Schedule B (7b)
Guideline on Exposure Scenarios and Exposure Settings

NEPC

National Environment Protection
(Assessment of Site Contamination)
Measure 1999

The following guideline provides general guidance in relation to Exposure Scenarios and Exposure Settings in the assessment of site contamination.

This Guideline forms part of the National Environment Protection (Assessment of Site Contamination) Measure 1999 and should be read in conjunction with that document, which includes a Policy Framework and Assessment of Site Contamination flowchart.

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7B

EXPOSURE SCENARIOS AND EXPOSURE SETTINGS

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Soil series
1. Health-based soil investigation levels (1996)
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EXPOSURE SCENARIOS AND EXPOSURE SETTINGS

Roscoe Taylor
Andrew Langley

1. INTRODUCTION

The *Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites* (ANZECC & NHMRC 1992) make reference to consideration of proposed land use in the development of site-specific soil acceptance criteria for contaminants, providing examples of settings such as 'residential, recreational, agricultural/horticultural, commercial/industrial' (eg. pp 32, 35, 35, 56).

However, little guidance is provided in that document regarding the ways in which such land uses would influence the conduct of exposure assessments and hence the development of either site-specific soil investigation levels or, following investigation, soil acceptance levels.

Refining exposure data for different types of landuse was subsequently identified as a priority by the Contaminated Sites Technical Review Committee (April 1993). Refinement of the *Guidelines* in this regard would enable better use of resources presently expended on assessments and consultancy reports, and perhaps more rational land use planning, site assessments and remediation decisions. Further, it is clearly preferable for risk assessment consultants and government agencies to share a common understanding of the 'standards' for exposed populations and exposure scenarios which should be taken into account for any particular land use. At a very basic level, we need to understand the meaning of terms such as 'residential', 'recreational' and 'industrial' in relation to a standardised set of default exposure assumptions.

Langley (1993) has already undertaken some of the groundwork in relation to default exposure assumptions, and in the Third National Workshop dealt with exposure factors in more depth (Langley & Saboredo 1996). The task of this paper is somewhat more simple - to outline a range of standard land use categories (henceforth referred to as **exposure settings,** for reasons described below) which adequately encompasses the majority of contaminated site situations faced by risk assessors, environment and public health agencies in this country. Once these are agreed, it becomes easier to consider appropriate exposure scenarios and apply the relevant exposure factors to either develop a greater range of investigation levels, or to form the basis for site-specific acceptance criteria.

Such an approach is consistent with the general thrust of the *Guidelines* towards establishing investigation levels and ensuring a site-specific approach to

contaminated site risk assessment, yet allows for a system that reduces unnecessary and costly site assessments whilst remaining protective of public health and the environment.

2. EXPOSURE SETTINGS: A COMPONENT OF EXPOSURE SCENARIOS

The USEPA (1992) describes 'exposure scenarios' as having several functions in risk assessment, as follows:

'First, they are calculational tools to help the assessor develop estimates of exposure, dose, and risk.

Whatever combination of data and models is used, the scenario will help the assessor to picture how the exposure is taking place, and will help organise the data and calculations. Second, the estimates derived from scenarios are used to develop a series of exposure and risk descriptors. Finally, exposure scenarios can often help risk managers make estimates of the potential impact of possible control actions. This is usually done by changing the assumptions in the exposure scenario to the conditions as they would exist after the contemplated action is implemented, and reassessing the exposure and risk.

An exposure scenario is the set of information about how exposure takes place. An exposure scenario generally includes facts, data, assumptions, inferences and sometimes professional judgement about the following:

- exposure setting
- exposure pathways
- characterisation of the chemical
- characterisation of the exposed population
- intake and uptake rates.'

(USEPA 1992, p 22918)

An 'exposure scenario' is then broadly defined as:

'A set of facts, assumptions, and inferences about how exposure takes place that aids the exposure assessor in evaluating, estimating, or quantifying exposures.' (USEPA 1992, p.22933).

In keeping with such an approach, this paper focuses on that component of exposure scenarios which may be seen as **exposure settings** (or standard land uses), with some reference to the characteristics of the populations potentially exposed in those settings. The intention is to define more clearly a standard range of exposure settings which regulators and risk assessors could use as baseline cases, to improve consistency of assessments, and provide a sound basis for land use/planning and remediation decisions based upon such risk assessments.

3. INTERNATIONAL APPROACHES TO EXPOSURE SCENARIOS AND SETTINGS

There is little uniformity internationally in either the use of or the choice of exposure settings or scenarios in contaminated site risk assessment. Some agencies (eg. USEPA) have a policy of site-specific risk assessments and do not appear to define particular exposure settings (in terms of future land uses) which risk assessors must take into account in establishing soil acceptance criteria. Other agencies have either developed or are in process of developing a set of exposure scenarios.

3.1 THE NETHERLANDS

Before examining the approach to exposure scenarios taken in the Netherlands, it is helpful to examine the regulatory framework for soil quality objectives.

