Former HLL Mercury Thermometer Factory, Kodaikanal, Tamil Nadu, India: *Site Specific Target Levels*

Hindustan Lever Limited

Report

September 2006

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REPORT

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Site Specific Target Levels

September 2006

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For and on behalf of
Environmental Resources Management

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EXECUTIVE SUMMARY

Environmental Resources Management Australia Pty Ltd (ERM) was commissioned by Hindustan Lever Limited (HLL) to generate risk-based site-specific target levels (SSTLs) to guide remediation of mercury impacted soils at the former thermometer factory situated in Kodaikanal, Southern India.

Elemental mercury was considered to be the main mercury species of concern on the Site as concentrations of other forms of mercury were not detected to a significant extent, therefore the risk-based SSTLs presented in this report were generated based on elemental mercury. The SSTLs can be applied to Total Mercury concentrations, for practical remediation validation purposes.

The SSTL derived in this report was generated using a probabilistic approach based on the assumed future use of the Site and not for current land-use. The receptor of concern was considered to be a future child resident that had the potential to be exposed to mercury impacts via vegetable ingestion, dermal contact, indoor dust inhalation, outdoor dust inhalation and soil ingestion exposure pathways.

In order to provide an indication of the relative significance of each pathway individual hazard quotients were calculated using an arbitrary input concentration of 1 mg/kg. The hazard quotients indicated that for residents (children aged 0 to 6 years) that ingested vegetables grown on the Site, the most significant pathways in decreasing order of significance were vegetable ingestion, indoor dust inhalation, dermal contact, outdoor dust inhalation and soil ingestion.

Under the assumed conditions of the Site, ERM considers that an SSTL of 25 mg/kg (total mercury) is a health protective clean-up value for the future potential residential receptors who may consume vegetables grown on the Site. This SSTL value was derived using a highly conservative Tier2 & Tier 3 probabilistic assessment based on potential mercury exposure to the future recreational users and residents taking into account the potential for ingestion of home grown vegetables

GLOSSARY OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
BCF	Bio-Concentration Factor
BW	Body Weight
CLEA	Contaminated Land Exposure Assessment
CNN	Central Nervous System
CSM	Conceptual Site Model
DEFRA	Department of Environment, Food and Rural Affairs
DIVs	Dutch Intervention Values
ERM	Environmental Resources Management
HgMe	Methly Mercury
HI	Hazard Index
HLL	Hindustan Lever Limited
HQ	Hazard Quotient
IARC	The International Agency for Research on Cancer
IRIS	Integrated Risk Information System
LOAEL	Lowest Observed Adverse Effect Level
LOR	Limit of Reporting
MPR	Maximum Permissible Risk
MARL	Maximum Allowable Risk Levels
NDNS	National Diet and Nutrition Survey
NOAEL	No-Observed Adverse Effect Levels
PDF	Probability Distribution Functions
PTWI	Provisional Tolerable Weekly Intake
RAGS	Risk Assessment Guidance for Superfund
RAP	Remedial Action Plan
RfC	Inhalation Reference Concentrations
RfD	Reference Dose
RME	Reasonable Maximum Exposure
RMEI	Reasonable Maximally Exposed Individual
RR	Respiration Rate
SD	Standard Deviation
SRC	Serious Risk Concentration
SSTL	Site Specific Target Levels

TDI	Tolerable Daily Intake
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation

1 INTRODUCTION

Environmental Resources Management Australia Pty Ltd (ERM) was commissioned by Hindustan Lever Limited (HLL) to generate risk-based site-specific target levels (SSTLs) to guide remediation of mercury impacted soils at former thermometer factory situated in Kodaikanal, Southern India.

The factory is located towards the south of the Kodaikanal township on St. Marys Road (the Site) (*Figure 1* of *Annex A*). Soil impacted with mercury has been identified on-site during several site investigations conducted by ERM and URS Australia Pty Ltd (URS) between 2001 and 2006. Remediation works are proposed to target mercury impacted soils identified on the Site and the SSTLs generated in this report are therefore required to assist in the design of remedial works.

The risk-based SSTL derived in this report was generated using a probabilistic approach and is based on the assumed future use of the Site and not for current land-use. ERM understands that following remediation, the Site will be redeveloped for residential use, where vegetables will be grown. Sections of the Site will be used as Open Space.

Information pertinent to the Site (e.g. location, geology, hydrogeology) and laboratory analytical results that were used to generate the risk-based SSTLs, were sourced from the following reports:

- URS (2002) Environmental Site Assessment and Risk Assessment for Mercury. HLL Thermometer Factory Site, Kodaikanal, Tamil Nadu, India, May 2002;
- URS (2002) Remedial Action Plan. Site Remediation, HLL Thermometer Factory Site, Kodaikanal, Tamil Nadu, May 2002;
- URS (2002) Health and Safety Plan. Site Remediation, HLL Thermometer Factory Site Kodaikanal, Tamil Nadu, May 2002;
- ERM (2005) Total Mercury Content in Sediment, Surface Water and Fish Samples Drawn from HLL in area surrounding Kodaikanal, June 2005; and
- ERM (2006) Former HLL Mercury Thermometer Factory, Kodaikanal, Tamil Nadu, India. Soil Vapour Investigation Project, May 2006.

1.1 SITE HISTORY

The Kodaikanal thermometer factory is understood to have operated from 1983 and has been under the ownership of HLL from September 1998, until the factory ceased operation in March 2001. Operations ceased due to public concerns regarding the disposal of mercury bearing glass scrap, originating from the factory, to a local scrap-yard in the Kodaikanal township.

approved hazardous waste land-fill site, HLL proposes to undertake soil remediation by alternate means.

1.3 RISK ASSESSMENT OBJECTIVES

The purpose of this risk assessment is to generate robust 'clean-up' standards that are protective of health to future receptors, to assist with site remedial works. The objectives of this risk assessment are therefore to produce a risk-based assessment that will derive site specific target levels (SSTLs) for remediation of the mercury impacted soils. The assessment must therefore be:

- protective of health;
- a robust scientific study;
- clearly auditable; and
- follow internationally accepted assessment reference/guidelines.

