soil, such as rock fragments or deleterious materials. Generally, the maximum particle size of the soils to be washed is approximately 50 mm.

2.1.2 *Physical separation*

Physical separation is generally only applicable to coarse grained materials and is not effective at treating contamination that is sorbed onto finer soil particles. However, attrition scrubbing can assist with stripping the contamination from soil particles prior to treatment. There are various operating units in a physical separation system, including:

- Mechanical screening, where particles are separated based on size using either mechanical vibrating or gyratory screens;
- Hydrodynamic classification, where particles are separated utilising the settling velocity of the soil particles or centrifugal force to achieve size separation, using either hydrocyclones or centrifuges;
- Gravity concentration, where high and low density particles are separated in a in a slurry using a shaking table or dense media separation;
- Froth flotation, where the differing hydrophobic properties of the soil particles are exploited to encourage contaminants to attach to air bubbles, using flotation undertaken in cell or column;
- Magnetic separation, where particles are separated based on their magnetic properties using dry or wet separators;
- Electrostatic separation, where separation is achieved using the surface electrical conductivity of the soil particles using electrostatic or electrodynamic separators; and
- Attrition scrubbing, where a slurry with a high solid content is agitated to encourage contaminants to sorb to the surface of the soil particles, using scrubbers.

2.1.3 *Chemical extraction*

Chemical extraction uses a fluid containing a chemical reagent to transfer contaminants from the soil into the wash solution. The chemical reagent used will depend on the soil type and contaminants to be treated but could be acids, surfactants, chelating agents, salts or redox agents. Acids can improve the solubility of contaminants, especially heavy metals. Surface active agents can be added to aid dispersion of oily contaminants. Chelating agents increase the solubility of metals via complexation. Combining chemicals may improve the efficiency of contaminant removal, as may increasing the temperature and / or addition of an oxidiser to enable chemical oxidation of the contaminants.

Following washing, the soil is separated from the washing liquid and the soils are then separated into coarse and fine fractions. The coarse soil fraction is then usually washed with clean water to remove any residual contamination and fine particles that may have adhered to the fine fraction. The fine particles are then separated in a sedimentation tank and the silt is removed using a cyclone or centrifuge device.

The fine silts and clays will require further treatment while the coarse fraction can be reused, providing it meets the remediation criteria.

2.1.4 *Waste water treatment*

The final stage of the process is to treat the contaminated fine fraction and waste water generated by the soil washing process. The liquid waste may require precipitation to remove soluble substances such as metals, and the addition of flocculating agents to assist in clarification and/or filtration to remove suspended solids as a sludge or filter cake. If there is a high fraction of clay or silt, the wastewater may be difficult to dewater to a solid consistency required for disposal, and it may remain as a slurry unacceptable for landfill disposal without the application of a high energy dewatering process. Note that the requirements for mechanical dewatering (such as the addition of a flocculant aid and separation with a belt filter or filter press) can add greatly to the cost. Where the resulting wastewater requires further polishing treatment to comply with discharge criteria, such as can occur with dissolved contaminants, the treatment may involve a granular adsorbent (such as activated carbon).

Soil washing will result in the contamination being concentrated in the fine soil fraction, and this will generally require further treatment. Emission controls might be necessary if volatile organic compounds are present.

Full-scale soil washing plants can be either portable units, or a fixed soil washing facility. A portable unit can process soil on the contaminated site, saving the cost of transporting the soil to the nearest fixed plant. However, there can be large costs associated with obtaining the necessary regulatory approvals and mobilising and demobilising a portable plant, and this can make a portable plant less preferred unless large volumes of soil are required to be treated.

2.2 Integration with other remediation technology

Soil washing is rarely a stand-alone treatment technology, as the fine soils and waste water will generally require additional treatment following completion of the washing process. While the waste water is generally treated using standard industry practices, the sludge generated during the waste water treatment may require treatment by an alternative remediation technology such as solidification/stabilisation, bioremediation, chemical treatment (e.g. the base catalysed decomposition process) or thermal treatment.

