National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April

Schedule B5a

GUIDELINE ON

Ecological Risk Assessment

The following guideline provides general guidance in relation to the framework for ecological risk assessment in the assessment of site contamination.

This guideline forms part of the National Environment Protection (Assessment of Site Contamination) Measure 2011 and should be read in conjunction with that document, which includes a policy framework and assessment of site contamination flowchart.

This Schedule, along with Schedule B5b and Schedule B5c replaces Schedule B5 to the National Environment Protection (Assessment of Site Contamination) Measure 1999.

The National Environment Protection Council (NEPC) acknowledges the contribution of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the NSW Department of Environment, Climate Change and Water (DECCW), and the NSW Environmental Trust to the development of this Measure.

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Ecological risk assessment

1 Background

The framework for conducting ecological risk assessment (ERA) was first set out nationally in the *Australian and New Zealand guidelines for the assessment and management of contaminated sites* (ANZECC & NHMRC 1992). It is based on the US EPA model and consists of four main phases: data collection and evaluation, toxicity assessment, exposure assessment and risk characterisation (US EPA 1989).

The National Environment Protection (Assessment of Site Contamination) Measure (NEPM) 1999 refined and expanded upon this model. The tiered approach outlined in the 1999 Measure consisted of three levels of assessment:

Level 1 - a comparison of measured concentrations to the (EILs)

Level 2 - a desktop study where site-specific factors were used to modify the EILs which were then compared to the measured concentrations

Level 3 - a detailed, site-specific, probabilistic ERA.

Each level consisted largely of the same basic four considerations but incorporated an increasing degree of complexity from Level 1 to Level 3.

The development of ERA in Australia was further enhanced by the risk-based hierarchical approach adopted in the *National water quality management strategy – Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC & ARMCANZ 2000).

2 Introduction

It is now well recognised that a risk assessment provides information to distinguish between important and trivial contamination issues. When coupled with political, social, cultural, economic and engineering considerations, it enables decisions about the need and methods to be used to reduce risk. ERA is this approach applied to ecological situations.

Inherent in an ERA is the need to recognise the following principles:

- It needs to be focused on maintaining ecosystem structure and function which are both vital to maintain healthy and sustainable ecosystems.
- It must recognise that all aspects of the environment are interdependent and cannot be considered in isolation, thus leading to a holistic approach.
- Its objectives must recognise the sustainable use of resources in an environmental, economic, social and cultural context. It is imperative that environmental values to be protected are the driving force for the assessment, noting that the values of sites with different land uses (for example, land used for industrial purposes or for a National Park) may be different. The existing or proposed land use of a site assessed for contamination will influence the selection of ecological values.
- An ERA requires an integrated approach using multiple lines of evidence gathered from physical, chemical and biological data combined with site-specific data about exposure, toxicological and chemical parameters and the consideration of properties of soil, sediments and water relevant to the site in order to estimate the level of effects. The movement of contaminants from soil to other environmental media (that is, air, water or sediment) and subsequent exposure to biota should be included in the ERA.
- Communication strategies are integral to the success of any ERA, so the process requires a cooperative approach to encourage effective communication among industry, government and communities.

The ERA process described in this guideline assesses the risk posed to terrestrial ecosystems (including soil processes, soil flora and fauna, and terrestrial invertebrates and vertebrates) from the adverse effects of chemical contaminants in soil.

This risk-based process is inextricably linked to the principles of ecologically sustainable development (ESD). ESD aims to protect biodiversity and maintain ecological processes and functions and it is a central paradigm to both Australian and international environmental regulations and policies. However, it is also acknowledged that all human activity impacts on the environment and hence it is not possible to protect all species, processes and functions. Rather, it is necessary to manage the risks associated with various human activities in order to achieve the goals of ESD.

In this way, we recognise that we aim towards protecting the vast majority of, but not all, species from the harmful effect of contaminants. The assumption here is that protecting the majority of species (the structure of ecosystems) will enable the functions conducted by the ecosystems (for example, nutrient cycling, leaf litter degradation) to be maintained. The actual percentage of species that are protected is a policy decision. Human health risk assessment uses a similar approach as it aims to protect not every human, but the vast majority (for example, acceptable cancer risks are one to ten in 100,000 over a lifetime).

3 The ecological risk assessment framework

The methodology provided in Schedule B5b provides the means for deriving ecological investigation levels (EILs) used within the ERA framework. In developing the EIL derivation methodology, the approaches used by other entities (such as the USA, the Netherlands, Canada, the EU and the UK, Germany and New Zealand) were considered. A summary of these approaches is presented in an appendix of Schedule B5b.

This risk-based methodology incorporates the latest scientific findings in the areas of ecotoxicology, soil science and geochemistry. It enables:

- protection of introduced and native animals, plants, micro-organisms and microbial processes (including nutrient cycling)
- setting levels of protection based on land use
- accounting of background concentration of contaminants
- accounting for changes in bioavailability of contaminants over time and in different soils
- accounting for contaminants that biomagnify.

The EILs are calculated using a species sensitivity distribution (SSD) method which permits the EILs to be set to protect any selected percentage of species (for example, for urban residential, it is 80%). They are derived based on the LOEC (lowest observed effect concentrations) and EC30 (30% effect concentration) toxicity data. Further information is provided below, but full details of the EIL derivation methodology can be found in Schedule B5b.

The toxicity of some contaminants is affected by physicochemical properties of the soils in which the contaminant is located. When empirical relationships able to model the effect of soil properties on toxicity are established, then soil-specific EILs can be developed. These soil-specific quality guidelines (SQGs) take into account the biological availability of the element in different soils. Thus, rather than having a single numerical limit for a contaminant, different soils will have different limits. The EIL derivation methodology generates, wherever possible, soil-specific EILs. However, in developing this ERA framework, it was not possible to derive soil-specific EILs for all contaminants; therefore, the EILs for some contaminants are soil-specific while for others they are generic.

In addition, most of the available toxicity data for contaminants in soil were obtained in laboratories where the contaminant is added to the soil immediately prior to commencing the test. However, it is known that contaminants become less bioavailable in the field and over time (they age). Thus, laboratory-based experiments may overestimate toxicity in the field.

Also, laboratory experiments that use soils spiked with soluble metal salts overestimate toxicity compared to equivalent field soils, due to a lack of leaching of soluble salts which affect metal sorption. These factors have been addressed in recent EU risk assessments for metals in soils using 'ageing/leaching' factors. Therefore, whenever ageing/leaching factors were available, they were used to correct the laboratory-based toxicity data (see Schedule B5c).

Where sufficient data permitted, EILs were derived for sites with fresh (< 2 years) and aged (≥2 years) contamination. For the contaminants with generic EILs, there is a single value for each combination of land use and age of the contamination. For the contaminants with soil-specific EILs, a suite of values was derived (based on the soil physicochemical properties that control the toxicity) for each combination of land use and age of contamination.

Soil-specific physicochemical properties and ageing are two characteristics that would have been considered in Level 2 ERAs in the previous Measure (NEPC 1999).

By deriving EILs that account for soil-specific properties and ageing, the first ERA component is, in effect, a combination of Level 1 and Level 2 of the previous ERA framework (NEPM 1999). In summary, the framework for conducting ERAs has been simplified and now consists of two levels: a Preliminary ERA and a Definitive ERA (see Figure 1).

A summary of the EILs for eight chemicals (arsenic, copper, chromium (III), DDT, lead, naphthalene, nickel and zinc) is provided in Appendix 1. More details on the methodology and the data used in the derivation of these EILs can be found in Schedule B5b and Schedule B5c.

It is important to note that the EILs only apply to soil down to a depth of two metres below the current soil surface.

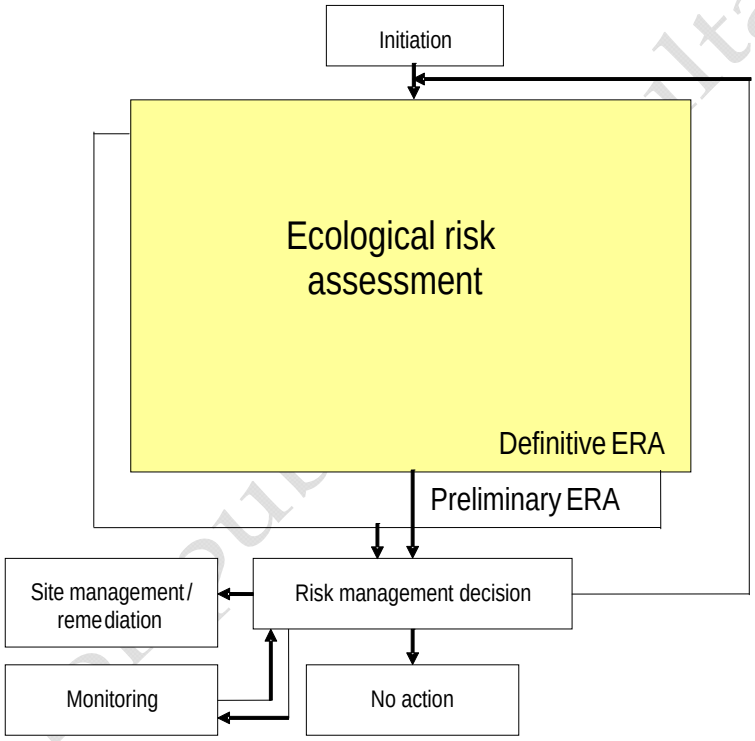

Figure 1. The framework for conducting ecological risk assessments

The tiered ERA approach used in this guideline permits:

- identification of the ecological receptors of concern
- estimation of the concentration of a contaminant of concern to which the ecological receptors are exposed
- consideration of the toxicity-modifying or toxicity-enhancing capacity of the receiving environment (whether that be soil, sediment or water)
- determination of whether the ecological receptors and ecological values may be at risk
- application of a multiple-lines-of-evidence approach to assess risks.