1.4 STRUCTURE OF THIS REPORT

This risk assessment has been conducted in general accordance with the internationally accepted protocols for the assessment of contaminated sites, including human health risk assessment frameworks.

The report is structured to provide an introduction to the report itself and the risk based assessment process. The site specific Conceptual Site Model (CSM) is then described with a discussion about the relevant compounds, receptors and pathways.

A hazard assessment is provided that discusses the toxicological impacts of mercury, followed by the exposure assessment that assess potential exposure via the pathways outlined in the CSM.

An uncertainty analysis has been undertaken, which considers potential weaknesses of the risk assessment and this is followed by the risk characterisation step where SSTLs are estimated.

Finally a summary and conclusions are provided.

2 THE RISK BASED APPROACH

2.1 INTRODUCTION

The international risk approach to contamination assessment is well defined in terms of the outline principles in the following guidance documents:

- ASTM (American Society for Testing and Materials). 1995. Standard Guide for Risk Based Corrective Action Applied at Petroleum Release Sites. E 1739-95 (Reapproved 2002). ASTM, USA.
- enHealth (2002) Environmental Health Risk Assessment Guidelines for assessing human health risks from environmental hazards. Department of Health and Ageing, Canberra ACT.

Risk assessment is a tiered process that begins with the definition of a Conceptual Site Model (CSM) in which the source-pathway-receptor pollutant linkages are assessed. This is followed by a comparison of observed chemical concentrations with conservative generic screening criteria, termed "Tier 1 levels". These levels are designed to identify contaminant concentrations that are likely to pose a significant risk to human health or the environment. If observed concentrations of chemicals detected at the site are less than the Tier 1 screen levels, the assessment will not proceed any further. If the Tier 1 screening criteria are exceeded, then further site specific analysis at a higher tier of analysis, Tier 2, will be carried out to evaluate whether the risks from the contaminant concentrations observed on the site are significant. Where Tier 1 criteria are exceeded or where no criteria are available, the Tier 2 process can be used to develop Site Specific Target Levels (SSTLs).

A Tier 3 assessment can be applied to reduce the conservatism of a Tier 2 assessment. The basis of a Tier 3 assessment is to provide a significant degree of confidence in the exposure scenarios and assumptions that are applied. A Tier 3 assessment is generally probabilistic and allows for decisions to be made using more realistic scenarios in contrast to the highly conservative over-predictions of Tier 2 assessment.

The process for generating SSTLs outlined in this report has not been tailored to assess the potential impact of contaminants to current receptors. Rather, the SSTLs have been generated using an arbitrary concentration to provide a sustainable remedial 'end-point' for the proposed remediation works.

2.2 ASSESSMENT METHODOLOGY

The risk assessment process can be defined as comprising four broad elements:

- Issues identification.
- Hazard assessment.
- Exposure assessment.
- Risk characterisation.

This assessment has been structured to address and discuss each of these elements and then provide ERM's final conclusions, SSTLs and the references for the study.

3 ISSUES IDENTIFICATION

3.1 INTRODUCTION

'Issues identification' is the initial stage of the risk assessment process. It is a process for generating and evaluating preliminary hypotheses about why human health or ecological effects have occurred, or may occur, from human activities (e.g. contamination).

The overall objective of the issues-identification process is establishing a context for the risk assessment. Identified issues may be related to social and economic factors as well as human perceptions and scientific matters. The issues-identification process aims to determine:

- what the concerns are;
- what is causing the concern;
- why is the concern an issue;
- whether the concern can be examined using risk assessment; and
- whether risk assessment is appropriate.

The most appropriate way of approaching these questions is generally considered to be by producing a detailed Conceptual Site Model (CSM) to qualitatively assess source-pathway-receptor pollutant linkages. Should pollutant linkages be considered to potentially exist, than risk assessment becomes an appropriate response.

3.2 CONCEPTUAL SITE MODEL

A CSM is the qualitative description of the plausible mechanisms by which receptors may be exposed to site contamination, and it is developed to provide an overall understanding of the site. For exposure to be considered possible, some mechanism ('pathway') must exist by which contamination from a given source can reach a given receptor. Such complete 'source-pathway-receptor' exposure mechanisms are commonly termed 'pollutant linkages'. Exposure via these pollutant linkages is quantified and evaluated at later stages in the assessment. Pollutant sources, exposure mechanisms and receptors at the Site are discussed below.

Site Description

The Site is approximately 85,000 m^2 and is located along St Mary's Road within the township of Kodaikanal, in a notified industrial area, which is located approximately 120 km north of Madurai town (*Figure 1* of *Annex A*). A former mercury thermometer factory is located on the Site in addition to a number of smaller buildings associated with the factory. The Site is located on top of a cliff at an elevation of approximately 2,180 m above sea level and is irregular in shape.

ERM understands that targeted remediation works are proposed for the Site in areas of mercury exceedences above the SSTLs generated in this report. Following remediation ERM understands that the Site will be redeveloped for residential and/or recreational use and there will be Open Space. A conceptual site model of the assumed future land use is illustrated in *Figure 3* of *Annex A*.

Land use surrounding the Site comprises residential and recreational areas. Low density residential properties lie to the west, north and north-east of the Site, and a few cottages and St Marys church are located to the west. The Site slopes steeply into the Pambar Shola Forest (a protected nature sanctuary of the Tamil Nadu Government) which is adjacent to the southern boundary. Levange path is located in between the forest and the Site. One residential dwelling is located on the eastern corner of the Site along Ponds Path (*Figure 2* of *Annex A*). A large television broadcast antenna tower is located approximately 200 m to the east of the Site.

URS reported that the factory ceased manufacturing operations in March 2001. During the most recent ERM site investigation (April 2006), it was noted that the Site is predominantly unsurfaced with areas of overgrown grass and dense vegetation surrounding the building structures. In April 2006, the factory was observed to be undergoing various stages of decommissioning.

Figure 2 of *Annex A* illustrates the Site layout (as noted in April 2006), indicating the location of various buildings and structures.