3. Feasibility assessment

Key considerations that will often determine the feasibility of applying soil washing systems as a potential remediation option include:

- Whether the contaminated material has a significant percentage of coarse material that can be separated as a clean fraction suitable for reuse or lower cost disposal;
- Whether the separated fine contaminated material (slurry) can be dewatered and disposed of;
- Whether the relative volumes and costs for disposal of the resulting coarse or clean fraction and the fine or contaminated fraction makes the process economic.

Appropriate remediation data must be collected to evaluate the applicability of soil washing and the chemicals (if any) that should be added to the washing liquid. If there is reasonable confidence that soil washing will achieve the required treatment outcome, other issues will need to be considered to determine if soil washing is likely to be an appropriate solution. These include:

- Will the relevant regulatory agencies accept soil washing as a viable means of remediation?
- Can the treated material be reused? Will the concentrations of inorganics and residual organics allow the treated material to be reused as backfill on the site or as clean fill elsewhere, or will subsequent treatment (e.g. stabilisation) or landfill disposal be required?
- Is it likely that other stakeholders (such as local government or members of the public) will accept the use of the technology, particularly those stakeholders that can have a significant bearing on whether the technology is applied at the site? Are there sensitive sites nearby that would not be compatible with the proposed operation?
- Is there a time constraint, and can the application of soil washing meet this constraint?
- Is the expected order of cost of treatment acceptable?

It is noted that soil washing will result in a higher concentration of contamination. For example, if the clean fraction constitutes 75% of the original material, the fine fraction can contain contamination with an average concentration in the order of four times the original. As such the ability and cost of dispose of or treat the more concentrated waste material must be considered within the remediation options assessment. Readers are directed to the NRF *Technology guide: Bioremediation* for more information on treating the slurry.

Even in cases where most of the contamination has been removed, the contaminant concentrations in the remaining soil must comply with the remediation criteria. To be cost-effective, the cleaned fraction of the soil should typically be about 70-80% of the original volume, however, in the case where the cost of soil disposal or treatment is particularly high, a somewhat lower cleaned fraction (perhaps 50%) might be feasible. Note that the volumes and mass resulting after treatment need to be considered: it may be difficult to dewater the fine fraction and if it has a high water content (which may be as high as 50 to 80% after dewatering) the volume and mass may be relatively high.

3.1 Data requirements

Successful implementation and design of a soil washing remediation program is dependent upon the following key technical considerations:

- The physical properties of the soil to be treated.
- The chemical composition of the soil to be treated.
- The chemistry and concentrations of contaminants.

There are some key data requirements to initially assess whether soil washing may be a viable treatment option. These include:

- Particle size distribution (0.24 to 2 mm is the optimum range, and there should not be a large fraction of clay or silt);
- Soil type (coarse grained materials best suited);
- Physical form / particulate shape;
- Handling properties and moisture content;
- Contaminant type(s) and concentration(s);
- Texture;
- Organic content;
- Cation exchange capacity;
- pH; and
- Buffering capacity.

3.1.1 *Physical properties of soil*

The physical composition of the material to be treated needs to be well characterised. Important factors include:

- Soil particle size and its variability needs to be characterised: coarse material (gravel or sand) is likely to be most amenable to soil washing with the finer fraction separated during the process and likely to require additional treatment;
- Soil heterogeneity: differing grain sizes and the presence of larger lumps of material (such as masonry in fill) can affect the distribution of the wash water in the contaminated soil;
- The permeability and plasticity of the material, which can also affect the distribution of wash water in the contaminated soil; and
- Water content, which may be high if soil from below the water table (or a sediment in a surface water body) is to be treated.

