Government of **Western Australia**
Department of **Environment Regulation**

GUIDELINE

Assessment and management of contaminated sites

Contaminated sites guidelines

December 2014

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Accessibility
This document is available in alternative formats and languages upon request.

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1 Purpose

The purpose of this document is to provide guidance on the assessment and management of contaminated sites in Western Australia (WA) within the legislative framework provided by: the *Contaminated Sites Act 2003* (CS Act) and the *Contaminated Sites Regulations 2006* (CS Regulations); and the revised national site assessment framework provided in the *National Environment Protection (Assessment of Site Contamination) Measure 1999* (NEPM).

This document includes guidance on:
• the assessment and management of contaminated sites; • the assessment of risks to human health, the environment and environmental values; • generic assessment levels specific to WA and their application; • application of the NEPM assessment levels in WA; and • information that should be included when reporting on the various stages of contaminated site assessment and management.

This guideline has been prepared to assist environmental practitioners, including environmental consultants and auditors, when planning and implementing the assessment and management of contaminated sites and when preparing reports to be submitted to the WA Department of Environment Regulation (DER) and accredited contaminated site auditors under the CS Act and the CS Regulations. It may also be useful for other purposes such as due diligence assessments. However, it may also be necessary to discuss site-specific circumstances with DER, refer directly to the CS Act and CS Regulations and/or seek specific legal advice.

2 Introduction

DER has prepared this guideline to help landowners, industry, consultants and auditors and other interested parties understand the requirements for investigating/assessing, remediating/managing contaminated sites in WA.

In WA, contaminated sites are regulated by DER through the CS Act and CS Regulations (available from the WA State Law Publisher at www.slp.wa.gov.au). DER works in consultation with the Department of Health in relation to public health issues at contaminated sites.

The NEPM provides guidance on the assessment of site contamination and is available at www.scew.gov.au/nepms/assessment-site-contamination. When referring to the NEPM, practitioners should also consult this website for *errata* and additional information provided in the NEPM toolbox. The *National Environment Protection Council Act 1994* limits the scope of the NEPM to site assessment and therefore it does not include guidance on remediation of contaminated sites.

DER provides additional guidance specific to WA within the Contaminated Sites Guidelines (CSG), which includes this guideline available at www.der.wa.gov.au/contaminatedsites.

Practitioners are expected to refer to the NEPM and DER guidelines when conducting site assessments. It is essential that practitioners keep up to date with current versions of guidance documents referred to herein and published *errata*.

This guideline forms part of DER's Contaminated Sites Guidelines, which provide updated guidance and replace the guidelines within the Contaminated Sites Management Series, as shown below. The guidelines were updated to reflect:

- the commencement of the CS Act and CS Regulations (some guidance was published before commencement);
- amendment of the NEPM in May 2013; and
- process improvements developed during the statutory five-year review of the CS Act.

Contaminated Sites Guidelines	Contaminated Sites Management Series (superceded)
Assessment and management of contaminated sites (2014)	*Development of sampling and analysis plans* (2001) *Community consultation* (2006) *Potentially contaminating activities, industries and land uses* (2004) *Assessment levels for soil, sediment and water* (2010) *Bioremediation of hydrocarbon contaminated soils in Western Australia* (2004) *The use of risk assessment in contaminated site assessment* (2006) *Reporting on site assessments* (2001)
Identification, reporting and classification of contaminated sites (2014)	*Reporting of known and suspected contaminated sites* (2006) *Site classification scheme* (2006) *Certificate of contamination audit scheme* (2000)
Use of monitored natural attenuation for groundwater remediation (2014)	*Use of monitored natural attenuation for groundwater remediation* (2004)
Contaminated sites auditors—accreditation, conduct and reporting (2014)	*Contaminated sites auditors—guidelines for accreditation, conduct and reporting* (2009)
Assessment, Remediation and Management of Asbestos-Contaminated Sites in Western Australia (joint publication with DoH) (2009)	*Assessment, remediation and management of asbestos-contaminated sites in Western Australia (joint publication with DoH)* (2009)
Contaminated sites and the land use planning process (proposed revision)	*Contaminated sites and the land use planning process* (2006)

3 Health safety and emergency response

3.1 Occupational health and safety

The assessment and management of site contamination can present risks to site personnel, the public and the environment.

Detailed guidance on occupational health and safety aspects of working on contaminated sites is outside the scope of this guideline. Brief discussion is included here to guide appropriate consideration of these issues in planning work on known or suspected contaminated sites. Site management strategies for the general protection of human health and the environment during site assessment and remediation are discussed in section 13.1.

Information on worker safety
Guidance Note—Occupational Safety and Health Management and Contaminated Sites Work (Commission For Occupational Safety and Health, 2005) www.safeworkaustralia.gov.au/sites/swa/about/who-we-work-with/regulators/wa-regulators/pages/wa-regulators

Occupational health and safety issues should be considered for all sites and managed according to national and state legislative requirements. The *Occupational Safety and Health Act 1984* and *Occupational Health and Safety Regulations 1996* (WA) provide the requirements for ensuring the health, safety and welfare of people in the workplace.

Prior to visiting a site, whether it is to conduct a non-intrusive site inspection, comprehensive sampling program or remedial work, a Health, Safety and Environment Plan (HSEP) should be prepared to address the anticipated site conditions including the potential contaminants and contaminated media. The HSEP is used to identify and implement appropriate measures to protect health, safety and the environment. Depending on the site-specific circumstances, site workers may require additional training prior to undertaking site work and/or participation in a health monitoring program. The contents of an HSEP should be adequately communicated to all site personnel prior to commencing work at the site, and documentation kept of all training, inductions and meetings.

DER is not responsible for assessing HSEP documentation and it is not necessary to include a copy of the HSEP and associated documentation in reports submitted to DER.

3.2 Pollution incidents and emergency response

Guidance on the appropriate response for the management of acute health risks, emergencies and pollution incidents such as from explosion, asphyxiation, bushfires, floods or recent spills is not within the scope of this document. These issues should be addressed immediately in consultation with the relevant authorities such as the Department of Fire and Emergency Services and DER (visit www.der.wa.gov.au/your-environment/reporting-pollution).

Pollution incidents with the potential to cause contamination, such as spills and leaks, should be cleaned up as soon as possible after the original incident or as directed by the relevant authorities. If a spill or pollution incident is not resolved through immediate clean-up response, the site may need to be reported to DER as a known or suspected contaminated site.

Refer to *Identification*, *reporting and classification of contaminated sites* (DER, 2014a) for guidance on reporting obligations, including statutory time frames.

4 Environmental practitioners

4.1 Environmental consultants

The assessment and remediation of contamination is a specialised field that requires knowledge and expertise in a variety of scientific disciplines. DER recommends that only suitably qualified and experienced consultants are engaged to carry out this type of work. Schedule B9 of the NEPM provides guidance on the necessary competencies and experience required by practitioners (environmental consultants and auditors) involved in contaminated site assessment.

Guidance on selecting and appointing an environmental consultant is provided in DER contaminated sites fact sheet 3—*Seeking help from contaminated sites experts*, available at www.der.wa.gov.au/contaminatedsites.

DER does not accredit or register environmental consultants to work in WA. At the time of publication, a national certification scheme for environmental consultants was in development. Further information is available from www.crccare.com/products-and-services/certification-scheme.

Asbestos

The WA Department of Health (DoH) considers that environmental consultants employed to investigate, remediate and manage asbestos contamination should be supervised by a lead consultant with appropriate asbestos qualifications and experience. The lead consultant should normally have a minimum of three years' continuous experience with asbestos soil contamination and relevant tertiary qualifications in environmental science, science or engineering. For more information, including lead consultant requirements, refer to *Guidelines for the Assessment, Remediation and Management of Asbestos-Contaminated Sites in Western Australia* (DoH 2009).

4.2 Accredited contaminated site auditors

4.2.1 Mandatory audits

Contaminated sites auditors are expert contaminated land professionals that have been accredited by DER under the CS Act to conduct audits in WA. Auditors provide an independent review of the investigations, assessments, monitoring and remedial works undertaken by environmental consultants. The auditor's findings are documented in an audit report.

Detailed guidance on the accreditation, conduct and reporting of auditors in Western Australia is provided in *Contaminated sites auditors—guideline for accreditation, conduct and reporting* (DER, 2014b).

Regulation 31 of the CS Regulations and s 44 of the CS Act, set out when a mandatory auditor's report (MAR) is required to accompany reports submitted to DER. Reports may be submitted in stages (e.g. at a particular milestone in the investigation or remediation of a site) or at the end of the process to 'close out' the site (e.g. after successful remediation of site in response to a planning condition).

CS Regulations r 31 when mandatory auditor's reports are required

(1) A mandatory auditor's report is to be provided to the CEO –

(a) in accordance with regulation 29(2)(d), when a request for a certificate of contamination audit is made in respect of land; or

(b) with every report provided to the CEO containing information as to, or which will be relevant to, the investigation, assessment, monitoring or remediation of a source site; or

(c) with every report containing information as to, or which will be relevant to, the investigation, assessment, monitoring or remediation of a site provided to the CEO for the purposes of—

(i) complying, or attempting to comply, with another written law; or

(ii) a requirement or condition (by whatever name called) imposed under another written law[1];

or taking a necessary step towards doing so; or

(d) at the written request of the CEO, in respect of a site –

(i) which, in the opinion of the CEO, presents particularly complex technical issues; or

(ii) in respect of which, in the opinion of the CEO, inadequate information or reports have been provided; or

(iii) in respect of which, in the opinion of the CEO, a mandatory auditor's report is required to enable the site to be properly dealt with for the purposes of the Act.

CS Act s 44 Auditor's report in relation to notice

A notice is to require a person on whom the notice is binding to engage an auditor to report on the actions taken to comply with the requirements of the notice.

[1] e.g. a planning or Ministerial condition or similar statutory requirement

DER does not have the power to waive a requirement to provide a MAR if one is prescribed under regulation 31.

4.2.2 Voluntary audits

An auditor can be commissioned to undertake a voluntary audit and prepare a voluntary auditor's report (VAR). A person may wish to consider obtaining a VAR when:

- planning (or similar) conditions are anticipated in the future; and/or
- for a greater level of confidence in the adequacy of the contamination assessment and/or remediation.

DER recommends that the general format and content of a VAR follows that of a MAR, however, the statutory forms and notification requirements for a MAR do not apply.

5 Key terms

5.1 Definitions relating to 'site'

5.1.1 Site

Section 3 of the CS Act provides the following definition of a site:

CS Act s 3—definition of "site"
"site" means an area of land and includes – (a) underground water under that land; and (b) surface water on that land

A site must be identified by the boundaries identified under the relevant certificate(s) of title. This enables DER to use the state land administration system to identify and record known and suspected contaminated sites on the Contaminated Sites Register and for lodging memorials under the CS Act.

In some circumstances it may be desirable to distinguish between the contaminated and uncontaminated parts of a land parcel so that the site classification and any memorial can be applied to the relevant portion of the site. This can be achieved through the registration of an ***interest only deposited plan*** with Landgate (refer to DER 2014a).

5.1.2 Source and affected sites

A site may comprise several land parcels or a single land parcel where the contaminating activities occurred. The CS Act differentiates between sites where contamination has originated, and sites that have become contaminated due to the movement or migration of contamination from another site, i.e. the off-site movement of contaminated groundwater, surface water or soil. Section 3 of the CS Act defines these types of sites as source sites and affected sites.

CS Act s 3—definition of "source site" and "affected site"
"source site" means a site – (a) on which contamination; or (b) on which a substance has originated and from which it has migrated to another site (the "**affected site**") causing, or contributing to, contamination on that other site. **"affected site"** means a site on which contamination is caused, or contributed to – (a) by contamination; or (b) by a substance, which has migrated to that site from another site (the **"source site"**).

5.2 Definitions relating to 'contaminated'

5.2.1 Contaminated

Section 4(1) of the CS Act provides the following definition of 'contaminated':

CS Act s 4(1)—definition of "contaminated"
"contaminated", in relation to land, water or a site, means having a substance present in or on that land, water or site at above background concentrations that presents, or has the potential to present, a risk of harm to human health, the environment or any environmental value.

Contamination can be present in the soil, groundwater or surface water of a site. It may be present in the solid, liquid or gaseous phases (e.g. soil or groundwater contamination giving rise to contaminant vapours in soil pore spaces). Where substances are present at above background concentrations, further assessment of those substances is required to assess the risk of harm to human health, the environment and environmental values.

Section 4(2) of the CS Act provides for exemptions from the definition of contaminated, which are prescribed in regulation 5 of the CS Regulations. Further information is provided in DER (2014a).

5.2.2 Substances that can present a risk of harm

The term 'substance' is used in the definition of contaminated in the CS Act. DER may also refer to a substance as a contaminant or potential contaminant. A range of substances may be considered contaminants when present at above background concentrations. A contaminant may be:

- inorganic (e.g. metals, asbestos fibres) or organic (e.g. petroleum hydrocarbons);
- man-made (anthropogenic) (e.g. pesticides and herbicides);
- radioactive (e.g. uranium, thorium, radon); or
- microbiological (e.g. pathogens).

A contaminant can be present in soil, groundwater or surface water of a site. It may be present as a solid, liquid, vapour or gas (e.g. contaminant vapours in soil pore spaces or ambient air).

The potential for a contaminant to cause harm is dependent on its toxicity, its concentration and the extent over which it occurs. For example, metals such as cadmium and mercury have a higher toxicity and may pose a risk at much lower concentrations (and over smaller areas) than less toxic metals such as iron and aluminium. In addition, the presence of more than one contaminant may have an additive or synergistic toxic effect.

5.2.3 Disturbance of naturally occurring substances

Some naturally occurring substances can present a risk of harm when they are disturbed, which may result in a site being considered contaminated. Examples include naturally occurring acid sulfate soils (ASS), radioactive minerals, asbestos and metals and metalloids in mineralised areas.

Naturally occurring substances that are disturbed and result in site contamination require risk-based assessment and management to protect human health and the environment in the same way as other sources of contamination. Refer to DER (2014c) for guidance on reporting known or suspected contamination in accordance with the CS Act and contact DER for advice in relation to specific site conditions www.der.wa.gov.au/your-environment/contaminated-sites.

5.2.4 Background concentrations

The meaning of 'background concentration' is not defined in the CS Act or Regulations. The NEPM, however, defines background concentrations as meaning:

NEPM—definition of "background concentrations"
means the naturally occurring, ambient concentrations of a substance in the local area of a site.

Ambient background concentration (ABC) is discussed in section 2.5.7 of Schedule B1 of the NEPM. The ABC of a contaminant is the soil concentration in a specified locality that is the sum of the naturally occurring background level and the contaminant levels that have been introduced from diffuse (non-point) sources by general anthropogenic activity not attributed to industrial, commercial, or agricultural activities—for example, motor vehicle emissions.

Methods for determining background concentration in soil are discussed in section 11.3.4 of this document. Background groundwater quality is discussed in section 3.3 of Schedule B6 of the NEPM.

The determination of whether a substance has the potential to pose a risk of harm is generally carried out by comparison of the concentration of a substance on a site with generic assessment levels and in the context of background concentrations. Further information is provided in sections 10 and 11 of this document.

5.2.5 Risk and risk of harm

The meaning of 'risk' is not defined in the CS Act or Regulations. Risk is defined in the NEPM as:

NEPM—definition of "risk"
means the probability in a certain time frame that 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 chemical substance, that is, it depends on both the level of toxicity of the chemical substance and the level of exposure*.

** The original definition of risk referred to 'hazardous agents' rather than 'chemical substance'. The change to 'chemical substance' was made in the May 2013 amendment to the NEPM to clarify the meaning of the term.*

5.2.6 Environmental values

Section 3(2) of the CS Act provides for the use of definitions in the EP Act to apply to the CS Act, unless otherwise stated. The term 'environmental value' is included in the definition of contaminated in the CS Act and is defined in the EP Act as:

EP Act s 3—definitions relevant to "environmental value"

environmental value means—

(a) a beneficial use; or

(b) an ecosystem health condition;

beneficial use means a use of the environment, or of any portion thereof, which is—

(a) conducive to public benefit, public amenity, public safety, public health or aesthetic enjoyment and which requires protection from the effects of emissions or of activities referred to in paragraph (a) or (b) of the definition of **environmental harm** in section 3A(2); or

(b) identified and declared under section 35(2) to be a beneficial use to be protected under an approved policy.

ecosystem health condition means a condition of the ecosystem which is—

(a) relevant to the maintenance of ecological structure, ecological function or ecological process and which requires protection from the effects of emissions or of activities referred to in paragraph (a) or (b) of the definition of **environmental harm** in section 3A(2); or

(b) identified and declared under section 35(2) to be an ecosystem health condition to be protected under an approved policy

EP Act s 3A—definition of "environmental harm"

(2) In this Act —

environmental harm means direct or indirect —

(a) harm to the environment involving removal or destruction of, or damage to —

(i) native vegetation; or

(ii) the habitat of native vegetation or indigenous aquatic or terrestrial animals;

or

(b) alteration of the environment to its detriment or degradation or potential detriment or degradation; or

(c) alteration of the environment to the detriment or potential detriment of an environmental value; or

(d) alteration of the environment of a prescribed kind;

Environmental values may relate to land or water. Within the NEPM, environmental values of land are referred to in land use categories, such as urban residential/public open space, commercial/industrial and areas of ecological significance. The NEPM defines an area of ecological significance as one where the planning provisions or land use designation is for the primary intention of conserving and protecting the natural environment (s 2.5.3 Schedule B1).

Schedule B6 of the NEPM defines environmental values, in relation to groundwater, as values or uses of the environment that are conducive to public benefit, welfare, safety or health that require protection from the effects of pollution, waste discharge and deposits and include uses of water—drinking water, recreational use, agricultural use such as stock or irrigation and aquatic ecosystems.

Consistent with the NEPM, environmental values of water relevant to the assessment of site contamination in WA include:

- groundwater dependent ecosystems;
- aquatic ecosystems (fresh, marine and estuarine waters);
- drinking water (e.g. direct consumption but also applicable to bathing, filling swimming pools, food preparation or cooking);
- non-potable use of water (e.g. irrigation of gardens or parks and reserves, washing cars and clothes, flushing toilets);
- recreational use (e.g. water sports, swimming);
- agricultural use (e.g. stock water and commercial irrigation); and/or
- industrial use (e.g. process water).

The current and potential[1] uses of water should be taken into account when considering whether a particular environmental value of water is relevant to a site. Detailed guidance on the environmental values of groundwater and surface water and application of Tier 1 assessment levels is provided in section 11.7, and Tier 1 assessment levels for water are provided in Appendix D.

5.3 Definition of remediation

The CS Act provides the following definition of remediation:

[1] (realistic future uses)

CS Act s 3—definition of "remediation"

"remediation" in respect of a site that is contaminated includes—

(a) the attempted restoration of the site to the state it was before the contamination occurred;

(b) the restriction, or prohibition, of access to, or use of, the site;

(c) the removal, destruction, reduction, containment or dispersal of the substance, causing the contamination, or the reduction or mitigation of the effect of the substance;

(d) the protection of human health, the environment or any environmental value from the contamination.

Although the CS Act definition of remediation includes measures to manage contamination such as by restricting access or use of the site, the term 'remediation' is commonly used in the literature to refer to active clean-up measures such as treating, removing or engineered means of containing contamination. The terms 'remediation' and 'management' are also used interchangeably in the literature.

In this document, the term 'clean-up' is used when specifically referring to active and passive (e.g. monitored natural attenuation) forms of remediation and 'remediation' when the broader definition (under s 3 of the CS Act) is intended.

The clean-up and management of contaminated sites are discussed in sections 12 and 13 of this document.

6 Overview of site assessment and management

6.1 Triggers for site assessment

The purpose of site assessment is to determine whether substances are present at above background concentrations that present, or have the potential to present a risk of harm to human health, the environment or any environmental values.

The assessment of site contamination may be required under the CS Act or the *Planning and Development Act 2005.* It may also be carried out voluntarily.

Triggers for site assessment and/or clean-up

Regulatory triggers

- Classification under the CS Act. Action is required to assess contamination at sites classified as *possibly contaminated—investigation required* and to remediate or manage contamination at sites classified as *contaminated—remediation required*. In some circumstances, action may be required for sites classified *contaminated—restricted use* and *remediated for restricted use*.
- Regulatory notice (investigation, clean-up or hazard abatement notice).

Planning and development conditions

- Action is required to assess potential contamination at sites where a condition has been applied by a planning authority for approval of rezoning, subdivision or development to ensure that the site is suitable for the proposed land use.
- Ministerial conditions applied under Part IV of the EP Act.

Other triggers

- Action may be taken voluntarily by site owners, occupiers or other interested persons as part of a due diligence process, e.g. establishing the contamination status of land prior to purchase or lease, or for insurance or financial purposes.

6.2 Prescribed premises under the EP Act

Certain industrial premises with the potential to cause emissions and discharges to air, land or water are regulated under Part V of the EP Act. The prescribed premises categories are listed in Schedule 1 of the *Environmental Protection Regulations 1987* (EP Regulations).

Under s 52 of the EP Act, an occupier who changes a premises to become, or to become capable of being, a prescribed premises, commits an offence unless it is done in accordance with a works approval. Under s 56 of the EP Act, occupiers of prescribed premises are to be licensed for emissions. A works approval and licence may include conditions in accordance with s 62A of the EP Act; for example, a requirement to carry out regular groundwater sampling and analysis to monitor the effectiveness of management measures used to prevent emissions and discharges to the environment.

A Ministerial Statement under Part IV or a licence under Part V of the EP Act may permit the proponent/licensee to emit or discharge substances up to a specified limit.

However, a licence does not permit a premises or licensee to cause contamination, and does not negate reporting requirements or other statutory obligations arising under the CS Act. If emissions or discharges at a prescribed premises cause contamination, the site should be reported to DER as a known or suspected contaminated site under the CS Act (refer to DER 2014a). Contamination issues at the site will be regulated under the CS Act, while all other matters will continue to be regulated under the EP Act.

Information obtained for the purpose of licence compliance, such as groundwater monitoring results, should be provided to DER Contaminated Sites if it is relevant to the contamination status of the site (refer s 6.5 on submitting reports).

In addition to the data collected to comply with licence conditions, further monitoring and investigation may need to be undertaken in order to delineate and characterise contamination and assess the risk to potential receptors.

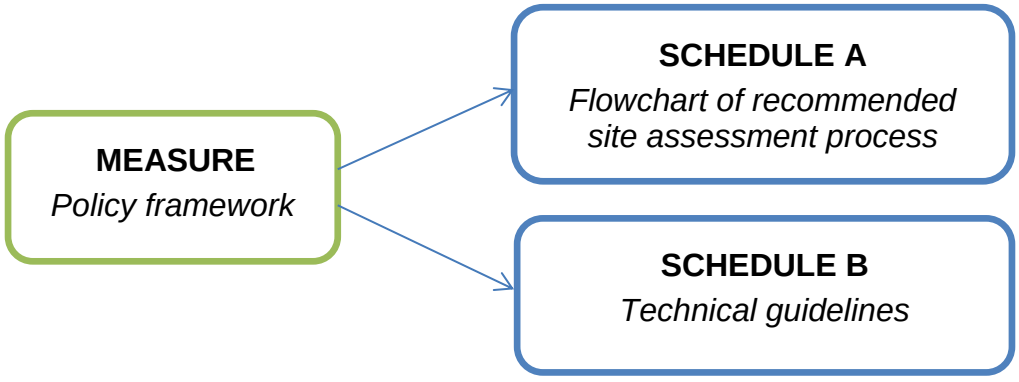
Further information on prescribed premises including DER contact details can be found at www.der.wa.gov.au/our-work/licences-and-works-approvals

6.3 NEPM framework for site assessment

The NEPM provides a national framework for the assessment of site contamination and recommends that the investigation of contaminated sites is carried out in stages. The staged approach allows information obtained during each stage to be used to inform and update the conceptual site model (CSM) and plan the subsequent scope of work. The staged approach forms the basis for a risk-based approach to the assessment and management of contaminated sites. It allows resources to be focused on the most critical issues associated with a site in a prioritised and defensible manner to address unacceptable risks. Risk assessment may be carried out at more than one stage of the site assessment and management process.

The NEPM comprises a policy framework supported by two schedules as shown in Figure 1 below:

Figure 1: Structure of the NEPM



Schedule B of the NEPM is comprised of general guidelines for the assessment of site contamination, which are listed below. Supporting information to the NEPM is provided at www.scew.gov.au/nepms/assessment-site-contamination and includes frequently asked questions (FAQs), *errata* and the NEPM Toolbox. This supporting material is periodically updated.

Guidelines that form Schedule B of the NEPM
Schedule B1 Guideline on investigation levels for soil and groundwater
Schedule B2 Guideline on site characterisation
Schedule B3 Guideline on laboratory analysis of potentially contaminated soils
Schedule B4 Guideline on site-specific health risk assessment methodology
Schedule B5a Guideline on ecological risk assessment
Schedule B5b Guideline on methodology to derive ecological investigation levels in contaminated soils
Schedule B5c Guideline on ecological investigation levels for arsenic, chromium (III), copper, DDT, lead, naphthalene, nickel and zinc
Schedule B6 Guideline on the framework for risk-based assessment of groundwater contamination
Schedule B7 Guideline on derivation of health-based investigation levels
Schedule B8 Guideline on community engagement and risk communication
Schedule B9 Guideline on competencies and acceptance of environmental auditors and related professionals

Although the NEPM does not provide guidance on the clean-up or management of contaminated sites, it does provide a preferred hierarchy of options for site clean-up and/or management in Principle 16 of the Assessment of Site Contamination Policy Framework, which is discussed in section 12.4 of this document.

6.4 Reporting framework

Reporting of site contamination works is generally undertaken according to the framework below. Appendix A provides a checklist of information that should be considered when planning, implementing and reporting on site assessment, clean-up and management. The checklist is not exhaustive as location, physical characteristics, contaminants and potential risks need to be considered on a site-specific basis. Therefore, there may be additional site-specific factors that require consideration in developing the scope of work and subsequent reporting. Guidance provided in the NEPM should also be consulted when determining the issues relevant to a particular site.

Site contamination reporting framework
Preliminary site investigation (PSI) consists of a desktop study, a detailed site inspection and interviews with relevant personnel. A PSI may also include limited sampling and analysis. The information is used to develop an initial CSM. If contamination or sources of contamination (potential areas of concern) are identified, further detailed site investigation is necessary. **Detailed site investigation (DSI)** assesses potential or actual contamination through an appropriate sampling and analysis program. Several phases of investigation (including risk assessment) may be required to adequately characterise the site, particularly for complex sites. The CSM is refined on an iterative basis until there is sufficient information and understanding of the site to devise risk-based strategies to manage the identified risks. **Remedial action plan (RAP)** documents the type and extent of remediation required to ensure that the site is suitable for its current or intended future use, and to protect the surrounding environment and land uses. The plan details the clean-up techniques proposed to achieve the remedial objectives and criteria for assessing the effectiveness of the clean-up in the site validation process. **Site remediation and validation (SRV)** is the process of cleaning up the site (remediation) and evaluating the effectiveness of the clean-up (validation). Where the remedial objectives are not met, further work may be required such as further remediation, risk assessment or ongoing site management. **Site management plan (SMP)** documents ongoing management of the site if this is required, such as long term monitoring and assessment of residual contamination. The SMP may require periodic revision and updating to ensure it remains relevant over time. A relevant stakeholder, such as the land owner or body corporate, must assume responsibility for maintaining and implementing the SMP.

Monitoring of a site, such as groundwater, surface water or vapour monitoring, over a period of time is often a necessary part of contamination assessment and management. For example, it may be carried out to assess trends in contaminant behaviour or confirm the successful remediation or containment of contamination. In order to obtain representative data, monitoring events should be carried out in a consistent and comparable manner that considers issues that may affect the interpretation of longer term trends, such as diurnal, seasonal or climatic effects. Monitoring may be carried out as part of a detailed site investigation, site remediation and validation program, or ongoing site management.

6.5 Report presentation

6.5.1 General report requirements

This section provides guidance on DER's general requirements for the presentation of information when reporting on site contamination. Section 14 and Appendix D of Schedule B2 of the NEPM provide further guidance on report presentation, including data presentation.

Hard copy reports should be printed on A4 size paper, with a durable cover and ring binding (or similar), and dividers to facilitate cross-referencing between different sections or appendices of the report. The report title should identify the site, the type of report (e.g. PSI, DSI, RAP) and the month and year the work was carried out. It is preferable that the title includes the legal lot number, street name and locality as a minimum and remains consistent if multiple reports are produced for one site. Pages should be numbered and information presented in a logical sequence with appropriate subject headings to guide the reader through the document.

Diagrams and tabulated data should be clearly legible in both printed and electronic formats. As a guide, text should be at least font size 11 in the main text, tables and figures when printed. This requirement applies to both tabulated data in the main body of the report and the appendices, including laboratory data.

6.5.2 Graphics and data presentation

Site contamination reports should present and discuss all of the available information to accurately illustrate the nature of the site and surrounding land and describe the work carried out.