Geology

A geological study was carried out by ERM in May 2006. Observations made during this study indicated that the regional geology of the Southern Indian Peninsula comprises a granite-greenstone terrain in the north and granulite facies terrain in the south. It was noted that the terrain is dissected by a number of late Proterozoic shear zones. ERM geological investigations indicated that the Site geology comprises banded Charnockite rock with minimal variation in felsic and mafic mineral components. Medium to coarse grained pleochroic orthopyroxene is the predominant mafic mineral. The

Charnockite rocks exposed on the Site are massive and exfoliated near the surface.

The URS (2002) Remediation Action Plan states that "*the whole site is underlain by shallow Archaean bedrock, mainly granite gneiss and Charnockite, which is impermeable apart from limited fracture porosity related to the vertical and sub-horizontal joints and exfoliation joints in the uppermost weathering profile*".

Hydrology

The Site is located on the southern slope of a ridge which acts as a drainage divide between the Pambar River basin to the south and the Kodai Lake catchment to the north. According to the URS (2002) *Environmental Site Assessment* report, the nearest surface water body to the Site is the Pambar River located approximately 0.5 km to the south. Kodai Lake is approximately 1.0 km to the north of the Site, within a different catchment area.

During the ERM geological investigation, it was noted that two streams drain the Site, one near the north-eastern corner of the Site and the second stream located in the north-western corner of the Site. Both streams eventually converge towards the southern end of the Site and flow into the Pambar Shola Forest. Two wells have been excavated into the massive charnockite bedrock, one along each stream line. There is seepage of water from the shallow stream sediments into the wells but this is ephemeral depending on the season.

Several other seepages from shallow exfoliation joints have been reported in the steeply sloping charnockite towards the Levange path that are known to become dry during summer.

3.3 CONTAMINATION SOURCES

During the factory operation, ERM understands that 136,486 kg of triple distilled mercury (99.999%) was imported and used on the Site for the manufacture of thermometers. Soil sampling conducted by URS in 2002, detected mercury impacts on the Site above 10 mg/kg in soil. Soil samples were collected at depths from 5 to 130 cm below ground level, with the majority of soil samples collected at 10 cm depth. For sampling conducted on-site, soil was the main medium (346 samples), while sediment (2) water (5) (collected from the stream running through the site), lichen (7) and bark (7) samples were also collected.

The on-site sampling indicated that the majority of mercury impacts occurred in the top 10 cm of the soil profile; however, at several locations, elevated mercury concentrations were recorded at depths of 50 cm (441 mg/kg), 70 cm (145 mg/kg), 85 cm (315 mg/kg) and 100 cm (58 mg/kg). The sampling also indicated a number of hot spots, where mercury concentration exceeded

100 mg/kg and a few where the concentration exceeded 1,000 mg/kg. The highest concentration detected was 5,286 mg/kg of total mercury.

3.3.1 *Mercury Speciation*

Mercury occurs in three distinct forms in the environment: elemental, inorganic and organic. Following a review of the ERM and URS laboratory reports, it was noted that 'Total Mercury' was analysed in the majority of the samples. Mercury species characterisation has been undertaken, with 33 samples tested for organic mercury (e.g. methyl mercury (HgMe)). These samples consisted of soil (14 samples), sediment (9) and lichen (10). The results from this speciation study indicated that limited methylation has occurred in the top 5 to 10 cm of soil, decreasing to near or below detection limits at 40 to 80 cm depth. The highest concentration of HgMe in the on-site soil samples was 0.0094 mg/kg, with concentrations ranging between <0.0001 to 0.0094 mg/kg. The ratio of HgMe to total mercury in the on-site samples reached a maximum value of 0.0002, indicating that little, if any methylation has occurred to the mercury identified on the Site. The ratios of the other samples decreased with depth, probably reflecting a decrease in the concentration of mercury with depth and a possible decrease in microbial activity.

Elemental mercury is strongly absorbed by sediments and soil, and slowly desorbed. The maximal absorption by clay minerals occurs at pH6, whilst for Fe-oxides, the maximal absorption is at neutral pH. In acid soils, most mercury is absorbed by organic matter, but when organic matter is absent, mercury becomes relatively more mobile.

3.3.2 *Mercury Species Of Concern*

Following a review of the ERM and URS site investigation and laboratory reports, the main mercury species considered to be present on the Site is elemental mercury. Therefore, the SSTLs generated in this report are based on elemental mercury. ERM understands that laboratory analysis of mercury is often reported as 'Total Mercury' which is a combination of elemental, organic and inorganic mercury. Therefore, as a practical approach for validation sampling during the proposed remediation, the SSTLs generated in this report may be applied to 'Total Mercury' concentrations on the basis that contamination comprises predominantly elemental mercury with some inorganic and little or no methyl mercury.

3.3.3 *Mercury Vapour*

Results from a recent soil vapour survey, conducted by ERM in April 2006, indicate that mercury vapour concentrations across the Site range from below the limit of laboratory reporting (LOR) (i.e. 0.002 $\mu g/m^3$) to a maximum concentration of 13 $\mu g/m^3$. The maximum vapour concentration was recorded in the vicinity of the former crusher plant building, in an area with elevated mercury soil concentrations (200 to 500 mg/kg in soil). ERM understands that targeted remediation is proposed for this area; therefore, it is considered that this vapour concentration is unlikely to be indicative of future vapour concentrations following remediation. Of the remaining 15 sample locations tested for vapours, nine locations did not record vapours above the LOR and six locations recorded concentrations between 0.007 and 0.046 $\mu g/m^3$; the average vapour concentration was 0.01 $\mu g/m^3$ ($n = 15$ sample locations).

A number of international agencies have proposed a range of mercury vapour reference concentrations for ambient air based on laboratory studies:

- World Heath Organisation (WHO) Air Quality Guidelines (2000) recommended an ambient air quality guideline of 1.0 $\mu g/m^3$ as an annual average for mercury vapour. This concentration was based on a Lowest Observed Adverse Effect Level (LOAEL) for mercury vapour between 15 to 30 $\mu g/m^3$ and an uncertainty factor of 20.