Table 3-A

Land Use Categories in the Netherlands

Main Land Use	Subtype
Residential	With vegetable garden
	With garden
	No garden
Traffic	High traffic density
	Low traffic density
Workplace	In industrial area
	Outside industrial area
Social/Cultural	
Agricultural	Dairy cattle
	Other
Recreational	
Environmental	
Body of water	

From this classification the C_{soil} model derives eight exposure settings for the purposes of risk assessment:

1. **Residential** - with vegetable garden
2. **Residential** - with garden
3. **Residential** - no garden
4. **Traffic**
5. **Workplace** (industry)

6. **Recreational**

7. **Social/Cultural** (schools, churches, museums etc)

8. **Environmental** - 'green areas' (parks etc)

'Target values' have been developed as environmental quality objectives for soil in the Netherlands, and are considered to be levels for contaminants in soil at which the risks of adverse effects to ecosystems, humans and functional properties of the environment are considered to be negligible. Target values for soil represent multi-functional soil quality (perhaps analogous to the concept of 'maximum beneficial land use' used in some states in Australia).

Target values are only invoked when a site can be shown to exceed an intervention value, in which case the site should be cleaned up to the Target value. Target values are not laid down in law, nor is there specified a time period within which the Target values must be realised. 'Limit values' and 'guidance values' however, must be adhered to and are determined by considering environmental interests, economic and social interests and technical options (the guiding principle for negotiation and consideration being known as the ALARA principle - As Low As Reasonably Achievable) (Ministry of Housing, Spatial Planning and Environment 1994).

Within this policy context, an exposure assessment model 'C$_{soil}$' has been developed by the National Institute of Public Health and Environmental Protection (RIVM) and is now in provisional use. Eight different types of soil use have been defined, and for each soil use a scenario is identified using standardised exposure parameters. These enable human exposures to be calculated for a specific soil use (Bockting et al 1994).

These eight scenarios were proposed by RIVM (1994) in a document which makes reference to a Planning Ministry (VROM 1989) classification of land uses for planning purposes but notes that in practice a variety of other land uses may occur on any particular site - eg living quarters are sometimes situated in industrial premises, or temporary accommodation such as camping can occur on lands classified as 'recreational'. The RIVM document describes the classification of eight land use types, some with two or more subdivisions (see Table 3-A).

For each of these settings, standard exposure assumptions are utilised in the CSOIL model for children and adults.

The 'Residential - with garden' setting forms the basis for a standard scenario from which human toxicology based intervention values are derived. It is important to note, however, that if volatile contaminants are involved and inhalational exposures or plant uptake could exceed standard default values then actual measurements (eg indoor/outdoor air levels, plant tissue analysis) are required to assess risks rather than relying upon Intervention values derived from the model (Swartjes 1995). There is also a particular emphasis in the Netherlands on analysis and protection of groundwater as it is commonly used for human consumption and may also enter and adversely affect aquatic ecosystems.

3.2 UNITED KINGDOM

The Contaminated Land Exposure Assessment Model (CLEA) currently being developed for the Department of the Environment by the Centre for Research into the Built Environment at Nottingham Trent University (Ferguson 1995a) assumes that land use falls into one of five categories:

- Residential with gardens
- Residential without gardens (or with communal gardens)
- Allotments (used as communal vegetable gardens)
- Parks, playing fields, open space
- Commercial/industrial

CLEA estimates (using a probabilistic model) likely human exposures via a variety of routes. The importance of each route depends on the type of contaminant and on the category of proposed land use (as listed above), and the model takes into account background exposures, receptor characteristics and exposure duration to calculate a range of possible exposure values and their probability of occurrence.

To illustrate the CLEA model, preliminary soil action guideline values for mercury have been proposed in a draft discussion paper (Ferguson 1995b). Based on the 95th percentile of a lifetime exposure distribution derived from 2000 Monte Carlo simulations using the CLEA model, a soil action guideline value of 15 mg/kg dry soil for total mercury was derived for a residential-with-vegetable-garden scenario where soil organic matter content is 10%. For parks, playing fields and open space, however, the guideline value was 120 mg/kg, and for commercial/industrial land use the value was 400 mg/kg. Table 3-B also shows draft soil guideline values for several other contaminants.

Horticultural and agricultural land use is not currently included in this model (because acceptable contaminant levels in agricultural soils are governed by considerations other than site-user risks), but its modular structure allows this to remain as a future option.

Table 3-B

Draft Soil Action Guideline Values (mg/kg dry soil) - CLEA model

(based on 95th percentile lifetime exposure distribution, soil pH 7.0)

Land Use	Arsenic	Cadmium	Lead	Mercury
Residential with garden	175	7	560	15
Residential without garden	300	150	620	120
Allotment	250	7	1500	15*
Parks, open space	300	150	2000	120
Commercial/industrial	1000	600	8500	400

at 10% soil organic matter

It is important to note the U.K. government policy context for this model, which is that site remediation should not normally aim to restore the land for all possible future uses, since the cost of such an approach would often significantly outweigh benefits and would merely shift the contamination elsewhere. The aim of remediation is seen as ensuring 'fitness for purpose', balancing a number of local and national environmental, economic and social issues (Department of the Environment 1990).

3.3 USEPA REGIONS

Although there appears to be no explicit USEPA policy defining particular exposure settings, Regional USEPA offices have established risk-based concentration (RBC) tables distinguishing residential from industrial land use, with the RBCs being intended for risk assessment screening and 'spot-checking' rather than regulatory purposes (Smith 1994). The RBC document provides limited information about exposure variables, for example, in the residential setting, exposure is assumed to occur on 350 days per year, and for a total duration of 30 years, whereas occupational exposure (industrial setting) occurs on 250 days per year for a total duration of 25 years.