Site plans (including geological and aquifer cross-sections) are a valuable tool for depicting complex information obtained during site assessment and remediation. It is essential that any graphics (such as site plans, cross-sections and CSM), site photographs and aerial photographs are provided at an appropriate scale, colour and quality to clearly display the relevant information. Site photographs should be accompanied by a location and aspect plan and aerial photographs should clearly identify the site boundaries.

It may be useful to use an aerial photograph as the basis for a site plan, if it was taken at a time that is relevant to the information being presented, and to overlay other features and labels. Graphics should use colour and shading to highlight different features such as current and former infrastructure, sample types, results and exceedences of assessment criteria. Graphics should be presented on A4, or A3 paper that folds out. Where the scale or complexity of the project warrants drawings larger than A3, these should be securely attached to the report, for example within a clear plastic pocket.

Reports should include tables and site plans presenting field and laboratory results and be supported by clear and concise descriptive text. Where more than one land parcel is involved, the identity/location of land parcels should be included in the tabulations and site plans.

It is important to differentiate between raw data and interpreted or inferred information. Site plans depicting contours interpreted from groundwater elevations or contaminant concentrations should ensure contour intervals are labelled and appropriate for the quantity and quality of data available. Copies of laboratory analytical reports and chain of custody forms should be included as received from the laboratory, generally as an appendix.

6.5.3 Data interpretation

The analytical results should be tabulated and a summary provided to indicate areas (land parcels) that have previously been assessed or remediated and to facilitate the assessment of temporal trends. Apparent trends in groundwater conditions should be discussed, such as differences in groundwater flow direction, or reducing or increasing contaminant concentrations between monitoring events.

Statistical analysis may be necessary to determine whether trends are significant. A decrease in the concentration of a contaminant between two consecutive groundwater monitoring events (in isolation) should not be referred to as a reducing trend as there is insufficient information to support this statement. The application, data limitations and outcomes of statistical analysis should be discussed in the report and the raw data, formulae and calculations provided in an appendix.

Schedule B2 of the NEPM (section 8.3.4) provides general discussion of the attenuation of groundwater contaminants. Detailed guidance on assessing trends from groundwater monitoring data and attenuation of groundwater contamination is provided in DER (2014c).

6.5.4 Conclusions and recommendations

The report should provide a clear and concise summary of the assessment/work carried out, conclusions drawn from the assessment/work carried out and recommendations as to whether further assessment or remediation is considered necessary (refer to Appendix A).

6.6 Report submission

Practitioners are expected to provide sufficient information to demonstrate that the site assessment and remediation has been carried out in accordance with DER guidelines and the NEPM. Documentation of the rationale for decision-making is essential and all relevant supporting information should be provided in the report(s) (refer to the report checklist in Appendix A).

Reports should preferably be submitted to DER and/or the auditor for assessment at the completion of each stage as it can be advantageous for site investigation and remediation objectives to be developed in consultation with the auditor and DER prior to the commencement of the next stage of work. This staged submission can reduce delays in the final assessment and clearance of sites. It also allows DER to periodically update the site classification, which ensures that accurate and timely information is available to relevant decision-making bodies and other stakeholders including the public.

In prescribed circumstances, reports submitted to DER must be accompanied by a mandatory auditor's report (MAR) as discussed in section 4.2 of this document. Refer DER (2014b) for further information on submitting a MAR.

In general, DER requires **one** full colour hard copy of each report including appendices plus one electronic copy. However, DER requires **two** copies of reports, including a MAR or VAR, which contain information on the assessment, remediation and/or management of human health-related issues such as asbestos, air quality, human health risk assessment, community health concerns or potential human health exposure as these will be referred to DoH for review.

Reports are to be submitted to DER addressed to the Senior Manager, Contaminated Sites.

DER may return reports without assessment if they are considered to be inconsistent with this guideline in either content or format, or if they contain graphics or data that have significant errors, or are illegible due to poor quality printing or inappropriate font size.

7 Conceptual site model

7.1 Overview

A critical element of any site assessment is the development of a conceptual site model (CSM). The CSM describes the environmental setting, identifies contaminant sources (potential areas of concern and associated contaminants), modes of contaminant movement (migration pathways), the person/ecosystem components/environmental values potentially affected by the contamination (potential receptors) and how exposure may occur (exposure routes).

The development of the CSM is an iterative process, whereby the initial CSM is developed in the first stage of site assessment and revised as more detailed information on the site and the nature of contamination becomes available. The CSM is used to identify risks to human health, the environment and environmental values, as well as uncertainties or critical gaps in information that need to be addressed in subsequent stages.

For exposure to occur, a complete pathway must exist between the source of contamination and the receptor (i.e. complete source-pathway-receptor linkage). Where the exposure pathway is incomplete, exposure cannot occur and hence no risk is present via that pathway under the existing site-specific circumstances. However, the potential for new exposure pathways to be created or completed, for example by a proposed change of land use, should be considered in the CSM.

An exposure pathway typically consists of the following elements:

- a source of contamination (e.g. a spill or leak);
- a release mechanism (e.g. migration in soil, leaching to water, emission to air);
- retention in the transport medium (e.g. soil, groundwater, surface water, air);
- an exposure point (e.g. where a person comes into contact with contaminated dust or soil or contaminated groundwater from a bore, or in a building overlying volatile contamination); and
- an exposure route (e.g. inhalation, ingestion, absorption through the skin).

The presence of contamination may give rise to a number of issues that require consideration. For example, soil contamination may pose a risk to human health through direct ingestion of soil particles or, if volatile, through volatilisation and entry into buildings as vapours. If the contamination is leachable, it may pose a risk through migration via groundwater and exposure where the groundwater is used for drinking or garden irrigation or supports a groundwater dependent ecosystem.

The CSM should include discussion of the following elements:

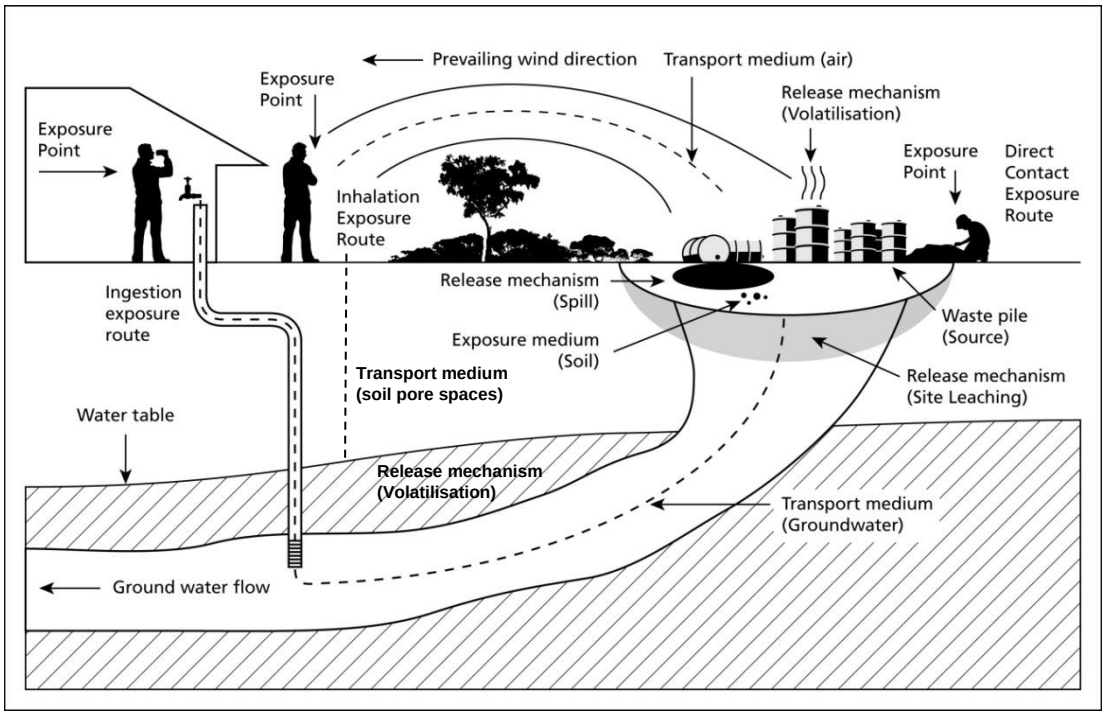
- the locations of sources and the nature, extent and concentrations of contamination;
- contaminant migration pathways in air, surface water, groundwater, sediments, soil and dust (a separate report may be warranted for detailed fate and transport assessments);
- potential receptors and exposure routes; and

uncertainties or limitations of the assessment, e.g. conclusions of the data evaluation or areas that could not be sampled because of the presence of infrastructure.

The above information should be discussed in appropriate detail and summarised in a table to clearly identify source-pathway-receptor linkages and risks that require further assessment or management. A graphical CSM, as shown in Figure 2 can also be helpful to illustrate the linkages.

Guidance on developing CSMs is also provided in section 4 of Schedule B2 of the NEPM.

Figure 2: An example of a simple CSM illustrating potential source-pathway-receptor linkages



7.2 Aesthetics

Materials potentially presenting an aesthetic concern include:

- inert materials such as construction and demolition waste, e.g. concrete, bricks, scrap metal, timber and plastics;
- trivial amounts of bonded asbestos-containing materials in good condition; and
- substances that cause soil or water discoloration or odour

These materials do not pose an unacceptable risk to human health, the environment or environmental values from a contamination point of view, however, they may be considered undesirable in the context of the site-specific land use or surrounding land uses depending on the sensitivity of the land use.

Caution should be used in concluding that some materials have aesthetic effects alone, and the risk of contamination should be considered in the context of the site history and the origin of the materials.

Section 3.6 of Schedule B1 of the NEPM provides further guidance on the consideration of aesthetic issues. The assessment of sites with asbestos-containing materials should be carried out in accordance with DoH (2009). Assessment levels for water provided in Table 7 of Appendix D include aesthetic criteria for some substances.

If a site is only affected by aesthetic issues, it is not necessary to report the site to DER as a known or suspected contaminated site. However, it may be appropriate that the site is managed under other legislation, such as groundwater monitoring conditions for sites licensed under the EP Act or for groundwater abstraction licenses issued by the Department of Water, or conditions or directions issued by planning authorities. DER may be contacted for advice on the Contaminated Sites Information line **1300 762 982**.

8 Preliminary site investigation

8.1 Introduction

The purpose of a preliminary site investigation (PSI) is to identify the potential sources of contamination and contaminants of concern, the receptors that may be exposed to contamination and the relevant exposure pathways. The scope of work should be sufficient to provide an initial indication of a site's contamination status, the nature and location of likely sources and receptors, and to determine whether detailed site investigation is warranted.

A PSI generally comprises:

- desktop study (records and published information relevant to the environmental setting and site history);
- detailed site inspection(s);
- interviews with site representatives (managers, owners, former employees, neighbours etc);
- data evaluation;
- development of an initial CSM; and
- identification of potential risks and any uncertainties or limitations.

Sampling as part of a PSI is generally not recommended as insufficient information may be available at this stage to inform the HSEP. Sampling of an opportunistic type is sometimes carried out to inform the sampling and analysis quality plan (SAQP) for the DSI.

The initial CSM, developed from the findings of the PSI, forms the basis of further site investigations. It is recommended that as much information on the site as possible is obtained and assessed in this phase of investigation. An assessment should be made of the accuracy of the information and any significant data gaps identified. A poor-quality PSI will result in a lack of confidence in the findings of any subsequent investigations completed at the site. For example, a PSI report that does not specifically comment on the presence or absence of bonded-asbestos containing materials on the land surface where fences may have historically been composed of asbestos, may lead to additional work later on in the assessment.

Reporting under s 11 of the CS Act

Where information obtained during a PSI suggests potential contamination, the site may require reporting as a known or suspected contaminated site in accordance with s 11 of the CS Act (refer to DER 2014a). A detailed site investigation may be necessary to ascertain whether contamination exists, and whether it poses a risk to human health, the environment or environmental values.

A PSI should be carried out in accordance with guidance provided in section 3 of Schedule B2 of the NEPM. Elements of a PSI are discussed below and the checklist in Appendix A of this document provides examples of information that should be included in a PSI report.

Refer to section 9.2 of this document for guidance on preparing an SAQP, which should be included with the PSI report if relevant. In some cases, an SAQP may be developed and reported as part of a PSI or it may be prepared as a separate document.

8.2 Potentially contaminating activities

A PSI should include consideration of whether activities carried out at a site have the potential to cause contamination. A list of potentially contaminating activities that should be considered during site assessment is provided in Appendix B. The list is not exhaustive and it may be necessary to consider whether other activities carried out at a site could cause contamination. Potentially contaminating activities carried out on surrounding land should also be considered. It should be noted that a site is not necessarily contaminated solely because an activity listed in this guideline has occurred on the site. A weight of evidence approach should be taken by assessing all available sources of information.

Some sites may have hosted more than one potentially contaminating activity during their history and all such activities should be considered for assessment purposes. For example, 'Work Depots' may have had components of fuel storage, asphalt manufacturing/storage, pesticide mixing and vehicle maintenance.

Information regarding the site's history, such as manifests and inventories, should inform the potential contaminants of concern and this may include chemicals listed in Appendix B. Some chemicals are specifically named in Appendix B—for example, persistent organic pollutants recognised as causing adverse effects on humans and the ecosystem under the Stockholm Convention on Persistent Organic Pollutants (Stockholm Convention 2004). It is acknowledged that some of these substances may not have been used in Australia, or may not be currently registered for use in Australia. The site history and the CSM should inform whether they need to be considered when planning investigations.

8.3 Site history

The history of a site can provide valuable information on the nature and extent of potential contamination and pathways for contaminant migration. A log should be kept of all information sources and the report should include details of all documents reviewed during the investigation of the site history. A chronology or timeline should be developed of the relevant events to assist interpretation (e.g. Table 1 and Figure 1 in Schedule B2 of the NEPM). Section 3.3 of Schedule B2 of the NEPM provides discussion on site history information that is relevant in a PSI.

8.4 Environmental setting

The environmental setting includes the surrounding land uses, geology and hydrogeology, surface waters, wetlands, tidal regime, seasonal or climatic conditions or any other feature of the environment that may be relevant to the assessment. The purpose of describing the environmental setting is to identify potential receptors, understand how contaminants may behave in the environment and identify potential off-site sources of contamination. The area that is assessed should be determined based on the likely distances that potential contaminants could migrate (site-specific and contaminant-specific considerations apply). A 500 m radius around the site may be assumed in initial assessments.

8.5 Site inspection

The site inspection should seek to identify potential sources of contamination, pathways and receptors, confirm the layout of the site and identify constraints to site access for sampling. The site inspection should be used to describe the current condition of the site and validate plans or other information obtained during the desktop investigation, and photographs should be taken for future reference. Where possible, the site inspection should be carried out in the company of a person familiar with the site, for example, the site manager or knowledgeable employee.

Any areas of the site that were not accessible or accessed during the site inspection should be noted. Observations should be recorded at the time of the inspection and the information included in the assessment report as descriptive text within the main report body together with a plan of site features and photographs (accompanied by a location and aspect plan). Depending on the nature of the site, it may also be relevant to note the absence of potential contaminants (e.g. asbestos on the site surface) or indicators of contamination.

8.6 Information sources

Section 3.3 of Schedule B2 of the NEPM provides a list of information sources that should be considered when compiling a PSI. Details of WA-specific sources of information that should also be consulted are provided below:

- DER's register of known or suspected contaminated sites, including the publically available Contaminated Sites Database—obtain a basic or detailed summary of records (BSR or DSR) by submitting a Form 2 to DER with the prescribed fee (refer DER 2014a)
- DER acid sulfate soils information www.der.wa.gov.au/your-environment/acid-sulfate-soils
- DER information on current environmental licences and works approvals www.der.wa.gov.au/our-work/licences-and-works-approvals. Other information (e.g. expired licences, complaints and spills) can be accessed through an application under the *Freedom of Information Act 1992*. Visit www.der.wa.gov.au/about-us/legislation/freedom-of-information.
- Landgate—certificates of title, aerial photographs.
- Department of Water (DoW)—details of registered bores, *Perth Groundwater Atlas* (DoW 2014b) and drinking water source protection reports.
- WA Planning Commission—land use and water management strategies.
- Water Corporation—annual reports and 10-year plan for Western Australia (Water Corporation, 2012).
- State Library of WA—site history.
- Geological Survey Maps e.g. 1:50,000 Environmental Geology Series.
- Dial Before You Dig service (www.1100.com.au or phone 1100)—for the location of underground services prior to undertaking any subsurface investigations.

- Department of Mines and Petroleum (DMP) for information on dangerous goods licence records, licensees, location and types of USTs, inspections, licence compliance etc.
- local government authorities for zoning details, service infrastructure and planning approvals and complaints walga.asn.au/AboutLocalGovernment/CouncilWebsites.aspx.

9 Detailed site investigation

9.1 Introduction

A detailed site investigation (DSI) involves the collection and evaluation of site-specific data, including the sampling and analysis of environmental media (soil, soil gas, surface water, groundwater, sediment) to characterise the site and the nature and extent of contamination. The information obtained is used to refine the CSM and identify potential or actual risks to human health, the environment or environmental values that require further assessment, and/or remediation. Risk assessment is discussed further in section 10.

DER acknowledges the role of targeted site investigations at some sites without the completion of a comprehensive PSI (for example, when investigating a spill or leak, or for due diligence investigations where an existing potentially contaminating land use will continue). It is important to note that at least some of the information usually obtained in a PSI (described in section 8) will be necessary for planning a targeted investigation. In some circumstances a comprehensive PSI will be necessary at a later date to ensure all possible sources of contamination have been considered and addressed.

A DSI generally involves:

- development of data quality objectives (DQO), which includes the formulation of project objectives;
- planning and implementing an SAQP to meet the DQOs;
- data evaluation;
- refining the CSM; and
- identifying risks and any uncertainties or limitations.

In circumstances where a risk is identified, further risk-based assessment and/or remediation will be required, which may involve further desktop investigation, site investigation and/or risk assessment.

Site classification under the CS Act

Reported sites that require investigation will usually be classified *possibly contaminated— investigation required* under the CS Act (refer to DER 2014a for more information on site classifications).

A DSI should be carried out in accordance with Schedule B2 of the NEPM. Elements of a DSI are discussed below and the checklist in Appendix A of this document provides examples of information that should be included in a DSI report if it is relevant to the site.

The detailed investigation of some types of contamination requires consideration of issues not specifically discussed within the NEPM. Some additional sources of information are provided below.

Issue	Reference
Assessment of surface waters and sediments	*Australian Guidelines for Water Quality Monitoring and Reporting* (ANZECC & ARMCANZ 2000)
Clandestine drug labs	*Clandestine Drug Laboratory Remediation Guidelines* (Attorney-General's Department 2011)
Service stations and other fuel storage sites	*Technical Note: Investigation of service station sites* (NSW EPA 2014b)
Radiological contamination	Contact the Radiological Council of Western Australia and DER

For all matters relating to risk associated with radiological contaminants, DER relies on technical advice provided by the Radiological Council of Western Australia (RCWA).

Neither this guideline nor the NEPM specifically address radionuclide contamination risks. It is therefore recommended that any assessment of radiation risk should be conducted by a recognised radiation health professional in consultation with RCWA. DER expects that risks associated with radionuclide contamination will be assessed with reference to guidelines issued by Western Australian and Australian regulatory authorities, such as the Department of Mines and Petroleum (DMP) and the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

DER recommends that authorative international guidance is consulted to address any issues that are not included in WA or other Australian guidelines.

9.1.1 Site assessment in acidic landscapes

Special considerations apply when sampling soils and groundwater in acid sulfate soil (ASS) or acidic landscapes in Western Australia. Detailed guidance on the identification, assessment and management of ASS is provided in DEC (2011b) and DEC (2013) and at www.der.wa.gov.au/ass.

In ASS landscapes, the oxidative state of soils and groundwater will vary in response to seasonal conditions in the zone of water table fluctuation. When planning a site investigation in these areas, the practitioner will need to consider specific measures to obtain representative site data and representative background data, such as:

- collecting samples over different seasons, and at different depths within the range of groundwater fluctuation, to assess the range of conditions;
- considering whether trends are present in historical data and whether the most recent data available are representative of current conditions;
- conducting field tests for soil and groundwater pH;
- using field oxidation tests as an indicator of oxidation potential;
- laboratory analysis to characterise the nature of ASS; and
- using appropriate sampling and handling techniques to minimise oxidation of samples between collection and laboratory analysis.

Disturbance of ASS, which can result from human activities such as excavation or dewatering, or through water table fluctuations in response to climate change, can lead to the formation of acidity, a drop in groundwater pH and the mobilisation of metals and metalloids.

If soil pH at a site in an ASS landscape is found to be less than 4, this is an indicator that ASS has been disturbed and oxidised, which may require investigation and management in accordance with DEC (2011b) and DEC (2013). The CSM should be revised to determine whether there is likely to be a risk to human health or the environment—for example, via direct contact with soils or leaching to groundwater or surface water. If a potential risk to human health or the environment is identified, DER Contaminated Sites should be consulted. The requirement for management, monitoring and/or clean-up will be considered by DER on a site-specific basis.

Development or remediation-related disturbance of ASS that leads to degradation of groundwater quality (for example, due to dewatering without appropriate management) may lead to sites being classified under the CS Act. Whether a particular site is classified will depend on the severity and extent of groundwater impacts and will be assessed on a site-specific basis.

9.2 Sampling and analysis quality plans

Systematic planning is essential to ensure the data collected meets the objectives of the investigation stage and the overall objectives for the site. A sampling and analysis quality plan (SAQP) should be prepared to ensure that the data collected are representative and sufficient to address critical gaps and uncertainties identified in the CSM so that the information obtained provides a reliable basis for making site management decisions. This includes the collection of statistically robust data where the assessment includes comparison with investigation/screening/assessment/clean-up levels.

An SAQP should be developed in accordance with the NEPM prior to the collection of any samples on a site and documented in the site assessment report. The scope and detail of the SAQP will depend on the complexity of contamination issues relevant to the site.

Section 5 and Appendix B of Schedule B2 of the NEPM describes the process of developing data quality objectives (DQO) and an SAQP, including guidance on what should be considered when determining the appropriate field quality assurance and quality control (QA/QC) procedures for a site (section 5.4 and Appendix C). Guidance on laboratory QA/QC procedures is provided in section 3 of Schedule B3 of the NEPM.

The SAQP should demonstrate the rationale for sample locations and data to be collected by linking the areas of concern identified in the CSM to the sampling program. Areas of concern can be identified on a site plan that also shows the sampling locations. The sampling program can be summarised in a table that lists each area of concern and details of the sampling and analysis to be carried out in each area. This approach is particularly useful for large and/or complex sites with multiple potential sources of contamination.

Sample naming protocols should be determined prior to implementing the SAQP and should:

- be logical so that the different types of samples are easily recognisable (e.g. surface soil SS, soil bore SB, monitoring bore MB, test pit TP, soil validation SV etc);
- be consistent in report text, site plans, tables, chain of custody forms and laboratory analytical certificates;
- include the depth from which they were obtained for soil samples (e.g. SB1-0.5, TP1-0.75) or multi-depth groundwater samples (e.g. shallow MB1s, middle MB1m, deep MB1d) to reduce the need for the report reader to cross-reference this information; and
- be consistent and numbered sequentially throughout multiple stages of work at a site.

9.3 Sampling design

9.3.1 Overview

Selecting an appropriate sampling design requires the use of professional judgement and a sound understanding of the objectives of the sampling program. Collecting data that are of suitable type and quality will minimise the need to collect more data at a later date. Selection of appropriate sampling design(s) in developing the SAQP should include consideration of the type of information that would be required to carry out a rigorous and meaningful risk assessment.

Judgmental sampling may be the most appropriate sampling design where there is comprehensive knowledge of potential sources of contamination. Probability-based designs such as grid-based sampling may be useful where there is limited information on the historical use of the site, or where there is a large area that is potentially contaminated (e.g. the cultivated area at a market garden site). In many circumstances, practitioners may adopt a combination of both judgmental and probability-based sampling programs as this allows the targeting of contamination based on expert knowledge as well as the ability to make quantitative statements about contamination at a site.

The sampling designs employed should be adequately justified with reference to the CSM and DQOs. Detailed guidance on sampling designs and their applications is provided in section 6 of Schedule B2 of the NEPM.

Minimum number of samples
There is no minimum number of sampling points recommended for a given size of site as this will be determined by consideration of the site-specific characteristics (CSM) and the DQOs for the assessment. Sufficient statistically robust and representative data should be collected to enable meaningful comparison with the relevant investigation/screening and/or assessment levels for the site. Regardless of the sampling design adopted, the SAQP should include the rationale for the selected sampling design and comment on the robustness of the data.

9.3.2 Composite sampling

Composite sampling involves combining a number of soil samples from adjoining locations into a single sample for analysis. Composite samples should be prepared from field-moist samples in a laboratory environment and not in the field to ensure well-mixed samples. Although composite sampling has limitations it may be suitable where it can meet the data quality objectives (DQOs) for the site.

DER does not accept the use of composite sampling under the following circumstances:

- sampling groundwater;
- sampling clay or silt soils which are unable to be adequately homogenised when field-moist; and/or
- assessment of pH, semi-volatile or volatile substances (which includes some organochlorine (OC) and organophosphate (OP) pesticides as well as low molecular weight polycyclic aromatic hydrocarbons (PAHs))

General guidance on composite sampling is provided in section 6.2.6 of Schedule B2 of the NEPM and in Appendix B of AS4482.1-2005.

When comparing analytical results for composite samples with assessment levels, the relevant assessment levels should be divided by the number of sub-samples making up the sample for analysis. For example, if a composite sample has been prepared from four soil sub-samples, the relevant assessment level should be divided by four, and the analytical result compared with the adjusted assessment level.

The use of composite sampling needs to be explicitly addressed in the DQOs for the site (with appropriate justification for their use) and included in the discussion of uncertainties.

Field descriptions of each sample and the compositing methodology should be documented and included in the report.

9.4 Data evaluation

A DSI report should include an evaluation of the data against the investigation objectives as incorporated in the DQOs and provide discussion on the precision, accuracy or bias, representativeness, completeness, and comparability of the data and the implications for decision-making.

Detailed guidance on the assessment of data quality is provided in section 13 and Appendix C of Schedule B2 of the NEPM.

9.5 Soil assessment

9.5.1 Overview

Detailed guidance on soil assessment, including guidance on the collection of soil samples and field screening techniques, is provided in section 7 of Schedule B2 of the NEPM. Schedule B3 provides guidance on the laboratory analysis of potentially contaminated soils.

Guidance on how to apply screening criteria for assessing risks from soil contamination is provided in Schedule B1 of the NEPM and section 9 of this document. Specific kinds of soil assessment, including stockpile characterisation, asbestos and acid sulfate soils are discussed further below.

9.5.2 Asbestos in soils

The primary source of guidance for the assessment of potential asbestos contamination and asbestos-contaminated sites in WA is the *Guideline for the Assessment, Remediation and Management of Asbestos-Contaminated Sites in Western Australia* (DoH, May 2009).

DoH also provides additional information on its website (www.public.health.wa.gov.au/3/1144/2/contaminated_sites.pm) including an asbestos guidelines summary, and guidance notes on laboratory procedures and the management of low-risk asbestos contamination. A summary of assessment requirements is provided in section 11 of Schedule B2 of the NEPM.

9.5.3 Stockpile characterisation

Characterisation of stockpiled soil is generally carried out to determine its suitability for re-use or disposal requirements. The characterisation methodology should be consistent with the approach detailed in section 7.5 of Schedule B2 of the NEPM. The management of stockpiles is discussed in section 13.1.5.

In WA, material that is to be disposed to landfill should be characterised in accordance with section 7.5 of Schedule B2 of the NEPM and classified using the criteria provided in *Landfill Waste Classification and Waste Definitions, as amended 2009* (DEC 2009) to determine the appropriate type or class of landfill that can accept it.

Any fill material brought to a site, such as for backfilling excavations, should be assessed in accordance with this guideline unless it can be demonstrated to be material that consists of rock or soil arising from the excavation of undisturbed natural material that will have no harmful effects on human health or the environment. Documentation confirming the source of imported materials and the results of any sampling and laboratory analysis should be included in the assessment report.

9.6 Groundwater assessment

9.6.1 Overview

Groundwater is a valuable resource in WA and shallow groundwater in particular is vulnerable to being impacted by surface and near-surface sources of contamination. The potential for groundwater impact should be considered in all contaminated site assessments conducted in WA.

An initial hydrogeological assessment should be carried out in the first stage of site assessment to determine whether a risk to groundwater quality exists. Further investigation will be required where there is a risk of harm to any current or potential future environmental values of groundwater, or where groundwater could create a potential exposure pathway that could result in a risk to human health or the environment. Schedule B6 of the NEPM provides a risk-based framework for the assessment of groundwater contamination.

Triggers for groundwater investigation include the presence of:

- potential primary sources of groundwater contamination, such as sumps, drains, pipework or storage tanks;
- soil contamination which potentially extends to the zone of water table fluctuation;
- soil contamination above the water table which has the potential to leach or may have already leached; and
- potential preferential pathways.