- The US EPA (Integrated Risk Information System) reports a chronic reference exposure concentration (RfC) for elemental mercury of 0.3 $\mu g/m^3$ based on extensive occupational studies. This study used a LOAEL concentration of 25 $\mu g/m^3$ based on an exposure activity of 8 hours/day for 5 days/week. The LOAEL was multiplied by factors of 10/20 and 5/7 to obtain a continuous exposure of concentration of 8.9 $\mu g/m^3$. Uncertainty factors for sensitive humans (x10) and deficiencies in the database on developmental and reproductive studies (x3) were applied to produce a RfC of 0.3 $\mu g/m^3$.

- The ATSDR (Agency for Toxic Substances and Diseases Registry) has suggested a minimal reference concentration of 0.2 $\mu g/m^3$ for elemental mercury vapour (ATSDR, 2000). This RfC is an estimate of the daily human exposure that is likely to be without appreciable risk.

ERM considers that the average vapour concentration (0.01 $\mu g/m^3$) detected during the April 2006 soil vapour survey is below the above mentioned guidelines (0.2 to 1.0 $\mu g/m^3$) Consequently potential risks posed by vapour inhalation to future site receptors will not be assessed further in this report.

3.3.4 *Mercury In Groundwater*

The WHO (1999) guidelines value for total mercury in drinking water is 0.001 mg/L based on a tolerable weekly intake (PTWI) of 5 $\mu g/L$ of body weight of total mercury. During the URS 2002 site investigation, surface water samples were collected from "*the main stream, the minor stream and the on-site springs*". Elevated concentrations of total mercury (0.031 to 0.085 mg/L) were detected in two surface water samples that were collected on-site following a heavy storm. URS considered that these elevated results represented anomalous readings because both samples contained silt and were reported to have been analysed unfiltered. Consequently, these results were not considered to represent surface water concentrations. The remaining surface water samples collected across the Site returned total mercury concentrations below the laboratory detection limit (i.e. <0.0003 mg/L) which is below the WHO (1999) drinking water guideline of 0.001 mg/L.

It is understood that a proportion of the surface water seeps into the two on-site wells however this supply is limited and seasonal. One of the wells is located directly downstream of the mercury impacted area and has been excavated into charnockite bedrock. Surface water samples collected by URS in the vicinity of this well returned mercury concentrations below the laboratory detection limit of 0.0003 mg/L. Similarly, mercury concentrations in surface water seepage from exfoliation joints in other locations on the Site were below the laboratory detection limit.

3.4 POTENTIAL RECEPTORS

The Site currently comprises a non-operational mercury thermometer factory, and associated buildings, that was in operation for 18 years before its closure in 2001. ERM understands that the future land-use of the Site will be residential with domestic vegetable gardens and a small portion of the Site, along the main stream, will be Open Space.

The receptors of concern for this risk assessment are considered to be future residential receptors who consume home-grown vegetables and recreational users. Children are considered to be a more sensitive receptor than adults and consequently often drive the risk assessment process. Therefore, potential risks to children aged 0 to 6 years will be assessed in this report.

The aim of this risk assessment is to derive risk-based SSTLs for those future potential receptors that may be present on Site following the proposed remediation.

For exposure to the identified receptors to be considered possible, some mechanism ('pathway') must exist by which contamination from a given source can reach a given receptor.

3.5 PATHWAYS AND POLLUTANT LINKAGES

Potential exposure pathways are evaluated for completeness based on the existence of:

- a source of chemical contamination;
- a mechanism for release of contaminants from identified sources;
- a contaminant retention or transport medium (e.g. soil, air, groundwater etc.);

- potential receptors of contamination; and
- a mechanism for chemical intake by the receptors at the point of exposure (ingestion, dermal contact or inhalation or a combination of).

Whenever one or more of the above elements is missing, the exposure pathway is incomplete and there is therefore no risk to the identified receptor (human health for example). An exposure pathway can be either "direct", where the receptor comes into direct contact with the affected environmental media (e.g. soil ingestion) and "indirect", where exposure occurs at a different location or in a different medium than the source (e.g. soil vapours volatilising to ambient air).

Considering that proposed future use of the Site is to be for recreational/residential purposes, it is likely that much of the Site may be un-surfaced. Exposure may therefore potentially arise due to direct (i.e. ingestion and dermal contact) pathways from mercury soil impacts. Indoor and outdoor dust inhalation by residential receptors (adults and children) is also a potential pathway.

As indicated previously, site specific soil vapour data collected in April 2006 indicates that the potential for mercury vapour generation on site is minimal. Further the average concentration detected (0.01 µg/m^3) is below internationally recognised reference concentration values (0.2 to 1.0 µg/m^3). Therefore, the vapour inhalation pathway for the future receptors will not be assessed further in this report.

The exposure pathways identified for the future on-site receptors are illustrated in *Table 1.*

Table 1 ***Summary of Pollutant Linkages***

Potential Pathway	On-site Residents with vegetable gardens	On-site Recreational Users
Direct Ingestion of Soil	✓	✓
Dermal contact with Soil	✓	✓
Vegetable Ingestion	✓	X
Indoor inhalation of dust derived from Soil Contamination	✓	X
Outdoor inhalation of dust derived from Soil Contamination	✓	✓
X	Incomplete pollutant linkage	
✓	Complete pollutant linkage	

1. *Residents and recreational users are considered to be children aged 0 to 6 years of age.*

The above table identifies the potential source – pathway – receptor pollutant linkages at the Site which may potentially drive human health risk. An assessment of these risks is discussed further below.

3.6 CONCEPTUAL SITE MODEL SUMMARY

In summary, the SSTLs presented in this report were generated based on elemental mercury which is considered to be the main mercury species of concern on the Site. As a practical approach for the proposed remedial works, the SSTLs should be applied to total mercury concentrations. ERM understands that following the proposed remediation, the Site will be redeveloped for residential use with some open space. Consequently, the potential future receptors are considered to be residents and recreational users (adults and children). The identified exposure pathways are considered to be via soil ingestion, dermal contact and inhalation of dust derived from mercury impacted soil for recreational users, as well as vegetable ingestion for residents.