3.1.2 *Chemical composition of soil*

The composition of the material to be treated needs to be well characterised. Important factors include:

- The distribution concentrations and mass of contaminants in soils at the site, and the requirement to locate and treat contamination that exceeds certain concentrations, noting that contamination may be irregular in extent and location;
- The maximum allowable concentration and variation in concentration of the contaminants in the treated soil. If very stringent remediation criteria are applicable, then several rounds of washing may be required, or a higher volume may need further treatment or removal from the site;
- Humic acids and organic material. Contaminants tend to sorb to organic particles so if the soil has a high organic content, it is likely to be less receptive to being treatable by washing;
- Maximum allowable concentrations and forms of miscellaneous material such as plastic lining systems, steel, rock or asbestos, and the requirement for exclusion of unacceptable material. Soils are generally screened prior to washing to remove oversize or deleterious material prior to treatment; and
- Salt content, such as can occur if sediments in saline water are to be washed, and whether the resulting saline waste stream can be disposed of.

3.1.3 *Waste streams*

Once the soil has been washed, there will be waste streams generated by the process that will need further treatment and/or disposal, including for example:

- Treated material (that does not meet the remediation criteria).
- Oversized material rejected during pre-screening.
- Fine fraction material containing higher concentrations of contaminants and water.
- Used PPE and associated consumables.

3.2 Treatable contaminants

Soil washing is most commonly used to treat:

- Heavy metals;
- Petroleum hydrocarbons; and
- Some volatile organic compounds.

However, it can also be effective at treating the following contaminants:

- Polychlorinated biphenyls;
- Polycyclic aromatic hydrocarbons;
- Acids;
- Pesticides and herbicides; and
- Cyanides.

3.3 Treatable matrices

Soil washing is most suitable for treatment of coarse grained or sandy soils that have a clay and silt content less than approximately 30% of the soil. Soils with a more dominant fine fraction may be able to be remediated using this method, however, it is likely that significant volumes of waste material will need to be disposed of or require further treatment after completion of the process, which can reduce cost effectiveness. Readers are directed to the NRF *Technology guide: Bioremediation* for more information on treating the slurry.

Soil washing via chemical extraction, in comparison, may not be subject to such matrix constraints, as the contaminant may be able to be leached from relatively fine material.

3.4 Regulatory requirements

Regulatory agencies, particularly those responsible for protection of the environment, town planning, and licensing treatment facilities should be consulted to determine the specific requirements relating to obtaining the necessary approvals, permits and licences, and controls that can be expected, prior to conducting the soil washing remediation program.

4. Treatability studies

If there is uncertainty as to whether soil washing will achieve the desired outcome in terms of treated soil, or there are other issues that make it uncertain as to whether soil washing will be effective, it may be necessary to conduct treatability tests to investigate the application and results of soil washing in the conditions prevailing at the site to be remediated.

Designing the treatability study may require input from several technical specialists including environmental specialists, chemical engineers, mechanical engineers and air quality specialists to ensure that the study is targeted to obtain the data required to develop an appropriate implementation strategy.

The additional information required may be able to be determined by reviewing the published literature and information on case studies on the application of soil washing.

There are generally three stages of testing that can be undertaken:

- Desktop assessment: to determine whether soil washing is a viable treatment solution for the specific site;
- Bench testing: to assess the effectiveness of soil washing for the specific site conditions and contaminant concentrations. In general, the RAP can be designed and written upon completion of this stage.
- Pilot trial: to determine specific operating parameters and performance criteria and provide sufficient information to enable completion of the RAP.

The data from each stage of treatability testing should be reviewed and interpreted jointly by the consultant and remediation contractor, with a projection being made of the results that will be achieved under full scale operation and requirements established for implementation.

4.1 Desktop assessment

Desktop assessment aims to broadly assess the applicability of soil washing to the general site conditions. In many cases, this stage may be preceded by some testing of discrete soil samples at the site assessment stage as a preliminary options screening, and as part of determining suitable materials for the treatability tests.

Soil washing feasibility is usually assessed based on a review of the data available from a previous contamination assessment where, for example, soil bore records document the ground conditions present at the site and analytical reports will detail the contaminant concentrations. The particle size distribution should be known and the constraints on disposal of the concentrated fine fraction are likely to be critical factors in determining whether soil washing will be feasible. However, where insufficient data are available to assess the potential for soil washing to work, tests can be undertaken at bench scale, using soil and wash water in jars. These preliminary tests can usually be completed within a few hours.