Groundwater investigations should be designed and undertaken by appropriately qualified and experienced groundwater professionals (refer to Schedules B6 and B9 of the NEPM for further information).

Detailed guidance on the characterisation of groundwater contamination, groundwater monitoring and the application of contaminant fate and transport modelling is provided in section 8 of Schedule B2 of the NEPM. Refer to section 11.7 of this document for guidance on selecting and applying appropriate assessment levels for groundwater in WA. Considerations for the assessment of groundwater in acidic landscapes are provided in section 9.1.1 of this guideline.

A desktop investigation should be undertaken before developing a groundwater sampling program. Examples of information that should be considered when compiling a desktop assessment of groundwater and/or reporting on a groundwater investigation are provided in Appendix A of this guideline.

Enquiries regarding groundwater resources in WA should be made to the Department of Water (DoW). Refer DoW (2014b) and the following sources of information for desktop assessment of regional groundwater conditions:

- DoW's database of registered groundwater bores throughout the state wir.water.wa.gov.au (as registration of domestic groundwater bores is not compulsory the DoW database should not be relied on for identifying all potential receptors);
- the Perth Groundwater Atlas www.water.wa.gov.au/idelve/gwa/, which provides an indication of the quality, depth and flow direction of local groundwater in the Perth area; and
- the Hydrogeological Atlas (www.water.wa.gov.au/idelve/hydroatlas/), which describes regional geology and superficial and confined aquifers, including information on groundwater salinity.

A groundwater investigation may not be ruled out based on an absence of current abstraction bores when bores may reasonably be installed in the future as needs for access to water resources changes over time.

9.6.2 Groundwater sampling methods

Development of an SAQP that includes groundwater sampling should consider what sampling methods are appropriate for the aquifer conditions and contaminants of concern. Section 8.2.4 of Schedule B2 of the NEPM provides detailed guidance relevant to planning and implementing a groundwater sampling program. In particular, the use of bailers or high speed pumps is not recommended because of their

limitations in obtaining representative groundwater samples. These methods are prone to agitating groundwater, which can cause increased turbidity and aeration resulting in chemical alteration of the sample such as partial or total loss of volatile or semi-volatile contaminants or changes in metal speciation. Refer to section 9.1.1 of this document for discussion of groundwater sampling in ASS landscapes.

9.7 Vapour assessment

9.7.1 Overview

Contaminated soil and groundwater may emit vapours or gases that are derived from the contaminating substances or the breakdown of substances, which have the potential to be explosive, flammable, toxic or behave as an asphyxiant. Volatile substances include, but are not limited to, methane, carbon dioxide, carbon monoxide, hydrogen sulfide, radon and other (non-methane) volatile organic compounds. These gases may be referred to as soil vapour, soil gas or ground gas depending on the context, and may be present within the ground, outdoor and indoor air and may accumulate in confined spaces such as service conduits or buildings. An informative discussion of the differences between petroleum hydrocarbons and chlorinated hydrocarbons and their potential for vapour intrusion is provided in US EPA (2012).

In WA, a vapour assessment is most likely to be required in association with the presence of landfills, petroleum products and/or organic solvents. However, volatile contaminants may also be encountered in other circumstances such as at sewage disposal sites, fill or made ground and human or animal burial grounds (CIRIA 2007). Hydrogen sulfide can also be released during the disturbance of ASS materials (refer to section 4.4.1 of DEC 2011b) and from the decomposition of vegetation (CIRIA 2007).

Guidance on assessment of vapour intrusion (VI) is provided in Schedules B2, B4 and B7 of the NEPM. The South Australian Environmental Protection Authority (SA EPA) is also planning to publish a framework for the assessment of VI including guidance on associated technical considerations.

The US EPA provides a number of technical documents and tools prepared to support guidance development at www.epa.gov/oswer/vaporintrusion/index.html including:

- Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990—2005): A Compilation of Statistics for Assessing Vapor Intrusion information on indoor air concentrations of VOCs
- EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings
- Conceptual Model Scenarios for the Vapor Intrusion Pathway
- Indoor Air Vapor Intrusion Mitigation Approaches
- Petroleum Hydrocarbons And Chlorinated Hydrocarbons Differ In Their Potential For Vapor Intrusion

The US EPA CLU-IN (Clean-Up Information) website www.clu-in.org/issues/default.focus/sec/Vapor_Intrusion/cat/Site_Investigation_Tools/ is a useful source of extensive guidance on various VI related issues including sampling and analysis, predictive modelling, building design, forensic approaches and site investigation case studies.

The Interstate Technology & Regulatory Council (ITRC) has also published a number of guidance documents on VI and related fields including:

- Vapour Intrusion Pathway: A Practical Guideline (ITRC 2007a)
- Vapour Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b)
- Integrated DNAPL Site Strategy (ITRC 2011)

The science informing VI assessment continues to develop and practitioners should understand the limitations outlined in the NEPM and other technical guidance documents when undertaking vapour assessments.

Multiple lines of evidence, documented in a weight-of-evidence approach, are required to demonstrate that the vapour intrusion/emission pathways are unlikely to be complete or to present a significant risk where NAPLs and/or significant dissolved concentrations of volatile substances are present.

Assessment of vapour risk is a specialist area and should only be undertaken by qualified and experienced professionals.

The assessment of petroleum hydrocarbon vapour, chlorinated hydrocarbon vapour and landfill gas are discussed below in sections 9.7.2, 9.7.3 and 9.7.4 respectively.

9.7.2 Petroleum hydrocarbon vapour assessment

Health screening levels (HSLs) for assessing VI risks from petroleum hydrocarbons are provided in Schedule B1 of the NEPM, which includes guidance on their application in sections 2.4 and 3.3. Additional guidance on their application is also provided in section 11.4 of this document.

Detailed guidance on the assessment of petroleum vapour intrusion (PVI), including guidance on the use of screening PVI assessments to identify sites requiring further assessment of risk from VI is provided in *Technical Report 23 - Petroleum Hydrocarbon Vapour Intrusion Assessment: Australian Guidance* (CRC CARE 2013). This report provides guidance on procedures to follow when the HSLs are not applicable (e.g. shallow groundwater) or where there are exceedences of the HSLs and how to conduct a detailed PVI assessment. The report also provides detailed guidance on installing soil vapour probes/wells and field sampling procedures.

9.7.3 Chlorinated hydrocarbon vapour assessment

The NEPM (schedules B2, B4 and B7) outlines the fundamental framework for undertaking VI assessment in Australia).

Schedule B1 of the NEPM provides interim health investigation levels for volatile organic chlorinated compounds in soil and guidance on their application in section 2.3.

Guidance provided in CRC CARE Technical report 23, is specific to assessing PVI and should not be applied indiscriminately to the assessment of chlorinated hydrocarbon vapours.

Consistent with the NEPM, practitioners should apply a tiered risk-based approach, using multiple lines of evidence for the assessment of CVI.

9.7.4 Landfill gas assessment

Specific guidance on the assessment of landfill gases (such as methane, carbon dioxide, carbon monoxide, hydrogen sulfide and hydrogen cyanide) is not provided in the NEPM. However, landfill gas assessments in WA should follow the same broad approach outlined in the NEPM and this guideline including: the development of an SAQP, data evaluation and CSM. Assessments should adequately characterise the nature and extent of contamination, including 'reasonable worst-case scenario conditions', so that current and future gas generation trends, migration and accumulation can be reasonably predicted, assessed and managed.

Detailed guidance on assessing ground gases associated with operating or closed landfills, or other sites where putrescible wastes have been buried, is provided in the following documents:

- '*Assessing Risks Posed by Hazardous Ground Gases to Buildings*' (CIRIA 2007). Includes assessment levels for ground or soil gases such as methane and carbon dioxide at landfill sites and additional information necessary for their correct application.
- '*Guidelines for the Assessment and Management of Sites Impacted by Hazardous Ground Gases*' (NSW EPA 2012)

A detailed human health risk assessment may be required if a ground gas investigation identifies that non-methane volatile organic compounds are present at the site which may pose chronic risks to human health via inhalation.

9.8 Sediment assessment

Although the assessment of sediments is not covered in detail in the NEPM, the underlying principles and general approach for the assessment of site contamination outlined in Schedule B2 are applicable.

Sediments comprise soils, sand, organic matter, or minerals that accumulate on the bottom of a water body. Sediments may represent a source and/or a sink of dissolved contaminants, influence surface water quality, and/or represent a source of bio-available contaminants to benthic biota (and hence potentially to the aquatic food chain). Impacts from contaminated sediments can therefore degrade aquatic ecosystems and pose a threat to human health via bioaccumulation in edible aquatic organisms.

A sediment investigation may be required where:

- wetlands/rivers/streams form part of, or are located in the vicinity of, a site;
- an aquatic environment such as a harbour, estuary, river bed, etc forms the whole or part of a site; or

- sediment is required to be dredged as part of port/harbour construction/expansion works or development in a riverine or marine environment.

The assessment of contamination in sediments should:

- consider the relationship between sediment, sediment pore water and water quality including the potential for mobilisation of contaminants into the water column and/or aquatic food chain;
- identify and enable protection of uncontaminated sediments; and
- identify where contamination is likely to result in adverse impacts to sediment ecological health.

General guidance on sediment sampling design is included in Appendix C. Additional guidance on assessing sediment quality is provided in:

- *Handbook for Sediment Quality Assessment* (Simpson et al. 2005);
- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000);
- AS/NZS 5667.12:1999 *Sampling of bottom sediments*.

If sediments are being assessed for dredging and ocean disposal, reference should be made to the *National Assessment Guidelines for Dredging* (Commonwealth of Australia 2009).

Expert advice should be sought from suitably qualified and experienced professionals to ensure that the appropriate sediment assessment methodologies are employed.

10 Risk assessment framework

10.1 Introduction

Risk-based assessment is fundamental to the assessment and management of contaminated sites in WA as the concept of risk of harm is included in the definition of contamination in the CS Act.

The primary guidance on conducting health and ecological risk assessments in WA is provided by the NEPM. The DoH (2006) guideline, *Health Risk Assessment in Western Australia*, provides a general overview of health risk assessment in WA.

Depending on the scope of the risk assessment, it may be preferable to present the results in a separate report. All assumptions, input data and calculations should be documented and justified in the report. A checklist of information that should be included when reporting is provided in Appendix A.

Risk assessment of contaminated land requires a high degree of objectivity and scientific skill and should be carried out by suitably qualified and experienced professionals.

10.2 Objectives of risk assessment

In contaminated site assessment, risk assessment involves assessing the likelihood of exposure to potential contaminants of concern and the severity of the effect of such exposure. It formalises the process of identifying the key issues requiring further consideration. Risk-based assessment provides the basis for determining an appropriate management response to eliminate or mitigate the identified unacceptable risks in an appropriate time frame (refer to section 10.9).

10.3 Staged approach to risk assessment

Schedule A of the NEPM provides a flowchart depicting the decision-making process for assessing site contamination and demonstrates the relationship between the tiered approach to risk assessment and the staged approach to investigation.

A risk assessment is required for all known and suspected contaminated sites reported to DER. The level of risk assessment undertaken should be appropriate to the problem and the level of detail in the CSM. It is not appropriate to carry out a detailed quantitative risk assessment if only limited site characterisation has been undertaken.

More than one phase of risk assessment may be undertaken at a site as the risk assessment should be revised as more information is obtained or if conditions change (e.g. proposed change of land use) at the site.

There are three levels or tiers of risk assessment:

- Tier 1 (screening) risk assessment
- Tier 2 risk assessment
- Tier 3 risk assessment

In the tiered approach, simple conservative assumptions are applied in the initial assessment to identify which issues are likely to present the greatest risk, allowing more detailed, site-specific risk assessment to focus on these issues. This allows resources to be focused on the most critical issues associated with a site in a prioritised and defensible manner.

Most contaminated site assessments begin with a Tier 1 screening risk assessment, and progress to a site-specific Tier 2 or Tier 3 risk assessment if necessary. As the level of site characterisation increases with each stage of investigation, uncertainties in the CSM decrease, which enables the risk assessment to consider more of the site-specific conditions.

Throughout the site assessment process, options exist to carry out more detailed assessment, or proceed directly to risk management. Figure 3 shows the decision-making process (after site assessment has been triggered) assuming that potentially unacceptable risks are identified in the CSM. The path that is taken to reach a management decision should consider:

- The uncertainties in the data and risk assessment outcomes – have the risks been adequately characterised?
- The potential costs and benefits of undertaking more detailed investigation and risk assessment compared with making potentially more conservative management decisions based on the available information.

10.4 Tier 1 screening risk assessment

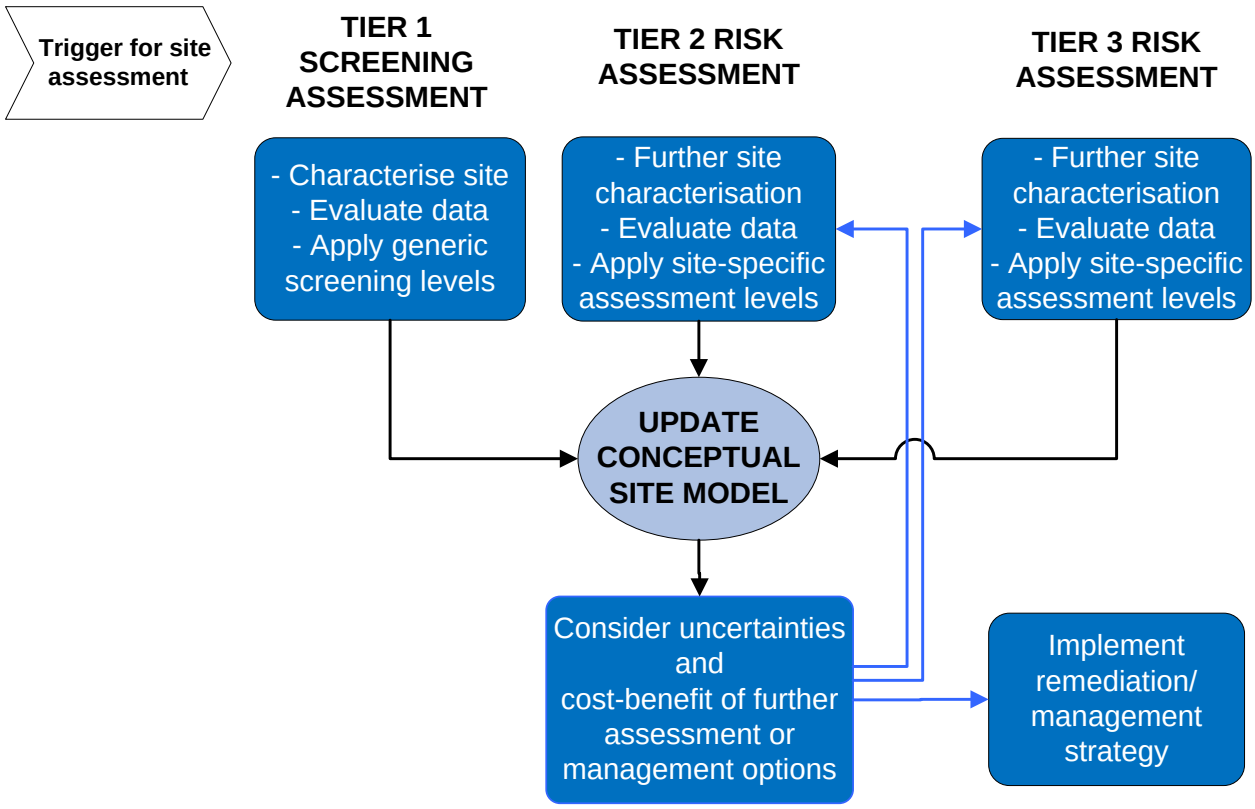
The primary guidance on carrying out Tier 1 assessments is Schedule B1 of the NEPM.

In a Tier 1 screening assessment, site data are compared with generic assessment levels. In most circumstances it is also necessary to obtain data on background levels relevant to the site. If unacceptable risks are identified, or if significant uncertainties exist, a Tier 1 risk assessment should be followed by a Tier 2 or 3 risk assessment. Alternatively, an appropriate management strategy may be implemented.

Section 11 of this document provides additional assessment levels and issues for consideration in WA.

Before applying the generic assessment levels, consideration needs to be given to the appropriateness of the assessment levels to the site, including the site setting and the exposure assumptions (refer section 11). The assessment levels have been developed based on various generic exposure scenarios. If the site conditions are significantly different from the assumptions, then some adjustment may be required (refer to Tier 2 assessments below).

Figure 3: Decision-making framework for risk assessment



Example of a Tier 1 screening risk assessment

A site proposed for a residential development contains elevated concentrations of metals (e.g. lead and copper) in surface soil.

In order to determine if the contamination of the soil might adversely affect the suitability of the site for residential purposes or nearby ecological receptors, detailed sampling is carried out on the site and at a reference site to establish ambient background concentrations. A screening assessment is then carried out comparing the measured concentrations of metals in the soil with the relevant ecological investigation levels and health-based investigation levels.

The concentrations are below the ecological investigation levels and health-based investigation levels, suggesting no further action is required with respect to these substances in soil to protect human health and terrestrial ecosystems.

The assessment also needs to consider what impacts there may be if the soil was left in place (refer box below).

A Tier 1 screening risk assessment also needs to consider whether there are other factors relevant to the nature and extent of contamination which require further assessment:

Examples of issues that should be considered in a Tier 1 screening risk assessment

- the presence of substances that are above background concentrations and may pose a risk and no generic assessment levels are not available;
- the combination of contaminants that have similar toxicological effect mechanisms (additive or synergistic effects may require Tier 2 or 3 assessment);
- leachability of contaminants—giving rise to groundwater contamination;
- erodability of contaminated materials e.g. erosion of metal-impacted soil following rain, leading to contamination of adjacent properties or waterways;
- odour (refer to section 7.2 on aesthetic impacts); and
- emission of volatiles that could enter buildings or service conduits and accumulate (vapour intrusion), adversely affecting the health of residents or occupants (refer to section 9.7 on vapour assessment).

10.5 Tier 2 risk assessment

A Tier 2 risk assessment may be necessary if:

- one or more contaminants exceed the generic assessment levels;
- assessment levels are not relevant to the exposure scenario; or
- there are uncertainties that limit the reliability of the Tier 1 assessment.

If the site setting and exposure scenario differ significantly from the assumptions that underlie the generic assessment levels, it may be possible to develop site-specific criteria by adjusting the assessment levels to more closely reflect the exposure scenario.

Caution is required when modifying Tier 1 assessment levels, because some of the underlying assumptions reflect policy positions that should not ordinarily be changed (for example, consumption of two litres of water per day in the development of the *Australian Drinking Water Guidelines*). It may still be appropriate to apply the unmodified generic criteria for the assessment of contaminant concentrations at off-site locations (e.g. contaminant concentrations in groundwater at a sensitive receptor).

It is essential that the basis for any modification of the generic assessment levels is justified and clearly documented. The exposure scenario should adequately represent the site land use and potential off-site impacts with a reasonable degree of conservativeness.

Modified generic investigation levels/site response should be submitted for review by the auditor or DER (and DoH for health-related assessments), to ensure they are acceptable prior to implementing a remedial action plan that is based on those levels.

Example of a simple Tier 2 risk assessment

A site proposed for high-density residential development is found to have metals (e.g. lead and copper) in soil at concentrations that exceed health-based assessment levels for residential development with minimal opportunities for soil access (HIL B). In this case the screening assessment has identified that further investigation and possibly clean-up is required.

As soil contamination is located where the building footprint is proposed to be, the contamination could be effectively contained under the building floor slab and direct contact with the contamination would be prevented. This assessment recognises that the soil assessment levels are based on effects arising through ingestion of soil, absorption through the skin, and inhalation of soil particulates (dust).

In this specific exposure scenario, it may be considered acceptable to permit soils with contaminant concentrations in excess of the generic assessment levels (HIL B) to remain on site. However, before this proposal could be accepted, there are a number of factors to consider:

- The works associated with the building's construction should not result in the redistribution of contaminated soil elsewhere on the site where subsequent exposure could occur. The development and implementation of a suitable site management plan may be required to address this issue.
- The building works should be carried out so as not to pose an unacceptable level of risk to the occupational health of workers (consider application of relevant WorkSafe standards).
- Future works or maintenance that would involve excavation and exposure of soil under the building, which may occur if new utilities or services were to be provided, or existing services required maintenance. If such works are anticipated, then a site management plan may be required to describe appropriate measures for managing the disturbance of contaminated soil. If all building works were subject to control through a management body, such as a body corporate, then it may be reasonable to assume that the site management plan would be implemented.
- The contamination is not volatile such that volatile contaminants could migrate through the sub-base or building floor or along service conduits or trenches (unlikely if the contamination only involves metals).
- The contamination is above the seasonal high water table (if the contamination was below the water table it could give rise to groundwater contamination), and will not leach into groundwater.
- The presence of contamination may be indicated by the classification of the site (such as *contaminated—restricted use* or *remediated for restricted use*) and a memorial on the relevant certificates of title, and development of a site management plan (refer to section 13.2) where necessary, to ensure the transfer of information on contamination at the site if it is sold or redeveloped.

10.6 Tier 3 risk assessment

A Tier 3 risk assessment is carried out when a Tier 1 screening risk assessment and/or a Tier 2 risk assessment (which are based on generic assessment levels) does not, or cannot, adequately assess the level of risks present at the site, for example, if soil assessment levels are not available for the contaminants of concern, or the proposed use of the site does not match any of the land use scenarios for which soil assessment levels have been defined (e.g. agricultural land).

A Tier 3 risk assessment usually focuses on the risk-driving contaminants and exposure pathways to identify unacceptable risks that require clean-up or management. It may include specialised contaminant fate and transport modelling and/or a toxicity assessment of particular contaminants. It usually involves deriving hazard indices or increased lifetime cancer risks for the contaminant concentrations observed at a site to determine the acceptability of risks or developing site-specific investigation or response levels for contaminants.

In a Tier 3 risk assessment the use of site-specific information may result in less conservative exposure assumptions being adopted, reflecting a greater understanding of the site and consequently reduced levels of uncertainty. These more realistic assumptions may result in site-specific risk based criteria that correspond to higher concentrations of contaminants than the generic assessment levels used for screening purposes, but which are nevertheless protective of human health, the environment and environmental values. Site-specific response levels and the site information upon which they are based should be reviewed by DER and/or the auditor (and DoH for health-related levels) to ensure they are acceptable prior to implementing a remedial action plan that is based on those levels.

For example, soil contamination was found to be acceptable in the Tier 1 screening risk assessment with regard to human health and ecological risk, but there was uncertainty regarding the migration of contaminants in groundwater to a nearby water body and the risks to the health of recreational users and the aquatic ecosystem. The Tier 3 risk assessment then concentrates on evaluating the risks associated with groundwater contamination and the requirements for management of these risks.

If it is clear that a serious problem exists and immediate action is required, the available resources should initially be directed to manage the risks. Such management may include the implementation of immediate mitigation measures followed by an assessment of the residual risks. If it is clear from the subsequent assessment that the contamination no longer poses an unacceptable risk, no further action would be required.

A Tier 3 risk assessment may not be necessary where the issues are self-evident and the Tier 1 screening risk assessment or Tier 2 risk assessment process will provide sufficient information to determine a suitable risk management strategy.

Example of where a Tier 3 risk assessment may be required

In the previous example of a Tier 2 risk assessment, it was suggested that it might be acceptable for high levels of metals in soil to remain on site if the contaminated soils were contained beneath a building slab.

However, this may not be the case if contamination was found to be present throughout the soil profile (e.g. the contamination was associated with deep fill) and found to extend to the zone of seasonal water table fluctuations. Contamination may leach into groundwater despite the presence of overlaying buildings that would prevent leaching through rainfall infiltration.

For example, consider the case where groundwater is of potable quality, an extraction bore exists on the down gradient neighbouring property, and analysis of a groundwater sample from an on-site bore in the vicinity of the contamination indicates that the relevant assessment levels for both potable and non-potable uses of water are exceeded. The soil was deposited at the site one year ago to level the site for development.

Further investigation shows that the groundwater impact extends beyond the zone of fill to within 100 metres of the neighbour's bore and soil leachate testing has identified that the contamination has a high potential for ongoing leaching of metals. The neighbour's bore is used to irrigate the garden, which includes some edible produce.

Although initial testing of the neighbour's bore water does not find elevated concentrations of metals, this scenario indicates a potential risk to the neighbour by the contamination leaching from the soil and migrating via the groundwater to the neighbour's bore.

In this example a decision is made to further characterise the risk, rather than carry out clean-up based on the available information (based on a simple cost-benefit analysis). A Tier 3 risk assessment is carried out to assess the risk to the neighbour, inform the extent of clean-up necessary (if any) and the urgency with which it should be carried out. Contaminant fate and transport modelling is used to evaluate the potential migration of the contamination in groundwater and a toxicity and exposure assessment used to characterise the risk to bore users and devise risk-based management strategies.

10.7 Contaminant fate and transport modelling

In some circumstances, modelling of the fate and transport of contaminants may be necessary to adequately assess the risk posed to receptors. There are a number of modelling tools available and their functions and limitations should be considered when determining the appropriate modelling approach. Section 10 of Schedule B2 of the NEPM provides guidance on contaminant fate and transport modelling.

The report detailing the contaminant fate and transport modelling undertaken should include documentation of all assumptions, input data and calculations. The checklist in Appendix A provides examples of information that should be included.

10.8 Material change in site condition

A risk assessment should take into account all relevant information relating to the site. The risk assessment is likely to require revision should conditions materially change at the site or new information become available after the risk assessment has been completed (e.g. change of land use and/or site layout, the identification of new contamination that was not accounted for in the risk assessment). The outcomes of the revised risk assessment may result in changes to the recommended risk management strategy.

Example of a material change in site conditions requiring notification to DER

A groundwater plume has been laterally and vertically delineated, and a Tier 3 risk assessment undertaken involving contaminant fate and transport modelling. The site has been assessed in accordance with DER (2014c) and found suitable for remediation via monitored natural attenuation (MNA).

An SMP was developed that established an extensive groundwater monitoring program to assess the progress of natural attenuation in reducing groundwater contamination. However, after three years of monitoring it is evident that the levels of contamination are not decreasing as predicted, and trigger levels are likely to be exceeded. In these circumstances it is not appropriate to wait until trigger levels have been exceeded before implementing contingency measures.

The custodian of the SMP should notify DER and implement contingency measures. Contingency actions may include active clean-up to some extent, followed by revision of the risk assessment and implementation of a new management strategy.

10.9 Risk management

Risk management involves evaluating options for the management of unacceptable risks identified through a risk assessment. The main objective of risk management is to ensure that the risks associated with a contaminated site are appropriately and proportionately managed.

Selecting the most appropriate risk management option will necessarily involve value judgements that take into account the results of the human health and/or ecological risk assessment, the relative costs of different options, regulatory requirements and community expectations. The process of risk management also includes any necessary monitoring and evaluation of the outcome of risk management actions, and community engagement.

Australian Standard AS/NZ 4360 presents a framework for carrying out risk management. It provides general guidance that can be applied to decision-making for contaminated sites when considering the likelihood that a situation or consequence will arise, the severity of that situation or consequence, and prioritising action(s) that should be undertaken. In AS/NZ 4360 risks are defined as “event driven” and risks are ranked in terms of probability of occurrence or frequency (i.e. likelihood) and severity (i.e. consequence). The likelihood and consequence is ranked on a simple basis (e.g. 1—5) and the resulting estimate of risk is qualitative or semi-quantitative.

Standards Australia handbook HB203:2006 *Environmental Risk Management—Principles and Process* explains the principles and process of environmental risk management and provides guidance on its implementation. It is based on the generic risk management process developed in AS/NZS 4360 and offers a clear, consistent model and an integrated framework for environmental risk management.

Example of a situation where the approach outlined in AS/NZ 4360 may be useful

A decision needs to be made if contamination present at depth poses such a high risk that it requires remediation. The contamination is at depth (e.g. more than 5m below surface) and exposure is very unlikely to occur in the course of normal activities that would take place on the site. If the contamination is minor and exposure unlikely to give rise to serious health effects or affect groundwater, then it may be concluded from **an assessment of likelihood and consequence that the overall risk is low** and that it might be acceptable to leave the contamination in place.

However, if the depth of contamination is relatively shallow (e.g. less than 2m below surface), it is possible that maintenance works (e.g. re-laying or repairing service trenches), could result in contaminated soil being exposed. If significant levels of contamination are present that could adversely affect human health if the soil were to be exposed, it may be concluded from **the assessment of likelihood and consequence that the risk is unacceptable** and some form of remediation or management is required.

11 Tier 1 assessment levels

11.1 Introduction

Generic assessment levels should be used in the context of a Tier 1 screening risk assessment (refer to section 10.4), to determine whether substances at a site potentially present a risk to human health, the environment or environmental values. Where a substance is present above the relevant assessment level and/or background concentrations, further investigation or assessment is required to determine whether the site is contaminated such that it poses a risk to human health, the environment or environmental values.