4 HAZARD ASSESSMENT

4.1 INTRODUCTION

The hazard assessment stage of a risk assessment is separated into two functions, hazard identification and dose-response assessment. The hazard identification stage is a qualitative description of the capacity of a contaminant or agent to cause harm. Dose-response is a more quantitative assessment of how much exposure to an agent may lead to harm.

4.2 HAZARD IDENTIFICATION

The hazard identification process provides a means in which to consider the capacity of a specific agent to produce adverse health or environmental affects. Hazard identification comprises the initial part of the hazard assessment process involving the consideration of the types of adverse health effects that might be caused by a given agent and uncertainty analysis of toxicological data.

4.2.1 *Elemental Mercury (Hg) Toxicological Profile*

Each form of mercury (i.e. elemental, inorganic and organic) has differing toxicological effects which will depend upon a number of factors e.g. the chemical form (species) of the mercury, the concentration and dose, age of exposed person, rate and duration of exposure. Elemental mercury is classified by the International Agency for Research on Cancer (IARC) as non-carcinogenic (Level 3).

Elemental mercury is a silver-grey metal which is liquid at room temperature. It has a melting point of -38.87°C and a vapour pressure of 0.3 Pa at 25°C. The vapour pressure doubles for every 10°C increase in temperature. The primary pathway for elemental mercury absorption is via inhalation of mercury vapours, where approximately 80% may be absorbed. When inhaled the mercury vapour easily passes through the pulmonary alveolar membranes and enters the blood, where it distributes primarily to the red blood cells, central nervous system (CNS) and kidneys. Ingested elemental mercury is only sparingly soluble in the gastrointestinal tract (less than 0.1%). Dermal absorption is about 2.5% when exposed to mercury vapour (DEFRA & Environment Agency, 2002b).

Elemental mercury is readily absorbed by sediments and soil, and slowly desorbed. The maximal absorption by clay minerals occurs at pH6, whilst for iron-oxides, the maximal absorption is at neutral pH. In acid soils, most mercury is absorbed by organic matter, but when organic matter is absent, mercury becomes relatively more mobile whereby evaporation and leaching to groundwater occurs.

Elemental mercury is lipid soluble, enabling it to readily cross the blood-brain barrier. Elemental mercury in contact with tissue oxidizes to mercuric ion (Hg^{2+}), which is much less able to cross the blood-brain barrier. However, when the conversion occurs in the CNS, it is less able to diffuse out.

At high exposures, mercury vapour inhalation causes acute necrotizing bronchitis and pneumonitis, which can lead to death from respiratory failure. At lower exposures, the effects of mercury include insomnia, forgetfulness, loss of appetite, and mild tremor. Continued exposure may produce progressive tremor, erethism, emotional lability and memory impairment. Mercury also accumulates in kidney tissues, directly causing renal toxicity, including proteinuria (nephrotic syndrome). The half-life of elemental mercury in adults is 60 days (range 35 to 90 days), with excretion being mainly through the urine, with lesser amounts through exhalation.

4.3 TOXICITY DATA USED IN THE ASSESSMENT

Non-carcinogenic risks (or threshold) are considered to have a threshold mode of action, whereby exposure below the threshold dosage (termed the Tolerable Daily Intake (TDI) or Reference Dose (RfD)) is considered to result in no observable, or adverse, effect.

Table 2 provides a summary of the toxicity dose response data used in this risk assessment.

Table 2 ***Toxicity Dose Response Data***

Compound	Oral RfD[1] (mg/kg-day)	Reference	Inhalation RfD[1] (mg/kg-day)	Reference
Elemental Mercury	0.0003[2]	IRIS	8.58E-05[3]	IRIS

1. *75% of the reference dose has been allocated to background exposure*
2. *There is a Provisional Peer Reviewed Toxicity value of 0.003 mg/kg-day for elemental mercury but this is less conservative than mercuric chloride. Therefore, the oral toxicity value for mercuric chloride was used*
3. *The RfD was calculated from a reference concentration (RfC) of 3.0E-04 for a 70 kg adult with a breathing rate of 20 m³/day*
4. *IRIS: US EPA Integrated Risk Information System (data current to 27 June 2006)*

4.3.1 *Background Exposure*

Risk assessment guidelines generally require that risk-based Environmental Health Criteria be derived by taking into account factors such as exposure to the studied substances from other potential sources such as food, water and air. This is commonly referred to as background exposure. Where reliable published data on background chemical intake are available this can be addressed by allocating a fraction of the TDI to background intake and calculating risks on this basis. However, in practice, due to the large variations in human behaviour patterns, it is extremely difficult to obtain meaningful quantitative data for total background mercury intake by the identified receptors.

The World Health Organisation (WHO) drinking water guidelines (1993) state that "*Where possible, data concerning the proportion of total intake normally ingested in drinking-water (based on mean levels in food, air and drinking-water) or intakes estimated on the basis of consideration of physical and chemical properties were used in the derivation of the guideline values. Where such information was not available, an arbitrary (default) value of 10% for drinking-water was used. This default value is, in most cases, sufficient to account for additional routes of intake (i.e. inhalation and* *dermal absorption) of contaminants in water"*. The WHO drinking water guidelines therefore assume that 10% of the TDI, as described by the RfD, of a compound comes from drinking water.

Dietary intake and exposure to mercury from dental amalgams appear to be the major source of mercury exposure to the human population (NEPC, 1999). Mercury is commonly used in the manufacture of batteries, in electrical appliances, and as a component of paints to prevent mildew. Mercury also occurs in minor amounts in fertilizer, lime and manure applied to agricultural land and was historically in fungicides and seed disinfectants (Steinnes, 1995).

Therefore, taking this into consideration this assessment has assumed a 10% allocation of the TDI to exposure in drinking water and a further allocation of 15% of the TDI to other sources therefore leaving 75% of the TDI allocated to potential exposure to mercury soil contamination.