The Massachusetts Department of Environmental Protection (1995) recently established soil (and groundwater) categories describing a range of potential exposures to that soil, based upon analysis of the accessibility of the soil (determined by depth of soil, and whether covered by pavement), in combination with information about the site activities and uses (including frequency and 'intensity' of use). Three categories of potential exposure are described and a matrix approach used to incorporate different exposure settings into these three categories. For example, sites where soil is accessible and used for vegetable production, or where a child might have frequent access or 'intense' use (residential, day care or school use), are placed in the 'highest' potential exposure category.

Table 3-C

Canadian scenarios: Generic exposure assumptions for land use categories

	Agricultural	Residential	Commercial	Industrial
Sensitive receptor	child adult	child adult	child adult	adult
Exposure period	24 hours/day 365 days/year	24 hours/day 365 days/year	12 hours/day 5 days/week 48 weeks/year	8 hours/day 5 days/week 48 weeks/year
Direct soil exposure pathways	ingestion dermal particulate inhalation	ingestion dermal particulate inhalation	ingestion dermal particulate inhalation	ingestion dermal particulate inhalation
Indirect soil exposure pathways	groundwater consumption inhalation indoor air volatiles on-site produce consumption: -100% milk -50% produce -50% meat	groundwater consumption inhalation indoor air volatiles garden produce consumption: -10% of produce ingested grown on-site	groundwater consumption inhalation indoor air volatiles	groundwater consumption inhalation indoor air volatiles

3.4 CANADA

Following on from the land use categories foreshadowed by Beaulieu (1992), the National Contaminated Sites Remediation Program currently follows a draft protocol for derivation of soil criteria developed by the Canadian Council of Ministers of the Environment (CCME) Subcommittee on environmental quality criteria for contaminated sites. One of the basic steps in setting generic remediation criteria is the definition of generic exposure scenarios appropriate to each land use.

Four categories of land use are described:

- Agricultural
- Residential/parkland
- Commercial
- Industrial

Direct and indirect exposure pathways are considered for each scenario, and the choice of sensitive receptor is linked to land use considerations. Exposure duration assumptions in these scenarios depend on whether the hazardous substance is regarded as having a threshold of action: for non-threshold substances, the hazard is assessed for an adult with continuous exposure over 70 years, whilst for threshold substances exposure is averaged over (and Tolerable Daily Intakes measured against) the most sensitive life stage (generally taken as six months to four years, although the most sensitive receptor may vary for some contaminants such as mercury, when a pregnant adult female could be seen as the appropriate receptor to protect the foetus).

In developing generic soil remediation criteria for a contaminant the Canadian approach takes into account the estimated normal daily 'background' intake of that contaminant from air, water, food, consumer products and soil, and subtracts this intake from the Tolerable Daily Intake (TDI). The remainder is then divided into five equal portions, one of which is allocated as the soil component (the other four are allocated once again to air, water, food and consumer products). Generic exposure scenarios (see Table 3-C) then enable the back-calculation of a specific soil quality criterion for each particular land use.

3.5 AUSTRALIA

The current version of the Australian *Guidelines* mentions the need to consider the proposed land use in developing soil acceptance criteria, but does not develop this concept by outlining the various exposure pathways or assumptions that would need to be made for each particular land use.

At the same time, contaminated site risk assessment consultancy reports in this country generally do not pay systematic attention to the range of exposure scenarios or land uses described in the *Guidelines*, and do not necessarily relate the proposed land use adequately to the exposure assumptions used in risk assessment. Not surprisingly there has also been a tendency to adopt the most conservative soil

acceptance criteria, or to opt for the convenience of using investigation levels as *de facto* acceptance levels. This can potentially lead to expensive remediation options for sites that may not need extensive decontamination because of the particular land use proposed (the obvious example being that many industrial sites may not need the same degree of remediation as residential property for protection of health), and in some cases to stand-off situations where site remediation and utilisation are stalled and potentially useful sites become fenced wastelands.

For some sites with non-critical land uses, less stringent criteria have been used (Markey 1996). These criteria have been set on a site specific basis, however there has been a lack of consistency in setting the scenarios for these sites and one of the objectives of this paper is to provide a more consistent basis for setting such scenarios.

4. WHICH EXPOSURE SETTINGS ARE APPROPRIATE FOR THE AUSTRALIAN SITUATION?

4.1 POLICY INFLUENCES

The development of a range of exposure settings for application in Australia raises the need to consider existing policy, planning, and regulatory influences on soil quality and uses.

A site which contaminates a waterway via leachate or runoff and adversely affects an aquatic ecosystem, for example, gives rise to different issues in terms of policy, regulations or standards than if the same site contaminated groundwater is used for human consumption. Contamination of agricultural land may lead to failure of produce to comply with the Australian Food Standards Code, or create problems with export market standards - at soil contaminant levels which might be lower than those regarded as acceptable for a residential property, even taking into account home-grown food production on the property (part of the reason for this being that Maximum Residue Limits and Maximum Permitted Concentrations for contaminants in commercially-produced foods, whilst taking protection of health into consideration, tend to be based upon what is achievable with good agricultural practice rather than purely toxicological/public health grounds).

A further policy consideration is the principle, espoused perhaps more strongly in some states than others, of 'maximum beneficial land use', which represents an ideal situation where remediation of contaminated sites occurs to the point where the land becomes suitable for all potential uses. If such remediation does not occur, and only one particular type of land use is deemed safe or permitted to occur on a contaminated site, then clearly there need to be planning control mechanisms so that changes to more sensitive land uses are restricted. This was recommended in the ANZECC position paper, '*Financial Liability for Contaminated Site Remediation*' (1994):

'Governments should put in place appropriate mechanisms within the planning process to ensure that potentially contaminated land is not rezoned to allow a more sensitive use without adequate assessment of environmental and human health risks and appropriate remediation where necessary.'