Before applying generic assessment levels, the practitioner should always consider the quality and relevance of the data in the context of the CSM and the SAQP by:

- evaluating the data against the DQOs to determine whether they are acceptable and adequate for the purpose of the assessment (refer to section 9.4 of this guideline and sections 5.6, 13.1 and Appendix B of Schedule B2 of the NEPM);
- understanding the effect of uncertainties in the CSM;
- identifying appropriate assessment level(s) for the site based on the receptors, migration pathways and exposure routes identified in the CSM; and
- understanding the limitations associated with the relevant assessment levels.

Sources of assessment levels to be used in WA for soil, soil gas, water and sediment are listed below. The assessment levels provided are the most relevant available at the time of publication.

It is the practitioner's responsibility to check whether these criteria or guidance on their application have been updated in the relevant source documents such as through publication of *errata* or whether new criteria have been published.

At the time of publication, revisions to the *Australian guidelines for fresh and marine water quality* (ANZECC & ARMCANZ 2000), including sediment quality, were in progress.

DER can be contacted for advice if necessary.

11.2 Sources of assessment levels

The documents that contain Tier 1 assessment levels to be used in WA are referenced in Tables 1 to 6 below. Schedule B1 of the NEPM is the primary reference for assessment levels and contains detailed guidance on the correct methods for their application. Additional sources of information for the application of assessment levels in WA (specified in Tables 1 to 6) should also be referred to. Section 3 of Schedule B1 and section 13.2 of Schedule B2 of the NEPM provide guidance on the appropriate use of summary statistics for data analysis and assessing the significance of exceedences of Tier 1 assessment levels.

If relevant assessment levels are not provided in the sources listed below, alternative assessment levels may be developed on a site-specific basis using the methods in the NEPM or sources contained therein. Where assessment levels, other than those listed or referenced in this guideline or in the NEPM, are adopted by the practitioner (e.g. alternative assessment levels from other states of Australia or international jurisdictions), a greater level of justification is required to demonstrate that the derivation methodology and exposure scenarios are relevant to the site. Practitioners should consult DER, the auditor and/or DoH before applying alternative assessment levels. Where appropriate generic assessment levels cannot be sourced, it may be necessary to adopt a site-specific approach, as discussed in section 10 (risk assessment).

Table 1: Ecological assessment levels for soil

Environmental receptor	Contaminants	Assessment level	Reference	Application in WA
Terrestrial ecosystems	Arsenic (aged contamination >2yrs)	Ecological investigation level (EIL)	NEPM B1 Table 1B(5)	section 11.3
Terrestrial ecosystems	Arsenic (fresh contamination <2yrs)	EIL	NEPM B5b Table 34*	s11.3
Terrestrial ecosystems	Zinc, copper, lead, nickel, chromium III (aged contamination >2yrs)	EIL (ambient background concentration ABC + added contaminant limit ACL)	NEPM B1 Zn Table 1B(1) Cu Table 1B(2) Ni Table 1B(3) Cr Table 1B(3) Pb Table 1B(4)	s11.3
Terrestrial ecosystems	Zinc, copper, lead, nickel, chromium III (fresh contamination <2yrs)	EIL (ABC + ACL)	NEPM B5c Zn Table 19 Cu Table 55 Pb Table 65* Ni Table 77* Cr Table 85*	s11.3
Terrestrial ecosystems	Naphthalene, DDT (fresh contamination <2yrs)	EIL	NEPM B1 Table 1B(5)	s11.3
Terrestrial ecosystems	Petroleum hydrocarbons	Soil ecological screening levels (ESLs)	NEPM B1 s2.6	No specific considerations
Terrestrial ecosystems	All other contaminants	Site-specific EILs	NEPM B5b	No specific considerations
Aquatic ecosystems (leaching)	All contaminants	Site-specific EILS and/or aquatic ecosystems protection guidelines	NEPM B3 and B5b; ANZECC & ARMCANZ 2000	s11.3.5; Table 7 in Appendix D

* LOEC & EC30 data has been adopted in the NEPM for the derivation of EILs and are the relevant data from these tables to be used as ACLs and EILs.

Table 2: Human health assessment levels for soil

Exposure pathway	Contaminants	Assessment level	Reference	Application in WA
All exposure routes (chronic risk)	Metals and organic substances	Health investigation levels (HILs)	NEPM B1 s2.2 and B7	No specific considerations
Inhalation of vapours (chronic risk)	Petroleum hydrocarbons	Soil health screening levels (HSLs) for vapour intrusion	NEPM B1 s2.4	s11.4.1
Direct contact (ingestion, dermal contact)	Petroleum hydrocarbons	HSLs for direct contact	Friebel and Nadebaum 2011	s11.4.2
Inhalation	Asbestos	HSLs for asbestos in soil	DoH 2009; NEPM B1 s4	DoH (2009)
Aesthetics, fire/ explosion risk, effects on buried infrastructure	Petroleum hydrocarbons	Management limits	NEPM B1 s2.9	s3.2 and 7.2
Interim screening level to identify the presence of MTBE	Methyl tertiary butyl ether (MTBE)	Interim screening level for MTBE	Adopted by DER in consultation with DoH	s11.5

Table 3: Human health assessment levels for soil vapour

Exposure pathway	Contaminant(s)	Assessment level	Reference	Application in WA
Inhalation (long-term/chronic risk)	Selected volatile organic chlorinated compounds (VOCCs)	Interim soil vapour health investigation levels (interim HILs)	NEPM B1 s2.3 NEPM B4 and B7	No specific WA considerations
Inhalation (long-term/chronic risk)	Petroleum hydrocarbons	Soil vapour health screening levels (HSLs) for vapour intrusion	NEPM B1 s2.4	s11.4.1
Inhalation	Petroleum hydrocarbons	Screening distances (minimum clean soil thickness for biodegradation)	CRC CARE 2013	s11.4.3
Explosion or short-term/acute risks	Landfill gas (LFG) (methane and carbon dioxide)	Gas screening values	CIRIA 2007	s3.2

Table 4: Human health assessment levels for groundwater (petroleum hydrocarbon vapour intrusion)

Exposure pathway	Contaminant(s)	Assessment level	Reference	Application in WA
Inhalation of vapours	Petroleum hydrocarbons	Groundwater health screening levels (HSLs) for vapour intrusion	NEPM B1 s2.4	s11.4.1

Table 5: Ecological and human health assessment levels for groundwater and surface water

Environmental value to be protected	Assessment levels	Reference	Application in WA
Fresh, estuarine or marine aquatic ecosystems	Fresh and/or marine water aquatic ecosystem protection guidelines	ANZECC & ARMCANZ 2000	s11.7.1; Table 7 in Appendix D
Drinking water source	Australian Drinking Water Guidelines (ADWG) Microbiological assessment levels (MALs)	NHMRC & ARMCANZ 2011	s11.6 and 11.7.1; Tables 7 and 8 in Appendix D
Non-potable use	Non-potable use guidelines (NPUG) Interim screening level for MTBE	DoH 2014	s11.5 and 11.7.3; Table 7 in Appendix D
Recreational use	NPUG MALs	DoH 2011; DoH 2014; EPHC 2006	s11.6 and 11.7.4; Tables 7 and 8 in Appendix D
Agricultural or industrial use	Irrigation water guidelines (short-term and long-term use) MALs	ANZECC & ARMCANZ 2000	s11.6 and 11.7.5; Tables 7 and 8 in Appendix D

Table 6: Ecological assessment levels for sediment

Environmental value to be protected	Assessment levels	Reference	Application in WA
Sediment quality in fresh, estuarine or marine aquatic ecosystems	Interim sediment quality guidelines (ISQG)	ANZECC & ARMCANZ 2000	s11.8; Table 9 in Appendix D
Sediment pore water quality	Fresh and/or marine water aquatic ecosystem protection guidelines	ANZECC & ARMCANZ 2000	s11.7.1 and 11.8; Table 7 in Appendix D

11.3 Ecological assessment levels for soil

11.3.1 Overview

Ecological investigation levels (EILs) provided in the NEPM are for assessing risks to terrestrial ecosystems and are applicable to the root zone and habitation zone of many species (generally the top two metres of soil but may be extended to three metres in arid areas).

Schedules B1 and B5c of the NEPM provide EILs for selected metals and metalloids (zinc, copper, chromium III, nickel, lead and arsenic), DDT and naphthalene. Schedule B5b provides the methodology for deriving EILs for other substances and additional guidance on deriving EILs for protecting aquatic ecosystems and incorporating the bioavailability of contaminants.

The NEPM methodology uses a combination of lowest observed effect (LOEC) and 30% effect (EC30) data to derive EILs.

The EIL methodology assumes that ecosystems are adapted to the ambient background concentration (ABC) and that it is only adding contaminants over and above this background concentration, referred to as the added contaminant limit (ACL), which has a potential adverse effect on the environment.

NEPM Schedules B1 and B5b present ACL values for selected metals and metalloids that should be added to the ABC to derive the EIL. ACLs are not provided for arsenic, DDT and naphthalene, as there was insufficient data available and generic EILs are provided for these substances instead of ACLS. The ABC should not be added to the EIL for these substances.

Depending on the characteristics of the contaminant, knowledge of certain soil physicochemical properties (pH, cation exchange capacity and clay content) and the land use scenario is required to determine the ACL (refer NEPM Schedules B1 and B5b and B5c). Consideration of background concentrations is only relevant for the calculation of EILs when assessing metals or metalloids as the background concentration of most organic compounds of anthropogenic origin should be zero.

A spreadsheet for calculating site-specific EILs is provided in the NEPM Toolbox (available at www.scew.gov.au/node/941#hils).

11.3.2 Fresh and aged contamination

As metals age in soils they generally decrease in bioavailability due to the action of soil attenuation processes. However, the ageing process may be partially reversed by changes in environmental conditions (e.g. pH decreases). In circumstances where contaminated soil undergoes redox changes (e.g. as a result of fluctuating water table) that could result in the complete or partial remobilisation of bound contaminants, through reduction or oxidation processes, then the contamination should be considered as fresh.

The majority of EILs provided in Schedule B1 of the NEPM are applicable to aged contamination defined as contamination that has been present in the soil for at least two years. EILs for fresh contamination, i.e. where the contamination has been present for less than two years, are provided in NEPM Schedule B5c. The relevant tables for fresh contamination in NEPM Schedule B5c are listed in Table 1.

11.3.3 EILs, acid sulfate soils and acid drainage

The EILs are relevant to certain soil conditions likely to be relevant to many sites in WA. However, the EILs have more limited application where the soils have been affected by the oxidation of iron sulfides and/or other sulfidic minerals, resulting in low pH (generally pH<4). This includes sites affected by acid sulfate soils and sites affected by acid and metalliferous mine drainage (refer also to section 11.3.4).

Acid sulfate soils are widespread around coastal regions of WA and are also locally associated with freshwater wetlands and saline, sulfate-rich groundwater in some agricultural areas. In developing the CSM for the site, consideration should be given to whether acid sulfate soils or potential acid sulfate soils may be present. Soil field pH provides a quick indication of the likely presence and severity of actual ASS. If soil pH at a site is found to be 4 or lower, this is an indicator that metal sulfide minerals may have been disturbed and oxidised. The possibility of actual ASS being present should also be considered if the soil pH is found to be in the range pH 4-5. Refer to DEC (2013) for detailed information and methodology.

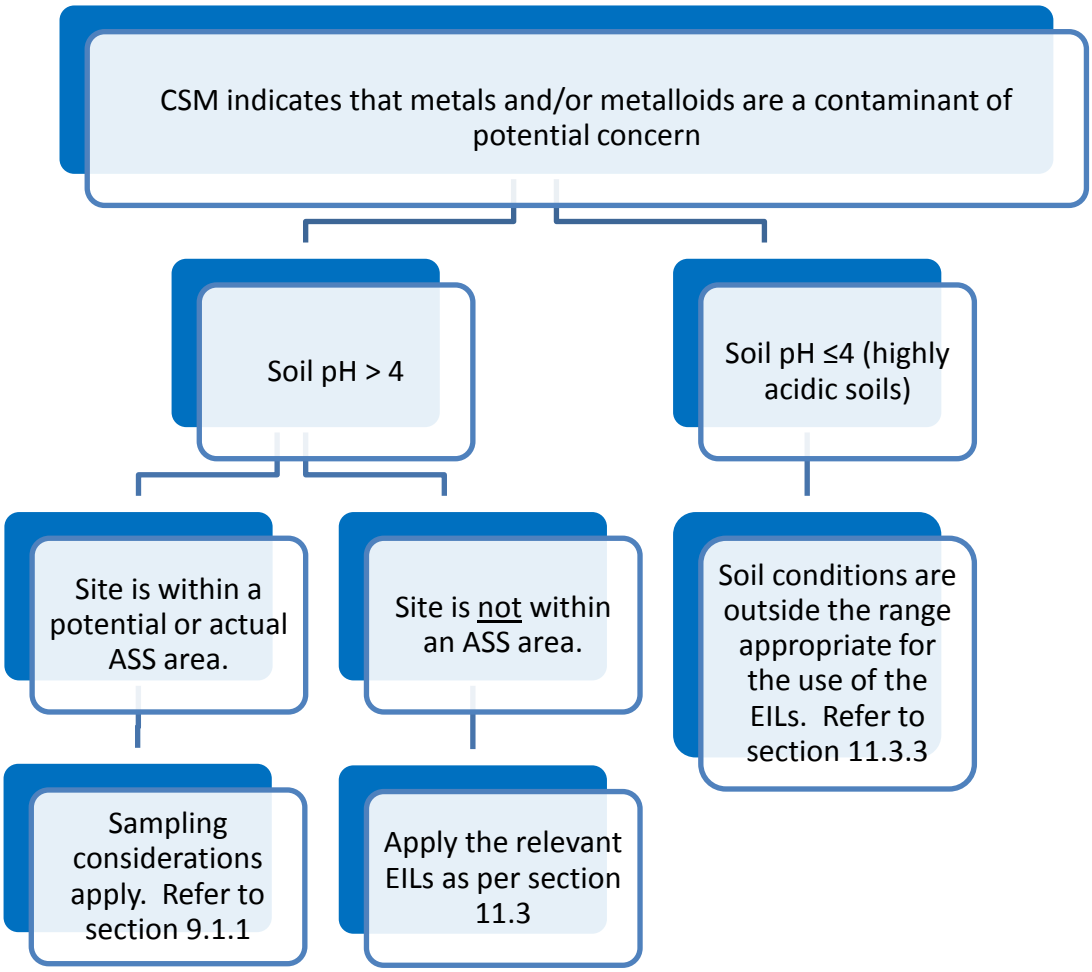
Particular areas of concern for the occurrence of acid sulfate soils (DEC 2013)

- Peaty wetlands in the Perth metropolitan area (e.g. Stirling, Gwelup, Bayswater and Ashford);
- Estuarine, floodplain, damp land and seasonal wetland areas between Perth and Dunsborough, including the Peel-Harvey, Leschenault and Vasse-Wonnerrup estuarine systems;
- Tidal, intertidal and supratidal flats along the northern coastline including the Pilbara and Kimberley coasts;
- Swan Coastal Plain (including iron-cemented and/or organic-rich ‘coffee rock’ sands in Bassendean Sands);
- Scott Coastal Plain; and
- Parts of the Wheatbelt where secondary land salinisation has occurred.

The CSM should be revised to determine whether there is likely to be a risk to human health or the environment, for example via direct contact with soils or leaching to groundwater or surface water. If a potential risk to human health or the environment is identified, DER should be consulted. The requirement for management, monitoring and/or clean-up will be considered on a site-specific basis.

The process for applying the EILs in WA is summarised in Figure 4. Each relevant soil unit in the soil profile should be considered separately.

Figure 4: Procedure for applying EILs in WA

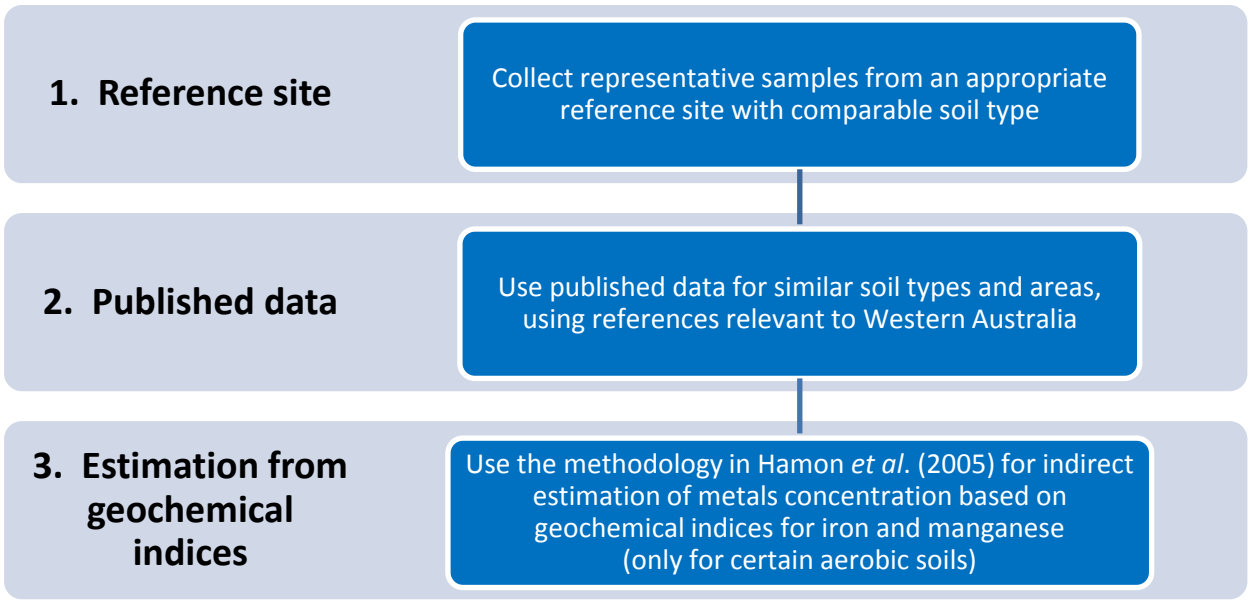


11.3.4 Determining ambient background concentrations

The ambient background concentration or ABC is only relevant when considering metals or metalloids as the background concentration for organic compounds of anthropogenic origin should normally be zero. ABC methods may not be appropriate for the assessment of fill material that has originated from another location because of likely differences in soil characteristics.

Schedule B5b of the NEPM presents three approaches for determining the ABC for metals or metalloid compounds. A summary is provided in Schedule B1. A hierarchy of options for determining ambient background concentration for soils in WA, when applying the EILs is summarised in Figure 5 and described further below.

Figure 5: Hierarchy of options for determining ABC for soils in WA.



1. Reference site (preferred approach)

Consistent with the NEPM, DER's preferred method for determining the ABC is to characterise it at an appropriate reference site, analysing sufficient samples to obtain representative values (refer section 2.5.7 in Schedule B1 of the NEPM). This approach is essential in areas where there is a high naturally occurring background level, such as mineralised areas. For some sites, it may not be possible to find a non-impacted area on the site being assessed and if possible, off-site reference samples should be obtained.

Whether on or off site, the reference site should:

- be located as close as possible to the site being investigated;
- be up-gradient of the site to minimise the risk that surface runoff or shallow groundwater flow will have transported contaminated material to the reference site;
- not be contaminated (sufficient historical information should be provided to demonstrate that the background site has not been affected by land uses carried out on the investigation site or preferably any other potentially contaminating activity (refer to sections 5.2.1 and 8.2); and
- be a site with a comparable soil type (different soil units should be sampled separately).

If necessary, more than one reference site may be selected to address the range of sources and associated contaminants. Soil samples from reference sites should be collected using the same sampling equipment and sample collection and handling methods to those used to collect samples at the investigation site. Samples should be collected from comparable depths and soil horizons.

2. Published data

Where an appropriate reference site is not available, published data on background metal or metalloid concentrations for the relevant soil unit may be used. The data on background metal concentrations presented in Schedule B5b of the NEPM from Olszowy et al. (1995) does not include data from WA. However, Olszowy et al. (1995) does provide limited data from a site in Canning Vale obtained prior to metropolitan development.

Other sources of published data relevant to WA conditions include:

- Australian Soil Resource Information System (ASRIS) (CSIRO, ACLEP & DAFF 2013)
- Mineralogy and chemistry of sandy acid sulfate soils in the Perth metropolitan area of the Swan Coastal Plain (DEC & UWA 2011)
- Soil guide: A handbook for understanding and managing agricultural soils (Moore 1998)
- Geomorphology, soils and landuse in the Swan Coastal Plain in relation to contaminant leaching (Salama et al. 2001)
- Reference soils of south-western Australia (McArthur 2004)
- Soil groups of Western Australia (Schoknecht & Pathan 2013)
- Soil data collected during DER's acid sulfate soil risk mapping project, available online (Landgate 2014)

Published data may not be adequate for estimating ABC or soil parameters in ASS landscapes, particularly for complex sites (refer section 11.3.3).

3. Geochemical indices (least preferred approach)

Estimating background concentrations of metals and metalloids from geochemical indices is not a DER preferred method due to its limitations.

In certain circumstances, background metal and metalloid concentrations can be estimated based on the concept of geochemical indices. For example, the method published by Hamon et al. (2004) assumes a relationship between the concentration of iron (as iron oxyhydroxide minerals) present in soil and the quantity of metal and metalloids bound to the soil. There are limitations to this method, in particular, the relationship is less strong for soils with very low concentrations of iron. The method should only be considered where iron is present in a chemically stable form.

The use of geochemical indices is not suitable where:

- soils are affected by seasonal waterlogging (fluctuating water table or surface flooding);
- anoxic conditions are present (e.g. oxygen is depleted through the decay of organic matter); or
- the soil profile is highly leached (minerals are leached from the surface horizons and accumulate deeper in the soil profile (where well-cemented, known as 'coffee rock').

Anoxic conditions result in chemical reduction and partial dissolution of iron oxyhydroxide minerals, known as 'gleying', and affected soils are typically grey, green or mottled orange or red and grey/green. This process is likely to cause the release of adsorbed metals and metalloids into soil pore-water on a seasonal basis.

The Hamon et al. method may be used for soils developed on deep, iron-rich weathered profiles. Due to the limitations of this method, it should not be used for iron-poor sandy soils, including the Safety Bay Sand and Tamala Limestone on the Swan Coastal Plain, or where soils are seasonally waterlogged and/or anoxic.

11.3.5 Mine sites and mineralised areas

Background levels for metals and metalloids in soil profiles at metalliferous mine sites are likely to be naturally high. However, it should not be assumed that comparable metal and metalloid levels in soils contaminated by mine wastes (e.g. waste rock and tailings) indicate that there is a negligible environmental risk posed by these materials. This is because metals and metalloids are likely to be in a more bioavailable and/or leachable form in a disturbed soil profile or in soils affected by acid drainage compared with the undisturbed materials. Therefore, the application of EILs may not be appropriate at sites that have been extensively disturbed by mining activities and should be considered on a site-specific basis

Practitioners should consider the geochemical processes relevant to the site-specific contaminants of concern. For example, metals and metalloids that form stable oxyanions in solution such as chromium, uranium, arsenic and selenium may be leached from waste rock under neutral or alkaline conditions. Other metals and metalloids such as aluminium, cadmium, lead and copper will be more available in soils affected by acid drainage. Arsenic and uranium may also be mobilised under acidic conditions.

If the EILs in the NEPM are not applicable to the site conditions, a site-specific assessment should be undertaken which considers contaminant leachability, bioavailability and bioaccumulation and the potential risk to ecological receptors and environmental values.

Information on assessing bioavailability and accounting for bioaccumulation when deriving site-specific EILs is provided in Schedule B5b of the NEPM, and discussion of bioavailability and leachability testing is provided in Schedule B3. Refer also to the ecological risk assessment framework in Schedule B5b.

11.3.6 Leaching of soil contamination and protection of environmental values of water

The EILs and ESLs in the NEPM do not take into account the potential for soil contamination to leach and contaminate groundwater or affect aquatic ecosystems. Where necessary, site-specific EILs that protect groundwater quality and aquatic ecosystems may be developed using the method included in Appendix B of Schedule B5b of the NEPM. However, this method requires an understanding of the local groundwater catchment as well as information on the soil-water partition coefficient for the contaminant. Example calculations are provided for zinc and arsenic in Schedule B5c.

An alternative approach is to consider the extent of and potential for contaminant leaching. Practitioners should consider the physicochemical properties of the contaminants, the likely age of contamination and the duration of the potentially contaminating activity in evaluating whether contamination has the potential to be leached or to have already impacted groundwater when developing and refining the CSM. Potential changes in hydrogeological conditions should also be considered; for example, the oxidation of iron oxyhydroxides on a seasonal basis resulting in the mobilisation of previously bound metals and metalloids.

The potential for contaminated soils to leach contaminants can be assessed by soil leachate tests. Guidance on leachability tests for soil is included in Schedule B2 (section 7.6) and Schedule B3 (sections 2.7 and 11) of the NEPM. Samples to be tested for leachability should be selected with reference to the CSM and be representative of the impacted materials. Analysis of appropriate background samples is also recommended, consistent with Schedule B2 of the NEPM and section 11.3.4 above.

Appropriate assessment levels for comparing concentrations of substances within soil leachate should be selected based on the potential receptors identified in the CSM. If groundwater is a potential receptor, the environmental values of groundwater and the applicable assessment levels discussed in section 11.7, should be considered.

For inorganic substances, leachability is affected by soil pH, contaminant solubility and redox conditions. Assessments of leachability in WA should therefore consider whether the site is within an ASS or acidic landscape, and how that may affect contaminant mobility (refer to section 11.3.3).

11.4 Health screening levels for petroleum hydrocarbons

11.4.1 Health screening levels for vapour intrusion

Health screening levels (HSLs) are presented in Schedule B1 of the NEPM to assess health risks related to petroleum vapour intrusion. HSLs are included for petroleum hydrocarbons in soils, groundwater and for direct measurements of soil vapour. They depend on specific soil physicochemical properties, land use scenarios, and the characteristics of building structures. The HSLs were developed for the assessment of petroleum hydrocarbon sites and should not be applied to complex mixtures of contaminants or pure solvents. In these cases, a site-specific risk assessment may be necessary, including an assessment of the cumulative effects of substances present.

It is the responsibility of the assessor to ensure that the assumptions underlying the HSLs are applicable to the site. Completion of the *HSL Application Check List* (Friebel & Nadebaum 2011) will assist in identifying whether the HSLs are applicable to the site and what circumstances require more detailed, site-specific assessment. A copy of the completed check list should be included in any related assessment report submitted to DER.

11.4.2 Health screening levels for direct contact with soil

HSLs)for the direct contact exposure pathway via incidental oral ingestion, dermal contact and dust inhalation of petroleum hydrocarbon contaminated soils are available in Friebel & Nadebaum (2011).

The direct contact criteria for soil should be applied with caution as surface soils with concentrations equal to the levels of the relevant HSLs may give rise to odour concerns and potentially headaches, nausea and eye/respiratory irritation in persons exposed. The direct contact HSLs should be applied in combination with consideration of odours/aesthetics in sensitive locations such as residential and parks/public open space land uses (refer section 7.2).

11.4.3 Screening distances for clean aerobic soil

CRC CARE (2013) provides an assessment approach applicable to certain petroleum hydrocarbon sites, which uses screening distances to screen out sites that do not pose a risk to human health via vapour intrusion. The screening distance is the minimum thickness (vertical) of soil with a high potential for bioattenuation that is sufficient to effectively attenuate petroleum vapours such that they do not pose a risk to human health (i.e. the potential for PVI is considered negligible) and no further assessment of PVI is required.

Limitations apply, and it is the responsibility of the assessor to ensure that the selected approach is applicable to the site. These screening distances are relevant to sites with a high potential for bioattenuation of petroleum hydrocarbon vapours and are not applicable to:

- large contaminant plumes with a significant area of LNAPL (such as leaks associated with major pipelines or refinery/bulk terminal sites);
- LNAPL sources below large slabs/buildings (≥7.5 m minimum distance from the centre to the edge of a continuous sealed slab); and/or
- ASS landscapes (these typically have reducing, anaerobic, conditions).

In these circumstances, a detailed PVI assessment is more appropriate as discussed in CRC CARE (2013).

11.5 Interim screening levels for MTBE

An interim screening level of 0.5mg/kg has been adopted for methyl tertiary-butyl ether (MTBE) in soil to identify the presence of MTBE because of its high solubility and potential for impacting groundwater.

An interim screening level of 0.02 mg/L has been adopted for MBTE in water, based on odour and taint of water supplies.

DER should be notified of the detection of MTBE in soil at concentrations above the interim screening level as soon as practicable. Reporting requirements under the CS Act will be considered on a site-specific basis. Any exceedences of the screening levels should be identified and discussed in the assessment report. DoH should be consulted through DER where the interim screening level is exceeded—preparation of a detailed human health risk assessment may only be necessary at concentrations much greater than these screening levels.

11.6 Microbiological assessment levels

Potential sources of microbiological contamination include septic tanks, sewage sludge or biosolids, 'night soil', landfills, animal and bird manures, buried animal carcasses, wastewater systems, wastewater treatment plants, sewers, cesspools, landfills and livestock operations (animal manures and animal carcasses). The NEPM does not provide specific guidance on the assessment of microbiological contamination of soil or water.