4.2 Bench testing

Bench testing aims to assess whether soil washing can meet the remediation objectives and its applicability to the specific waste type under the specific site conditions.

Soil washing bench testing generally comprises laboratory testing to enable a mass balance to be calculated and assess the contaminant concentrations in the washed soil. The results should allow an estimate of the quantity of soil that will be sufficiently treated that it meets the remediation criteria (i.e. the success rate for soil washing).

Likely data objectives for the second stage of treatability testing are:

- Assess what chemicals/reagents will be needed to treat the contaminants in the soil (e.g. acids or surfactants) which may impact the treatment requirements for the waste residue. Can they be treated?
- Assess contaminant concentrations in the clean soil fraction achieved following treatment (to determine whether the nominated remediation criteria can be met), and what percentage of the soil can meet the remediation criteria
- Assess contaminant concentrations in the concentrated waste soil fraction following treatment (to determine the requirements for dewatering and disposal or treatment). The variability in contaminant concentrations needs to be considered, as soil washing will result in magnified concentrations in the waste material. Will soil washing be cost effective?
- What is the likely water balance – the extent to which water can be recycled and make up is required? Will there be a build-up of soluble salts in recycled water? What is likely to be the most effective soil:wash water ratio?

Bench testing is more expensive than a desktop assessment and generally takes several weeks to plan and implement. These tests have the objective of more closely replicating the physical and chemical parameters of the site under investigation.

The information obtained in the second stage of testing is usually sufficient to enable development of the RAP.

4.3 Pilot trial

If insufficient data was obtained during bench testing to design the RAP, a third stage of treatability testing can be undertaken to obtain information necessary for the design of the soil washing remediation program, specific to the conditions of the site.

Field trials usually comprise a small-scale test of the full remediation program. A large volume of the soil to be remediated may be taken to a soil washing facility and put through the unit with various chemical mixtures to assess the soil washing efficiency under differing operating conditions.

The cost of this stage of testing is high (comparable to the full remediation program) so clear data objectives should be determined at the outset. On completion of this stage of treatability testing, it should be possible to establish the requirements for the full-scale implementation, the time scale for the completion of remedial works, and an improved estimate of the level of cost.

5. Validation

The following information describes the specific validation appropriate for soil washing, to assist validation planning within the RAP. Readers are directed to the NRF *Guideline on validation and closure*, which among other things, provides further information on each of the lines of evidence.

The primary lines of evidence for the validation of soil washing are:

- Reduction in contaminant concentration over time; and
- Analysis of geochemical and biochemical parameters

Where remediation is a moving stream, validation soil sampling may be from:

- Fixed points (with or without composite samples); or
- Homogenised treated stockpiles using statistically appropriate sampling and analysis.

Where the remediation is an active process, validation soil sampling may be from:

- Locations within and around the remediation area; and
- Locations within the reagent delivery/contaminant extraction system.

6. Health and safety

Soil washing units, like many types of industrial equipment, pose hazards to workers. If these hazards are properly evaluated and controlled, the technology can be used safely.

Some of the hazards associated with soil washing and control mechanisms are outlined in Table 1. The list is intended to provide an indication of the hazards potentially associated with soil washing application. They will vary significantly from site to site and the list is not intended as a substitute for a detailed hazard assessment of the operation, which should be provided in the RAP.

Readers are directed to the NRF *Guideline on health and safety* for further information on health and safety on remediation sites, including risk assessment, the hierarchy of controls and suggested documentation.