This tiered approach relatively quickly and cheaply screens out those sites where the environmental risk is minimal. It thus focuses resources on those sites that pose the greatest potential risk. It should be emphasised that the majority of sites will only require a Preliminary ERA.

3.1 Preliminary ERA

Generally the first step in ERA is to decide whether a Preliminary ERA is necessary for the site in question. In some jurisdictions at least some level of ERA is mandatory. Reasons for initiating a Preliminary ERA should be clearly stated in all ERA reports. ERAs are conducted using conservative assumptions (that is, they tend to favour protecting the environment). Thus, if a Preliminary ERA indicates the site faces a low risk from the contaminants, then there can be confidence that this is the case.

3.2 Definitive ERA

A Definitive ERA is required only in a situation where the concentration of the contaminant(s) is sufficiently high that it may pose a risk. A Definitive ERA requires greater data collection, uses more complex and environmentally realistic methods and reduces the uncertainty in the outcome of the ERA compared to the Preliminary ERA. As a result, Definitive ERAs are considerably more time consuming and costly than ERAs.

3.3 Components of an ecological risk assessment

Both Preliminary and Definitive ERAs consist of the same five basic components:

1. **Problem identification** is a scoping phase that establishes the objectives of the ERA and identifies the data required to achieve those objectives. It is essential that engagement with various stakeholders is undertaken early in this phase to provide opportunities for their input.

2. **Receptor identification** focuses on 'what species may be at risk?' and 'what do we want to protect?'. Of importance in this phase is the need to introduce the concept of what is acceptable risk in the context of the ecological values need to be protected. This requires the identification of local species, communities and ecological processes that are of ecological value based on the relevance and significance of societal, cultural, ecological, and economic factors.

3. **Exposure assessment** characterises the site, identifies potential exposure pathways and estimates exposure duration, concentrations and intakes.

4. **Toxicity assessment** involves estimating the concentration of contaminants at which species and ecological functions experience no harmful effects and those at which toxic effects are caused. These data are in turn used to determine the concentration of contaminants that an ecosystem can be exposed to without adverse effect or with adverse effects of a certain magnitude (that is, EILs).

5. **Risk characterisation** involves combining data and information from the exposure and toxicity assessments to determine the risk that ecosystems at the site face from the contaminants. This is usually done by comparing the measured contaminant concentrations with the EILs.

The relationships between the five components are shown in Figure 2 below. Receptor identification, exposure assessment and toxicity assessment components are interrelated, as the assessment of any of these components is dependent upon the characteristics of the other two. Risk characterisation includes the combination of information gained in the exposure and toxicity assessments. The types and amount of information available to a risk assessor are always limited — whether it be information about the chemical levels at the site or the potential effects on an organism that a chemical could cause — so all ERAs are estimates of what the risks might be. Hence, it is important that the objectives (developed in the problem formulation stage) are re-set taking into account any additional information gleaned at every phase. Any assumptions or extrapolations made in an ERA should be highlighted where they occur. Uncertainty is discussed further in a later section of this Schedule.

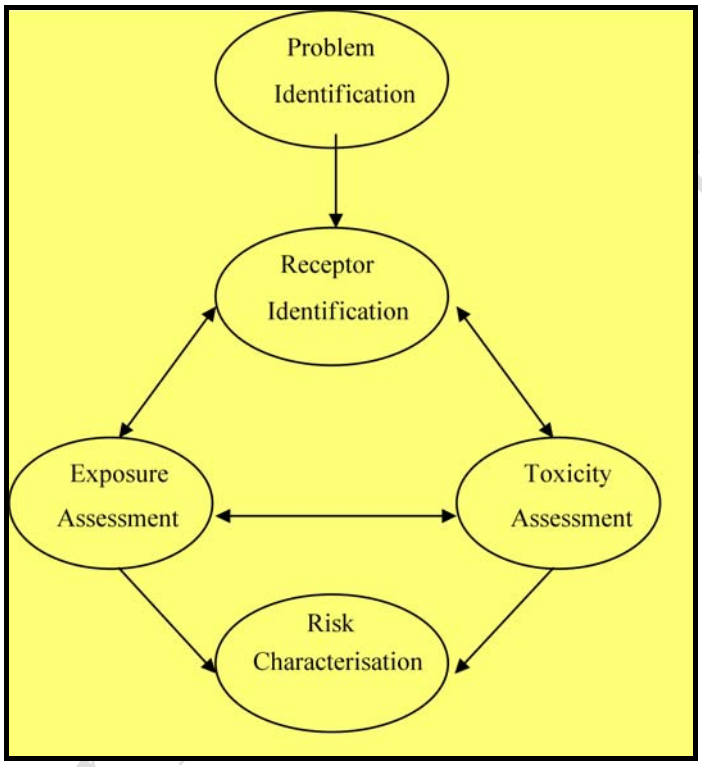

Figure 2. Components of an ERA

The objectives and what is done in each component varies depending on whether the components are being conducted as part of a Preliminary ERA or a Definitive ERA.

A detailed discussion of what should be done in each component of Preliminary and Further ERAs is presented in later sections of this Measure.

3.4 Risk management decision

At the conclusion of an ERA, a risk management decision needs to be made (as depicted in in later discussions of Preliminary and Definitive ERAs). This decision is based on both the risk characterisation component of ERA and risk management considerations (such as economic, social, cultural and engineering matters) and should be made by the decision manager in compliance with jurisdictional requirements. This step ensures that both risk assessment and risk management considerations (including conflicting results and uncertainty in any part of the ERA) are reviewed prior to the outcome being determined. It also ensures that risk assessors and risk managers are each aware of the objectives of the other.

The risk management decision determines the outcome of the assessment. There are four potential outcomes:

1. To take no action
2. To monitor the site
3. To remediate or actively manage the site
4. To proceed from a Preliminary ERA to a Definitive ERA.

Additional information on each of these potential outcomes is provided in the following sections.

3.4.1 No action

The 'no action' outcome implies that no site management or remediation, monitoring or further assessment is required at the site. It reflects a high degree of confidence that the ecological values of the site are adequately protected from the effects of the contamination based on the relevance and re-setting of objectives and taking into consideration multiple lines of evidence. This outcome ends the ERA process.

It is also possible that this could be the outcome even if there was some level of risk estimated, depending on the use of the site and the technological options available.

3.4.2 Monitoring

Biological and/or chemical monitoring may be considered where there remains uncertainty if an impact has occurred, is occurring, or may occur at some time in the future. Biological monitoring may focus on individual species, selected biota in a given environment, or communities and ecosystems for signs of chemical impact or exposure. Examples of parameters that may be monitored in individual species or selected biota include chemical or enzyme concentrations in tissues to assess exposure, or histopathological examination and behavioural change to assess impact. Typical parameters monitored when examining populations and communities may include species number, population number, number of offspring and biomass. Chemical monitoring can also be conducted, but its aim is to identify and quantify the chemical present in the various exposure media (for example, soil, surface water, groundwater, air, dust or food).

Ecological systems are stochastic (chaotic) and thus slight variations in initial conditions can make a big difference to the outcome. Therefore, monitoring is also often undertaken to demonstrate that the actual remediation or management process is not impacting on-site or off-site ecological values. Post-management/remediation monitoring may also be used to demonstrate the effectiveness of site management or remediation.

Monitoring may include chemical monitoring to demonstrate that the level of exposure continues to be acceptable, or biological monitoring to demonstrate that exposure continues to be acceptable and/or that residing species and populations are not being affected or that key species are returning to the site. Results from this monitoring process feed back into the risk management decision-making process to determine further outcomes.