5 EXPOSURE ASSESSMENT

The exposure assessment stage of the study determines the magnitude, frequency, extent character and duration of exposure. This section presents a description of the potentially complete pathway between contamination sources and human receptors described in the CSM.

An exposure assessment combines the pollutant linkages identified in the CSM with exposure assumptions taken from international guidance and the recorded mercury concentrations at the Site. This is achieved using mathematical algorithms published by recognised bodies which calculate contaminant intake. The formulae used in this assessment are those described in ASTM (1995).

5.1 MAGNITUDE AND EXTENT OF EXPOSURE

The character of the exposure (including the magnitude and extent) will be generally defined by a combination of physio-chemical properties, site factors and behavioural and physiological factors.

The magnitude of exposure will be largely dependant on the source properties including physio-chemical factors such as gas-liquid phase partitioning rates, volatilisation rates and associated soil and site properties such as soil pore spaces, moisture and the distance between the mercury impacts and the receptor or the air environment. Inhalation rates and behavioural properties will also impact the magnitude and extent of a given exposure.

5.2 PROBABILISTIC EXPOSURE MODELLING

Deterministic exposure modelling is a traditional approach to modelling where in any calculation a single point estimate is assigned to each variable. Point estimates are commonly used to represent human behavioural assumptions (e.g. body weight) for exposure assessments and are typical values that represent a population or an estimate of an upper end of the population's value (enHealth, 2002). This upper end value may be chosen to provide a 'worse-case' scenario or provide conservatisms in the risk assessment process. When modelling multiple exposure pathways for a given receptor the 'worse-case' scenario can often result in a worse than 'worse-case' scenario due to the compounding effects of the point estimates.

Alternatively, the use of probability distribution functions (PDFs) can be used when modelling exposure assessments which can often provide more informative and inherently more representative human behavioural data. A PDF can be defined as "*A mathematical representation of a parameter of interest* *that is based on observations of the variability or uncertainty in the underlying data"* (DEFRA & Environment Agency, 2002a). Hence, probabilistic modelling uses a range of values selected from a defined probability distribution and variability in the data can be more accurately characterised.

Commonly, two types of computational techniques are used during probabilistic modelling: the Monte Carlo method and the Latin Hypercube technique. The Monte Carlo method selects random or pseudo-random values from the input distribution so that samples are more likely to be drawn from values that have higher probabilities (AIHC, 1994); consequently, use of this method is more likely to result in unduly frequent combinations of modal exposure scenarios. The Latin Hypercube technique uses random sampling within equi-probable intervals of the distribution so that there will not be clustered sampling near the mode. This technique maintains complete independence of the variables and as such will be adopted for exposure modelling in this risk assessment (enHealth, 2002).

Probability distributions created by the Latin Hypercube method allow determination of a particular risk or exposure level that represents the 50^{th}, 90^{th}, 95^{th} percentile or any other percentile level of risk. For this risk assessment, the 95th percentile for the Mean Daily Intake (MDI) dose for each child age group was used to estimate potential risks. This value is considered to represent the highest MDI dose of total mercury to 95% of the receptor population on the Site. Since the 50^{th} percentile (50% probability) is generally considered the most likely value, using the 95^{th} percentile insures a more conservative answer. Use of the 95^{th} percentile is the generally accepted risk assessment practice and is adopted as policy in the UK in deriving soil guideline values using the Contaminated Land Exposure Assessment (CLEA) model (CLR10, 2000a).

In this risk assessment, deterministic exposure modelling was used to estimate the potential risks to recreational users via three exposure pathways (refer to *Table 1*). Two additional exposure pathways (i.e. vegetable ingestion and indoor dust inhalation) were considered for residents therefore the compounding effect of using point estimates when modelling exposures are likely to generate an overly conservative clean-up criteria for the Site. Hence probabilistic modelling was used to estimate potential risks to residential receptors with the aim of more accurately characterising variability within the population and reduce uncertainly incorporated in the additional exposure pathways.

5.3 *HUMAN BEHAVIOURAL SIMULATIONS*

The statistical software *Crystal Ball* (version 7.2.2) was used as an analytical tool to perform simulations of the human behavioural PDFs in order to model exposure. Using standard mathematical formulae (adopted from ASTM guidance) 10,000 iterations of a mathematic model were performed using *Crystal Ball*. For each iteration, values for each parameter were selected randomly from each distribution based on the probability of occurrence. The estimated risk values were then combined to provide a frequency distribution of the probable risk.

The PDFs and formulae are used to calculate the dose that the potentially exposed residential receptor would receive from each exposure pathway under the assumed exposure scenarios. This dose estimate, termed a Mean Daily Intake (MDI), is used in the calculation of risk for threshold (non-carcinogenic) compounds. The estimated MDI value from the 95% percentile distribution was then used to estimate potential risks. Exposure algorithms are provided in *Annex B*.

PDFs used in this risk assessment were adopted from *"The Contaminated Land Exposure Assessment (CLEA) Model: Technical Basis and Algorithms. Department for Environment, Food and Rural Affairs & Environment Agency, UK (2002)"* guidelines which are in turn sourced from fundamental work conducted by a number of sources described below. The PDFs adopted are specific to each child age group (i.e. 0-1, 1-2, 2-3, 3-4, 4-5 and 5-6 year old child) and are illustrated in *Table 3*.

Within the CLEA Model for the standard residential scenario, the receptor is assumed to be a female child with the duration of exposure covering the first six years of life. Activity patterns for the residential land use have been based on the studies of Gershuny et al. (1986) and Gershuny (2000) looking at the time budget analysis of adults a.nd children. Allowance was made for school attendance in calculating the number of hours on-site used primarily for the purposes of assessing exposure to airborne dust and vapours. Children up to school age have been assumed to spend all their time in or close to home. A further discussion of the assumptions inherent within each PDF is presented below.