Table 1: Common soil washing hazards and suggested controls

Hazard	Sources of hazard	Suggested controls
Process Chemicals	• Splashing or leaking chemicals while mixing into wash water. • Responding to an emergency release of process treatment chemicals or fuel.	• Use and store smaller quantities of process chemicals. • Install eye wash and emergency shower. • Prepare and train for spill containment. • Personnel are trained in the use of the equipment and handling of chemicals • Ensure use of personal protective equipment (PPE).
Site contaminants	• Releasing volatile contaminants as soil is moved to soil washing unit. • Releasing or coming in contact with contaminants while sampling or handling.	• Work 'up-wind' of disturbed soil, when possible. • Segregate treated feedstock until tested. • Routinely monitor work areas; some contaminants require an initial assessment of exposure (e.g. lead). • Ensure use of PPE.
Storage of slurries	• Physical danger of access by personnel (quicksand)	• Security; • Signage; • Training.
Dust	• Releasing dust while excavating and transporting soil.	• Spray water or use dust suppressants on storage piles and exposed soil. • Do not operate earth moving equipment during high winds Cover untreated and treated soil stockpiles. • Ensure use of PPE.
Ergonomic risks	• Lifting or performing any other movement with too much force and/or in an awkward position or repeating the lift/movement too often.	• Provide conveniently located equipment for the job including correctly sized tools. • Train workers on ergonomic risks and prevention.

Hazard	Sources of hazard	Suggested controls
Flying particles and falling material	• Falling soil from excavator or soil washing unit.	• Designated work areas and plant movement routes • Ensure workers use proper PPE.
Noise	• Working near soil washing unit.	• Locate noisy operations away from other workers. • Identify and mark areas requiring hearing protection.
Slips, trips and falls	• Storing construction materials or other unnecessary items on walkways and in work areas. • Creating and/or using wet, muddy, sloping, or otherwise irregular walkways and work surfaces. • Constructing and/or using improper walkways, stairs, or landings or damaging these surfaces. • Creating and/or using uneven terrain in and around work areas. • Working from elevated work surfaces and ladders.	• Keep walking and working areas free of debris, tools etc. and maintain a policy of good housekeeping. • Keep walking and working areas as clean and dry as possible. • Install handrails, and guardrails on work platforms. • Clean and inspect ladders and stairs routinely. • Ensure use of PPE, including fall arrest systems. • Train workers on fall hazards and use of ladders.
Moving vehicles	• Moving and stockpiling untreated and treated soil. • Loading and unloading soil washing unit. • Receiving and transferring process chemicals and other materials from commercial vehicles.	• Train affected employees on limitations of equipment and drivers. • Train equipment and vehicle operators in safe operation. • Set acceptable speed limits and traffic patterns Ensure that equipment has, and workers use, back-up alarms, mirrors, and seat-belts. • Establish vehicle inspection schedules and procedures. • Do routine maintenance on plant, vehicles and road ways.

Appendix A – Case studies

Soil washing has been attempted several times in Australia, but projects demonstrating a successful outcome were not identified in this review. Examples include:

- The application of soil washing for the treatment of mercury contaminated soil at Botany NSW in 2012 was not found to be successful due to low productivity, even after a bulk treatability study;
- A full-scale soil washing plant was mobilised at Cabarita NSW to treat lead contaminated soil from paint coatings in the mid-1990s, but this was not successful. It is not known if a treatability study was undertaken;
- Soil washing was trialled for application to Homebush Bay sediments in NSW, but this was not successful; and
- Soil washing was tested for treating PAH contaminated sediments from the Swan River in WA, but this was not pursued because of the difficulty of dewatering and disposing of the resulting waste slurry.

Soil washing has also been undertaken overseas. Examples include:

- Avenue Coking Works field trial: http://www.claire.co.uk/index.php?option=com_phocadownload&view=file&id=9:case-study-bulletins&Itemid=230 ;
- King of Prussia Technical Corporation Superfund site cost performance trial: http://costperformance.org/profile.cfm?ID=125&CaseID=125
- 37 case studies for the application of soil washing to treat metal contaminated soils in Europe, the USA and Canada are summarised and fully referenced in Table 1 of DERMONT, BERGERON, MERCIER & RICHER-LAFLECHE (2008);
- Remediation of Basford Gasworks using Soil Washing: http://www.claire.co.uk/index.php?option=com_virtuemart&view=productdetails&virtuemart_product_id=18&virtuemart_category_id=6&Itemid=124
- London Olympic Park: http://www.icevirtuallibrary.com/content/article/10.1680/geng.11.00109

Appendix B – References

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