3.4.3 Site management/remediation

Site management/remediation is one of two potential outcomes when the on-site soil concentration of contaminants, including mixtures of the contaminants, exceed the EIL or $EIL_{mixture}$. Site management includes any active control at the site that reduces the ecological impact to an acceptable level. This may include reducing the exposure of biota to the contaminants by reducing their exposure to the site (for example, fencing), maintaining a physical condition of the soil that reduces the contaminants' availability/mobility, immobilising the soil contaminants or removing the soil contaminants (that is, remediation). Monitoring is an essential part of any site management/remediation program to assess the effectiveness of the program in reducing ecological impact.

3.4.4 Proceeding from a Preliminary ERA to a Definitive ERA

Alternately, where there is reasonable certainty that an impact has occurred, is occurring or may occur at some time in the future, the decision may be made to move from a Preliminary ERA to a Definitive ERA.

3.5 Ecological values

An important part of assessing a contaminated site is identifying what ecological values are present at the site or nearby and which are to be protected. Ecological values are flora, fauna and supporting ecological processes (that is, factors that influence a species' ability to grow, survive, develop and reproduce, and remain viable) that are associated with a defined piece of land and are considered to have societal, cultural, ecological and/or economic significance.

Ecological values naturally vary from site to site according to variation in the natural habitat, the degree to which humans have physically altered the natural environment and the expectations of society. Ecological values can be established for any environment being assessed. There are two types of ecological values – generic and site specific. Both are discussed below.

3.5.1 Generic ecological values

The aim of the EILs is that varying levels of protection will be provided to the following ecological receptors at all sites:

- biota supporting ecological processes, including micro-organisms and soil invertebrates
- native flora and fauna
- introduced flora and fauna
- transitory or permanent wildlife.

Hereafter, the above list of protected organisms will be referred to as 'species and supporting ecological processes'.

The level of protection provided to species and supporting ecological processes varies depending on the land use and whether the contaminant in question biomagnifies. Differing levels of protection are provided by protecting differing percentages of species and supporting ecological processes (see Table 1).

By using SSD methods to derive the EILs and having different levels of protection for different land uses, it is assumed that not every individual organism or species can be or needs to be protected.

Due to the fact that the concentration of biomagnifying chemicals increases as food webs are ascended (for example, higher trophic level organisms such as eagles have higher tissue concentrations than lower trophic organisms such as algae), a high level of protection is warranted for such chemicals. The levels of protection provided for biomagnifying chemicals in the three land uses are presented in Table 1.

Table 1. Percentage of species and soil processes to be protected for different land uses depending on whether the contaminant is classed as a non-biomagnifying or biomagnifying chemical.

Land use	Standard % protection	Biomagnification[A] % protection
National parks and areas with high ecological value	99	99
Urban residential and public open space	80	85[B]
Commercial and industrial	60	65[C]

[A] if a contaminant has a logarithm of the octanol-water partition coefficient (K_{oc}) of equal to or greater than 4
[B] if surface area exceeds 250 m^2
[C] if surface area exceeds 1000 m^2

As the types of organisms being protected by the EILs does not change, irrespective of the land use, they are based on a generic set of ecological values. Generic ecological values are conservative in that they protect all biota considered of value within the land use regardless of whether or not they occur at the contaminated site. It is also possible to derive generic ecological values for biota that inhabit a state, region or local area regardless of land use.

EILs have been developed for three land uses: national parks and areas of high ecological value, urban residential and open public space, and commercial and industrial. The land uses are defined below:

National parks and areas of high ecological value are areas which are primarily used for conservation and, to a lesser extent, passive recreation, such as national parks and state parks. These reserves are generally considered to be of high ecological value and quality and worthy of maintaining at as close to a pristine state as possible.

Urban residential and public open space is land where the primary activity is (a) human residency, such as at separate dwellings and townhouses, and is usually associated with an area of exposed soil or garden that is used for recreational purposes although some is used for vegetable and other consumables production, and (b) reserves, sporting grounds, parks, golf courses and other areas used for recreation and which are located in an urbanised area. Urban parklands may include urban land adjacent to waterways and rivers. In most circumstances, hospitals, day care centres, pre-schools, primary schools and secondary schools belong to this land use.

Commercial and industrial land is land where the primary activity is related to (a) commercial operations and occupancy (for example, service stations, railways, roads, warehouses/distribution depots, convenience shops, shopping complexes and the main streets of towns), and (b) the production, manufacture or construction of goods (for example, manufacturing factories, warehouses, transport depots, refineries and timber treatment plants).

Commercial and industrial land, particularly in long-established industrial areas, is often heavily contaminated by past activities or fill material used to level the area. In these cases, jurisdictions may determine that HILs are the most appropriate soil quality criteria and that EILs are not applicable. In many cases, the only generic ecological value for this land use will be 'transitory wildlife'.

In cases of a site having a mixed land use (for example, an industrial site with a nature reserve), it is necessary to either apply the appropriate EIL to each land use or to apply the EILs for the most sensitive land use to the entire site.

In cases where land is to be converted from one land use type to a more sensitive land use, the ecological values identified for the more sensitive land use should be applied to the entire site.

3.5.2 Site-specific ecological values

Site-specific ecological values are those ecological values that are specific to the site under investigation. Identifying site-specific ecological values involves knowledge of the biota and supporting ecological functions that are expected to inhabit or visit the site. It also requires identification of stressors that may be present in the locality as well as an in-depth understanding of the relevance of the species.

Site-specific ecological values would be identified during a Definitive ERA, in conjunction with relevant stakeholders including appropriate government agencies, local government, community groups and/or by conducting a biological survey of the site.

Site managers and consultants should carry out appropriate community engagement and consult with the site auditor/third party reviewer and/or relevant jurisdictional agency before finalising site ecological values. Further information can be found in Suter (1993) and in Schedule B8.

4 Preliminary ecological risk assessment

This section provides guidance for conducting a Preliminary ERA. A Preliminary ERA is a screening level assessment of generic situations and should protect a selected percentage of all biota and supporting ecological processes that are likely to inhabit soils with specific land uses.

ERAs may be undertaken for a variety of reasons. The main reasons are listed below:

- A previous assessment of soil contamination at a site identifies significant areas where contaminant concentrations are above background levels.
- Site history suggests that chemicals may be present that may pose an adverse environmental effect.
- There are knowledge gaps in the soil contamination assessment that may be potentially important.
- There are ecological values that are important at the site or nearby (e.g. rare and/or endangered species or habitats).
- As part of due diligence investigations, an owner or occupier of a site may voluntarily conduct an ERA. Such risk assessments may also be conducted as part of environmental reporting requirements.
- An assessment of the suitability of land for its existing or proposed use has identified contaminants at concentrations above the background concentration.

The main question that a Preliminary ERA seeks to answer is whether the generic ecological values used to derive the EILs, and that therefore should be protected, are adversely affected by on-site contamination. This enables an informed risk management decision to be made.

A Preliminary ERA should:

- set clear objectives, taking into consideration the scale of concern, conceptual site model (CSM) and data quality objectives
- identify the ecological values relevant for the site
- determine if the ecological values used to derive the EILs are consistent with those identified for the site
- identify contaminants of concern
- establish the extent and degree of contamination on the site
- assess the linkages between cause and effects of the contamination on the site
- identify the most appropriate EILs for the soil contaminants
- determine whether the identified EILs are exceeded
- identify elements of uncertainty (including an assessment of the appropriateness of all the scientific tools used in the ERA (e.g. criteria, benchmarks, data evaluation and relevance of objectives)
- provide justification for the conclusion of the Preliminary ERA or for proceeding on to conducting a Definitive ERA.

The various components that comprise a Preliminary ERA, the order in which they are conducted, and the inter-relationships between each component are presented in Figure 3 below. A summary of the types of data and other information needed for each component of a Preliminary ERA is set out in Table 2.