An assessment of microbiological risks via soil exposure is generally not required unless sewage treatment-related activities have been carried out on site (excluding domestic systems), or where intensive livestock operations or waste disposal (particularly large-scale disposal of manure or animal carcasses), or the historical application of biosolids are involved and a change to a more sensitive land use is proposed.

Where the CSM indicates that there may be human exposure to microbiological contamination in surface water or groundwater the initial assessment should include screening for *E. coli* (thermotolerant coliforms) as an indicator of faecal contamination and compared with the relevant microbiological assessment levels (MALs) in Table 8.

Further information relevant to the assessment of microbiological risks from pathogenic organisms can be found in EPHC et al. (2006), EPHC et al. (2008), Pedley et al. (2006), CRC for Water Quality and Treatment (2004) and DoH (2011).

Public health risks related to wastewater overflows will generally be managed by DER and DoH in the first instance as an immediate pollution response issue in accordance with *Wastewater Overflow Response Procedures 2013* (DoH et al. 2013). Emergency response (such as for floods) is outside the scope of this document, as stated in section 3.2.

11.7 Assessment levels for surface water and groundwater

Groundwater and surface water contamination assessment in WA is risk-based, consistent with the framework provided in Schedule B6 of the NEPM. The site assessment should consider background water quality, which is considered to be the sum of both ambient and natural sources in the local area of a site. Background water quality is relevant when considering pH, nutrients, metals and metalloids, but organic compounds of anthropogenic origin should normally be assumed to have zero concentration. More information is provided in section 3.3 of Schedule B6 of the NEPM.

In WA, the assessment levels discussed below should be considered in the assessment of both groundwater and surface water in the identification of human health and environmental receptors (including risks to environmental values) and the development of the CSM.

11.7.1 Aquatic ecosystems

Assessment levels for fresh and marine aquatic ecosystem protection are provided in Table 7 in Appendix D of this guideline, and are sourced from ANZECC & ARMCANZ (2000).

Fresh water aquatic ecosystems include lakes, reservoirs, wetlands, rivers and streams and marine water aquatic ecosystems include estuarine, coastal and marine environments (ANZECC & ARMCANZ 2000). They also include groundwater dependent ecosystems (discussed below). ANZECC & ARMCANZ (2000) does not provide assessment levels for inland salt lakes and a site-specific assessment may be necessary.

Assessment levels for fresh or marine aquatic ecosystems should be applied to substances in the relevant surface water body or to groundwater where it discharges to an aquatic ecosystem. The assessment of estuarine systems may require consideration of both fresh and marine assessment levels and should be considered on a site by site basis.

The Australian Water Quality Guidelines for Fresh and Marine Water Quality 2000 (ANZECC & ARMCANZ 2000) lists trigger values at three different protection levels:

- *high conservation/ecological value* ecosystems—effectively unmodified or other highly-valued ecosystems, typically (but not always) occurring in national parks, conservation reserves or in remote and/or inaccessible locations;
- *slightly–moderately disturbed* ecosystems—aquatic biodiversity may have been adversely affected to a relatively small but measurable degree by human activity, such as rural streams receiving runoff from land disturbed by grazing or pastoralism, or marine ecosystems adjacent to metropolitan areas; and
- *highly disturbed* ecosystems—measurably degraded ecosystems of lower ecological value, such as shipping ports and harbours serving coastal cities, urban streams receiving road and stormwater runoff, or rural streams receiving runoff from intensive agriculture/horticulture.

Practitioners should refer to the NEPM and to ANZECC & ARMCANZ (2000) for further information on applying these assessment levels.

The assessment levels presented in Table 7 are applicable to *slightly—moderately disturbed* aquatic ecosystems. Additional assessment levels for *high conservation/ecological value* ecosystems and *highly disturbed* ecosystems are provided in ANZECC & ARMCANZ (2000). The assessment report should contain a justification for the level of protection selected. For some substances Table 7 states ‘refer to guideline’ if the assessment level is considered to be of low reliability because it was derived using limited data (ANZECC & ARMCANZ).

At the time of publication, the Australian Water Quality Guidelines for Fresh and Marine Water Quality 2000 (ANZECC & ARMCANZ 2000) were under revision. More information is available from www.environment.gov.au/topics/water/water-quality/national-water-quality-management-strategy

Assessment levels for iron based on Dove (2007) and total nitrogen and total phosphorus based on Swan River Trust (2008) are also presented in Table 7 for application in WA.

11.7.1.1 Groundwater-dependent ecosystems

Consistent with Schedule B6 of the NEPM, groundwater environmental values should include ‘ecosystem protection’, which refers to aquatic ecosystems partly or fully dependent on groundwater to maintain ecosystem health (groundwater-dependent ecosystems). This includes wetlands and rivers reliant on groundwater base flow,

some estuarine and near-shore marine systems, cave ecosystems and subterranean fauna.

Subterranean fauna include stygofauna (aquatic organisms living in groundwater) and troglofauna (air-breathing organisms living in caves and voids). WA's subterranean fauna is recognised as being globally significant because of its high species richness and high levels of endemism, and particularly high biodiversity occurs in Cape Range, Barrow Island, and the Yilgarn and Pilbara regions (EPA 2013). If subterranean fauna are likely to be present, they should be considered a relevant groundwater environmental value.

The decision whether to apply the fresh or the marine guidelines to sites where a groundwater-dependent ecosystem has been identified as a relevant receptor, should be considered on a site-specific basis based on the CSM.

11.7.2 Drinking (potable) water

Drinking water assessment levels are provided in Table 7 in Appendix D of this guideline and are derived from NHMRC & NRMMC (2011). For microbial drinking water quality standards, refer directly to NHMRC & NRMMC (2011).

Drinking (potable) water is defined as water intended primarily for human consumption, either directly as supplied from the tap or indirectly in beverages, ice or foods prepared with water. Some domestic uses of water, such as bathing and showering, are also considered potable uses because they involve a high potential for dermal absorption and incidental ingestion of substances in water (NHMRC & ARMCANZ (2011).

The public drinking water supply in WA is sourced from a combination of surface water (freshwater dams), groundwater and desalination of seawater. Public drinking water source areas are proclaimed under the *Metropolitan Water Supply, Sewerage and Drainage Act 1909* or the *Country Areas Water Supply Act 1947* as a Water Reserve, a Catchment Area or an Underground Water Pollution Control Area.

When to apply the Australian Drinking Water Guidelines (ADWG)

Drinking water should be considered a relevant environmental value and the ADWG used to assess concentrations of substances in groundwater or surface water if:

- a public drinking water source area is a potential receptor;
- scheme water is not available (in this situation it is reasonable to assume that groundwater or surface water may be used for potable purposes); and/or
- there is a reasonable expectation that the groundwater or surface water could be used as a drinking water resource, even where it is not currently being used for that purpose.

Factors to consider with regard to whether the use of water as a drinking water resource is feasible include background water quality, yield or flow, hydrogeology or hydrology, the potential for saline intrusion into aquifers and/or impact on groundwater-dependent ecosystems. Saline groundwater is desalinised for potable use in many Mid-West and Goldfields towns.

In accordance with DoH (2014) advice, domestic bore water should not be used for drinking, bathing, filling swimming and paddling pools, food preparation or cooking

unless it has been appropriately tested and treated.

Information on public drinking water sources in WA is available from the Department of Water's drinking water source protection reports, the Western Australian Planning Commission's land use and water management strategies and various Water Corporation publications, including its 10-year plan for WA (Water Corporation 2012).

11.7.3 Non-potable use of water

Assessment levels for the non-potable use of water are provided in Table 7 in Appendix D of this guideline and are derived from DoH (2014).

DoH has developed guidelines for non-potable use (NPUG) to protect the public who may be exposed to contaminated groundwater in a non-potable setting (DoH 2014). The method by which they were derived is consistent with the National Health and Medical Research Council's *Guidelines for Managing Risks in Recreational Water* (NHMRC 2008), which is also applicable to recreational waters (refer section 11.7.4 below).

The NPUG are applicable to surface water and groundwater that may be used for watering gardens (including growing edible produce), irrigating parks and reserves, washing cars and clothes, and flushing toilets. They apply to groundwater prior to abstraction, i.e. the NPUG should be applied at the point of monitoring in the first instance. Exceedences of the NPUG at the point of use, e.g. in water abstracted from a domestic bore, may require immediate action to mitigate risks to the relevant receptors.

The DoH (2014) guideline value is generally a factor of 10 times the corresponding ADWG health value (or equal to the aesthetic value where there is no health value) except for certain odoriferous chemicals where the health value is retained. Guideline values for pesticides not listed in the ADWG have been derived using the same methods as for the NPUG (DoH 2014).

When to apply the NPUG

'Non-potable use' should be considered an environmental value and the NPUG used to assess concentrations of substances in groundwater or surface water if:

- the water source is currently used for that purpose (for example, a groundwater bore is present on the site);
- the site is up-hydraulic gradient of an area where water is used for that purpose (e.g. nearby groundwater bores) which may be impacted by contamination; and/or
- there is a reasonable expectation that water could be used for non-potable purposes in the future (e.g. owners or occupiers could install a new groundwater bore).

DoW has published maps of areas considered suitable and unsuitable for the development of a groundwater bore within the Perth superficial aquifer (*Operational policy 5.17—Metropolitan domestic garden bores* (DoW 2011). Areas may be considered unsuitable for domestic garden bores by DoW due to:

- the groundwater salinity;
- the potential for saline intrusion;
- the proximity to conservation wetlands or groundwater-dependent ecosystems;
- the unreliable yield (e.g. Guildford clay);
- the presence of ASS;
- abstraction adversely affecting an underlying confined aquifer; or
- the area already being over-allocated to existing users.

In unsuitable areas DoW does not support the establishment of new domestic garden bores. However, with the exception of groundwater in the Albany area and the Exmouth north-west cape of the Gascoyne (DoW 2014a), there is generally no requirement to obtain a licence to install a groundwater bore into superficial aquifers for low abstraction volumes (such as for garden bores), and registration of bores is not compulsory.

Therefore if contamination is present in the superficial aquifer, the potential for current and future non-potable use of water should be considered in the development of the CSM. DER may consider that clean-up or management is necessary to protect human health or the environmental values of groundwater at a site even in an 'unsuitable' area or where no bores are registered with DoW.

11.7.4 Recreational use

Consistent with the NEPM, where the CSM indicates that there may be public exposure to contaminants in surface water (or in groundwater where it discharges to a river, lake or estuary), via recreational activities such as water sports and swimming, the *Guidelines for Managing Risks in Recreational Water* (NHMRC 2008) apply.

Consistent with NHMRC (2008), DoH (2014) has specified that the NPUG (section 11.7.3) should be applied for the assessment of chemical substances in recreational waters, or groundwater that discharges to recreational waters.

11.7.5 Agricultural or industrial use

Assessment levels for water used for agricultural or commercial irrigation are provided in Table 7 in Appendix D of this guideline, and are derived from ANZECC & ARMCANZ (2000).

The short and long-term irrigation water guidelines (listed in Table 7), apply to commercial and agricultural applications. It is important to note that these guidelines are not usually applicable to an urban setting. These guidelines were developed to minimise the build-up of contaminants in surface soils during irrigation and to prevent the direct toxicity of contaminants in irrigation waters to standing crops. Short-term irrigation water guidelines (STIWG) apply for up to 20 years of irrigation and long-term irrigation water guidelines (LTIWG) apply for up to 100 years.

For some substances Table 7 states 'refer to guideline' if the assessment level is considered to be of low reliability because it was derived using a limited quantity of data (ANZECC & ARMCANZ). Refer to ANZECC & ARMCANZ (2000) for additional assessment levels and guidance on their application to aquaculture or stock watering.

11.7.6 Pesticides

The term 'pesticide' includes agricultural chemicals such as insecticides, herbicides, nematicides, rodenticides and miticides. The use of pesticides within WA is subject to regulation. When used correctly and in accordance with label and material safety data sheet directions, leaching of pesticides to groundwater is not considered likely. The detection of pesticides in groundwater suggests inappropriate use (such as repeated application at concentrations unsuitable for the environmental setting), or illegal disposal, spills or dumping.

The Department of Health Environmental Health Directorate (DoH) should be notified if pesticides are detected in surface water or groundwater, even if the concentrations do not exceed the assessment levels provided in Table 7. Whenever pesticides are detected, the DoH may require an investigation to ensure appropriate controls are in place.

11.8 Assessment levels for sediment

The interim sediment quality guidelines (ISQGs) presented in Table 9 in Appendix D are sourced from the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000). The ISQGs have limitations relating to the availability of appropriate ecotoxicology data and the small number of species on which they are based. The quality of sediment pore water should be assessed against the criteria relevant to the adjacent water body (refer section 11.7.1).

The ISQG guidelines contain two concentrations, the ISQG-Low concentration (or trigger value) and the ISQG-High concentration. The ISQG-Low trigger value is a threshold concentration and below this concentration the frequency of adverse effects is expected to be very low. The ISQG-High concentration is intended to represent a concentration above which adverse biological effects are expected to occur more frequently.

Where aquatic ecosystems are considered to be pristine and therefore of high environmental value, such as in marine parks and marine sanctuary areas, a precautionary approach to assessment is required. In these ecosystems, there should be no detectable change from natural background conditions permitted (ANZECC & ARMCANZ 2000).

For more information relevant to the application of the ISQGs, the practitioner should refer directly to the ANZECC & ARMCANZ (2000). At the time of publication, this guidance was under review. For more information, refer: www.environment.gov.au/topics/water/water-quality/national-water-quality-management-strategy.

Where the investigation site is within an acid sulfate or acidic landscape, disturbance of sediments could cause the formation of acidity, a drop in pH and the mobilisation of metals from sediments. In that circumstance, the ISQG triggers in Table 9 are not directly relevant and a site-specific assessment should be undertaken. Further information on the assessment and management of ASS and acidic landscapes is available in DEC (2011b and 2013) available at www.der.wa.gov.au/ass and sections 9.1.1 and 11.3.3.

The *National Assessment Guidelines for Dredging* (DEWHA 2009) should be consulted where the sediments being assessed are within marine waters, and are being assessed for dredging and ocean disposal. Note that these guidelines are not appropriate for assessing disposal of dredged sediment to land. This would require characterisation of the material and assessment of its compatibility with the receiving environment and associated land uses on a site-specific basis (in accordance with guidance provided in Schedule B2 of the NEPM).

12 Remediation

12.1 Introduction

The assessment process outlined in this guideline recommends assessment of site contamination to the extent necessary to provide sufficient information to enable risk-based decision-making. If the risk assessment process identifies unacceptable risks to human health, the environment and/or environmental values, some form of remediation (clean-up and/or management) will be required to mitigate those risks.

Site classification under the CS Act

Sites that require remediation are classified *contaminated—remediation required* under the CS Act [Refer to DER 2014c for further information on when a site is likely to be classified as *contaminated—remediation required*].

An appropriate site remediation and validation (SRV) report must be submitted for assessment (refer to Appendix A for a report checklist) in order for DER to reclassify a site that has been remediated. If residual contamination is present, it may also be necessary to submit a site management plan (SMP).

The revised site classification will be *decontaminated*, *contaminated—restricted use* or *remediated for restricted use* depending on the extent of remediation carried out.

If poorly selected, designed and/or implemented, remediation (clean-up) has the potential to cause greater impact than the contamination it seeks to address. DER therefore supports consideration of sustainability issues:

- at the planning stage for a project (as the remediation solution may influence the project design and vice versa); and
- when evaluating and selecting the remedial strategy/option.

Sustainable remediation

'a remedial 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'

A Framework for Assessing the Sustainability for Soil and Groundwater Remediation, Sustainable Remediation Forum (SuRF) Australia (2011).

www.surfanz.com.au

The remediation of contaminated sites includes three distinct stages:

- development of a remedial action plan (RAP)—planning the active remedial work and how its success will be evaluated (validated);
- implementation of the RAP and validation; and
- if necessary, management of residual contamination via a site management plan (SMP)—refer section 13.2.

A remedial action plan (RAP) should be prepared when some form of active remediation (clean-up) is required. The RAP defines the purpose and specific objectives of the remediation, documents the evaluation of remedial options, and specifies how the remediation will be carried out and how it will be validated.

The remedial activities undertaken and the validation of the remedial works should be documented in a site remediation and validation (SRV) report. Appendix A provides guidance on the information that should be included in RAP and SRV reports.

Remediation should be planned and undertaken by suitably experienced and qualified consultants and/or contractors.

At the time this guideline was written, CRC CARE, in consultation with regulators (including DER), industry and others, was in the process of developing a national remediation framework (NRF) addressing both clean-up and management of contaminated sites. It is anticipated that the NRF will form a source of authoritative guidance on site remediation.

The NRF will provide guidance on the following issues:

National Remediation Framework		
Development of remediation plans	*Implementation of remediation plans*	*Post remediation considerations*
• site-specific remediation objectives • identifying remedial options • selection of remedial technologies • treatability studies • cost-benefit and sustainability analysis	• work health and safety • stakeholder engagement • documentation and record keeping	• remediation validation and closure • long-term monitoring • auditing/third party review • institutional controls

For further information, refer to the CRC CARE website: www.crccare.com/knowledge-sharing/national-remediation-framework.

12.2 Remediation objectives

Defining the remediation objectives is an important first step in developing the RAP. Issues that should be taken into consideration include but are not limited to:

- the risks to be mitigated and the desired outcomes;
- the time frame available to carry out the remedial works (refer section 12.3);
- the sensitivity of the current or proposed land use and the environmental values applicable to the site;
- the views of stakeholders, particularly owners of affected sites; and
- the acceptability of post-remediation institutional controls such as ongoing site management or a memorial on the certificate of title (refer section 13.2).

A remedial strategy, which prioritises actions to be undertaken (addressing the highest risks to human health and the environment first), may be necessary depending on funding and other constraints.

The RAP should detail the remedial objectives, including the specific remedial targets to be achieved, and the rationale and method by which they were derived. The remedial targets may be derived through adjustment of generic assessment levels appropriate to the site conditions (refer section 10.5), and/or a site-specific risk assessment process. If site-specific remedial targets have been developed, it is recommended that these are agreed with the auditor or DER (and DoH for health-related criteria), by submitting the relevant report(s) —detailing the risk assessment and derivation of the site-specific remedial targets — for assessment prior to finalising the RAP.

12.2.1 Remediation of source and affected sites

Persons responsible for the remediation of source sites should consider the land use and environmental values of affected sites when developing the RAP. The views of owners and occupiers of affected sites should be sought, for example, regarding the remediation objectives and time frame for completion. Guidance on engaging with stakeholders is provided in Schedule B8 of the NEPM and section 14 of this guideline.

DER's default position when assessing the acceptability of a RAP is that the clean-up will restore and protect the environmental values of affected sites, such as rendering groundwater suitable for domestic irrigation and enabling restrictions on land use to be removed.

Remediation of a source site to the extent that it achieves a restricted use classification for affected sites (i.e. *remediated for restricted use*), may be acceptable where the negotiated remediation outcome and likely classification under the CS Act are acceptable to the affected parties, providing that human health and ecological receptors are protected. The RAP should document the negotiated outcomes with stakeholders and include copies of the relevant agreements.

12.3 Time frame for remediation

DER expects that the time frames proposed in the RAP will be reasonable and appropriate for the level of risk posed by the contamination and the sensitivity of the receptors. The time frames should be linked to the remedial objectives and site-specific factors, such as the remediation necessary to prevent contamination migrating off site and affecting additional properties and sensitive environmental receptors.

Issues that should be taken into consideration include but are not limited to:

- the degree of risk posed to human health, the environment and environmental values and whether actual or potential harm is occurring;
- the nature and extent of contamination and the potential for further contaminant migration (for example, is a groundwater plume increasing, stable or contracting in extent?);
- the results and reliability of contaminant fate and transport modelling;
- the acceptability of time frames to stakeholders, particularly the owners of affected sites; and
- intergenerational equity (remediation should be completed in a time frame that ensures the polluter bears the cost rather than future generations).

12.4 Evaluation of remedial options

The RAP should document the process that has been undertaken to select the proposed remediation approach and demonstrate that the relevant issues relating to the site have been taken into consideration. For large-scale projects, a stand-alone RAP may be developed, whereas for small-scale projects, a chapter within the DSI report may adequately address the requirements for a RAP.

The evaluation of remedial options should include consideration of the preferred hierarchy for site clean-up and/or management as described in Principle 16 of the NEPM:

Principle 16 of the NEPM—Hierarchy of options for remediation

…the preferred hierarchy of options for site clean-up and/or management which is outlined as follows:

- on-site treatment of the contamination so that it is destroyed or the associated risk is reduced to an acceptable level; and
- off-site treatment of excavated soil, so that the contamination is destroyed or the associated risk is reduced to an acceptable level, after which soil is returned to the site; or,

if the above options are not practicable:

- consolidation and isolation of the soil on site by containment with a properly designed barrier; and
- removal of contaminated material to an approved site or facility, followed, where necessary, by replacement with appropriate material; or
- where the assessment indicates remediation would have no net environmental benefit or would have a net adverse environmental effect, implementation of an appropriate management strategy.

When deciding which option to choose, the sustainability (environmental, economic and social) of each option should be considered, in terms of achieving an appropriate balance between the benefits and effects of undertaking the option.

In cases where no readily available or economically feasible method is available for remediation, it may be possible to adopt appropriate regulatory controls or develop other forms of remediation.

The remediation approach should also consider the views of relevant stakeholders. Guidance on carrying out community engagement is provided in section 14 and NEPM Schedule B8.

The evaluation of remedial options should consider the constraints applying to the site itself as well as the environmental setting and surrounding land uses. Issues that should be taken into consideration include but are not limited to:

- technical constraints (technical ability to remove, destroy or reduce (treat), contain or manage the substance(s) causing contamination and restore the relevant environmental values);
- logistical constraints (such as site access, availability of materials and infrastructure and waste disposal);

- site management issues that may arise from the preferred method(s) (refer section 13.1);
- acceptability of preferred method(s) to stakeholders, particularly owners of affected sites and neighbours; and
- sustainability, including waste minimisation.

Appendix A provides guidance on the information that should be considered when evaluating remedial options and included in the RAP report.

Information relevant to evaluating remedial options and specific clean-up technologies can be found on the following websites:

- CRC CARE www.crccare.com/publications/technical-reports including the National Framework for Remediation guidance (in progress) and:
    - CRC CARE Technical report 15: *A technical guide for demonstrating monitored natural attenuation of petroleum hydrocarbons* (Beck & Mann 2010)
    - CRC CARE Technical Report 18: *Selecting and assessing strategies for remediation LNAPL in soils and aquifers* (CRC CARE 2010).
- US EPA CLU-IN www.clu-in.org/
- ITRC www.itrcweb.org/Guidance
- CL:AIRE www.claire.co.uk/
- SURF ANZ www.surfanz.com.au/

Guidance on specific clean-up technologies has been published by NSW EPA and DER:

- *Best Practice Note: Landfarming* (NSW EPA 2014a)
- *The use of monitored natural attenuation for groundwater remediation* (DER 2014c).

12.5 Requirements for a works approval under the EP Act

There are currently no requirements under the EP Act to obtain a works approval or pollution prevention licence to undertake clean-up on the site on which contamination has originated. However, some clean-up methods carried out off site may result in that other site being considered a prescribed premises under Part V Division 3 of the *Environmental Protection Act 1986* (EP Act) (refer to section 6.2 of this guideline), which would trigger the requirement for a works approval.

Off-site soil treatment facilities that would be considered to be prescribed premises
An off-site bioremediation facility would be considered a Category 61A Premises (solid waste facility), if 1,000 tonnes or more per year of solid waste is stored, reprocessed, treated or discharged onto land. This may also trigger Category 67A Premises (compost manufacturing and soil blending), in which case Part V Division 3 of the EP Act would apply and a works approval would be required.

Visit www.der.wa.gov.au/our-work/licences-and-works-approvals for more information.

12.6 Validation

Validation enables clean-up performance, in the context of the remediation objectives and remedial targets, to be evaluated. All clean-up carried out should be validated and documented otherwise DER cannot provide 'sign-off' for a planning condition or confirm in the site classification that remediation has been successfully undertaken at the site.

Clean-up is validated by implementing an SAQP that has been designed to characterise the post-remediation condition of the site and provide results that can be assessed against the remediation objectives and remedial targets. The SAQP should consider the potential for contaminant rebound and other site-specific factors such as seasonal effects.

Although the NEPM does not specifically discuss validation, guidance within Schedule B2 is relevant to developing the SAQP and implementing the sampling program and data evaluation to characterise (i.e. validate) a site after clean-up.

The remedial activities and the results of validation should be documented in a site remediation and validation (SRV) report. The checklist in Appendix A of this document lists issues for consideration in an SRV report.

Site classification under the CS Act

An appropriate site remediation and validation (SRV) report must be submitted in order for DER to reclassify a site that has been cleaned-up. If a satisfactory SRV is not submitted, an 'endpoint' classification such as '*decontaminated*' or '*remediated for restricted use'* cannot be issued.

12.7 Bioremediation of soils

Bioremediation, when appropriately managed, can be an environmentally sound and cost effective method of treating contaminated soils containing certain organic compounds. Successful bioremediation may enable the reuse of treated soils and minimise disposal of soil to landfill.

There are numerous types of bioremediation methods that include both *in situ* and *ex situ* methods for treating soil and groundwater.

Meaning of 'bioremediation'

Bioremediation means an accelerated process using micro-organisms (indigenous or introduced) and other processes to degrade and detoxify organic substances to less toxic compounds, such as carbon dioxide and water, in a controlled environment.

Bioremediation, in the context of soil treatment, includes bio piles (also known as bio cells, bio heaps and bio mounds), which are above ground engineered systems that use oxygen to stimulate the growth and reproduction of aerobic bacteria, which in turn, degrade the contaminants adsorbed onto soil. Bio piles are aerated by forcing air to move by injection or extraction through slotted or perforated piping placed through the pile. Landfarms are similar to bio piles but are usually aerated by tilling.

This section discusses *ex situ* treatment of soils, which is generally undertaken in contained and managed bio piles or, subject to limitations, by land farming either on site, or at an approved off-site location. Depending on the scale of the operations, a bioremediation facility may be considered a prescribed premises (refer to sections 6.1.1 and 12.5).

The design requirements for bioremediation facilities are site-specific and are outside the scope of this guideline.

The location and construction of bioremediation facilities should be carefully considered to avoid negatively impacting the surrounding environment and the community. Guidance on site selection and other considerations for establishing and managing a bioremediation facility is provided in *Best Practice Note: Landfarming* published by New South Wales Environment Protection Authority (NSW EPA 2014).

Bioremediation facilities should incorporate contemporary emission and control systems.

DER expects that effective stakeholder engagement will be undertaken by proponents prior to constructing a bioremediation facility.

It is generally not advisable to construct bioremediation facilities in close proximity to sensitive land uses such as residential areas, child care centres, schools or public open spaces or sensitive environmental receptors.

Depending on the nature of the facility, surface and groundwater monitoring may be required for the duration of the bioremediation operation and for a period post-completion, to evaluate the performance of the emission control measures.

Guidance on groundwater monitoring is provided in Schedules B2 and B6 of the NEPM.

Guidance on monitoring of air quality is provided in DEC (2011a). Note that some ambient air standards are prescribed in the National Environment Protection Measures for ambient air (NEPC, 2008) and air toxics (NEPC, 2004).

Considerations for site management are discussed in section 13.1 below.

13 Site management

13.1 Site management during assessment and remediation

13.1.1 Introduction

Careful planning and implementation of site management measures during the assessment and remediation phases, together with appropriate community engagement, are essential to ensure that disturbance of contamination does not result in a risk to human health, the environment or environmental values, or cause concern or nuisance to the surrounding community. The measures to be adopted should protect public and worker health and safety, the environment and address aesthetic issues. Work, health and safety considerations are discussed briefly in section 3.1.

The site management measures to be adopted should be documented in the SAQP, the RAP, or in a stand-alone Site Management Plan (SMP) report, as appropriate for the scale of the operation. This type of SMP documents transient measures to be adopted as opposed to that required for ongoing site management (discussed in section 13.2.2).

The EP Act provides for the prevention, control and abatement of pollution and environmental harm. Part V of the *Environmental Protection Act 1986* places a clear obligation on persons to prevent pollution and specifies pollution and environmental harm offences and notices, orders and directions that can be enforced to address pollution and environmental harm.

Section 15 of Schedule B2 of the NEPM provides guidance on the protection of human health and the environment during site assessment, which is also relevant to site management during remediation. Some elements of site management are discussed below and additional sources of information provided. Schedule B8 of the NEPM and section 14 of this guideline should be consulted for guidance on community engagement and risk communication.

13.1.2 Dust and odours

Dust and odours generated during the excavation and/or disturbance of soils need to be managed at their source. Odours may impact the local community because they cause nuisance, but also because of concerns regarding potential risks to human health and the environment.