Table 3 *Probability Distribution Functions (PDFs)*

PDF	Age	Mean	SD
Body weight (kg)	0-1	7.4	0.968
	1-2	10.65	1.344
	2-3	14	1.622
	3-4	15.9	2.201
	4-5	18.65	2.982
	5-6	20.31	3.434
Soil ingestion (mg/kg-day)	0-6	100	101.5
Skin surface (cm^2)	0-1	380	25
	1-2	490	40
	2-3	610	40
	3-4	670	50
	4-5	750	70
	5-6	800	75
Outdoor inhalation rate (m^3/day)	0-1	5.328	0.551
	1-2	7.68	0.77
	2-3	10.08	0.924
	3-4	11.45	1.62
	4-5	13.44	3.41
	5-6	14.616	1.968
Indoor inhalation rate (m^3/day)	0-1	1.944	0.21
	1-2	2.808	0.29
	2-3	3.696	0.336
	3-4	4.2	0.456
	4-5	4.92	0.62
	5-6	5.352	0.732
Root vegetable ingestion rate (g/kg-bw/day (fresh weight))	0-1	1.3	0.13
	1-6	0.62	0.61
Non-root vegetable ingestion rate (g/kg-bw/day (fresh weight))	0-1	0.29	0.53
	1-6	0.32	0.4

1. Standard deviation (SD) values were derived from percentile observations on the assumption that 95% of observations will fall within two SD from the mean (Davis, 1973).
2. Source of data: Contaminated Land Exposure Assessment (CLEA), CLR10 (2000a).

5.3.1 *Body Weight*

Body weight was treated as a probabilistic parameter with a normal shaped PDF truncated at 2.5 standard deviations to remove extreme values. For age groups 3-4, 4-5 and 5-6 years old, the mean and the standard deviation have been calculated from survey results collected by the UK Department of Health (DH, 2000) using the analysis software SPSS (version 10.1). Body weight data from the 1991 survey has been adopted for the age group 1-2 years old (DH, 1991).

5.3.2 *Soil Ingestion*

The probabilistic soil ingestion parameter was modelled using a natural log-normal PDF and is specific for children from birth to 6 years. Information used to derive this PDF was derived from the US EPA (1999). The PDF has an approximate mean soil ingestion rate of 100 mg/day and a 95^{th} percentile rate of 303 mg/day.

5.3.3 *Total Skin Surface*

Total skin surface area (A_t) was derived from body weight (*BW*) using the following equation as found in ICRP (1975):

$$At = \frac{(4 \times BW) + 7}{BW + 90}$$

A_t is a secondary probabilistic variable because it is calculated from body weight with a normal shaped PDF. A number of studies support deriving total skin area from easily measured body characteristics such as weight (ICRP, 1975; Burmaster, 1998; McKone & Daniels, 1991; US EPA, 1985).

5.3.4 *Inhalation Of Dust And Vapours*

Outdoor Inhalation Rate

Respiration rate PDFs are considered to be a secondary probabilistic parameter because respiration is a function of body weight. Active respiration rates were used under the residential land use scenario assuming that that the majority of time spent outdoors will be in active respiration.

The most relevant measure of lung function is the minute volume (measured in litres of air per minute) and the breathing frequency. The minute volume depends partly on the physical characteristics (age, gender, body size and fitness level) and partly on the activity and the work rate. In the CLEA model, the units of minute volume are converted to cubic metres per hour. McKone & Daniels (1991) used ICRP (1975) to estimate respiration rate (RR) as a function of body weight and whether a person is carrying out an active or a passive task in the following equation:

$$RR = \alpha_{act} \times BW$$

Where RR is the respiration rate (m^3/h), α_{act} is the breathing rate (m^3/kg bw/h) which varies according to age and activity category (active or passive) and BW is the body weight (kg).

Indoor Inhalation Rate

It is assumed that a certain fraction of contaminated soil is tracked back into the home from the garden or nearby open space and contributes to exposure to contamination from the soil-derived fraction of indoor dust. Passive respiration rates were under the assumption that the majority of time spent indoors will be in passive respiration.

5.4 VEGETABLE INGESTION

The vegetable ingestion pathway considers the potential transfer of mercury soil contamination to child receptors at the Site. The chemical exposure rate of soil contaminants is assessed based on the consumption of garden vegetables only. This assessment is dependant on the potential for vegetables to accumulate mercury from the surrounding soil, the proportion and amount of home-grown vegetables consumed and the absorbed of mercury in the vegetables by the child receptors. Key features of this pathway are illustrated in *Figure 4* of *Annex A*.

It was considered necessary to assess exposure to mercury from the ingestion of both 'root' and 'leafy' vegetables because the ingestion rate differs markedly between plant species (CLR10, 2002a). In addition, uptake behaviour differs between plant species, specifically 'root' and 'leafy' vegetables. When estimating vegetable uptake it is recommended that the concentration of the contaminant in the edible parts of the relevant vegetable is estimated rather than the concentration in the whole plant. For 'root' vegetables the edible portion is below ground and the soil-to-plant concentration factor is based on root zone accumulation of soil contaminants. For 'leafy' vegetables the edible portion is above ground with the soil-to-plant concentration factor based on stem and leaf accumulation of soil contaminants.

5.4.1 *Mercury Uptake Into Vegetables*

The plant uptake of metals occurs predominantly from the soil solution where as the direct uptake of material sorbed on soil surfaces or on organic matter is relatively minor (Alloway, 1995). Generally, the concentration of a contaminant measured in the soil solution represents only a fraction of the total contaminant present in soil (DEFRA & Environment Agency, 2002a); and the ratio of the concentration in soil solution to the total soil depends on a number of factors (e.g. soil pH, redox potential, soil chemistry) (Alloway, 1995).

Limited information is available on the uptake of mercury by plants however, the translocation of mercury from roots to aerial plant parts is generally considered to be low (Cross & Taylor, 1996). The uptake of mercury into vegetables grown on the Site was estimated using an equation proposed by

Baes (1982). This equation is based on experimental data which incorporates a relationship between Kd and BCF (relationship between the concentration in tissue of the above ground part of plants (stem) and an environmental compartment); and is illustrated below.

$$\ln BCF_{plant} = 2.67-(1.12*(\ln K_d))$$

5.4.2 *Gastrointestinal Absorption Of Elemental Mercury*

The gastrointestinal absorption factor (0.0001) adopted for this risk assessment was derived based on information provided by the Risk Assessment Information System (2005) and work conducted Goyer (1991).