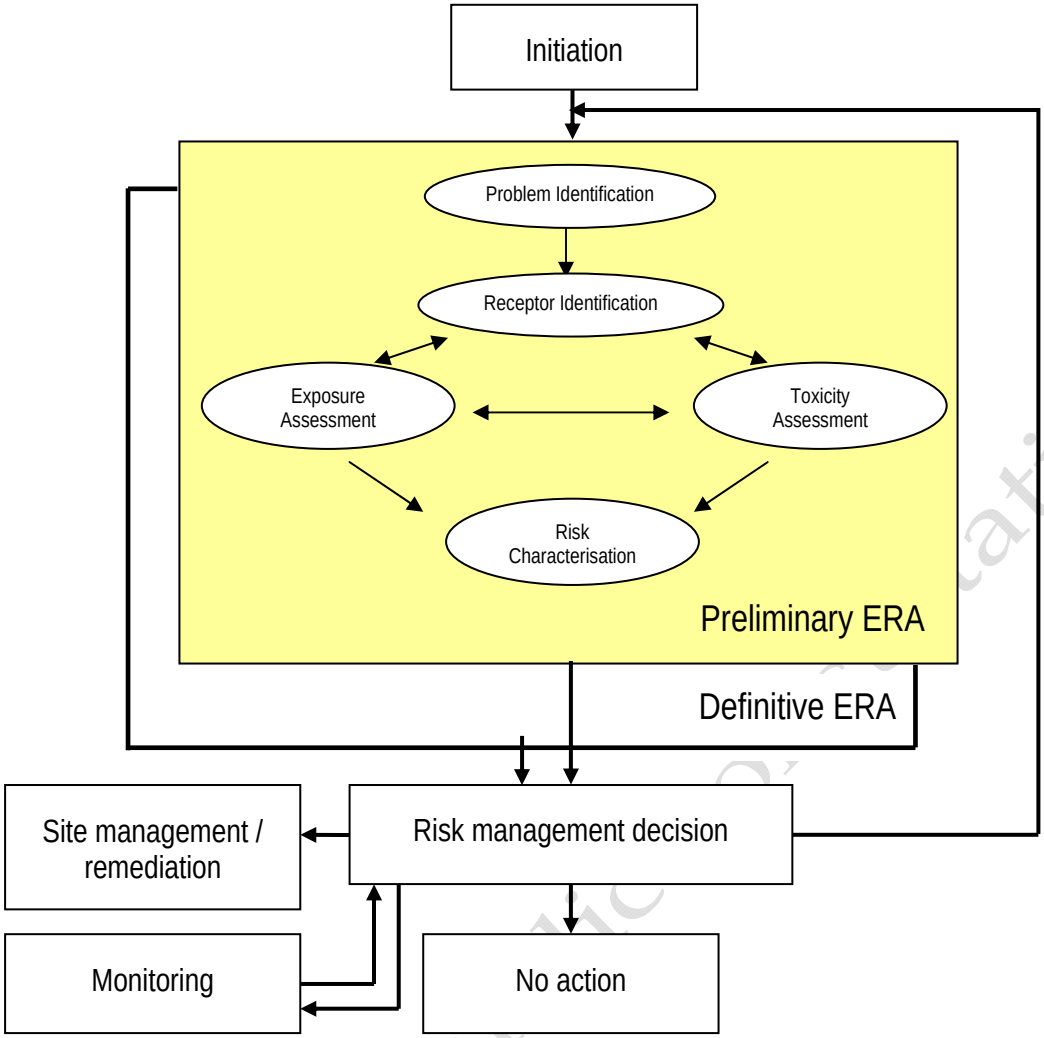

Figure 3. Preliminary ERA

Table 2. Information that may be collected for each component of a Preliminary ERA

ERA component	Indicative requirements for a Preliminary ERA
Problem identification	Clear objectives Site history Extent and degree of on-site soil contamination and development of a CSM Most appropriate EILs Identification of stakeholders and implementation of communication strategies
Receptor identification	Identification of information required to set the most appropriate EILs The components of the ecosystem that constitute the ecological value of the site
Exposure assessment	Exposure pathways used to calculate the most appropriate EILs Exposure pathways relevant to the site
Risk characterisation	On-site soil concentrations of contaminants of concern, The most appropriate EILs
An assessment of the appropriateness of the requirements for each component should be part of an uncertainty analysis	

4.1 Problem identification

The Preliminary ERA begins with problem identification to assist in the development of a CSM which summarises all that is known about the site. Where there is potential for off-site migration of contamination from a contaminated site to surrounding areas or groundwater, this should be identified and included in the site model. The model is then used to establish the objectives of the Preliminary ERA that are to be addressed. Once the objectives have been identified, the data and other information requirements of the ERA are determined. Problem identification is critical to ensure that the degree of assessment is appropriate for the problem. If there is the potential for off-site migration of contamination, a qualitative evaluation of the risk this poses should form part of the Preliminary ERA.

Depending on the data quality objectives (DQOs), in some cases the extent and degree of site contamination and the contaminants present at a site will already have been established by the existence of a soil contamination assessment. Where an ERA has been initiated in the absence of on-site soil contamination data, a soil contamination assessment should be undertaken.

This assessment should include information such as site history, site conditions, proposed land use and relevant environmental policies or regulations that may affect the site or actions to be taken. Sampling and analysis of contaminated soil should be undertaken in accordance with guidance contained in Schedule B2 and Schedule B3.

The preceding work identifies both the extent and degree of on-site contamination and the contaminants of concern. At this point in the ERA framework, contaminants of concern are those chemicals that have concentrations above the background concentrations or those that may have concentrations above the background based on the site history.

The selection of the most appropriate EILs to apply for the contaminants of concern is dependent on whether soil-specific EILs are available for the appropriate land uses(s). If soil-specific EILs are available, then the decision should be based on the physicochemical properties of the soil at the site. Otherwise, the selection will be based on land use.

4.2 Receptor identification

In a Preliminary ERA, it is assumed that all biota and supporting ecological processes that are of ecological value to the land use (that is, national parks and areas of high ecological value, urban residential and open public space, commercial and industrial) are of ecological value to the site. However, where a particular species (for example, giant Gippsland earthworm) or type of organism (for example, soil microbial processes) that is an important part of the ecological value[1] at a site was not considered in the derivation of the most appropriate EILs (see Section 5.5), the EIL may not provide adequate protection and a Definitive ERA should be undertaken. The basis for such a decision should be clearly presented in the Preliminary ERA report.

4.3 Exposure assessment

In a Preliminary ERA, it is assumed that all exposure pathways considered in the derivation of the EILs are applicable. The physical setting of the site significantly influences exposure since features such as soil type, soil organic matter content, paving and buildings can impact upon exposure pathways and contaminant availability. Exposure is also influenced by physical and chemical properties of the contaminants (for example, solubility in water, n-octanol/water partition coefficient (K_{oc}), soil/water partition coefficient and volatility). Each of these parameters may be evaluated to take account of site conditions, therefore providing a more site-specific estimate of the amount of a chemical an organism or a population may receive. If the results of the above analysis indicate that exposure pathways that are thought to be significant have not been considered, or that the magnitude of an exposure pathway is suspected to be underestimated in the derivation of EILs, a Definitive ERA should be undertaken. The basis for such a decision should be clearly presented in the Preliminary ERA report.

[1] The species or organism type not included must be important to the ecological value of the site because the method used to calculate the EILs uses all the existing high quality toxicity data as surrogates to represent the sensitivity of all organisms at the site.

4.4 Toxicity assessment

In a Preliminary ERA, it is assumed that the toxicity data and methods used to calculate the endorsed EILs are sufficiently protective of the biota at the site. However, where it is suspected that this is not the case, a Definitive ERA should be undertaken. The basis for such a decision should be clearly presented in the Preliminary ERA report.

4.5 Risk characterisation

In a Preliminary ERA, risk Characterisation consists of the comparison of on-site soil contaminant concentrations with the most appropriate EILs for the contaminants of concern.

If the on-site soil concentration of any contaminant of concern is equal to or less than the most appropriate EIL, then the site contamination is considered unlikely to be having an adverse impact on ecological values.

If the on-site soil concentration of any contaminant of concern is greater than the most appropriate EIL, the site contamination may be having an adverse impact on ecological values. Due to the general nature of data collected and the methods used to calculate EILs, the EILs are generally conservative. Therefore, levels of contamination above an EIL should not automatically necessitate remedial or clean-up action, rather they trigger further evaluation.

The uncertainty associated with on-site soil concentrations (due to spatial heterogeneity both horizontally and vertically) and EILs and any conflicting results should be highlighted and discussed in the Preliminary ERA report.

If there is more than one contaminant of concern at the site then the risk posed by the combined effects of the contaminants should be assessed using the method set out in Appendix 2 of this Schedule.

It is important to consider the background concentration of contaminants of concern at the site or in sites with similar soil. If the most appropriate EIL for a contaminant of concern is lower than the background concentration, the background concentration becomes the EIL. It should be noted that this could only occur for EILs that are based on total concentrations rather than added concentrations[2].

4.6 Risk management decision and ERA outcomes

After risk characterisation, a risk management decision is necessary. This decision weighs up the findings of the Preliminary ERA against risk management considerations.

[2] Wherever possible, the EILs were derived by expressing the toxicity data in terms of added concentrations (e.g. mg Cu added/kg soil). Then an added contaminant limit (ACL), the amount of a contaminant that can be added to a soil, was determined. To derive the EIL, the ambient background concentration was added to the ACL. Therefore, where the EIL is expressed in terms of added contaminant concentration, it is not possible for the EIL to be less than the background concentration (Heemsbergen et al. 2009).

Factors that may influence a risk management decision (and therefore determine ERA outcomes) are generally based on economic, ecological or societal considerations as well as the scientific information and results generated within the Preliminary ERA. Examples include:

- the size of the site, land value, and cost of remediation (economic)
- the type of contaminants present, current and potential site land use, surrounding land use (societal)
- the ecological significance of the values identified in the receptor identification component of Preliminary ERA that are to be protected (e.g. a rare and endangered species or a species that supports a valued ecological process or a sensitive introduced species of low ecological significance, e.g. a rabbit).