Odour management should include the use of contemporary odour mitigation measures which may include the use of odour suppressants, foggers and biodegradable foams. Monitoring at the site boundary should be undertaken if the risk of potential emissions is significant.

The DoH (2009) asbestos guidelines include guidance on air quality monitoring and principles and methods applicable to the management of nuisance dust as well as potential asbestos contamination issues.

Additional information on managing dust and nuisance/noxious odours can be found in DEC (2011a) and NEPC (2004 and 2008).

13.1.3 Water management

Water management including appropriate controls should be considered during the planning stage of site assessment and remediation. Water should be managed to ensure that potential run-off, leachate or wastewater generated at the site does not result in the movement of contaminated soils or water to uncontaminated portions of the site or off site. A discharge of contaminated soil and/or water to the environment (including stormwater drains), may be considered an offence under the *Environmental Protection (Unauthorised Discharge) Regulations 2004* and may result in a reporting obligation under the CS Act.

Recycling water for dust suppression of stockpiles is considered acceptable where it can be demonstrated that it will not cause unacceptable risks to the environment, human health or environmental values.

In the event that all other mitigation measures have been exhausted, the following options may be considered for the disposal of wastewater:

- on-site treatment;
- disposal to sewer—the Water Corporation considers applications for a one-off discharge of industrial wastewater to sewer (further information is available at www.watercorporation.com.au/home/business/trade-waste); or
- off-site treatment and/or disposal (refer to section 13.1.6 on transportation).

The approval of the relevant authority (such as the Swan River Trust, local government authority or DER), is required for water to enter wetlands or waterways, either directly or indirectly, via the stormwater or the associated drainage system. For further information refer to section 5.3 of DEC (2011b).

Additional information on water management

Water Quality Protection Note 26: Liners for containing pollutants, using synthetic membranes (DoW 2013) www.water.wa.gov.au/PublicationStore/first/84590.pdf.

Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC & ARMCANZ 2000).

13.1.4 Noise

Noise generated at a site can pose a potential health risk to workers and a nuisance to occupants of neighbouring properties. Potential sources of noise (and vibration) include earthmoving equipment, trucks and other mobile plant and drilling activities and fixed plant such as pumps and generator sets.

Potential noise issues should be addressed in accordance with the *Environmental (Noise) Regulations 1997* (Noise Regulations), which are regulated by the local government authority, unless the site is a Prescribed Premises, in which case it is regulated by DER.

Reversing beepers on mobile plant are not exempt from the Noise Regulations and the use of broad-band beepers or non-acoustic warning systems should be considered.

For further information, contact the relevant local government authority www.dlg.wa.gov.au/content/directory/default.aspx or DER www.der.wa.gov.au/your-environment/noise.

13.1.5 Stockpiling

Contaminated soil may need to be stockpiled while awaiting results of laboratory analysis for its characterisation, or before transport to another site for re-use, treatment or disposal. To prevent potential re-contamination of the site or adverse impacts to the surrounding environment, stockpiled soils should remain on site for the shortest practical time after being excavated. Uncovered stockpiles should not be sited in close proximity to sensitive receptors such as residential properties, child care centres, schools or public open spaces.

Guidance on the characterisation of stockpiled materials is provided in section 9.5.3 of this guideline and section 7.5 of Schedule B2 of the NEPM. Consideration should be given to the following factors:

- maintaining a log of stockpile locations, their origins, relevant sample locations and result and transport details off site;
- use of an effective liner or sealed surface in combination with bunding to prevent run-off or soil erosion;
- restricting the maximum height of a stockpile to be generally less than 3 metres/ and/or lower than boundary fence heights;
- avoiding locating stockpiles adjacent to, or in close proximity to, site boundaries;
- maintaining an effective dust and/or odour mitigation cover; and
- maintaining appropriate soil moisture content to reduce dust emissions (particularly during handling).

Additional information on stockpile management
Guideline for stockpile management: Waste and waste-derived products for recycling and re-use (SA EPA 2010)
Treatment and management of soils and water in acid sulfate soil landscapes (DEC 2011b)

13.1.6 Transportation

The transportation of contaminated materials may be required when materials are being moved around a site or moved off site for treatment, re-use or disposal. Whatever level of contamination is present, materials being moved off site should be transported in a manner that ensures there is no spillage from the vehicle. Care should be taken when moving contaminated material within the boundaries of a site to ensure that contamination is not spread to previously unaffected areas.

If contaminated material requires transport on a road and is determined to be a controlled waste in accordance with the *Environmental Protection (Controlled Waste) Regulations 2004* (Controlled Waste Regulations), the waste holder (the person who is in possession or control of the controlled waste), has statutory obligations under the Controlled Waste Regulations. Additional information is available at www.der.wa.gov.au/controlledwaste.

Documentation of the volumes taken off site, the nature of the materials, licences (such as a Controlled Waste Licence) and acceptance receipts from the receiving facility should be included in the relevant assessment/remediation report.

13.2 Ongoing site management

13.2.1 Overview

A site management approach based on preventing exposure to contamination may be necessary where it is not possible/desirable or viable to remediate a site to a standard suitable for all land uses. Ongoing site management may involve the implementation of control measures to mitigate risks by restricting or prohibiting access to, or use of a site and/or containing contamination in such a way that protects receptors from exposure.

To be an acceptable approach, contamination risks need to be adequately characterised and the proposed management measures:

- suitable to mitigate the risks to human health, the environment and environmental values; and
- acceptable to stakeholders, particularly the owners of affected sites.

The site classification scheme provides a framework for the management of contaminated sites by placing restrictions on the use of certain sites and enables the transfer of information regarding contamination issues when the site is proposed for a new land use, redeveloped, leased or sold.

Site classification under the CS Act

Contaminated sites where the risks to human health, the environment and environmental values have been adequately characterised and where current and potential future receptors can be protected through restrictions on use of the site will be classified as *contaminated—restricted use* or *remediated for restricted use*.

The classification will specify the restrictions relevant to the site, for example:

- the site is suitable for commercial/industrial land use (excluding sensitive uses such as child care centres, schools and residential);
- contaminated soil that is safely contained at a site is not to be disturbed; or
- the abstraction of contaminated groundwater is prohibited as it is not suitable for non-potable uses such as garden irrigation.

Further contamination assessment or remediation will be required when activities are proposed that are not in accordance with the restrictions on use or if there is a change in site use.

Examples of measures that can be implemented to manage contamination on site include:

- construction of a purpose built containment cell; or
- maintenance of a cover of clean soil or buildings over a contaminated layer; and
- development of an SMP that details how contamination at the site is to be managed.

Periodic monitoring of soil, groundwater and/or air may be required to monitor the effectiveness of the implemented measures e.g. groundwater monitoring around an engineered containment system or vapour monitoring in connection with a building that has a vapour control system. Monitoring requirements will depend on the nature of the remediation carried out. For example, groundwater monitoring may be required on a quarterly basis for a number of years to evaluate seasonal variation. This might decrease to annual monitoring once the variation is understood.

13.2.2 Site management plans

13.2.2.1 When to prepare an SMP

In some cases, specifying restrictions in the site classification is not considered by DER to provide adequate control on the long term use of the site. In these cases, DER will require a site-specific SMP to document the necessary site management procedures such as periodic maintenance and monitoring and procedures to be followed when carrying out intrusive works.

Examples of instances when an SMP may be necessary are provided below (these assume appropriate risk assessment has been carried out and site management provides effective mitigation of the risks).

SMP necessary	SMP not generally necessary
Contaminated soil is buried beneath a warning barrier and one metre of clean fill at a commercial site. Activities at the site are likely to include the installation and maintenance of underground services. An SMP is necessary to ensure the correct thickness (elevation) of clean fill is maintained over the contaminated material and detail the requirements for protecting workers and preventing the material being brought to the surface during sub-surface activities.	Contaminated soil is contained beneath a warning barrier, two metres of clean fill and a permanent building. The site classification includes a restriction on disturbing soils beneath the clean fill layer. An SMP is not generally necessary as the material is unlikely to be disturbed unless there is a significant change in use of the site. This is likely to involve planning authorities who would be alerted to the presence of contamination by the memorial on title and as such, the planning authority will be required to seek advice from DER under s 58(6) of the CS Act.
A site has been remediated by placing contaminated soil into an engineered containment cell. However, if the containment cell were to fail, the material could pose a risk to groundwater and groundwater users.	Soil at a residential development site has been remediated by removal and off-site disposal however groundwater is contaminated and not suitable for non-potable uses such as garden irrigation. Monitoring has demonstrated that substances are naturally attenuating and further

Periodic groundwater monitoring is required to assess performance of the containment cell. An SMP is necessary to formalise the monitoring plan—who is responsible, details of the monitoring to be carried out, who the information is to be provided to, relevant trigger levels and contingency actions if these are breached.	monitoring is not considered necessary. The site classification (*remediated for restricted use*) includes a restriction on the installation of bores and use of groundwater. An SMP is not generally necessary as new owners are required to be notified by the vendor of the presence of contamination under s 68 of the CS Act.

13.2.2.2 Purpose and objectives

An SMP defines how the site is to be managed or monitored to ensure the risks from contamination remain at an acceptable level. The preparation of an SMP should consider the following issues:

- a summary of the contamination issues at the site including the CSM;
- the purpose and objectives of site management;
- the specific risks to be mitigated as identified in the CSM;
- the time frame for which site management is necessary (potentially in perpetuity for a containment cell);
- details of how site activities are to be managed, or monitoring and maintenance actions required, such as groundwater monitoring or minimum elevation/thickness of clean soil cover to maintained;
- reporting framework;
- contingency measures to be taken in the event that any action criteria/trigger levels are exceeded;
- contact details for the person or body corporate responsible for implementing the SMP; and
- time frame for the SMP to be reviewed and revised.

An SMP may be required for a finite period, and may be attached to a site in perpetuity or until further remedial work is carried out. The checklist in Appendix A of this document provides examples of information that should be considered and included in an SMP report.

13.2.2.3 Stakeholder statement

In order for DER to endorse an SMP, it should include a statement from each of the key stakeholders (e.g. local government authority, owners, occupiers, infrastructure owners, affected site owners) that they are aware of the SMP, agree to its content and agree to abide by it.

Examples of DER endorsed management plans are available at www.der.wa.gov.au/your-environment/contaminated-sites/74-environmental-management-plans.

13.2.2.4 Contingency measures

An SMP should specify the circumstances that would be considered a material change in conditions requiring action, the actions to be taken and the time frame for action to be taken. A material change in conditions may comprise, but is not limited to:

- the minimum thickness/elevation of clean soil to be maintained over a contaminated layer;
- the integrity of sealed surfaces, buildings or fencing;
- concentrations or extent of contaminants that are monitored;
- a change in land use or certain activities at a site;
- the identification of new contamination that has not been considered in the SMP; and
- the period of time that the SMP remains relevant to the site.

An SMP should provide clear instructions for the actions to be carried out and time frame for action in the event that a trigger level or other management measure is exceeded. Actions may include, but are not limited to:

- re-instating the cover of clean soil, or repairing sealed surfaces or fencing;
- increased monitoring or further site characterisation;
- active clean-up and/or risk assessment;
- decommissioning groundwater bores, treatment of water at the point of use or provision of an alternative water source;
- revision of the SMP;
- re-reporting the site to DER if new contamination is known or suspected; and
- community engagement to inform stakeholders and engage them in the process of evaluating further actions such as remediation and revision of the SMP.

13.2.2.5 Monitoring

If periodic reporting of results or conditions is required, the SMP should specify the format and frequency of reporting, and who the report(s) will be provided to. If monitoring of the site includes sampling and analysis of environmental media, then a detailed SAQP should be included in the SMP to ensure consistency in sampling and analysis over time. Reports detailing the results of periodic sampling and analysis should meet equivalent requirements to those applicable to a DSI report.

The SAQP should be periodically reviewed and updated to ensure that the monitoring regime is appropriate for the site conditions.

14 Community engagement

14.1 Introduction

Community engagement is an integral part of contaminated site assessment and remediation and should be considered in the planning and implementation of all stages of such work in Western Australia.

Schedule B8 of the NEPM provides guidance on developing community engagement programs and sets out the benefits and key principles of community engagement and risk communication. It includes a suggested step-by-step procedure, useful engagement techniques and Australian case studies of well-planned and successful community engagement strategies.

Community engagement should be carried out by suitably qualified and experienced professionals.

14.2 Identifying stakeholders

Members of the community who live, work or visit the area in the vicinity of a contaminated site may be directly or indirectly affected by investigation and remediation activities at the site and should be considered relevant stakeholders. These are people who may be affected by:

- potential health risks;
- potential impacts to the environmental values of their property such as contaminated groundwater that has migrated from a source site to their property, or near to their property;
- loss of amenity; and/or
- short term nuisance, such as noise generated during site investigations and clean-up.

DER requires site owners, or persons who are responsible for investigations or remediation, to carry out more extensive community engagement for sites that pose a significant risk to human health, the environment or environmental values; sites that are affecting adjacent land (source and affected sites); or where the contamination has the potential to migrate off site or affect sensitive off-site receptors (e.g. residential properties, day care centres, wetlands).

The scope and detail of community engagement will depend on the size of the project and the level of community interest or concern. The level of community engagement required varies from site to site and is influenced by a number of factors.

What level of community engagement is appropriate?
Is the site high profile or controversial within the community because of the industry, contaminants involved or proposed land development? How much involvement does the community want? How long will the site assessment, clean-up work or ongoing management be carried out for? Are there issues related to the management of works being carried out at the site that could cause concern in the local community (refer section 13.1).

The extent of community engagement will also vary, depending on the sensitivity of adjacent land uses. For example, removing underground storage tanks at a disused service station site and backfilling with clean fill might only require a letter drop to neighbouring properties if the works are planned and managed appropriately (refer section 13.1 and section 15 of Schedule B2 of the NEPM). However, remediating a former gasworks, located alongside the Swan River and close to a residential suburb, a primary school and a child care centre may be of interest and concern to a broader part of the community and would require more extensive community engagement.

When discussing site contamination, plain language should be used and jargon should be avoided. Visual aids such as diagrams and aerial photos of the site are helpful. Care should be taken to ensure that information is accessible to all, including people with disabilities or whose first language is not English.

The level of community interest and stakeholders who should be involved will vary on a site by site basis. Consider including the following people:

Who should be engaged?		
Landowners and occupiers affected by contamination moving off site	Residents living near the site	Local government authorities
Local member of Parliament	Local businesses	State government agencies
Community groups (e.g. rate payers' associations)	Indigenous custodians	Environmental action groups
Industry and professional associations	Local schools	Public utilities/service providers, e.g. Western Power, Water Corporation
Media	Unions	

14.3 Timing of community engagement

Community engagement should be started as early as possible in the contaminated site assessment process, particularly for contentious sites. It is important to maintain open communication at all times and ensure that the community is able to access information throughout the process by providing appropriate contact details to the relevant stakeholders.

Site assessment and management stage	Community engagement
Preliminary site investigation (PSI)	Generally only necessary for contentious sites.
Detailed site investigation (DSI)	Let the relevant stakeholders know there is known or suspected contamination at the site that requires investigation, and what the likely or actual contaminants are. Tell people what to expect—hours of operation at the site, drilling, traffic management, noise and/or dust management, who will be carrying out the work and contact details. If appropriate, give people an opportunity to comment on the proposed investigation and any specific concerns they may have. Communicate the DSI findings and provide information on future work, e.g. further investigations or potential remedial work.
Site remediation planning	Discuss the preferred clean up options with stakeholders. Involve them in the decision-making process on remedial objectives and the evaluation of remedial options (methods). This is particularly important for the owners and occupiers of affected sites.
Clean-up, validation and ongoing management	Communicate remediation and monitoring results to meet any commitments made to the community and provide closure for participants. If monitoring is continuing, update the community as results are known.

14.4 Reporting on community engagement

Community engagement should be properly documented and include a rationale for determining the extent and timing of consultation and identification of the relevant stakeholders. Several stages of community engagement may need to be carried out relating to the different stages of the site assessment and remediation process. The engagement process will generally comprise three phases:

- planning—identifying stakeholders and the appropriate level of engagement, planning how stakeholders will be engaged and how the information obtained will be used;
- implementation—engaging with stakeholders, gathering and disseminating information and involving stakeholders in the decision-making process; and
- feedback and evaluation—seeking feedback from all involved and evaluating the success of community engagement.

All three phases of community engagement should be documented in the relevant assessment and/or remediation reports. For large or contentious projects, it may be appropriate to prepare stand-alone reports on the community engagement carried out at each stage. For smaller sites, the information could be reported within the relevant DSI, RAP or SRV report.

An auditor appointed to review the investigation and clean-up of a site is also responsible for reviewing the community engagement undertaken.

Reporting should include, but is not limited to:

- stakeholders (individuals and groups) who were identified and invited to participate;
- how stakeholders were contacted (e.g. newspaper advertisements, letter drops);
- number of community members who participated;
- where and when events took place;
- information provided to the community;
- the community's input and comments;
- how the community's input was considered and included in the decision-making process; and
- an evaluation of the effectiveness of the community engagement carried out.

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Abbreviations

ABC	Ambient background concentration
ACL	Added contaminant limit
ADWG	Australian Drinking Water Guidelines
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AS/NZS	Australian / New Zealand Standard
ASRIS	Australian Soil Resource Information System
ASS	Acid sulfate soils
AWQG	Australian Water Quality Guidelines
BSR	Basic summary of records
CIRIA	Construction Industry Research and Information Association
CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
CS Act	*Contaminated Sites Act 2003*
CS Regulations	*Contaminated Sites Regulations 2006*
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSM	Conceptual site model
CVI	Chlorinated hydrocarbon vapour intrusion
DEC	Department of Environment and Conservation (WA) (now DER)
DER	Department of Environment Regulation (WA)
DEWHA	Department of The Environment, Water, Heritage and the Arts (now the Department of Environment) (Commonwealth)
DMP	Department of Mines and Petroleum (Western Australia)
DNAPL	Dense non-aqueous phase liquid
DoH	Department of Health (Western Australia)

DoW	Department of Water (Western Australia)
DQO	Data quality objective
DSI	Detailed site investigation
DSR	Detailed summary of records
EIL	Ecological investigation level
EPA	Environmental Protection Authority (Western Australia)
EPHC	Environment Protection and Heritage Council
ESL	Ecological screening level
GIL	Groundwater investigation level
GMRRW	Guidelines for managing risk in recreational waters
HIL	Health investigation level
HSEP	Health, safety and environment plan
HSL	Health screening level
ISQG	Interim sediment quality guideline
LNAPL	Light non-aqueous phase liquid
LOR	Limit of reporting
MAR	Mandatory auditor's report
MNA	Monitored natural attenuation
MTBE	Methyl tertiary-butyl ether
NAPL	Non-aqueous phase liquid
NEPM	*National Environment Protection (Assessment of Site Contamination) Measure 1999*
NHMRC	National Health and Medical Research Council
NPUG	Non-potable use guidelines
NSW EPA	New South Wales Environmental Protection Authority
PQL	Practical quantification limits
PSI	Preliminary site investigation

PVI	Petroleum hydrocarbon vapour intrusion
QA/QC	Quality assurance / quality control
RAP	Remediation action plan
RCWA	Radiological Council of Western Australia
SAQP	Sampling and analysis quality plan
SMP	Site management plan
SRT	Swan River Trust
SRV	Site remediation and validation
US EPA	United States Environmental Protection Agency
VAR	Voluntary auditor's report
VI	Vapour intrusion
WA	Western Australia

Appendices

Appendix A
Reporting checklists

The lists provided are a guide only.

Assessment checklist

Report section and recommended information to be included if relevant	Reference*	PSI	DSI
Executive summary			
Background including identification of the client and the reasons the report was commissioned		Yes	Yes
Statement as to whether the site (list land parcels) has been reported to DER as a known or suspected contaminated site and the current classification(s)			
Contaminated sites auditor details if a mandatory auditor's report is required			
Objectives of investigation and/or remediation			
Summary of work undertaken			
Summary of the conceptual site model and risks to human health, the environment and environmental values			
Summary of conclusions and recommendations			
Introduction			
Background including identification of the client and the reasons the report was commissioned		Yes	Yes
Statement as to whether the site has been reported to DER as a known or suspected contaminated site under the CS Act and the current classification(s)			
Contaminated sites auditor details if a mandatory auditor's report was required			
Licence details if licensed as a prescribed premises under the EP Act			
Objectives of the scope of work—investigation and/or remediation			
Clear statement of the scope of work carried out			
Site identification and general information			
Site identification • address—street number and/or lot number, street name and suburb • common name of site (e.g. local business or landmark) • certificates of title (copies of documents including survey plan)	B2 s 3.1 - 3.3	Yes	Yes
Location map(s)			
Coordinates of site boundaries (Northings/Eastings—specify datum)			
Land area (m^2 or ha as appropriate)			
Current ownership and occupant/lessee details and any proposed changes			
Current site plan with scale bar and north arrow showing site infrastructure and environmentally significant features			
Current use and status of the site (e.g. vacant, operating service station operating paint factory, market garden etc.); if non-operational state if infrastructure is decommissioned/*in situ* as applicable			
Local government authority and relevant town planning scheme			
Current zoning and any proposed changes			

Report section and recommended information to be included if relevant	Reference*	PSI	DSI
Proposed future use including site plans showing the proposed new boundaries and/or buildings			
Previous environmental investigations and remediation			
List of previous reports and summary of previous environmental investigations, risk assessment and remediation (include appropriate site plans, diagrams and/or tables)	B2 s 3.3	Yes	Yes
List of previous site contamination audit reports (if contaminated sites auditor engaged)		Yes	Yes
Site history			
Land ownership (copies of historical certificates of title to be included)	B2 s 3.3	Yes	Summary
Previous occupiers such as lessees, franchisees, managers, users			
Land uses (including any periods where the land was unoccupied or not in use) highlighting past and current potentially contaminating activities and land uses			
Past and current aerial photographs at sufficient frequency and scale to show activities/changes over time, with the site boundary identified			
Building and infrastructure—location, construction and demolition/decommissioning waste disposal (soak wells, sumps, lagoons, landfills)			
Earthmoving activities			
Location and extent of imported and locally derived fill			
Documentation for material imported to the site (source of clean fill)			
Documentation for material disposed off site (e.g. transport dockets, landfill receipts)			
Description of manufacturing processes Inventory of chemicals, wastes and by-products used at the site and associated potential contaminants			
Details and locations of past and present underground and aboveground storage tanks, transfer lines and dispensing locations			
Site, state and local government records - • relevant licences, approvals and trade waste agreements • product spills, losses and incidents including fire at the site or in the vicinity of the site • discharges to land, water and air (authorised and unauthorised) • complaints			
Information obtained from site representatives, residents, staff and neighbours (both present and former)			
Summary of local literature about the site e.g. newspaper articles			
Heritage matters (Aboriginal and other)			
Summary of the above information and presentation as a chronology or timeline from initial site use to present day and indicating gaps in information			
Data evaluation (gaps in knowledge, uncertainties/unsubstantiated information)			
Site Inspection and interviews with site personnel			
Site inspection date(s) and personnel	B2 s 3.4, s3.6	Yes	Summary
Site photographs (with date, location indicated on site plan, direction photo was taken)			
Access to areas of the site /inaccessible areas and reasons why inaccessible			
Topography and elevation (m AHD), flood potential, surface drainage			

Report section and recommended information to be included if relevant	Reference*	PSI	DSI
Nature and condition of site boundary such as type and condition of fencing, soil stability, evidence of soil erosion	B2 s 3.4, s3.6	Yes	Summary
Visible signs of contamination, such as discolouration or staining of soil, bare soil patches—both on site, and off site adjacent to site boundary			
Visible signs of vegetation stress			
Presence of drums, wastes and fill material			
Type and conditions of buildings, roads, site infrastructure e.g. ASTs			
Aesthetic issues including presence/intensity of odours			
Nature of site surface - sealed and unsealed, integrity of seal, e.g. is the concrete hardstand cracked?			
Location and types of stockpiled materials			
Presence/absence of asbestos and asbestos containing materials (ACM) e.g. fragments of ACM on the site surface			
Information obtained from site occupants, residents and neighbours			
Local use of ground/surface waters, and location of groundwater bores			
Presence and condition of surface water bodies / groundwater bores			
Location and nature of potential preferential pathways for contaminant migration e.g. location of underground services and drains			
Surrounding land uses			
Location of receptors on and within 500m of the site boundary including sensitive receptors such as child care centres, schools, aged care, residential and relevant local sensitive environments e.g. surface water, wetlands and reserves			
Geology and hydrogeology (regional and site-specific)			
Surface elevation and topography (also identify any man-made features controlling surface water)	B2 s3.5	Yes	Yes
Regional and site-specific soil and geological records - • stratigraphy • potential for acid sulfate soils / risk ranking • location of water bodies, springs and bores within 500m of the site • drilling logs/well logs • aquifer type (confined, unconfined, perched etc) and properties (e.g. clay content, permeability, known karst/potential for karstic conditions) • groundwater elevation, flow direction, flow rate • groundwater discharge locations / surface water interactions (e.g. tidal effects, saline intrusion) • seasonal effects on groundwater (fluctuations in elevation and flow direction) • groundwater quality and use/potential for use	B2 s3.5	Yes	Yes—include summary of previously reported data
Location, construction and condition of on-site wells **(NB cross-contamination of aquifers may occur if multi-layered aquifer conditions are not taken into account when designing and installing bores)**	B2 s3.5	Desk top	Yes
Background soil and groundwater quality			
Background soil quality e.g. literature / reference site	B1 s 2.5.7	Desk top	Yes
Ambient and up-gradient groundwater quality	B6 s 3.3	Desk top	Yes
Conceptual site model (CSM)			
The initial CSM is based on desktop information supplemented with information gathered from site inspections and interviews which is refined with the results of site-specific investigation and assessment.	B2 s4 and s 9	Initial desk top	Yes
Known and potential sources of contamination (areas of concern, potential contaminants, toxicity, mobility, volatility, potential for degradation, potential media affected)			

Report section and recommended information to be included if relevant	Reference*	PSI	DSI
Potential and complete contaminant migration pathways (including preferential migration pathways) and exposure routes			
Potential receptors (human, ecological and environmental values)			
Data gaps and uncertainties			
Tabulation of potential source-pathway-receptor linkages			
CSM graphic			
Assessment levels			
Identification and rationale for the assessment levels selected (discuss assumptions and limitations in the context of the site)	B1	Initial desk top	Yes
Table(s) listing all assessment levels and reference (e.g. NEPM)			
Sampling and analysis quality plan (SAQP)			
Objectives of the sampling programme	B2 s 5-6 Appendix B and B3		Yes
Specific data gaps that have been identified and limitations on sampling, such as the presence of infrastructure (e.g. location of underground storage tanks, fuel lines and buildings)			
Define data quality objectives (DQO)			
Media to be sampled (soil, groundwater, surface water, vapour, NAPL etc.)			
Analyte selection and analysis methods			
Sampling design and justification • sample locations, depths and frequency (with rationale) • field screening methods and purpose • samples for laboratory analysis			
Sampling methods and procedures • sampling procedures • sample containers • preservation of samples • storage and transport • quality assurance and quality control procedures *(see below)*			
Field procedures including QA/QC			
Completed standardised forms for recording relevant field data (copies to be included in the report) • sample logs (primary samples, trip and field blanks, rinsate samples, replicate samples, decontamination events etc.) • soil bore, groundwater bore / vapour probe installation logs (fill, lithology, grain size, clay content, odours, staining etc.) • sampling logs (field screening results, depths to water/LNAPL, purging details, observations etc.) • field instrument calibration records • field instrument detection limits (e.g. field XRF analysis) • chain of custody form identifying (for each sample) the sampler, media, collection date and time, sample preservation method, analyses to be performed, sender signature and departure date and time • summary of field QA/QC outcomes	B2 s5	Yes	Yes
Laboratory analysis including QA/QC			
Chain of custody form as above with laboratory signature, receipt date and time and comment on condition of samples (e.g. chilled, warm, damaged/missing samples etc.)	B2 s5 B3		Yes
Laboratory analytical certificates			

Report section and recommended information to be included if relevant	Reference*	PSI	DSI
Laboratory QA/QC report • analytical methods and laboratory accreditation for methods used • holding and extraction times for each analysis/sample • sample splitting techniques • surrogates, spikes and recoveries • instrument/method detection limits and matrix/practical quantification limits • standard and reference solution results • certified reference material results • laboratory duplicate and blanks results • summary of QA/QC outcomes			
Data evaluation			
Comparison of field and laboratory data with the DQO, including • deviations from the SAQP • acceptability of field QA/QC sample results • acceptability of laboratory QA/QC results • evaluation of factors which may materially affect the results (such as the collection and analysis of samples by different personnel, different methodologies, spatial and temporal variations)	B2 Appendix C	Yes	Yes
Implications for decision-making—precision, accuracy, representativeness, completeness and comparability of the data			Yes
Site plans			
Detailed site plans should include, as a minimum: drafting date and date(s) of the information shown • north arrow • scale and ratio bar • site boundaries including legal, lease and location of fences/walls • excavation boundaries and date of excavation/fill • stockpile locations and dates of sampling • adjacent land uses • relevant site features such as current and historical above and below ground infrastructure, topography, surface finishes, fill • areas of concern (source locations and extent) and direction of groundwater flow • legend	NEPM B1 s 3.3.1 and B2 s 14.4	Yes	Yes
Simplified site plans may be used as a basis for showing relevant information and results relevant to the site assessment and/or remediation: • hydrogeological information such as groundwater elevation, elevation contours, direction of groundwater flow and estimated seepage velocity • geological and hydrogeological cross-sections • sampling locations, depth and results • exceedences of assessment levels • All site plans should contain a legend, north arrow, scale, units of measurement			
Results			
Tabulation of field and laboratory results including sample identification, sampling dates and times, depths (if applicable), laboratory detection limits, relevant assessment criteria and exceedences (incorporate previous results as appropriate)	NEPM B1 and B2 s 13 s14.5-14.7	Yes	Yes
Descriptive statistics for known and potential contaminants			
Summary of the vertical and lateral extent of contaminated areas			
Tables of historical results to support discussion of temporal trends—raw data and calculations used in graphs or statistical analysis should be included in the report			
Tier 1 and/or 2 risk assessment (human health and ecological)			
Objectives and scope of the risk assessment with reference to the CSM, identification of exposure risks that cannot be assessed in a Tier 1 assessment (e.g. no generic criteria)	NEPM B1, B2, B4, B5, B6 and B7		

Report section and recommended information to be included if relevant	Reference*	PSI	DSI
Comparison with generic/adjusted assessment levels including • identifying any adjustments and the rationale for each receptor • the nature of any exceedences in the context of the descriptive statistics and more detailed statistical analysis as appropriate			
Attach supporting information—e.g. HSLs checklist (Friebel & Nadebaum, 2011)			
Risk characterisation including uncertainties (data gaps) and material changes in conditions that would alter the reliability of the risk assessment undertaken			
Revised CSM and conclusions regarding risks requiring management or further assessment			
Tier 3 risk assessment (human health and ecological)			
Documented in a separate report if appropriate	NEPM B4, B5, B6, B7		
Objectives and scope of the risk assessment			
Exposure assessment			
Toxicity assessment			
Sensitivity analysis			
Limitations, assumptions and uncertainties (data gaps, changes in conditions that would alter risk scenarios)			
Risk characterisation with regard to each receptor evaluated			
Revised CSM and conclusions/recommendations regarding risks requiring management or further assessment			
Fate and transport modelling			
Documented in a separate report if appropriate	NEPM B2 s10 and B4 s 4		Yes
Uncertainties in the CSM and the objectives for contaminant fate and transport modelling			
Scope of work and rationale for model selection			
Model validation and model results			
Evaluation of modelling results and sensitivity analysis including the limitations, assumptions and uncertainties			
Revision of the CSM and conclusions/recommendations regarding risks requiring management or further assessment			
Community engagement			
Documented in a separate report if appropriate	NEPM B8	(Yes)	Yes
Community engagement plan • stakeholders (individuals and groups) invited to participate *(personal contact details not required)* • details of how stakeholders were contacted • where and when engagement events took place • summary of information provided to stakeholders (provide copies of flyers, letters etc. in an appendix)			
Outcomes of community engagement • summary of input and comments received • number of stakeholders/community members who participated • how stakeholder input was taken into account • document agreements reached and their effect on further investigation and/or remediation to be carried out			
Conclusions and recommendations			
Conclusions arising from the site assessment and the implications for decision-making with regards to the management of unacceptable and/or potentially unacceptable risks	NEPM B2 s14	Yes	Yes

Report section and recommended information to be included if relevant	Reference*	PSI	DSI
Recommendation on whether the site (including additional parcels of land) require reporting to DER as a known or suspected contaminated site under s 11 of the CS Act			
Recommendations on any limitations and constraints on the use of the site as relevant			
Recommendations for further investigation, risk assessment, remediation, validation and/or management as relevant			

Reference *— principal NEPM reference(s)—the DER CSG and the references therein may also be relevant.