Other considerations include the health and safety of employees on a contaminated site which is being used for commercial or industrial purposes (eg. exposure to volatiles must comply with standards set by WorkSafe Australia), and the occupational health and safety of workers potentially exposed during remediation of a site.

4.2 POPULATION AND HOUSING CHARACTERISTICS

Dwellings in Australia can conveniently be classified, in keeping with Australian Bureau of Statistics practice, into four main groups:

1. Separate house

2. Semi-detached, row or terrace house, town house (with one or more storeys)

3. Flat, unit or apartment (one or more storeys)

4. Other - including improvised dwelling, caravan, camping out, house or flat attached to a shop, office etc.

The percentage of households in each type at the time of the 1991 census is shown in Table 4-A.

Table 4-A

Australian dwelling types, 1991 (ABS 1994)

Dwelling type	% of households	occupants ('000)
Separate house	78.3	4,471.2
Row/terrace etc	7.7	442.6
Flat/apartment	11.4	653.6
Other (includes 'not stated')	2.5	143.4
Total	**100.0**	**5,749.4**

The combined proportion of Australian households who own or are buying their homes has remained reasonably stable at about 70% over the past thirty years (ABS 1994). Of the 16 million people counted in private dwellings in the 1991 census, 40% were in dwellings owned by a household member, 34% were in dwellings being purchased by a household member and 26% were in rented dwellings. At the time of the 1986 census, 98.3% of Australia's 3 636 845 children (aged under 15 years) lived in private dwellings (including both rented and privately-owned dwellings), and of these 3 21 741 or 90% lived in a separate house (ABS 1989). The average size of newly constructed private houses has risen by 12% to 187 square metres in the ten years to 1992 (ABS 1994a).

4.2.1 Duration of residence

There are few data available to indicate the mean duration of residence in Australia for home owners or renters. Langley and Sabordo (1996) reviewed available evidence and noted ABS data showing that about 50% of Australians aged 15 or over had changed their usual address at least once during the period 1987 to 1992. Mobility appears to decrease with advancing age, with about 80% of those age 65 or over remaining at the same address over that period, compared with only 26% of 25 to 34 year olds.

Some agencies (eg. American Industrial Health Council 1994; Finley *et al* 1994) have developed a simulated distribution of residential occupancy periods, and have proposed that a median value of 8.1 years (developed from U.S. data) should be adopted as the default value in risk assessments rather than the more commonly used 30 years - the latter being recommended by the USEPA (1991).

From a regulatory perspective, however, such information may be relatively unimportant. There is an (entirely reasonable) expectation amongst Australians that purchased or rented residential property sites should be 'safe' to occupy for as long as they wish - a lifetime or 70 years would seem the most acceptable and appropriate exposure duration assumption for residential settings. It is the personal opinion of this author that application of Monte Carlo or other distribution techniques should not be utilised for this particular parameter to develop either soil investigation or acceptance criteria, and that this is one instance where social implications and risk communication aspects may need to be taken into consideration within the regulatory framework for risk assessment.

4.2.2 Duration of occupational exposure

The American Industrial Health Council (AIHC 1994) note that 25 years is a commonly-used default assumption for number of years spent at a specific job ('working tenure') in regulatory-based risk assessment, with available information suggesting that 25 years would be the 95th percentile of the distribution. AIHC then proposes that the median job duration of 4 years would be a suitable value. But, as with residential settings and exposure duration described in the previous section, such a brief workplace exposure duration is likely to be difficult to portray to affected workers or communities, particularly from a risk communication point of view. An occupational exposure duration of 30 years is proposed as an appropriate point estimate default assumption.

4.2.3 Home grown produce

Domestic or backyard food production is a relatively small contributor overall to total food production in Australia, with the total annual home grown fruit crop estimated at 110 000 tonnes compared with 2 554 000 tonnes in the Agricultural Census (ie. 4.1%), and home grown vegetable production of 153 000 tonnes compared with an Agricultural Census vegetable crop of 2 725 000 tonnes (ie. 5.3%) (ABS 1994b). However, a reasonably large proportion of households engage in home food production, with 34.8% of households producing one or more vegetable types, 36.1%

producing one or more types of fruit, 6.6% producing eggs, and 1.3% producing poultry meat (ABS 1994b).

There are wide variations from state to state in amount and type of food produced, and production is also influenced by age and ethnicity of householders, in addition to geographic region. Australia-wide for the year ended April 1992, the average fruit bearing backyard produced 48.9 kg of fruit, and the average productive backyard garden grew 70.4 kg of vegetables. Households with egg-laying poultry collected an average 63.5 dozen eggs for the year, or 1.2 dozen per week (ABS 1994b).

For those households producing food, exposure to contaminants via this pathway may be quite significant. Cross and Taylor (1994) suggested that for the purposes of preliminary risk assessment, default assumptions that 35% of fruit and vegetables, 25% of poultry meat and 200% of egg consumption are derived from home-grown sources might be adopted in the absence of any specific information. The figure of 200% of average dietary intake is a precautionary one based on the possibility that households keeping poultry for eggs may consume significantly more eggs because of their ready availability and dietary preferences. The available information does suggest that such households produce about twice as many eggs as are consumed by the average general household. (Poultry meat and eggs could be excluded if poultry-keeping was not practised or permitted at that site).