The risk management decision may also be determined or affected by the need to refine the uncertainty of the information gathered and/or to fill data gaps. Where the risk assessor has identified a high level of uncertainty in the risk characterisation (for example, because there was limited data from a site characterisation or because there was limited toxicity information for particular chemicals) then a decision manager may decide to either:

- develop and implement a site management/remediation program

or

- undertake further assessment and proceed to a Definitive ERA.

If the Preliminary ERA finds that the decisions on exposure and ecological values that were made in deriving the EILs were appropriate for the site and the risk characterisation suggests that there is unlikely to be an adverse impact on ecological values, the risk manager must decide to either:

- adopt the 'no action' outcome

  or

- adopt the 'monitoring' outcome.

If however, the Preliminary ERA raises concerns about the suitability of decisions made in applying the EILs to the site and/or the risk characterisation suggests that there may be an adverse impact to ecological values, the risk manager must decide to either:

- develop and implement a site management/remediation program

or

- proceed to the Definitive ERA.

The decision that is taken depends on the level of estimated risk and the social, cultural economic and engineering considerations relevant to the site. Proceeding to a Definitive ERA may not be cost-effective where the cost of managing a site is relatively low. Risk reduction measures rather than further investigations can follow a Preliminary ERA if that is considered appropriate — this would be considered in consultation with the decision maker.

Where there is no suitable EIL[3] for a contaminant of concern and the on-site concentrations of the contaminant are above background concentrations, the risk manager must decide to either proceed to a Definitive ERA or develop and implement a site management/remediation program. The decision should be based on a multiple-lines-of-evidence approach.

The expected output from a Preliminary ERA is a report that highlights the extent and degree of the on-site soil contamination and justifies the use and selection of the most appropriate EILs. An analysis of uncertainty in all the data used should also be included. Uncertainty and reporting are discussed later in this Schedule. The rationale for the final risk management decision should be explained in detail.

Risk managers may find it useful to consider the DQO approach as described in Schedule B2 which emphasises the importance of ensuring data collected for use in decision making regarding a site is of an appropriate quality. A DQO approach should be adopted early in the assessment process in relation to data used in risk assessment and in making risk-management decisions based on estimates of risk.

[3] If available, EILs should always be used, but if they are not, then assessment levels from other jurisdictions can be adopted. However, it is important that any assessment levels adopted are calculated using a comparable method (preference to be given to SSD methodologies) and provide a comparable level of protection. A full justification for any limit adopted from another jurisdiction must be included in the Preliminary ERA report.

5 Definitive ecological risk assessment

Generally, a Definitive ERA is only commenced once a Preliminary ERA has been conducted and has demonstrated that the contaminants present at the site pose a potential ecological threat. This iterative procedure allows each tier of ERA to be reviewed to determine whether the assessment is meeting the objectives set and to establish what the next phase should be.

This section provides guidance on how to conduct a Definitive ERA (see Figure 4 below). In a Definitive ERA, the focus is on quantifying exposure levels through field studies and the use of sophisticated computer models. Emphasis is placed on gathering detailed, site-specific information as part of the receptor identification, exposure assessment and toxicity assessment. A summary of data that may be collected as part of a Definitive ERA is included in Table 3.

Based on site-specific information, site-specific EILs for soil are derived. The comparison of the on-site soil concentrations of contaminants of concern against the site-specific EILs characterises the ecological risk at the site and influences any outcomes.

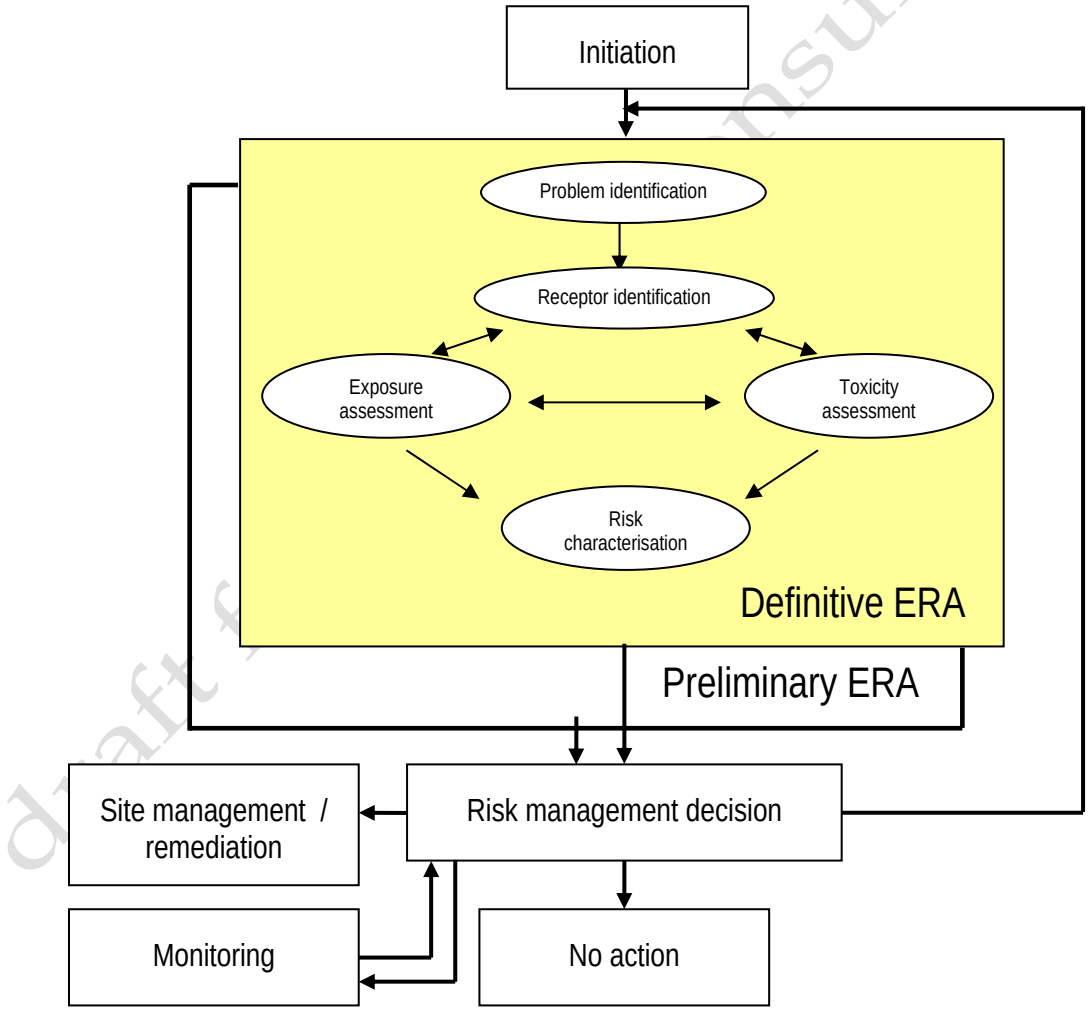

Figure 4. Definitive ERA

Table 3. Information that may be collected for each component of a Definitive ERA.

ERA component	Indicative requirements for a Definitive ERA
Problem identification	Refined objectives and updated CSM based on information in the Preliminary ERA. Identification of contaminants of concern (including mixtures and contaminant form) which exceed EILs. Formulation of the assessment end-point, e.g. will the assessment end point be based on species abundance; growth rates, frequency of chlorosis or necrosis in plants; or failure to develop?
Receptor identification	Flora and fauna surveys of the site and surrounding area. Identification of species of concern. Ecosystem function and ecosystem interaction established. Confident that the interface between biological monitoring plans and previous risk assessment is sufficiently robust to improve the risk assessment?
Exposure assessment	Fate and transport modelling of contaminants of concern. Species-specific inhalation, ingestion and absorption rates. Identification of on-site soil properties that affect contaminant mobility/availability (e.g. organic carbon content, pH, bulk density, porosity, soil moisture). Bioavailability factors. Sampling and analysis of food, water and air for effects of contamination. Information on biota behaviour relevant to assessing exposure.
Toxicity assessment	Detailed literature review of relevant toxicological studies since the EILs were derived. Results of in-situ field or laboratory toxicity tests.
Risk characterisation	Information on chemical mixtures, concentration of contaminants of concern (derived from problem identification)

5.1 Problem identification

When commencing a Definitive ERA, it is important to re-consider the objectives that were used for the Preliminary ERA, taking into account the results of the Preliminary ERA. If appropriate, new objectives should be identified. The main objectives for a Definitive ERA should be to:

- identify contaminants of concern (including mixtures and contaminant form, such as metal valency state, e.g. As3+)
- produce clearly defined, quantitative predictions regarding the current and future risks to site-specific ecological values due to contaminants at the site
- determine site-specific EILs that take into account the ecological values at the site.

The objectives of this stage may need to be revised from time to time and should always be informed by the outcomes of the preliminary ERA.