Remediation reporting checklist

Report section and recommended information to be included if relevant	Reference*	RAP	SRV	SMP
Executive summary				
Background including identification of the client and the reasons the report was commissioned		Yes	Yes	Yes
Date site was reported to DER as a known or suspected contaminated site and the current classification (list land parcels)				
Contaminated sites auditor details if a mandatory auditor's report was required				
Brief summary of the CSM and risks to human health, the environment and environmental values				
Remediation objectives and remedial targets to be achieved				
Summary of the work undertaken				
Conclusions and recommendations				
Introduction				
Background including identification of the client and the reasons the report was commissioned		Yes	Yes	Yes
Objectives of the scope of work and clear statement regarding the scope of work undertaken				
Site identification and general information (as for assessment)				
Confirmation of when the site (list land parcels) was reported to DER as a known or suspected contaminated site and the current classification				
Contaminated site auditor details if a mandatory auditor's report was required				
Summary of previous work, the CSM and risks to human health, the environment and environmental values				
Extent of remediation/management required - summary of the risks to be mitigated, stakeholder views and time frame available to achieve the desired outcomes				
Remediation objectives				
Remediation objectives and remedial targets to be achieved	A&M 12.2			
Table of remedial targets and derivation details (reference to site-specific risk assessment report or other document(s) detailing their derivation)		Yes	Yes	Yes
Remedial options				
Identify potential remedial options that could achieve the remediation objectives within the available time frame	A&M 12.4	Yes		
Discuss the results of case studies or pilot studies/trials undertaken that support or do not support particular remedial options				
Evaluate viable remedial options with reference to the preferred remediation hierarchy	NEPM Principle 16			

Report section and recommended information to be included if relevant	Reference*	RAP	SRV	SMP
Summarise the rationale for the selected remediation approach • active remediation and/or • management measures	A&M 12.4			
Remedial action plan				
Description of remedial method including design and construction details/plans as appropriate	A&M 12 - 13	Yes		
Discussion of limitations associated with the proposed remedial approach and the potential for additional clean-up and/or long-term site management				
Identification of regulatory compliance requirements such as licences and approvals (local and state government)				
Documentation of discussions with stakeholders and copies of relevant agreements (e.g. regarding remediation objectives/remedial targets)				
Site preparation requirements (fencing, erection of warning signs, stormwater diversion)				
Site management plan (operational phase), including management of stormwater, stockpiles, waste soil, sediment and water, excavations, noise, dust, odour, decontamination procedures, site security, incidents, chemical/equipment storage				
Detailed SAQP for any sampling required during or after remediation				
Key personnel and contact details as applicable (HSEP should be prepared but is not required in the report)				
Remediation schedule and hours of operation				
Location/source of any clean fill material to be used, validation requirements				
Details of decommissioning and infrastructure removal when remediation objectives/remedial targets are achieved (as applicable)				
Progress reporting format and recipients (as applicable)				
Site remediation and validation				
Document remediation work undertaken	A&M 12.6		Yes	
Evaluate validation results and compare with the remedial objectives and remedial targets				
Discussion of the revised CSM and any uncertainties in the remediation outcomes				
Provide recommendations for any further site clean-up or management and any restrictions on the use of the site				
Document off-site disposal of all wastes e.g. transport dockets, landfill or treatment facility receipts				
Document sources and quality of fill imported to the site				
Document approvals and licences obtained from regulatory authorities				
Site management plan				
Time frame for site management e.g. 1 year, 5 years, in perpetuity	A&M 13	(Yes)		Yes
Identification of the relevant stakeholders who have specific interests, roles and responsibilities in relation to the ongoing management of the site				
Documentation of stakeholder agreement to management roles and responsibilities				
Details of maintenance and/or monitoring requirements including trigger levels and an SAQP if applicable				
Contingency actions (e.g. repeat sampling, increased monitoring frequency, revision of the SMP, risk assessment) that will be carried out if trigger levels are exceeded		(Yes)		Yes
Notification procedures if trigger levels are exceeded				
Format and frequency of reporting, and who will be provided with copies of the reports				

Reference*—this guideline (*Assessment and Management of Contaminated Sites*) is the principal reference –the references herein may also be relevant.

Appendix B

Potentially contaminating industries, activities and land uses

The list provided is not exhaustive and it may be necessary to consider whether other contaminants could be present as a result of the activities carried out at the site or whether other contaminants could be present at the site.

Industry, activity or land use	Common contaminant types
Abattoirs and animal processing works*	Also refer to tannery and associated trades Nutrients (e.g. nitrogen, phosphorus) Biological oxygen demand Total suspended solids Oil and grease Pesticides and metals (by-products of rendering)
Abrasive blasting	Dependent on material being removed Metals(e.g. iron, lead) Tributyltin (boat yards/boat maintenance)
Acid/alkali plant, formulation and bulk storage	Metals (e.g. mercury) Acids (e.g. hydrochloric, nitric, sulfuric sodium) Alkalis (e.g. sodium and calcium hydroxide)
Airports, airstrips, aerospace facilities	Also refer to fire fighting/training (use of foams) Petroleum hydrocarbons Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene and xylene) Metals (e.g. aluminium, chromium, lead, magnesium) Solvents (e.g. trichloroethene) Also refer firefighting/training (use of foams)
Analysts, analytical laboratory sites (e.g. research, commercial, mine site)	Solvents (e.g. trichloroethene) Acids Metals
Asbestos production or disposal	ACM Asbestos fibres
Asphalt or bitumen manufacture or bulk storage*	Petroleum hydrocarbons Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene and xylenes) Polycyclic aromatic hydrocarbons (e.g. creosote) Metals (e.g. chromium, lead)
Automotive repair, engine works and spray painting	Solvents (e.g. trichloroethene) Petroleum hydrocarbons Monocyclic aromatic hydrocarbons (e.g. toluene, xylenes, white spirit) Phenol Chloroflurocarbons Metals (e.g. copper, chromium, lead, zinc) Alkalis Acids (e.g. sulfuric, phosphoric)

Industry, activity or land use	Common contaminant types
Battery manufacturing, recycling, disposal	Metals (e.g. antimony, cadmium, cobalt, lead, manganese, nickel, mercury, silver, zinc) Acids (e.g. sulfuric, hydrochloric)
Biosolids application, muck spreading, organic fertiliser application	Nutrients (e.g. nitrogen, phosphorus) Metals (aluminium, arsenic, cadmium, chromium, cobalt, lead, nickel, potassium, zinc) Phenols Pathogens (e.g. *E. coli*, *Enterococci)*
Boat building and maintenance*	Also refer to Automotive repair Metals (e.g. copper, chromium, lead, mercury, zinc) Antifouling paints (e.g. organotin, tributyltin)
Brake lining manufacturer	Asbestos Copper
Breweries/distilleries*	Alcohol (e.g. ethanol, methanol, esters) Nutrients (e.g. nitrogen, phosphorus) Biological oxygen demand (BOD)
Brickworks*	Metals (e.g. ammonium, arsenic, cadmium, mercury, lead) Polycyclic aromatic hydrocarbons (e.g. coke, tars)
Cement/concrete/lime manufacturing or batching*	Lime, calcium hydroxide, alkalis Hydrocarbons Asbestos Metals (e.g. nickel, zinc)
Cemeteries	Nitrates Heavy metals, lead Formaldehyde Biological hazards
Chemical manufacturing, blending, mixing, handling or storage*	
Acid/alkali	Metals (e.g. mercury) Acids (sulfuric, hydrochloric, nitric) Sodium and calcium hydroxides
Adhesive/resins	Polyvinyl acetate (e.g. adhesives) Phenol Formaldehyde (e.g. resins) Phthalate esters Polychlorinated biphenyls Solvents (e.g. trichloroethene)
Dyes/inks	Metals (e.g. cadmium, chromium, cobalt, lead, titanium, zinc) Solvents (e.g. trichloroethene) Cresols Chlorinated hydrocarbon (e.g. 1,1,1-trichloroethane, cis1, 2-dichloroethene)

Industry, activity or land use	Common contaminant types
Fertilisers	Metals (e.g. boron, cadmium, cobalt, copper, magnesium, molybdenum, zinc) Calcium phosphate, calcium sulfate, nitrates, ammonium sulfate, carbonates, potassium Pentachlorophenol
Flocculants	Aluminium
Foam (e.g. polyurethane)	Urethane Formaldehyde Styrene
Fungicides	Metals (e.g. chromium, copper chloride/sulfate, zinc) Carbamates Organochlorine pesticides (e.g. Pentachlorophenol) Chlorinated hydrocarbons (e.g. trichloroethene)
Herbicides	Ammonium thiocyanate 2,4,5-T and 2,4-D Dioxins Herbicides (e.g. triazine, atrazine, MCPA, bipyridyls, sulfonyl ureas, chlorophenoxys) Metals (e.g. arsenic, mercury)
Paints	Metals (e.g. arsenic, barium, cadmium, chromium, cobalt, lead, manganese, mercury, selenium, titanium, zinc) Boron Solvents (e.g. toluene oils natural or synthetic) Resins Chlorinated hydrocarbons Polychlorinated biphenyls
Pesticides	Wide range of insecticides, herbicides and fungicides Metals (e.g. arsenic, lead, mercury, tin, chromium) Organochlorine pesticides Organophosphate pesticides Carbamates Solvents (e.g. xlyenes, kerosene) Chlorinated hydrocarbons Polychlorinated biphenyls Synthetic pyrethroids Acid herbicides Chlorinated hydrocarbons (e.g. mirex)
Pharmaceutical	Solvents (e.g. acetone, ethyl acetate, butyl acetate, methanol,ethanol, isopropanol, butanol) Carbamates Metals (e.g. selenium)
Photography	Potassium bromide Metals (e.g. chromium, selenium, silver) Thiocyanate Ammonium compounds Sulfur compounds Phosphate Ethanol Formaldehyde
Plastics	Metals (e.g. cadmium) Carbonates Solvents (e.g. trichloroethene) Styrene

Industry, activity or land use	Common contaminant types
	Sulfates Phthalate esters Chlorinated hydrocarbons (e.g. 1,1,1 - Trichloroethane) Polychlorinated biphenyls Polybrominated diphenyl ethers
Rubber processing	Metals (e.g. lead, zinc) Sulfur compounds Reactive monomers (e.g. isoprene, isobutylene) Acid (e.g. sulfuric, hydrochloric) Monocyclic aromatic hydrocarbons (e.g. xylenes, toluene) Solvents (e.g. trichloroethene) Carbon Black Hexachlorobenzene Chlorinated hydrocarbons (e.g. mirex, cis 1,2-dichloroethene)
Soap/detergents	Potassium compounds Phosphates Ammonia Alcohols
Soap/detergents *continued*	Esters Sodium hydroxide Surfactants Silicate compounds Acids (e.g. sulfuric, stearic) Oils
Solvents	Ammonia Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene and xylenes) Chlorinated organics (e.g. carbon tetrachloride, trichloroethane) Natural oils (e.g. pine, tee tree, palm)
Chemical treatment/destruction facilities	As per substances being treated Polycyclic biphenyls (PCBs) Dioxins (refer to Schedule B2 of the NEPM for specific guidance on the occurrence of dioxins and guidance on circumstances where analysis is recommended)
Clandestine drug manufacture/ laboratories	Drug residues (various) Acids (e.g. hydrochloric, hydriodic, sulfuric) Metals (mercury, lithium, aluminium, nickel) Solvents (e.g. methanol, acetone, diethyl ether, methylated spirits) Anhydrous ammonia Nitrates Petroleum hydrocarbons Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene and xylenes)
Compost manufacturing*	Nutrients (e.g. phosphorus, nitrogen) Metals (e.g. aluminium, iron, potassium, zinc)
Defence works and defence establishments	Also refer Fire fighting training (use of foams) Metals (e.g. aluminium, beryllium, copper, lead, mercury, silver) Explosives (e.g. TNT, 2,4, DNT, 2,6 DNT, RDX) Petroleum hydrocarbons Solvents (e.g. trichloroethene)
Drilling	Drilling fluid additives
Drum or tank re-conditioning or recycling facility	Dependent upon contents of drums Solvents (e.g. methylene chloride, ortho-dichlorobenzene) Petroleum hydrocarbons
Dry cleaning establishments	Solvents (e.g. trichloroethylene, ethane, 1,1,1-trichloroethane, carbon tetrachloride, perchlorethylene) Volatile organic compounds (VOCs)

Industry, activity or land use	Common contaminant types
Electrical substations/transformers	Metals (e.g. copper, lead, mercury, tin) Polychlorinated biphenyls Solvents (e.g. trichloroethene)
Electricity generation/power stations*	Fly ash (can comprise of sulfates, metals, total dissolved solids, selenium) Petroleum hydrocarbons Polycyclic aromatic hydrocarbons (e.g. tars, benzo(a)pyrene) Asbestos Polychlorinated biphenyls (PCBs) Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene & xylenes) Metals (e.g. copper, lead)
Explosives production/bulk storage pyrotechnics	Acids (e.g. acetone, nitric, ammonium nitrate, sulfuric) Ammonia Solvents (e.g. methanol, PCP) Chlorinated hydrocarbons Metals (e.g. aluminium, copper, lead, manganese, mercury, silver) Explosives (e.g. TNT, 2,4 DNT, 2,6 DNT, RDX) Petroleum hydrocarbons (fuel) Hexachlorobenzene
Fertiliser manufacture or storage	Also refer Chemical manufacturing - fertiliser Calcium phosphate, calcium sulfate, copper chloride Sulfur, sulfuric acid Metals (e.g. boron, cadmium, cobalt, copper, magnesium, molybdenum, potassium, selenium) Nitrates, ammonia
Fibreglass reinforced plastic manufacturing*	Solvents (e.g. trichloroethene) Resins Styrene Boron
Fill material/ fill importation	Establish historical potentially contaminating landuse, industry or activity of source site and consider naturally occurring contaminants, e.g. asbestos
Fire fighting and training (use of foams)	Solvents (e.g. glycol ethers) Surfactants (hydrocarbon and fluorinated) Fluorotelomers Perfluorochemicals (e.g. PFOS, PFOA) Boron
Foundry operations	Metals and chlorides/fluorides/sulfates of metals (e.g. iron, aluminium, cadmium, chromium and oxides, copper, lead, magnesium, tin, nickel, zinc) Acids (e.g. sulfuric and phosphoric) Polycyclic aromatic hydrocarbons (e.g. coke residues) Petroleum hydrocarbons (e.g. fuel oil)
Furniture restoration	Solvents (e.g. trichloroethene)
Gasworks	Cyanide Nitrate Sulfide/sulfate Metals (e.g. aluminium, antimony, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, vanadium, zinc) Boron Thiocyanates Petroleum hydrocarbons Polycyclic aromatic hydrocarbons (e.g. creosote) Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene & xylenes) Phenols
Glass manufacturing	Metals (e.g. cobalt)

Industry, activity or land use	Common contaminant types
Iron and steel works	Also refer Gasworks Metals (e.g. chromium VI, cobalt, copper, lead, magnesium, manganese, nickel, selenium, zinc) Acids (e.g. sulfuric, hydrochloric) Mineral oils Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene, and xylenes) Polycyclic aromatic hydrocarbons (e.g. coke residues)
Intensive agriculture* (including feedlots and saleyards)	Carbamates Organochlorine pesticides (e.g. Endrin, Methoxychlor, Pentachlorophenol) Organophosphate pesticides Herbicides (e.g. Triazine, Atrazine, 2,4,5-T 2,4-D, MCPA, Picloram) Insecticides DDT, DDE and DDD, Bifenthrin Aldrin and Dieldrin Nitrates Salinity Metals (e.g. aluminium, arsenic, cadmium, copper, iron, lead, magnesium, potassium) Nutrients (e.g. nitrogen, phosphorus) Toxaphene
Landfill sites (and associated activities)*	Dependent on landfill type and waste disposed Polychlorinated biphenyls Alkanes Sulfides Metals Asbestos Organic acids Nutrients (e.g. nitrogen, phosphorus) Petroleum hydrocarbons Polycyclic aromatic hydrocarbons (e.g. benzo(a)pyrene) Ammonia Landfill gases (e.g. methane) Total Dissolved Solids (TDS) Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene & xylenes) Phenols
Livestock dips or spray races	Metals (e.g. arsenic) Carbamates Organochlorine pesticides Organophosphate pesticides Herbicides Synthetic pyrethroids
Market garden, orchards, poly-tunnels, plant nurseries	Metals (e.g. aluminium, arsenic, cadmium, copper, lead, mercury, magnesium, iron) Organochlorine pesticides (e.g. DDT, Dieldrin, Endosulfan) Organophosphate pesticides (e.g. Azinphos ethyl, Diazinon, Fenthion) Carbamates Petroleum hydrocarbon (fuel) Monocyclic aromatic hydrocarbons (e.g. Benzene, toluene, ethylbenzene & xylenes)
Metal finishing and treatments (e.g. electroplating/carburizing baths*)	Metals (e.g. aluminium, barium, cadmium, chromium, copper, lead, nickel, tin, zinc) Acids (e.g. sulfuric, hydrochloric, nitric, phosphoric) Paint residues Alkalis Solvents (e.g. 1,1,1-trichloroethane, tetrachloroethylene) Plating salts Monocyclic aromatic hydrocarbons (e.g. Benzene, toluene) Cyanide

Industry, activity or land use	Common contaminant types
Metal smelting or refining*	Metals (e.g. aluminium, copper, gold, lead, mercury, selenium, silver, tin) and their chlorides, fluorides and oxides
Mineral processing and extractive industries*, including mining, screening, crushing and tailing dams or storage facilities, but not voids where no other potentially contaminating activity has occurred	Acids, alkalis Total Dissolved Solids (TDS) Organic flocculants (e.g. sulfate, cyanide) Metals (e.g. aluminium, arsenic, chromium, cobalt, copper, iron, lead, manganese, mercury, zinc) Petroleum hydrocarbon Monocyclic aromatic hydrocarbons (e.g. Benzene, toluene, ethylbenzene & xylenes) Radioactive materials Polycyclic aromatic hydrocarbons asbestos pesticides Solvents (e.g. trichloroethene) Caustic
Motor vehicle manufacture, workshops, facilities, race venues	Petroleum hydrocarbons Monocyclic aromatic hydrocarbons (e.g. Benzene, toluene, ethylbenzene & xylenes) Solvents (e.g. trichloroethene) Resins Heavy metals Polycyclic aromatic hydrocarbons
Oil/gas exploration, production, refining and storage* Oil/gas exploration, production, refining and storage* *continued*	Petroleum hydrocarbon Monocyclic aromatic hydrocarbons (e.g. Benzene, toluene, ethylbenzene & xylenes) Acids (e.g. sulfuric) Alkalis Insulation lagging (e.g. asbestos) Metals should be determined through assessment of deposit composition and known impurities (e.g. arsenic, barium, cadmium, chromium, cobalt, copper, mercury, nickel) Methyl tertiary-butyl ether Cyanides Drilling fluid additives
Pest control depots	Carbamates Organochlorine and organophosphate pesticides (e.g. Diazinon) Herbicides (e.g. Atrazine) Insecticides (e.g. Fenamiphos) Fungicides
Printing shops	Also refer to Photography Acids Alkalis Solvents (e.g. trichloroethene) Metals (e.g. chromium)
Port/wharf/dock activities (including dredge spoil)	Metals (e.g. copper, tin, chromium, lead, mercury, zinc) Antifouling paints (e.g. organotin, tributyltin) Petroleum hydrocarbons Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene & xylenes) Polycyclic aromatic hydrocarbons
Railway yards/marshalling yards and transport corridors Railway yards/marshalling yards and transport corridors *continued*	Petroleum hydrocarbons Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene & xylenes) Phenolics (creosote) Metals (e.g. arsenic, cadmium, chromium, iron, lead, zinc) Nutrients (e.g. nitrates, ammonia) Carbamates Organochlorine pesticides (e.g. pentachlorophenol) Organophosphates pesticides Herbicides Asbestos Additional contaminants according to what has been transported by rail

Industry, activity or land use	Common contaminant types
Recycling (building materials)	Asbestos Metals (e.g. lead, zinc)
Rifle ranges and pistol clubs	Metals (e.g. lead) Polycyclic aromatic hydrocarbons
Scrap metal recovery	Metals (e.g. cadmium, lead, magnesium) Solvents Polychlorinated biphenyls Oil and grease Petroleum hydrocarbons Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene & xylenes) Polycyclic aromatic hydrocarbons
Service stations and fuel storage facilities	Petroleum hydrocarbons Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene & xylenes) Polycyclic aromatic hydrocarbons Methyl tertiary-butyl ether and other oxygenates Metals (e.g. barium, cadmium, copper, lead, nickel, zinc) Oil and grease Solvents (e.g. trichloroethylene)
Sewage/wastewater treatment plant*	Nutrients (e.g. nitrogen, phosphorus) Metals (aluminium, arsenic, cadmium, chromium, cobalt, lead, manganese, nickel, potassium, zinc) Phenols Pathogens (e.g. *E. coli*, *Enterococci)*
Tannery (and associated trades)*	Acids (e.g. hydrochloric) Metals (e.g. aluminium, chromium, copper, manganese) Formaldehyde Phenols Salts Solvents (e.g. trichloroethene) Petroleum hydrocarbons Oil and grease Cyanide Ammonia
Textile operations*	Metals (e.g. aluminium, cadmium, chromium, titanium, tin, zinc) Carbon Acid (e.g. sulfuric) Alkalis (e.g. caustic soda) Salts Solvents (e.g. perchloroethylene) Monocyclic aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene & xylenes) Organochlorine pesticides (e.g. Dieldrin, Aldrin) Dyestuff residues Sodium hypochlorite Phenols
Timber preserving/storage/saw mills wood product manufacturing*	Solvents (e.g. trichloroethene) Polycyclic aromatic hydrocarbons (e.g. creosote, naphthalene) Organochlorine pesticides (e.g. chlordane, endosulfan, pentachlorophenol) Aldrin and dieldrin Metals (e.g. arsenic, copper, chromium VI, zinc) Boron Ammonia Cresols
Wool scouring*	Nutrients (e.g. phosphorus, nitrogen) Total Dissolved Solids (TDS) Oil and Grease Detergents Pesticides Bleaching agents (e.g. hydrogen peroxide)

*Prescribed premises under the *Environmental Protection Regulations 1987*

References

Standards Australia 2005, *Guide to the Investigation and Sampling of Sites with Potentially Contaminated Soil Part 1: Non-volatile and semi-volatile compounds* Table J1 AS4482.1

NEPC 1999, *National Environment Protection (Assessment of Site Contamination) Measure (1999) Schedule B2, Appendix A: Possible analytes for soil contamination, National Environment Protection Council.* www.scew.gov.au/nepms/assessment-site-contamination)

Appendix C

Sediment sampling design

Inland sediments

As with soil sampling programs, the number of samples required is dependent upon the site history, distribution of contaminant sources and migration pathways of contamination. Where contaminated sediments are located along a stream or riverbed, the depth and downstream extent of contamination should be identified. Where water flow may have carried contamination downstream, samples should be collected progressively downstream, at regular intervals, from the contamination source and in areas where sediments are likely to settle (e.g. deep pools) until the extent of contamination is determined.

Marine sediments

Where sampling of marine sediments is being undertaken such as in a harbour, marina, port or estuary, the number of samples will depend upon the geography of the sampling location:

- where sediments are located at a site which is relatively uniform (e.g. in the centre of a large, flat-bottomed or gently sloping bay) and the site is distant from pollution sources (e.g. the centre of a large bay), then a minimum number of samples can be collected to adequately characterise the contamination status; whereas
- where sediments are near the shore in a geographically complex embayment, with significant changes in depth, shoreline configuration and many potential pollution point sources (e.g. Cockburn Sound) then a larger number of samples will be required.

Sampling design

As with soils, where detailed information is available for the site in terms of physical characteristics, potential contaminants and potential sources of contamination, then judgemental sampling can be used to investigate contamination. Where there is little or no data in relation to the potential contamination of the site, then a systematic (grid) sampling pattern should be adopted. Sampling types may be combined such as a systematic (grid) pattern, with judgemental sampling at locations where more information is available.

Refer to Schedule B2 of the NEPM for further information on various sampling patterns.

Where large sites are being assessed, such as bays, harbours and marinas, where little information on contamination is available, it is recommended that:

- the site be divided into sub-areas and then random samples collected from within each block. Sub-area size can be varied to increase sampling density in locations with greatest probability of high contamination levels, and areas can be increased if evidence indicates contaminant concentrations are unlikely to vary much across the site; or
- a pilot (or screening) study should be completed comprising 10-20 per cent of the locations anticipated for the full-scale study. Pilot samples should be analysed for the full range of chemical parameters anticipated to be present.