4.3   PROPOSED CATEGORIES OF LAND USE FOR A REGULATORY FRAMEWORK

Taking into account the current *Guidelines*, approaches adopted by overseas agencies, and patterns of land use and housing in Australia, the following basic categories of land use might be proposed:

1. Residential
   - soil accessible; substantial home-grown food consumption (with and without poultry)
   - soil accessible; minimal home-grown food consumption (less than 10% of diet)
   - minimal opportunities for soil access (eg high-rise apartments/fully paved flats or units)
2. Commercial/Industrial,
3. Parklands/Recreational,
4. Agricultural/Horticultural.

Taking the last category first, soil investigation levels for agricultural or horticultural land use will be significantly influenced by consideration of the Australian Food Standards Code, and also by ecological concerns. These are likely to dominate over exposure considerations for site users such as farm workers. For farm-dwellers on agricultural land it might be expected that exposure assumptions based on residential land use would apply, and that consumption of home-grown produce would also have to be considered.

The Agricultural/Horticultural category of land use is mentioned here for completeness but requires specific in-depth attention in its own right and will not be further discussed in this paper.

The above general categories can also be taken to accommodate other important land use situations where similar soil access occurs. For example, day-care centres and preschools (and primary schools to a lesser extent) potentially provide situations which are comparable to residential dwellings in terms of soil access by young children, and can be placed in the 'base case' residential setting.

Whilst inclusion of primary school sites in a 'residential' category may be seen as overly conservative in view of diminished mouthing behaviour and soil ingestion expected in this age group compared with infants and toddlers, primary school sites have been included in this category because some contain preschool or child-care centres; some contain special education units where children may be at increased risk of hand-mouth or pica behaviours; and social and community considerations about 'acceptable risk' have been taken into account in the regulatory framework. It is acknowledged that exposures in primary schools may be similar to exposures in secondary schools. If well-maintained barriers to soil access exist (eg in the form of paving such as cobblestones, gravel, or a substantial pine bark ground covering) then a primary school setting may not be comparable to a standard low-density 'residential with backyard garden' setting but more akin to high-density residential land use with reduced opportunities for soil access.

Similarly, a residence where the yard space is fully and permanently paved (eg concrete), or the contaminated soil is fully and permanently contained, affords minimal opportunities for contaminated soil access and investigation levels may be more appropriately considered in the context of a separate, lower-risk category.

A residential setting with accessible soil but minimal or negligible home food production has usually formed the baseline case for development of investigation levels to date in this country, but this approach has not explicitly quantified the home food production pathway.

It is advisable to distinguish those households with free-range poultry as special cases since this pathway may significantly influence exposure levels (Cross and Taylor 1994,1996). The great majority of urban local governments in recent times either prohibit poultry-keeping altogether, or require poultry to be kept on concrete pads where they remain out of contact with soil. If free-range poultry are being kept on contaminated soil then site-specific sampling of produce is likely to be the best means of determining exposure and the level of risk.

Further refining the categories listed above would result in the following exposure settings:

A. 'Standard' residential with garden/accessible soil (home-grown produce contributing less than 10% of vegetable and fruit intake; no poultry): this category includes children's day-care centres, kindergartens, preschools and primary schools.

B. †Residential with substantial vegetable garden (contributing 10% or more of vegetable and fruit intake) and/or poultry providing any egg or poultry meat dietary intake.

C. †Residential with substantial vegetable garden (contributing 10% or more of vegetable and fruit intake); poultry excluded.

D. Residential with minimal opportunities for soil access: includes dwellings with fully and permanently paved yard space such as high-rise apartments and flats.

E. Parks, recreational open space and playing fields: includes secondary schools.

F. Commercial/Industrial: includes premises such as shops and offices as well as factories and industrial sites.

A simplified classification such as that above is unlikely to completely provide for all the situations that can arise in practice, but can nevertheless form the basis for development of soil investigation criteria. Within each land use category, sites may vary significantly in the exposures that are actually occurring, because of variations in soil accessibility, frequency of site usage, 'intensity' of use in terms of activities carried out and whether or not children are exposed. This points again to the need for site-specific assessments once an investigation has been triggered, or where there may be particularly high or low exposure opportunities. The 'blind' application of soil criteria without first considering at least basic details of site characteristics and usage should be discouraged.

Where land is used predominantly for one purpose, but contains within it a more "sensitive" use, then the exposure setting relevant to that more sensitive use must be adopted for that particular parcel of land. For example, if an industrial site is also used for residential purposes such as a caretaker's residence, or there is an on-site creche within a commercial facility, then the appropriate residential setting "A" should be used for areas of the site that may give rise to soil exposure.

5. 'DEFAULT EXPOSURE RATIOS': ARE THEY APPLICABLE TO EXPOSURE SETTINGS?

One way to utilise exposure settings is in the development of soil investigation levels through the application of '**default exposure ratios**'. A standard multiplication factor (or fraction) can be applied to investigation levels for each setting, to take into account expected differences in levels of exposure. For example, a high-rise residential site with negligible soil access opportunities might be expected to give rise to significantly less soil and dust exposure by the ingestion pathway (from on-site sources at least) than a 'standard' residential site with accessible garden soil. Thus soil investigation criteria for high-rise apartment blocks with minimal soil access might routinely be considered to be substantially higher than those for standard residential developments. The difference between the two sets of criteria will depend on the default exposure ratio applied.

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† In the context of establishing exposure settings specifically for different land uses and to derive soil investigation criteria, it is considered appropriate for these particular settings to adopt a threshold of 10% domestic food production. The majority of households with vegetable gardens would not reach this level of food production. The threshold of 10% is an indicative rather than an absolute value. Where this value is likely to be exceeded the site should be assessed as a 'C' scenario.