5.2 Receptor identification

In a Definitive ERA, a biological survey of the site and surrounding areas that may be affected by off-site migration of the contaminants of concern (and/or public consultation on both areas) may be conducted. The objective of this is to identify the key ecosystems, processes and species that may be adversely affected by the contamination. Assumptions made linking site ecological values to receptors should be documented in the ERA report. If any ecological values that were identified are not to be protected then the basis of this decision should also be reported.

5.3 Exposure assessment

Advanced quantitative models may be used to describe present and future transport, transformation and environmental partitioning of the contaminants of concern. These models will need to be refined and calibrated using actual field data to enhance the level of assurance of the model predictions. Such fate and transport models should examine the partitioning of the contaminants of concern between the environmental compartments (for example, water, soil, sediment, biota and air) that are relevant for the site and areas that may receive off-site migration.

In addition to transport models, specific information regarding food, soil, water, ingestion rates and inhalation rates may be estimated from site-specific field data, providing a specific exposure assessment for each biota.

The sampling and analysis of other environmental media for contamination such as food, air and water supplies may also provide specific exposure information.

Other techniques of exposure assessment may include biopsy analysis of tissues, body fluids or excreta of biota from the site.

Detailed analysis of the uncertainty of the exposure assessment should also be conducted to define the boundaries of the risk posed by the uncertainty levels in the exposure assessment. Various statistical techniques are available to determine the level of uncertainty and also to identify the most sensitive exposure assessment parameters.

This may guide further studies and field activities to reduce the uncertainty.

5.4 Toxicity assessment

As part of the Definitive ERA, it may be useful to review the currency of the toxicity data used in the derivation of the generic EILs. A detailed review of the literature since the EILs were derived should be conducted to update the toxicological profile of each contaminant of concern and mixtures of the contaminants. If there are additional data then they should have their quality and appropriateness assessed using the data quality assessment method in Schedules B5b and B5c. The acceptable quality data should then be added to the toxicity data used to derive the current EILs and new generic or soil-specific EILs derived using the method in.

Alternatively, or in addition, the toxicity of each contaminant of concern and mixtures of the contaminants of concern may be measured directly. Such toxicity testing can be particularly useful where a site is contaminated by numerous contaminants and assessing the impact of the mixture from individual EILs is not straightforward, or where a site is contaminated by chemicals for which EILs do not exist, although in this case appropriately adapted data from similar studies may also be used.

Toxicity tests for a range of soil and terrestrial species have been developed by various regulatory and international agencies, for example, the American Society for Testing and Materials (ASTM), the International Standards Organisation (ISO,1993,1995), the Organisation of Economic Cooperation and Development (OECD 1984a, 1984b), Environment Canada (EC 2004, 2005) and the United States Environmental Protection Agency (US EPA). S uch standardised methods are generally preferred; however, at some sites it may be more appropriate to use endemic species which do not have standardised toxicity test methods. The use of such tests is appropriate providing the methods used are based on standardised toxicity tests that have been modified to suit the test species and/or site conditions. The species to be used in site-specific toxicity tests and their experimental design should be based on information provided by the problem identification, receptor identification and exposure assessment components of the Definitive ERA.

Where toxicity testing is undertaken as part of a toxicity assessment, it is crucial that the end-points measured are ecologically relevant. This includes tests with end-points such as growth and reproduction rather than just biochemical changes which may or may not be adverse. The suitability of such non-standardised tests can be determined using the method of in Schedules B5b and B5c which assesses the quality of terrestrial toxicity data in terms of experimental design, analytical and statistical techniques used, and whether appropriate quality assurance and quality procedure measures were in place.

The toxicity tests can be conducted using artificial soils or soil from the site. They can also be conducted in the field or in the laboratory. The most environmentally relevant toxicity tests are those that expose species that occur (or should occur) at the site or surrounding areas to the contaminants of concern in soil from the site. In addition, toxicity tests could be conducted using (1) uncontaminated soil from the site or similar sites that is spiked with increasing concentrations of the contaminants of concern, or (2) contaminated soil from the site diluted using an appropriate soil.

Toxicity tests which expose the test organisms for long periods of time; generally, greater than two weeks (that is, chronic tests) are preferred for the derivation of EILs rather than those with short exposure durations (that is, acute tests). In order to derive site-specific EILs, toxicity data for certain minimum numbers of species that belong to a minimum number of taxonomic groups are required (Heemsbergen et al. 2009). It is strongly advised that the advice of appropriately qualified and experienced ecotoxicologists is sought before commencing any toxicity testing in order to conduct toxicity tests that will be useable in deriving site-specific EILs.

A detailed analysis of the uncertainty, strength and relevance of the toxicity data that has been collated from the literature or generated through conducting toxicity tests should be reported.

The methodology for deriving soil-specific EILs is provided in Schedule B5b. Worked examples of the EIL derivation methodology can be found in Schedule B5c and details on how to derive relationships between soil physicochemical properties and toxicity are provided in Warne et al. (2008a, 2008b).

5.5 Risk characterisation

Data gained during the exposure and toxicity assessment phases are used to modify the assumptions underlying the EILs and to calculate site-specific EILs. The site-specific EILs should be calculated using the methodology described in Schedule B5b. The on-site concentrations of each contaminant of concern should then be compared to the site-specific EILs[4].

If the on-site soil concentration of contaminants is equal to or less than the site-specific EILs for each contaminant and the toxicity of the mixture of contaminants does not exceed the $EIL_{mixture}$ (see Appendix 2), the site contamination is considered unlikely to pose an adverse ecological impact.

If the on-site soil concentration of any contaminant of concern is greater than the corresponding site-specific EIL or the toxicity of the mixture exceeds the $EIL_{mixture}$ (see Appendix 2), the site contamination is considered to pose an adverse ecological impact.

5.6 Risk management decision and ERA outcomes

After risk characterisation, a risk management decision is necessary. If the risk characterisation suggests that there is unlikely to be an adverse impact to ecological values of the site (that is, on-site soil concentrations are equal to or less than the most appropriate site-specific EIL), the risk manager should decide between the no action or monitoring outcomes.

If the risk characterisation suggests that there may be an adverse impact to ecological values of the site (that is, on-site soil concentrations are greater than the most appropriate site-specific EIL), the risk manager should develop and implement a site management/remediation program.

[4] If a site-specific EIL for a contaminant is lower than the ambient background concentration for the same chemical, the background concentration becomes the EIL.

Figure 4 above shows an arrow leading from the risk management decision back into the ERA process. This loop has been designed to allow for the further refinement of the characterisation of ecological risk. It uses a predictive approach based on monitoring undertaken as part, or as a result, of site management/remediation.

Expected outputs from a Definitive ERA include a report that extends the problem identification of the Preliminary ERA, provides detailed exposure and toxicity assessments for the contaminants as well as conclusions and recommendations. The report should detail the derivation of any modified site-specific EILs for the contaminants and describe the uncertainties in the field data (that is, contaminant levels and distribution) as well as in the modified EILs.

6 Uncertainty

There are inherent limitations in ERA similar to those facing any science-based endeavour. Given the stochastic nature of ecosystems, we cannot expect to predict the precise outcome for a population, community or functional process as small changes in initial conditions can result in large differences in outcomes. The best we can do is estimate the probability of some outcome occurring.

Uncertainty also arises from the limitations we have in the data available. The scale of processes, the difficulty in understanding what the system should look like without the contamination, the limitations of our understanding and measurement of toxicity as well as our estimation of exposure, along with the fact that there are usually multiple stressors and complex stressors involved, all contribute to uncertainty in any ERA. An informative discussion on these limitations is presented in Kapustka (2008).

Risk assessors need to be mindful of all of these issues in considering the reliability of their risk estimates. In some cases, the risks will be clearly present or clearly not present. In these situations, a risk characterisation decision can still be reached, even with very limited data. In other situations, even a large database may not provide sufficient information to permit a risk characterisation decision to be made about whether site contamination poses an unacceptable risk. The importance of uncertainty in an ERA is quite site specific.

There is also some level of error in all the sampling, the measurements made and the modelling undertaken. These are additional aspects of uncertainty that need to be considered in any ERA.

Every ERA report should discuss the uncertainty in the risk estimate and the impact that uncertainty has on the decision.

Detailed discussion on the mathematical analysis of uncertainty may be found in Cox and Baybutt (1981), Hoffman and Gardener (1983) and Gardener et al. (1981). A number of uncertainty analysis computing programs have also been developed that may be useful in this context (for example, PRISM, @ RISK and Crystal Ball).

Depending on the site uncertainty, sensitivity analyses could be conducted to identify which sets of data are contributing the most to the uncertainty in the ERA. This could be used to direct subsequent work and thus reduce the overall uncertainty in the ERA.