When determining a sampling pattern the following should be taken into consideration:

- findings of the PSI;
- objectives of the SAQP;
- current and historical usage of the site;
- known and potential contaminants (and their distribution);
- nature of contaminants;
- beneficial uses of the site and adjacent sites;
- potential/proposed site use(s);
- climatological conditions;
  - seasonal variability of temperature, wind direction and wind force (e.g. wave movements may restrict sampling location access, storm conditions may disturb sediments to be sampled);
- hydrographical conditions;
  - mobility of sediments (dynamic zones can result in sediment mobilisation enhancing contaminant release, sediment deposition and sorting of grain sizes);
  - tidal areas (e.g. variations in water depth, current speeds and directions);
  - rivers (e.g. flow rates, presence of riffles and pools);
  - standing bodies (e.g. lakes and harbour areas may have negligible current to cause sediment disturbance);
  - sediment conditions (e.g. nature and composition of sediment layer, sorting of sediments, sediment depth);
  - influence of stream mixing; and mixing through the profile from wave action;
- nautical conditions (e.g. some sample points may need to be avoided due to marine traffic);
- sampling constraints;
  - physical constraints (e.g. boat size, water depth); and
  - safety of sample collection (e.g. presence of soft mud, quicksand, deep holes, swift currents and dangerous marine life);
- contaminant characteristics;
  - solubility, density, persistence and type of contaminants; and
  - proximity of sampling location to outfalls and sources of contamination;
- ecological considerations;
  - plant growth (e.g. disturbance of plant growth and restrictions on access to plant growth (algae on surface of water body, and riverbank vegetation)); and possible impacts on aquatic organisms (e.g. dispersion of contaminated sediments, disturbance of breeding grounds (timing of site access)); and
  - potential risks to human health and the environment.

Sampling depth

Determination of the depth of sampling should take into consideration:

- findings of the PSI;
- objectives of the SAQP;
- site history and possible depth of contamination through deposition;
- sediment geology (natural confining layers, preferential pathways);
- nature of contaminants (mobility, persistence);
- known or assumed maximum depth of contamination;
- field observations and identification of contamination (e.g. stained sediments);
- diffuse or point source contamination sources (diffuse contamination within a harbour, or point source contamination at depth from a pipe discharge);
- potential for mixing down the sediment profile; and
- human health and ecological risks.

Number of samples

Determination of the number of samples to be collected should take into consideration:

- findings of the PSI;
- SAQP objectives;
- size of the area to be sampled;
- sampling pattern applied;
- nature, complexity and distribution of known contaminants;
- sediment lithology and variability;
- potential remediation and management options; and
- small-scale variability in contaminant concentration.

Control points should be set up/identified to act as a reference point in determining the levels of contamination against ‘background’.

Frequency of samples

There is often some form of mobility of sediments, and therefore more than one sampling event may be required to build up a picture of temporal changes in sediment quality. Determination of sampling frequency should take into consideration:

- objectives of the SAQP;
- seasonal and diurnal changes in sediments due to tidal influences, etc.;
- sediment geology and stratification; and
- characteristics of particular contaminants (e.g. mobility, partitioning, etc.).

Appendix D

Assessment levels for water and sediment

Table 7: Assessment levels for water—excluding microbiological contaminants

Refer to section 9.8 of this guideline for information on the correct application of these assessment levels.
Cells shaded yellow are derived from 10x the ADWG health value, cells shaded orange are equal to the ADWG aesthetic value, values that are in **bold** text have changed since DEC 2010

	ANZECC & ARMCANZ (2000)[1]		ADWG (2011)[2]		DoH (2014)[3]	ANZECC & ARMCANZ (2000)[1]	
	Fresh Waters[4]	Marine Waters[4]	Drinking Water Health Value	Drinking Water Aesthetic Value	Non-Potable Groundwater Use (NPUG)	Short-Term Irrigation Water	Long-Term Irrigation Water[5]
	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Metals/Metalloids							
Aluminium, Al	55	-	-	0.2	**0.2**	20	5
Antimony, At	**-**	**-**	**0.003**	**-**	**0.03**	**-**	**-**
Arsenic, As	24 as As(III) 13 as As(V)	- -	**0.01**	- -	**0.1**	2	0.1
Barium, Ba	-	-	**2**	-	**20**	-	-
Beryllium, Be	-	-	**0.06**	-	**0.6**	0.5	0.1
Boron, B	370[6]	-	4	-	40	refer to guideline	0.5
Cadmium, Cd	0.2	0.7	0.002	-	0.02	0.05	0.01
Chromium, (unspeciated), Cr	-	-	-	-	-	1	0.1
Chromium, Cr(III)	-	27	-	-	-	-	-
Chromium, Cr(VI)	1[6]	4.4	0.05	-	0.5	-	-
Cobalt, Co	-	1	-	-	-	0.1	0.05
Copper, Cu	1.4	1.3	2	1	20	5	0.2
Iron, (Total) Fe	300[12]	pH > 6, 1000[13] pH < 6, 300[13]	-	0.3	**0.3**	10	0.2
Lead, Pb	3.4	4.4	0.01	-	0.1	5	2
Lithium, Li	-	-	-	-	**-**	2.5 (0.075 for citrus crops)	2.5 (0.075 for citrus crops)
Manganese, Mn	1900[6]	-	0.5	0.1	5	10	0.2
Mercury (Total), Hg	0.06[7]	0.1[7]	0.001	-	0.01	0.002	0.002
Molybdenum, Mo	-	-	0.05	-	0.5	0.05	0.01
Nickel, Ni	11	7	0.02	-	0.2	2	0.2
Selenium (Total), Se	5[7]	-	0.01	-	0.1	0.05	0.02
Silver, Ag	0.05	1.4	0.1	-	1	-	-
Tributyl tin (as Sn)	-	0.006[6]	-	-	-	-	-

	ANZECC & ARMCANZ (2000)[1]		ADWG (2011)[2]		DoH (2014)[3]	ANZECC & ARMCANZ (2000)[1]	
	Fresh Waters[4]	Marine Waters[4]	Drinking Water Health Value	Drinking Water Aesthetic Value	Non-Potable Groundwater Use (NPUG)	Short-Term Irrigation Water	Long-Term Irrigation Water[5]
	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Tributyl tin oxide	-	-	0.001	-	0.01	-	-
Uranium, U	-	-	**0.017**	-	**0.17**	0.1	0.01
Vanadium, V	-	100	-	-	-	0.5	0.1
Zinc, Zn	8[6]	15[6]	-	3	**3**	5	2
Other Inorganics							
Ammonia[8,9] (as NH_3-N at pH 8)	900[6]	910	-	-	-	-	
Ammonia as NH_3	-	-	-	0.5	0.5	-	-
Bromate, BrO_3	-	-	0.02	-	0.2	-	
Chloride, Cl^-	-	-	-	250	**250**	refer to guideline	refer to guideline
Cyanide (as un-ionised Cn)	7[10]	4[10]	0.08	-	0.8	-	-
Fluoride, F^-	-	-	1.5	-	15	2	1
Hydrogen sulfide	1[11]	-	-	0.05	0.05	-	-
Iodide, I^-	-	-	**0.5**	-	**5**	-	-
Nitrate (as NO_3)[9]	refer to guideline	refer to guideline	50	-	500	-	-
Nitrite (as NO_2)[9]	refer to guideline	refer to guideline	3	-	30	-	-
Nitrogen, N[9]	refer to guideline	refer to guideline	-	-	-	refer to guideline	5
Total nitrogen, N[14]	2000 (1000)[14]	-	-	-	-	-	-
Total phosphorus, P[14]	200 (100)[14]	-	-	-	-	-	-
Phosporus (as P)[9]	refer to guideline	refer to guideline	-	-	-	refer to guideline	0.05
Sulfate (as SO_4)	-	-	500	250	**1000**[15]	-	-
Organic Compounds							
Ethanol	1400	-	-	-	-	-	-
Ethylenediamine tetraacetic acid (EDTA)	-	-	0.25	-	2.5	-	-
Formaldehyde	-	-	0.5	-	5	-	-
Nitrilotriacetic acid	-	-	**0.2**	-	**2**	-	-
Methyl tertiary butyl ether (MTBE)	-	-	-	-	**0.02**[3]	-	-
Anilines							
Aniline	**8**	**-**	-	-	-	-	-
2,4-Dichloroaniline	**7**	**-**	-	-	-	-	-
3,4-Dichloroaniline	**3**	**150**	-	-	-	-	-
Chlorinated Alkanes							
Dichloromethane (DCM)	-	-	0.004	-	0.04	-	-

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	Fresh Waters[4]	Marine Waters[4]	Drinking Water Health Value	Drinking Water Aesthetic Value	Non-Potable Groundwater Use (NPUG)	Short-Term Irrigation Water	Long-Term Irrigation Water[5]
	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
(methylene chloride)							
Trihalomethanes (total, **including chloroform**)	-	-	0.25	-	2.5	-	-
Tetrachloromethane (carbon tetrachloride)	-	-	0.003	-	0.03	-	-
1,2-dichloroethane	-	-	0.003	-	0.03	-	-
1,1,2-Trichloroethane (TCE)	6500	1900	-	-	-	-	-
Hexachloroethane	290[7]	-	-	-	-	-	-
Chlorinated Alkenes							
Chloroethene (vinyl chloride)	-	-	0.0003	-	0.003	-	-
1,1-Dichloroethene	-	-	0.03	-	0.3	-	-
1,2-Dichoroethene	-	-	0.06	-	0.6	-	-
Perchloroethylene (PCE) also known as tetrachloroethene	-	-	0.05	-	0.5	-	-
Chlorinated Benzenes							
Chlorobenzene	-	-	0.3	0.01	0.01	-	-
1,2- Dichlorobenzene	160	-	1.5	0.001	0.001	-	-
1,3- Dichlorobenzene	260	-	-	0.02	0.02	-	-
1,4- Dichlorobenzene	60	-	0.04	**0.0003**	**0.0003**	-	-
1,2,3- Trichlorobenzene	3[7]	-	0.03	0.005	0.005	-	-
1,2,4- Trichlorobenzene	85[7]	20[7]	For individual or total trichlorobenzenes	For individual or total trichlorobenzenes	For individual or total trichlorobenzenes	-	-
1,3,5-Trichlorobenzene	-	-				-	-
Polychlorinated Biphenyls (PCBs)							
Aroclor 1242	0.3[7]	-	-	-	**-**	-	-
Aroclor 1254	0.01[7]	-	-	-	**-**	-	-
Other Chlorinated Compounds							
Epichlorohydrin	-	-	**0.1**	-	**1**	-	-
Hexachlorobutadiene	-	-	0.0007	-	0.007	-	-
Monochloramine	-	-	3	0.5	0.5	-	-
Monocyclic Aromatic Hydrocarbons							
Benzene	950	500[6]	0.001	-	0.01	-	-
Toluene	-	-	0.8	0.025	0.025	-	-
Ethylbenzene	-	-	0.3	0.003	0.003	-	-
Xylenes	350 (as o-xylene) 200 (as p-xylene)	-	0.6	0.02	0.02		-
Styrene	-	-	0.03	0.004	0.004	-	-

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	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	16	50[6]	-	-	-	-	-
Benzo[a]pyrene	-	-	0.00001	-	0.0001	-	-
Phenols							
Phenol	320	400	-	-	-	-	-
2-Chlorophenol	340[3]	-	0.3	0.0001	3	-	-
4-Chlorophenol	220	-	-	-	-	-	-
2,4-Dichlorophenol	120	-	0.2	0.0003	2	-	-
2,4,6-Trichlorophenol	3[7]	-	0.02	0.002	0.2	-	-
2,3,4,6-Tetrachlorophenol	10[7]	-	-	-	-	-	-
Pentachorophenol	3.6[7]	11[7]	-	-	-	-	-
2,4-Dinitrophenol	**45**	-	-	-	-	-	-
Phthalates							
Dimethylphthalate	3700	-	-	-	-	-	-
Diethylphthalate	1000	-	-	-	-	-	-
Dibutylphthalate	10[7]	-	-	-	-	-	-
Di(2-ethylhexyl) phthalate	-	-	0.01	-	0.1	-	-
Pesticides and herbicides							
Acephate	-	-	**0.008**	-	**0.08**	-	-
Acrolein	-	-	-	-	-	refer to guideline	refer to guideline
Aldicarb	-	-	**0.004**	-	**0.04**	-	-
Aldrin plus Dieldrin	-	-	0.0003	-	0.003	-	-
Ametryn	-	-	**0.07**	-	**0.7**	-	-
Amitraz	-	-	**0.009**	-	**0.09**	-	-
Amitrole	-	-	**0.0009**	-	**0.009**	refer to guideline	refer to guideline
Asulam	-	-	**0.07**	-	**0.7**	-	-
Atrazine	13	-	**0.02**	-	**0.2**	-	-
Azinphos-methyl	-	-	**0.03**	-	**0.3**	-	-
Benomyl	-	-	**0.09**	-	**0.9**	-	-
Bentazone	-	-	**0.4**	-	**4**	-	-
Bifenthrin[3]	-	-	-	-	**0.35**[3]	-	-
Bioresmethrin	-	-	**0.1**	-	**1**	-	-
Bromacil	-	-	**0.4**	-	**4**	-	-
Bromoxynil	-	-	**0.01**	-	**0.1**	-	-
Captan	-	-	**0.4**	-	**4**	-	-
Carbaryl	-	-	**0.03**	-	**0.3**	-	-

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	Fresh Waters[4]	Marine Waters[4]	Drinking Water Health Value	Drinking Water Aesthetic Value	Non-Potable Groundwater Use (NPUG)	Short-Term Irrigation Water	Long-Term Irrigation Water[5]
	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Carbendazim (Thiophanate-methyl)	-	-	**0.09**	-	0.9	-	-
Carbofuran	0.06	-	0.01	-	0.1	-	-
Carboxin	-	-	**0.3**	-	3	-	-
Carfentrazone-ethyl	-	-	**0.1**	-	1	-	-
Chlorantraniliprole	-	-	**6**	-	60	-	-
Chlordane	0.03[7]	-	**0.002**	-	0.02	-	-
Chlorfenvinphos	-	-	**0.002**	-	0.02	-	-
Chlorothalonil	-	-	**0.05**	-	0.5	-	-
Chlorpyrifos	0.01[7]	0.009[7]	0.01	-	0.1	-	-
Chlorsulfuron	-	-	**0.2**	-	2	-	-
Clopyralid	-	-	**2**	-	20	-	-
Cyfluthrin, Beta-cyfluthrin	-	-	**0.05**	-	0.5	-	-
Cypermethrin isomers	-	-	**0.2**	-	2	-	-
Cyprodinil	-	-	**0.09**	-	0.9	-	-
1,3-Dichloropropene	-	-	**0.1**	-	1	-	-
2,2-DPA	-	-	**0.5**	-	5	refer to guideline	refer to guideline
2,4-D [2,4-dichlorophenoxy acetic acid]	280	-	0.03	-	0.3	refer to guideline	refer to guideline
DDT	0.006[7]	-	**0.009**	-	0.09	-	-
Deltramethrin	-	-	**0.04**	-	0.4	-	-
Diazinon	0.01	-	**0.004**	-	0.04	-	-
Dicamba	-	-	**0.1**	-	1	refer to guideline	refer to guideline
Dichlobenil	-	-	-	-	-	refer to guideline	refer to guideline
Dichloroprop	-	-	**0.1**	-	1	-	-
Dichlorvos	-	-	**0.005**	-	0.05	-	-
Diclofop-methyl	-	-	**0.005**	-	0.05	-	-
Dicofol	-	-	**0.004**	-	0.04	-	-
Dieldrin plus Aldrin	-	-	0.0003	-	0.003	-	-
Diflubenzuron	-	-	**0.07**	-	0.7	-	-
Dimethoate	0.15	-	**0.007**	-	0.07	-	-
Diquat	1.4	-	**0.007**	-	0.07	-	-
Disulfoton	-	-	**0.004**	-	0.04	-	-
Diuron	-	-	**0.02**	-	0.2	refer to guideline	refer to guideline

	ANZECC & ARMCANZ (2000)[1]		ADWG (2011)[2]		DoH (2014)[3]	ANZECC & ARMCANZ (2000)[1]	
	Fresh Waters[4]	Marine Waters[4]	Drinking Water Health Value	Drinking Water Aesthetic Value	Non-Potable Groundwater Use (NPUG)	Short-Term Irrigation Water	Long-Term Irrigation Water[5]
	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Endosulfan	0.03[7]	0.005[7]	**0.02**	-	0.2	-	-
Endothal	-	-	**0.1**	-	1	-	-
Endrin	0.01[7]	0.004[7]	-	-	-	-	-
EPTC	-	-	**0.3**	-	3	-	-
Esfenvalerate	-	-	**0.03**	-	0.3	-	-
Ethion	-	-	**0.004**	-	0.04	-	-
Ethoprophos	-	-	**0.001**	-	0.01	-	-
Etridiazole	-	-	**0.1**	-	1	-	-
Fenamiphos	-	-	**0.0005**	-	0.005	-	-
Fenarimol	-	-	**0.04**	-	0.4	-	-
Fenitrothion	0.2	-	**0.007**	-	0.07	-	-
Fenthion	-	-	**0.007**	-	0.07	-	-
Fenvalerate	-	-	**0.06**	-	0.6	-	-
Fipronil	-	-	**0.0007**	-	0.007	-	-
Flamprop-methyl	-	-	**0.004**	-	0.04	-	-
Fluazifop-p-butyl[3]	-	-	-	-	0.1[3]	-	-
Flumetsulum	-	-	-	-	0.035[3]		
Fluometuron	-	-	**0.07**	-	0.7	refer to guideline	refer to guideline
Flupropionate	-	-	**0.009**	-	0.09	-	-
Flutriafol[3]	-	-	-	-	0.3[3]	-	-
Glyphosate	370	-	1	-	10	-	-
Haloxyfop	-	-	**0.001**	-	0.01	-	-
Heptachlor	0.01[7]	-	-	-	-	-	-
Heptachlor (including its Epoxide)	-	-	0.0003	-	0.003	-	-
Hexazinone	-	-	**0.4**	-	4	-	-
Imazapyr	-	-	**9**	-	90	-	-
Iprodione	-	-	**0.1**	-	1	-	-
Lindane (γ-HCH)	0.2	-	**0.01**	-	0.1	-	-
Malathion	0.05	-	**0.07**	-	0.7	-	-
Mancozeb (as ETU, ethylene thiourea)	-	-	**0.009**	-	0.09	-	-
MCPA	-	-	**0.04**	-	0.4	-	-
Metaldehyde	-	-	**0.02**	-	0.2	-	-
Metham (as methylisothiocyanate, MITC)	-	-	**0.001**	-	0.01	-	-

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	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Methidathion	-	-	**0.006**	-	0.06	-	-
Methiocarb	-	-	**0.007**	-	0.07	-	-
Methomyl	3.5		**0.02**	-	0.2	-	-
Methyl bromide	-	-	**0.001**	-	0.01	-	-
Metiram (as ETU, ethylene thiourea)	-	-	**0.009**	-	0.09	-	-
Metolachlor/s–Metolachlor	-	-	**0.3**	-	3	-	-
Metribuzin	-	-	**0.07**	-	0.7	-	-
Metsulfuron-methyl	-	-	**0.04**	-	0.4	-	-
Mevinphos	-	-	**0.006**	-	0.06	-	-
Molinate	3.4	-	**0.004**	-	0.04	-	-
Napropamide	-	-	**0.4**	-	4	-	-
Nicarbazin	-	-	**1**	-	10	-	-
Norflurazon	-	-	**0.05**	-	0.5	-	-
Omethoate	-	-	**0.001**	-	0.01	-	-
Oryzalin	-	-	**0.4**	-	4	-	-
Oxamyl	-	-	**0.007**	-	0.07	-	-
Paraquat	-	-	**0.02**	-	0.2	refer to guideline	refer to guideline
Parathion	0.004[5]	-	**0.02**	-	0.2	-	-
Parathion methyl	-	-	**0.0007**	-	0.007	-	-
Pebulate	-	-	**0.03**	-	0.3	-	-
Pendimethalin	-	-	**0.4**	-	4	-	-
Pentachlorophenol	-	-	**0.01**	-	0.1	-	-
Permethrin	-	-	**0.2**	-	2	-	-
Picloram	-	-	**0.3**	-	3	-	-
Piperonyl butoxide	-	-	**0.6**	-	6	-	-
Pirimicarb	-	-	**0.007**	-	0.07	-	-
Pirimiphos methyl	-	-	**0.09**	-	0.9	-	-
Polihexanide	-	-	**0.7**	-	7	-	-
Profenofos	-	-	**0.0003**	-	0.003	-	-
Propachlor	-	-	**0.07**	-	0.7	-	-
Propanil	-	-	**0.7**	-	7	refer to guideline	refer to guideline
Propargite	-	-	**0.007**	-	0.07	-	-
Proparzine	-	-	**0.05**	-	0.5	-	-
Propiconazole	-	-	**0.1**	-	1	-	-
Propyzamide	-	-	**0.07**	-	0.7	-	-

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	Fresh Waters[4]	Marine Waters[4]	Drinking Water Health Value	Drinking Water Aesthetic Value	Non-Potable Groundwater Use (NPUG)	Short-Term Irrigation Water	Long-Term Irrigation Water[5]
	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Pyrasulfatole	-	-	**0.04**	-	0.4	-	-
Pyrazophos	-	-	**0.02**	-	0.2	-	-
Pyroxsulam	-	-	**4**	-	40	-	-
Quintozene	-	-	**0.03**	-	0.3	-	-
Quizalofop-p-ethyl[3]	-	-	**-**	-	0.4[3]	-	-
Simazine	3.2	-	0.02	-	0.2	-	-
Spirotetramat	-	-	**0.2**	-	2	-	-
Sulprofos	-	-	**0.01**	-	0.1	-	-
2,4,5-T	36	-	0.1	-	1	refer to guideline	refer to guideline
TCA (Trichloroacetic acid)	-	-	-	-	-	refer to guideline	refer to guideline
Tebuconazole[3]	-	-	-	-	1[3]	-	-
Tebuthiuron	2.2	-	-	-	**-**	-	-
Temephos	-	0.05[7]	**0.4**	-	4	-	-
Terbacil	-	-	**0.2**	-	2	-	-
Terbufos	-	-	**0.0009**	-	0.009	-	-
Terbuthylazine	-	-	**0.01**	-	0.1	-	-
Terbutryn	-	-	**0.4**	-	4	-	-
Thiobencarb	2.8	-	**0.04**	-	0.4	-	-
Thiometon	-	-	**0.004**	-	0.04	-	-
Thiram	0.01	-	**0.007**	-	0.07	-	-
Toltrazuril	-	-	**0.004**	-	0.04	-	-
Toxafene	0.1[7]	-	-	-	**-**	-	-
Triadimefon	-	-	**0.09**	-	0.9	-	-
Triadimenol[3]	-	-	-	-	2[3]	-	-
Trichlorfon	-	-	**0.007**	-	0.07	-	-
Triclopyr	-	-	**0.02**	-	0.2	-	-
Trifluralin	2.6[7]	-	**0.09**	-	0.9	-	-
Vernolate	-	-	**0.04**	-	0.4	-	-
Surfactants							
Linear alkylbenzene sulfonates (LAS)	**280**	-	-	-	-	-	-
Alcohol ethoxylated sulfate (AES)	**650**	-	-	-	-	-	-
Alcohol ethoxylated surfactants (AE)	**140**	-	-	-	-	-	-

	ANZECC & ARMCANZ (2000)[1]		ADWG (2011)[2]		DoH (2014)[3]	ANZECC & ARMCANZ (2000)[1]	
	Fresh Waters[4]	Marine Waters[4]	Drinking Water Health Value	Drinking Water Aesthetic Value	Non-Potable Groundwater Use (NPUG)	Short-Term Irrigation Water	Long-Term Irrigation Water[5]
	(µg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Other parameters							
Hardness as $CaCO_3$	-	-	-	200	-	-	-
pH	6.5—8.5	8.0-8.4	-	6.5—8.5	-	-	6.0 - 8.5 (groundwater) 6.0 - 9.0 (surface water)

Table 7 notes:

1. ANZECC & ARMCANZ (2000) Australian Water Quality Guidelines for Fresh and Marine Water Quality.
2. NHMRC & ARMCANZ (2011) Australian Drinking Water Guidelines.
3. DoH (2014) Contaminated sites ground and surface water chemical screening guidelines.
4. Quoted values are trigger values for *slightly moderately disturbed ecosystems*. Additional values applicable to *high conservation/ecological value systems* and *highly disturbed ecosystems* may be available in ANZECC & ARMCANZ (2000).
5. Long-term irrigation values are applicable to the application of irrigation water for up to 100 years in a non-domestic setting. For shorter irrigation periods, short-term irrigation guidelines may be more appropriate, refer to Table 4.2.10 of ANZECC & ARMCANZ (2000).
6. Value may not protect key test species from chronic toxicity, refer to chapter eight of ANZECC & ARMCANZ (2000)
7. Chemicals for which possible bioaccumulation and secondary poisoning effects should be considered. Refer to section 8.3.3.4 and 8.3.5.7 of ANZECC & ARMCANZ (2000)
8. For changes in ammonia value with pH refer to section 8.3.7.2 of ANZECC & ARMCANZ (2000)
9. Refer to Table 3.3.6 and other information in ANZECC & ARMCANZ (2000)
10. CN as un-ionised CN measured as [CN]
11. H_2S as un-ionised H_2S measured as S
12. ANZECC & NHMRC (1992)
13. DER screening value based on Dove & Sammut (2007)
14. SRT (2008) Healthy Rivers Action Plan
15. Value less than 10x health value due to health effects on livestock and domestic animals

Table 8: Microbiological assessment levels for water

Intended Use (environmental value)	E.coli[1] (thermotolerant coliforms) (Trigger value)
Agriculture[2]	
Raw human food crops in direct contact with irrigation water	<10cfu[4] / 100ml
Raw human food crops not in direct contact with irrigation water	<1,000cfu / 100ml
Pasture and fodder for dairy animals (without withholding period)	<100 cfu / 100ml
Pasture and fodder for dairy animals (with withholding period of five days)	<1,000 cfu / 100ml
Pasture and fodder (for grazing animals excluding pigs and dairy animals)	<1,000cfu / 100ml
Silviculture, turf, cotton, etc. (with restricted public access)	<10,000cfu / 100ml
Urban recreational areas, open spaces, parks and gardens[3, 5]	
Municipal use—public open spaces, sports grounds, golf courses etc. with unrestricted access and application	<1cfu / 100ml
Municipal use with some restricted access and application	<10cfu / 100ml
Municipal use with enhanced restrictions on access and application	<1,000cfu / 100ml
Drinking water	Refer to ADWG

Table 8 Notes:

1 *E.coli* to be used as a faecal pathogen indicator. Where salinity exceeds one per cent (10,000 ppm) *Enterococci* should be substituted for *E.coli.*

2 ANZECC & ARMCANZ (2000)

3 EPHC (2006)

4 cfu = colony forming units

5 Adapted from Table 8 in DoH (2011)

Table 9: Sediment assessment levels

Parameter	ISQG-Low[1,2] (Trigger value)	ISQG-High[1,3]
Metals/Metalloids (mg/kg dry wt)		
Antimony, Sb	2	25
Arsenic, As	20	70
Cadmium, Cd	1.5	10
Chromium, Cr	80	370
Copper, Cu	65	270
Lead, Pb	50	220
Mercury, Hg	0.15	1
Nickel, Ni	21	52
Silver, Ag	1.0	3.7
Zinc, Zn	200	410
Organometallics (µg/kg dry wt)[4]		
Tributyltin (as Sn)	5	70
Organics (µg/kg dry wt)[4]		
Acenapthene	16	500
Acenaphthalene	44	640
Anthracene	85	1100
Fluorene	19	540
Naphthalene	160	2100
Phenanthrene	240	1500
Low Molecular Weight Polycyclic Aromatic Hydrocarbons (PAHs)[5]	552	3160
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600

Parameter	ISQG-Low[1,2] (Trigger value)	ISQG-High[1,3]
Organics (µg/kg dry wt)[4] *continued*		
Dibenzo(a,h)anthracene	63	260
Chrysene	384	2800
Fluoranthene	600	5100
Pyrene	665	2600
High Molecular Weight Polycyclic Aromatic Hydrocarbons (PAHs)[6]	1700	9600
Total Polycyclic Aromatic Hydrocarbons (PAHs)	4000	45000
Total DDT	1.6	46
P,p'-DDE	2.2	27
o,p'- + p,p'-DDD	2	20
Chlordane	0.5	6
Dieldrin	0.02	8
Endrin	0.02	8
Lindane	0.32	1.0
Total Polychlorinated Biphenyls (PCBs)	23	-

Table 9 Notes:

Extracted from the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000).

1. Interim Sediment Quality Guidelines—Low: Probable effects concentrations below which biological effects would rarely occur.
2. Interim Sediment Quality Guidelines—High: Probable effects concentrations below which biological effects would possibly occur. Concentrations above these values represent a probable-effects range within which effects would be expected to frequently occur.
3. Normalised to one per cent organic carbon. If the sediment organic carbon is markedly higher than one per cent the guideline value should be increased accordingly, since additional carbon binding sites reduce the contaminant bioavailability.
4. Low molecular weight PAHs are the sum of acenaphthalene, anthracene, fluorene, 2-methylnaphthalene, naphthalene and phenanthrene.
5. High molecular weight PAHs are the sum of benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene.
6. Values are expressed as concentrations on a dry weight basis. This does not imply that samples should be dried before analysis resulting in potential loss of some analytes, but that results should be corrected for moisture content.