By way of comparison, the Dutch C_{soil} model mentioned earlier distinguishes the different exposures encountered by children and adults in each of its eight scenarios.

For example, soil ingestion by children in the residential-with-garden scenario (the 'standard' scenario) is assumed to be five times the level of soil ingestion by children in residences without gardens.

Other factors considered include an apportionment of green vegetables and tubers consumed from the home garden (100% of all green vegetables and 50% of tubers, in the residential-with-garden scenario, compared with 10% of vegetables and tubers in the case of a residence without vegetable garden). C_{soil} also estimates the average amounts of time spent in each setting (in terms of hours per day or days per year). The underlying evidence upon which such assumptions are based is not apparent.

In the Australian setting, it is likely that there will often be inadequate data regarding patterns of exposure for various pathways.

Relatively 'arbitrary' assignment of default exposure ratios based upon judgements about what is likely to be protective of health is still a reasonable course of action from a regulatory perspective as long as the underlying reasoning is made transparent in any documentation that might be developed, and that such default exposure ratios do not purport to be completely scientifically founded.

The establishment of Australian health-based soil investigation criteria to date has largely focused on protecting children in the equivalent of the above 'standard' residential setting, with home-grown food production not a prominent exposure pathway. This residential exposure setting can be considered as the 'base case' with a default exposure ratio of one (1), against which the other settings can be compared. In the case of high-density residential land with minimal opportunities for soil exposure, for example, it is reasonable to assume that ingestion of contaminated soil or dust from on-site sources would be reduced by a factor of at least four; giving rise to a default exposure ratio for that setting of 0.25.

A default exposure ratio of 0.2 might be proposed for commercial and industrial settings, based on expected reduced opportunities (compared with the standard residential setting) for soil ingestion by children visiting these settings. Such a ratio should also be amply protective of adults using these sites, bearing in mind that occupational exposures (eg. to dust) are also regulated via standards established by Worksafe Australia. Whilst it might be argued that even a ratio of 0.1 would still be protective of health in these settings, there are potential problems arising from off-site migration of contaminated soil and dust from highly contaminated industrial sites into adjoining residential areas, that may go undetected and hence unappraised if investigation criteria are set too high. Therefore it is preferred to err on the side of conservatism for this category. If day care centres or creches are located within a commercial/industrial site, or if residential use is occurring, those parts of the site should be considered under the more appropriate category A: 'Standard Residential'.

Parklands, recreational open space and playing fields may occasionally be utilised on a regular basis by children and, as with industrial sites, there may be potential for off-site migration of contaminated soil or dust into adjoining residential areas.

Therefore a default exposure ratio of 0.5 is proposed for this setting, being protective of health for site users of all ages, and ensuring that investigation of aspects such as off-site exposures is not neglected.

Application of a generic default exposure ratio to residential sites where home-grown food production contributes a significant portion (≥10%) of the household diet is problematic because site- and contaminant-specific conditions can significantly influence contaminant uptake to the extent that a single set of exposure assumptions may be meaningless, even as a basis for investigation criteria. The wide range of Australian soil types and conditions compounds this problem even further. Until contaminant uptake modelling can be greatly refined it is suggested the best means of managing such sites would be based on sampling of produce and site-specific risk assessment.

Table 5-A

Exposure Settings and Default Exposure Ratios for establishment of soil investigation criteria

(from Taylor and Langley 1998, p14)

Exposure Setting	Duration of exposure and age of exposed person	Default Exposure Ratio
A. 'Standard' residential with garden and accessible soil. Home-grown food production contributing less than 10% of vegetable and fruit intake: includes daycare centres, kindergartens, preschools and primary schools	70 years, commencing from birth	1.0
B. Residential with vegetable garden (contributing ≥10% of vegetable and fruit intake) and/or poultry	70 years, commencing from birth	Not applicable: site and contaminant specific
C. Residential with vegetable garden (contributing ≥10% of vegetable and fruit intake) Poultry excluded	70 years, commencing from birth	Not applicable: site and contaminant specific
D. Residential with minimal opportunity for soil access	70 years, commencing from birth	0.25
E. Parks, recreational open space, playing fields: includes secondary schools	70 years, commencing from birth	0.5
F. Commercial/Industrial	30 years, adults	0.2

Notes to Table 5-A:

1. The default exposure ratios listed here are based upon judgement and designed to be conservative and protective of human health. They do not necessarily take into account environmental and aesthetic concerns, which may impact greatly upon remediation and management decisions. Therefore whilst an investigation level for commercial land use may be contemplated that is five times higher than that for residential land with garden, this may not be an acceptable investigation threshold from the perspective of protecting particular species or the ecosystem.
2. Health-based Investigation Levels have not been derived for exposure settings B and C because site-specific considerations need to be taken into account. In developing HILs for such sites, or conducting preliminary broad-based population risk assessments, it may be useful to refer to exposure assumptions detailed in Tables 8 and 9 in Taylor and Langley (1998).
3. For residential settings, it is assumed that 70 years is the duration of exposure. However for many contaminants (particularly those for which ADIs or PTWIs have been established) exposures over a much shorter period during childhood tend to dictate investigation criteria.
4. In the case of occupational exposure from a contaminated site currently used as a commercial or industrial site, it is assumed that 30 years is the duration of exposure.
5. These default exposure ratios should be seen as purely guideline values for development of soil investigation criteria rather than for derivation of soil response criteria.
6. Highly volatile substances are excluded from consideration in this table unless volatility has been taken into account in setting the HIL (see Taylor and Langley 1999, p 19).
7. National Occupational Exposure Standards have been developed with an undefined career duration.