7 Reporting

This section provides information about the recommended structure and content of both a Preliminary ERA and Definitive ERA report. Comments on the contents of ERA reports were included in previous sections about Preliminary and Further ERAs. The following is intended as guidance only, as the structure and content of reports will be heavily influenced by site-specific issues as well as client and regulatory requirements. The basic intent of this guidance is to provide a logical structure in a report that will facilitate understanding of the outcomes of the risk assessment by the risk managers, decision makers and other readers of the reports (for example, stakeholders).

The ERA report should have the following main components:

- summary
- table of contents
- introduction
- problem identification
- receptor identification
- exposure assessment
- toxicity assessment
- risk characterisation
- uncertainty
- conclusions and recommendations
- references
- appendices.

Some of the components of a report are self-evident (such as the table of contents, introduction and references) and will not be further discussed.

The tier of ERA will also determine the degree of complexity and completeness of the information and data analysis in each of these sections.

7.1 Summary

The summary should include the following information:

- the background to the site
- the rationale and objectives for conducting the ERA
- a description of the type of ERA conducted
- a description of the elements of the risk assessment
- a summary of the key conclusions of the risk assessment and recommendations arising from it.

The summary should be written in non-technical language and contain sufficient information to enable a non-technical reader to understand the approach and results of the risk assessment, independent of the rest of the document.

7.2 Problem identification

The problem identification section should include the following information:

- the objectives of the risk assessment
- DQOs and CSM considerations
- the background to the events leading to the conduct of a risk assessment
- the tier of ERA being conducted
- a site description and history
- a summary of site information and data contained in any previous site assessment reports. This could include information about land use, site geology, soil contaminant concentrations and distribution, background concentrations, and regional and local hydrology
- an evaluation of quality assurance/quality control data on any previous field measurements and laboratory analysis contained in site assessment reports
- uncertainty estimates with respect to the site assessment data
- identification of key contaminants of concern (based on site history and any previous site assessment reports)
- conclusions that can be drawn about problem identification.

7.3 Receptor identification

The receptor identification section should include the following information:

- ecological values to be protected
- CSM considerations
- the approach used to identify ecological values that are potentially at risk
- an assessment of the possible spatial and temporal overlap of receptors and contaminants of concern (this would link in with the exposure assessment)
- basic life history and behaviour information about species identified as key receptors
- the sources and estimates of uncertainty
- conclusions that can be drawn about receptor identification.

7.4 Exposure assessment

The exposure assessment section should include the following information:

- the sources of the contaminants (if not already discussed in problem identification)
- the environmental fate and transport of the contaminants
- the magnitude, duration and frequency of exposure
- the applicable pathways with respect to the ecological receptors
- the sources and estimates of uncertainty
- conclusions that can be drawn about exposure assessment.

7.5 Toxicity assessment

The toxicity assessment section should include the following information:

- the toxicity of the contaminants
- the potential ecological effects at the individual organism, population and community levels
- known toxicity modifying factors (both synergistic and antagonistic resulting from exposure to multiple contaminants)
- indicators of ecological responses (e.g. suitable end-points)
- the sources and estimates of uncertainty
- conclusions that can be drawn about toxicity assessment.

7.6 Risk characterisation

The risk characterisation section of the report should use information gathered during the exposure and toxicity assessments to estimate the magnitude, probability and significance of ecological impacts occurring as a result of the concentration of contaminants present. An analysis of uncertainty should accompany this risk estimate.

7.7 Uncertainty

The uncertainty section of the report should include the following information:

- a summary of the analyses of uncertainty that have been undertaken for each component of the ERA and documented in various sections of the ERA report
- a discussion of overall uncertainty based on an assessment of all levels of uncertainty
- a discussion of the implications of the uncertainty for the findings of the report
- methods and indicative costs of reducing uncertainty (e.g. moving to higher levels of data collection, exposure assessment, etc.)
- conclusions that can be drawn about uncertainty.

7.8 Conclusions and recommendations

The conclusion section of the ERA should be brief and use the conclusions that have been drawn for each component of the ERA and documented in various sections of the ERA report. This section should summarise the results of the ERA in the context of the objectives of the study. Recommendations by the risk assessor to the risk manager/decision maker regarding the characterisation of risk and possible ERA outcomes should be summarised in this section. Conclusions should be integrative in nature, combining all aspects of the assessment.

7.9 Appendices

Supporting documentation and information, such as previous site assessment reports, summary tables of all data used in the ERA, and maps/diagrams showing sampling locations, should be provided in the appendices of the report.

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9 Appendices

9.1 Appendix 1: Summary of the EILs for fresh and aged contamination in soil with various land uses

Contaminant	Age of contam.	Added contaminant limits (mg added/kg soil) for various land uses		
		National parks & areas with high ecological value[3]	Urban residential/ public open space[4]	Commercial & industrial[5]
Zinc[1]	fresh	7 – 130	25 – 500	45 – 800
	aged	15 – 280	70 – 1300	100 – 2000
Arsenic[2]	fresh	20	50	80
	aged	40	100	160
Naphthalene[2]	fresh	10	170	370
DDT[2]	fresh	3	170	640
Chromium (III)[1]	fresh	25 – 50	75 – 160	120 – 270
	aged	60 – 130	190 – 400	310 – 660
Copper[1]	fresh	15 – 60	30 – 120	45 – 200
	aged	20 – 80	60 – 230	85 – 340
Lead[1]	fresh	110	270	440
	aged	470	1100	1800
Nickel[1]	fresh	1 – 25	10 – 170	20 – 350
	aged	5 – 95	30 – 560	55 – 960

[1] = all the values presented are added contaminant limits based on added concentrations.

[2] = all the values presented are soil quality guidelines based on total concentrations.

[3] = The standard protection level is 99%

[4] = The standard protection level is 80%

[5] = The standard protection level is 60%

9.2 Appendix 2: Mixtures of chemicals

A number of different types of joint action exist for mixtures of contaminants. Of these there are only predictive models for concentration addition (also called simple similar joint action) and response addition (also referred to as independent joint action). When all the chemicals in the mixture have the same mechanism of action; that is, they exert their toxicity in the same manner at the same location, and they do not affect each other's biological activity in the organism, then the toxicity should conform to concentration addition (Plackett & Hewlett 1952). If, however, the chemicals have different mechanisms of action and they affect each other's biological activity, then the toxicity of the mixture should conform to response addition (Plackett & Hewlett 1952). Other types of joint action include synergism, antagonism, supra-addition, complex similar and dependent joint action.

The available literature shows that for the vast majority of mixtures, the toxicity conforms to concentration addition with relatively small numbers of antagonistic and synergistic mixtures. For example, Deneer (2000), Faust et al. (1994), Warne and Hawker (1995) and Ross and Warne (1997) found that approximately 10%– 30% of mixtures (regardless of the type of chemical, but focusing predominantly on organic chemicals) were antagonistic or synergistic, with each type of joint action being equally frequent and the remaining 70%–90% conforming to concentration addition, based on aqueous concentration toxicity data. Similar values but with higher percentages of antagonistic and synergistic mixtures; that is, 43% antagonistic, 27% additive and 29% synergistic, were found in a recent review by Norwood et al. (2003) of the aquatic toxicity of mixtures of metals.

It has also been shown (Backhaus et al. 2000a, 2000b; Chevre et al. 2006; Dyer et al. 2000; Faust et al. 1994; Junghans et al. 2006) that concentration addition overestimated the toxicity of mixtures and yielded slightly higher estimates of the toxicity of mixtures than response addition when chemicals had different mechanisms of action.

A two-step mixed model independently proposed by Junghans (2004), Altenberger et al. (2004), and De Zwart and Posthuma (2005) is, however, theoretically superior to the concentration addition method to estimate the toxicity of mixtures. In this model, the first step is to estimate the combined toxicity of components that have the same mechanism of action using concentration addition and then, if necessary, to estimate the combined toxicity of components or groups of components that have different mechanisms of action using the response addition model. But as the concentration addition method results in higher estimates of toxicity than the response addition method, it is not necessary to use the more complicated two-step mixed model method.

Given the above, it is appropriate to use the concentration addition model to estimate the toxicity of mixtures irrespective of the type of joint action, unless there is specific information in the literature about a mixture that shows that this model is inappropriate.

The hazard quotient (HQ) method described below is a modification of the concentration addition model that takes into account the use of EILs in the ERA framework. The HQ method requires the ratio of existing soil contaminant concentrations and the EIL for each individual chemical to be calculated.

$$HQ = X/E$$

where X is the concentration of a contaminant in soil, and E is the EIL_{soil} for that contaminant.

The sum of the HQ for each contaminant is calculated. The total toxicity of the contaminants present at a site, assuming they conform to concentration addition, is calculated by summing the HQs for each contaminant. The resulting value is called the Hazard Index (HI).

$$HI = HQ_A + HQ_B + HQ_C$$

where HQ_A is the HQ for contaminant A (that is, X_A/E_A), HQ_B is the HQ for contaminant B (that is, X_B/E_B), and HQ_C is the HQ for contaminant C (that is, X_C/E_C).

Where HI is equal to or less than 1, ecological values are assumed to be protected. Where HI is greater than 1, there is potential for adverse impacts to ecological values. That is, the sum of effects of simultaneous sub-threshold exposures to several contaminants may induce an effect equivalent to greater than the maximum tolerable dose for a single contaminant given in isolation.

10 Glossary

Aged applies to a soil that has contained a contaminant for more than two years.

Ageing is the natural process that occurs over time whereby the bioavailability of contaminants decreases due to binding to minerals, clays, and organic carbon.

Ambient background concentration (ABC) of a contaminant is the soil concentration in a specified locality that is the sum of the naturally occurring background and the contaminant levels that have been introduced from diffuse or non-point sources by general anthropogenic activity not attributed to industrial, commercial, or agricultural activities.

Area of ecological significance is an area where the planning provisions or land-use designation is primarily for the intention of conserving and protecting the natural environment. This would include national parks, state parks, wilderness areas and designated conservation areas.

Bioavailability is the ability of a contaminant to interact with the biological system of an organism. Not all of a contaminant that is present in environmental compartments (for example, soil, sediment, water and air) is biologically available – rather, only a fraction of the total (the bioavailable fraction) is available.

Biota of supporting ecological processes is the biota associated with supporting ecological processes that provide habitat, shelter, food and water and permit other organisms to reproduce and ultimately survive as a viable species. Examples include bacteria, fungi and soil invertebrates that sustain the nutrient cycling processes necessary for plant growth.

Contaminant is any chemical existing in the environment above background levels and representing, or potentially representing, an adverse health or environmental risk.

Contaminant of concern means a contaminant that is present at a site at concentrations that may result in adverse impacts to ecological values. Exactly how this is determined varies depending on the current situation and its place in the ecological risk assessment (ERA) framework. In the site contamination assessment phase, a chemical is considered a contaminant of concern when the concentration is greater than the background concentration of the chemical. At the conclusion of a Preliminary ERA contaminants of concern are those chemicals which have soil concentrations greater than the most appropriate ecological investigation levels (EILs). On completing a Definitive ERA, contaminants of concern are those chemicals that exceed the site-specific EILs.

Contamination means the condition of land or water where any chemical substance or waste has been added at above background level or bioavailability of a chemical substance has increased and represents, or potentially represents, an adverse health or environmental impact. This does not apply where materials are added in accordance with relevant government approvals or endorsements such as to improve its suitability for agriculture.

Definitive ecological risk assessment (Definitive ERA) is the second tier of ecological risk assessment that can be conducted within the ERA framework of this Measure. This type of ERA is more detailed and provides a site-specific assessment of the risk posed by the contaminants.

Ecological investigation level (EIL) is the concentration of a contaminant above which further appropriate investigation and evaluation of the impact on ecological values will be required. The EILs are calculated using EC30 or lowest observed effect concentrations (LOEC) toxicity data. EILs are the sum of the added contaminant limit (ACL) and the ambient background concentration (ABC) and the limit is expressed in terms of total concentration. All EILs, whether generic, soil-specific or site-specific, only apply to soil to a depth of two metres below the current soil surface.

Ecological risk assessment (ERA) is a set of formal, scientific methods for defining and estimating the probabilities and magnitudes of adverse impacts on plants, animals and/or the ecology of a specified area posed by a particular stressor(s) and the frequency of exposure to the stressor(s). Stressors include chemicals, changes in physicochemical properties such as temperature, other human actions and natural catastrophes.

Ecological risk management in the context of this Measure is a decision-making process that involves consideration of political, social, economic, scientific and engineering information together with risk-related information in order to determine the appropriate response to environmental contamination.

Ecological significance is the consideration of ecological significance and should include the impact of the contaminated site on the species, population or community and on-flowing impacts on the structure and function of the ecosystem.

Ecological values means plants, animals, fungi or ecological processes associated with a defined area that are considered to be of significant societal, ecological or economic significance.

Economic significance is the economic importance (for example, the contribution of local biota to tourism) and cost of maintaining biota.

ECx means effective concentration; the concentration which affects X% of a test population after a specified exposure time.

Exposure assessment is the estimation (qualitative or quantitative) of the magnitude, frequency, duration, route and extent (for example, number of organisms) of exposure of organisms present at a site to one or more contaminated media.

Exposure is the contact of a contaminant with the any portion of an organism, system or sub-population. The organism may be exposed by inhalation, ingestion or dermal contact.

Generic ecological investigation levels (EILs) are EILs that are derived without considering any physicochemical properties of soil. When a generic EIL is developed for a contaminant there is a single numerical maximum concentration that is applicable to all Australian soils within each specified land-use.

Generic ecological value is an ecological value associated with a state, region, local area or standardised land-use category.

Hazard is the intrinsic capacity of a chemical, biological, physical or social agent to produce a particular type of adverse health or environmental effect. For example, one hazard associated with dichlorodiphenyltrichloroethane (DDT) is that it can cause the thinning of eggshells of some predatory birds.

Hazardous substance is a chemical that has the capacity to produce adverse effects. For the purposes of this framework, hazardous substance does not include radioactive, physical or biological agents.

High ecological value (see **area of ecological significance**)

Introduced flora and fauna are biota that are not native to Australia but which are desired to inhabit the site. Such biota may include wildlife, domestic animals, flowering plants, conifers and ferns.

Land use is based on the human purposes or economic activities that are conducted on a piece of land. This Measure specifies three land-use categories: (1) national parks/areas with high ecological value, (2) urban residential and public open space, and (3) commercial and industrial land.

Mixture ecological investigation levels ($EIL_{mixture}$) are EILs that take into account the joint action (toxicity) of mixtures of contaminants. If the $EIL_{mixture}$ is not exceeded, then no further investigation is required, whereas, if the $EIL_{mixture}$ is exceeded, then further investigation is triggered. If the $EIL_{mixture}$ is not exceeded in a Definitive ERA, it is considered that the mixture will not pose an adverse ecological impact, whereas if the $EIL_{mixture}$ is exceeded, then it is considered that the mixture will pose an adverse ecological impact.

National Environment Protection Measure (Measure) means a Measure made under section 14(1) of the *National Environment Protection Council Act 1994* (Cwlth) and the equivalent provisions of the corresponding Acts of participating states and territories.

Native flora and fauna are biota that would naturally inhabit the site in the absence of the chemical contamination. Such biota may include flowering plants, ferns and terrestrial, subterranean or arboreal fauna.

Preliminary ecological risk assessment (Preliminary ERA) is the first tier of assessment conducted in the ERA framework of this Measure. A Preliminary ERA is a generic assessment of the risk posed as it involves comparison of measured concentrations to the generic or soil-specific EILs for the relevant land use.

Receptor is the entity (organism, population, community, or set of ecological processes) that may be adversely affected by contact with, or exposure to, a contaminant of concern.

Risk means the probability in a certain timeframe 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 hazardous agent, that is, it depends on both the level of toxicity of the hazardous agent and the level of exposure.

Site means the parcel of land being assessed for contamination.

Site-specific ecological investigation levels are EILs that have been derived during a Definitive ERA. These EILs have taken into account various factors of the site; they are therefore site specific and may not apply to any other particular site.

Site-specific ecological value is an ecological value that is specific to the site under investigation.

Societal significance is the significance that societies place on preserving biota and ecological processes. This can vary markedly depending on cultural issues and the type of species that are being considered (for example, cute and cuddly biota often have greater societal significance than insects, micro-organisms and other invertebrates) and is not constant over time (for example, the importance of tree hollows for bird and arboreal species habitat has only relatively recently been appreciated by the broad community).

Soil is a complex heterogeneous medium that consists of variable amounts of mineral material, organic matter, pore water and pore air, and is capable of supporting organisms, including plants, bacteria, fungi, protozoans, invertebrates and other animal life. For the purposes of this guideline, soil includes geological materials (gravels, sands, silts, clays and porous rock), and anthropogenically deposited fill material (for example, crushed rock, broken bricks, gasworks ash, foundry sand, 'clean' fill.).

Soil-specific ecological investigation levels are EILs that are specific for a specified set of soil physicochemical properties. These would apply to all soils or sites that have this combination of soil properties and have the same land use.

Toxicity assessment means the overall process of evaluating the type and magnitude of toxicity caused by a hazardous substance.

Toxicity means the quality or degree of being poisonous or harmful to plant, animal or human life.

Transitory or permanent wildlife includes wildlife that lives permanently or spends part of their life cycle on the site (for example, the site may be part of a bird's territory) in question.

11 Shortened forms

ANZECC	Australian and New Zealand Environment and Conservation Council
EC	Environment Canada
ISO	International Standards Organisation
OECD	Organisation of Economic Cooperation and Development
NHMRC	National Health and Medical Research Council
US EPA	United States Environmental Protection Agency