Highly volatile contaminants should be excluded from consideration in the default exposure ratios proposed in Table 5-A, because the exposure settings chosen here might lead to different conclusions about exposure, particularly if a significant proportion of time is spent indoors (when inhalation of volatile contaminants in indoor air may be a much more significant pathway than ingestion of outdoor soil). Work is currently being undertaken in Australia to provide appropriate methods to incorporate exposure to volatiles in exposure assessments.

Complex mixtures of contaminants are beyond the scope of this paper, but the possibility of additive and/or synergistic effects on health needs to be considered (Pollak, 1996).

Groundwater consumption may require special consideration as an exposure pathway if groundwater contamination is occurring, and could also affect the default exposure ratios shown here. It should be subject to site-specific assessment if used. The assessment should determine current or potential patterns of use (for example irrigation or domestic), and levels of exposure.

To illustrate the application of these default exposure ratios, take the example of the common contaminant, lead (see Table 5-B):

Table 5-B

Soil lead investigation levels[a] for proposed exposure settings

Exposure Setting	Default Exposure Ratio	Soil Lead Investigation Level (mg/kg)
A. Standard Residential	1.0	300
B. Residential	N/A	Site-specific[b]
C. Residential	N/A	Site-specific[b]

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[a] These values may be adjusted with site-specific assessment.

[b] In the case of lead, which has limited uptake and translocation by plants, it may be possible to assume a similar investigation level for categories A and B as for C.

D. Residential (minimal soil exposure)	0.25	1200
E. Parklands/recreational	0.5	600
F. Commercial/industrial	0.2	1500

The somewhat arbitrary judgemental and semi-quantitative nature of the categories defined above and their default exposure ratios must again be highlighted, although this does not invalidate the approach.

There are at least two reasons for this caution, the first being significant deficiencies in current data in relation to significant exposure pathways, and another being that the approach taken here is very much based upon a regulatory perspective.

The above approach tries to develop a system that is simple; is adequately protective of public health; is congruent with the Australian approach (including available data) used to date in development of 'investigation levels' rather than soil response criteria; and that will be compatible with efforts currently underway to refine an ecotoxicological risk assessment approach (eg Chek 1996).

It may be necessary to define specific circumstances in which the above categories and default exposure ratios (which should in general be the standard 'default' options) can be discarded in favour of other site-specific exposure assumptions. These circumstances could include situations where the potential for exposure is clearly going to be greater than the standard settings allow for (a possible example being a recreational land use where excessive dust exposure might arise, such as a motocross track).

For default assumptions <u>not</u> to be used, realistic and appropriately inclusive exposure opportunities for the proposed land use would need to be detailed, with sufficient safeguards for other potential future exposures. This may require annotations on the title documents or elsewhere stating the constraints on other possible land uses. The alternative exposure scenarios would have to differ markedly (possibly by an order of magnitude) from the defaults proposed here, in order for them to be used in preference to the defaults in establishing site-specific soil criteria.

Environmental and aesthetic considerations cannot be ignored in adopting and applying these exposure settings.

6. SUMMARY OF EXPOSURE SETTINGS AND DEFAULT EXPOSURE ASSUMPTIONS

The following tables summarise the exposure settings developed in this paper and the main default exposure assumptions proposed to be employed within them for the purpose of developing investigation levels, or, in the case of Settings B and C, that might be used in conducting a site-specific risk assessment.

Table 6-A

A. 'STANDARD' RESIDENTIAL - minimal home food production

Default Exposure Ratio: 1.0   (the 'base case')

Exposure Period: 24 hours/day
365 days/year
70 years occupancy duration

Assumptions: Residential garden and soil accessible
Less than 10% of intake of fruit and vegetables derives from garden
Refer Langley & Sabordo (1996) for specific exposure factors

Exclusions: On-site Poultry
Groundwater consumption
Volatile contaminants, unless already accounted for in setting HIL for that contaminant

Direct Soil Exposure Pathways:

- Direct soil and dust ingestion (Table 6.2, ANZECC/NHMRC 1992)
- Direct soil dermal contact
- Direct soil particulate inhalation

Indirect Soil Exposure Pathways:

- Uptake into and consumption of home-grown fruit and vegetables (limited)

Table 6-B

B. RESIDENTIAL LAND USE - fruit & vegetable garden and/or poultry.

Default Exposure Ratio: Site and contaminant specific
Exposure Period: 24 hours/day
365 days/year
70 years occupancy duration
Assumptions: Residential garden and soil accessible
10 % or more of intake of fruit and vegetables derives from garden.
Poultry kept on-site, providing all of household egg supply (note that egg consumption in such households may be up to 200% that of average Australian household consumption) and 25% of poultry meat intake.
Refer Langley & Sabordo (1996) for specific exposure factors
Exclusions: All other foods (dairy products, beef etc) *not* produced on-site
Groundwater consumption
Volatile contaminants, unless already accounted for in setting HIL for that contaminant
Direct Soil Exposure Pathways:
- Direct soil and dust ingestion [children 100 mg/day, adults 25 mg/day] (Table 6.2, ANZECC/NHMRC 1992)
- Direct soil dermal contact
- Direct soil particulate inhalation

Indirect Soil Exposure Pathways:
- Uptake into and consumption of home-grown produce including fruit, vegetables, eggs and poultry.

Table 6-C

C. RESIDENTIAL LAND USE - fruit & vegetable garden, poultry excluded.

Default Exposure Ratio: Site and contaminant specific

Exposure Period: 24 hours/day
365 days/year
70 years occupancy duration

Assumptions: Residential garden and soil accessible
10 % or more of intake of fruit and vegetables derives from garden.
Refer Langley & Sabordo (1996) for specific exposure factors

Exclusions: On-site poultry meat, eggs
All other foods (dairy products, beef etc) *not* produced on-site
Groundwater consumption
Volatile contaminants, unless already accounted for in setting HIL for that contaminant

Direct Soil Exposure Pathways:
- Direct soil and dust ingestion (Table 6.2, ANZECC/NHMRC 1992)
- Direct soil dermal contact
- Direct soil particulate inhalation

Indirect Soil Exposure Pathways:
- Uptake into and consumption of home-grown produce including fruit and vegetables.

Table 6-D

D. RESIDENTIAL LAND USE - minimal soil access: high density or fully paved residential (eg. high-rise apartments and flats).

Default Exposure Ratio: **0.25**
Exposure Period: 24 hours/day
365 days/year
70 years occupancy duration
Assumptions: Minimal soil contact opportunities: paving barriers are complete, and   permanent.
Refer Langley & Sabordo (1996) for specific exposure factors
Exclusions: Home-grown fruit & vegetables
Poultry
Groundwater consumption
Volatile contaminants, unless already accounted for in setting HIL for that contaminant
Direct Soil Exposure Pathways:
- Direct soil and dust ingestion (limited) (Table 6.2, ANZECC/NHMRC 1992)
- Direct soil particulate inhalation
Indirect Soil Exposure Pathways:
- Nil applicable.

Table 6-E

E. PARKLANDS/RECREATIONAL LAND USE

Default Exposure Ratio: **0.5**

Exposure Period: 2 hours/day
365 days/year
70 years occupancy duration

Assumptions: Soil contact opportunities arise during recreational activities.
Children will usually be the key exposure concern.
Refer Langley & Sabordo (1996) for specific exposure factors

Exclusions: Home-grown fruit, vegetables, poultry etc
Groundwater consumption
Volatile contaminants, unless already accounted for in setting HIL for that contaminant

Direct Soil Exposure Pathways:
- Direct soil and dust ingestion
- Direct soil dermal contact
- Direct soil particulate inhalation

Indirect Soil Exposure Pathways:
- Nil applicable.

Table 6-F

F. COMMERCIAL/INDUSTRIAL LAND USE

Default Exposure Ratio: **0.2**

Exposure Period: 8 hours/day
5 days/week
48 weeks/year
30 years duration

Assumptions: Soil contact opportunities arise during course of site utilisation by public and workers.
Adults will usually be the key exposure concern allowing a lower default exposure ratio than for Parklands/Recreational Land Use.
No residential land use occurring.(**NB** creches and day-care centres belong in category A).
Refer Langley & Sabordo (1996) for specific exposure factors

Exclusions: Home-grown fruit, vegetables, poultry etc.
Groundwater consumption
Volatile contaminants, unless already accounted for in setting HIL for that contaminant

Direct Soil Exposure Pathways:

- Direct soil ingestion
- Direct soil dermal contact
- Direct soil particulate inhalation

Indirect Soil Exposure Pathways:

- Nil applicable

7. ISSUES FOR FUTURE CONSIDERATION

The exposure settings and their associated default exposure ratios relative to the standard residential 'base case' as outlined above are intended to be used for the derivation of investigation levels, and are not necessarily to be translated into 'response' or 'acceptance' levels. Site and contaminant specific factors will be important in the derivation of acceptance or response levels, as may risk management and community consultation strategies. It is necessary to continue to expand the body of experience in this area to validate the approach taken, and in particular to keep investigational criteria under review in the light of any site-specific sampling data.

There remains a need to ensure a general understanding of the use and intention of '**investigation levels**'. Some regulatory authorities have noted that since specific soil response criteria have not been established in this country, the health-based investigation levels tend to be seen as *de facto* acceptance criteria by many consultants. However there are likely to be occasional instances where the existing investigation criteria are inadequately protective of ecosystems or groundwater resources, and perhaps even under-protective of humans if all possible exposure pathways are investigated and taken into account. Hence there always remains a need to consider sites on their respective merits, rather than unthinkingly comparing soil sample analytical results to established criteria. It appears too early to predict whether overseas efforts to develop elegant exposure and risk assessment models will actually resolve some of these problems, but it does appear likely that there will always be a place for professional judgement and a site-specific approach.

The exposure settings proposed here have been somewhat arbitrarily chosen based upon available information about patterns of land usage. Such categories will need to be kept under review to ensure they remain appropriate, and to allow for important variations to be incorporated as required.

Exposure assumptions (including indoor/outdoor activity patterns, soil ingestion, home-grown food production and consumption patterns) similarly need to be kept under review and our understanding improved at every opportunity, so that the links and differences between theoretical exposure scenarios and likely actual exposure patterns are made as explicit as possible.

To provide guidance on site-specific investigations once contaminants are deemed to exceed the investigation criteria for that particular land use, protocols on complex issues such as home-grown produce sampling, air monitoring for volatiles, groundwater testing, and the implications of complex mixtures for health risk assessment may need further development in future versions of the *Guidelines*.

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