5.4.3 *Vegetable Consumption Rate*

The vegetable consumption rate PDFs adopted for this risk assessment were derived based on information from The National Diet and Nutrition Surveys (NDNS) carried out by the Food Standards Agency and the American Department of Health. In this survey, food consumption rates for approximately 2500 individuals were recorded for the home-grown vegetable of interest. Children below 1 ½ years old were not considered in the NDNS programme, consequently consumption data for this age group were derived from a 1986 survey of the diets of 488 British infants aged 6-12 months (Mills & Tyler, 1992).

The NDNS information was taken for each age group and each vegetable and PDFs were fitted to a natural log-normal distribution using the mean and standard deviation values from the data sets.

5.5 POINT ESTIMATE RECEPTOR AND SITE ASSUMPTIONS

Receptor point estimate values were used for a number of variables where PDFs were not available (e.g. skin soil adherence factor). *Table 4* presents a list of the site parameter assumptions and *Table 5* presents the receptor point estimate assumptions that have been utilised for the exposure assessment algorithms. These assumptions have been adopted from the RAGS (US EPA, 1989), ASTM (American Society for Testing and Materials), WHO (World Health Organisation) and DEFRA & Environment Agency (2002a) default values for exposure assessments. Assumptions regarding fraction of home-grown vegetables and subsurface soil parameters and soil porosities have been adopted from the risk assessment software RISC 4.04.

The majority of the human behavioural point estimates are specific to child receptors between 1 and 6 years of age, and in some cases are separated by year age brackets (DEFRA & Environment Agency, 2002). A discussion of the age specific assumptions inherent in the human behavioural point estimate values is provided below.

5.5.1 *Exposure Duration*

The exposure duration of a child receptor for the first six years of a child's life from the age of 1 equates to an averaging period of 365 days per year. Since the lifetime of the child receptor assessed in this report is analysed on a yearly basis (i.e. age groups 1-2 through 5-6 years old), the exposure duration parameter is set at a lifetime exposure of 365 days for any given age group.

5.5.2 *Exposure Frequency To Surface Soil*

The exposure frequency to surface soil variable adopted in this risk assessment is based on the work by Gershuney et al. (1986) and Gershuny (2000). For ages 0 to 6 years old, it is assumed that the child will have an exposure frequency to surface soil of 180 days per year.

5.5.3 *Fraction Of Time Spent Outdoor/Indoor*

Fraction of time spent outdoors and indoors was adopted from the DEFRA & Environment Agency (2002) guidelines which separate the time into yearly age groups. These fractions were derived from studies conducted by Gershuny et al. (1986) and Gershuny (2000) and are based on the number of hours per day spent respirating (actively and passively) outside and inside. The scenarios were based on female activity patterns for a residential land-use scenario on the assumption that females spend more time at home.

Table 4 *Site Assumptions*

Parameter	Residents and Recreational Users	Reference
Dust Parameters		
Fraction of outdoor dust originating from soil	100%	ASTM[1]
Outdoor air dust concentration (mg/m^3)	0.07	WHO[2]
Fraction of indoor dust originating from soil	75%	ASTM
Indoor air dust concentration (mg/m^3)	0.07	WHO
Soil Parameters		
Soil fraction of organic carbon	0.7%	RISC[4] Sandy Loam

1. *ASTM: American Society for Testing and Materials (2000)*
2. *WHO: World Health Organisation (2000)*
3. *RISC 4.04*

Table 5 *Human Behavioural Assumptions (Child receptors only)*

Parameter	Age	Residents with vegetable gardens (Child)	Recreational Users
Exposure frequency to site (days/year)	0-6	350[3]	350[3]
Exposure duration (years)	0-6	1	6[3]
Body weight (kg)	0-6[2]	PDF[1]	16[4]
Soil Exposure			
Soil Ingestion (mg/day)	0-6[3]	PDF[1]	100[3]
Skin surface (cm^2)	0-6[2]	PDF[1]	3160[3]
Fraction of skin exposed to soil (%)	0-6	20%[2]	100[6]
Soil skin adherence (mg/cm^2)	0-6	0.5[3]	2.77[4]
Exposure frequency to surface soil (days/year)	0-6	180[2]	350[2]
Dust and Vapour Inhalation			
Outdoor inhalation rate (m^3 /day)	0-6[2]	PDF[1]	15.6[7]
Fraction of time spent outdoors (%)	0-1	8.3%[2]	21%
	1-5	12.5%[2]	
	5-6	8.3%[2]	
Indoor inhalation rate (m^3 /hour)	0-6[2]	PDF[1]	15.6[7]
Fraction of time spent indoors (%)	0-1	91.7%[2]	0%
	1-5	87.5%[2]	
	5-6	75%[2]	
Vegetable Ingestion			
Root vegetable ingestion rate (g/kg-bw/day (fresh weight))	0-6[2]	PDF[1]	-
Home-grown fraction of root vegetables (%)	0-6	10%[5]	-
Leafy vegetable ingestion rate (g/kg-bw/day (fresh weight))	0-6[2]	PDF[1]	-
Home-grown fraction of leafy vegetables (%)	0-6	10%[5]	-

1. *Probabilistic Density Function (refer to Table 3).*
2. *CLR10: DEFRA & Environment Agency (2002a).*
3. *ASTM: American Society for Testing and Materials (1995).*
4. *RAGS: US EPA Risk Assessment Guidance for Superfund Volume I, Human Health Evaluation Manual (Part A) (1989).*
5. *RISC 4.04; typical exposure parameter.*
6. *Site Specific behavioural assumption.*
7. *The inhalation rate for a child aged 3 to 5.9 years old undertaking 'light' activity (US EPA Exposures Factors Handbook, 1997).*
8. *-Indicates that exposure pathway is not considered to be present.*

6 RISK CHARACTERISATION

6.1 INTRODUCTION

Risk characterisation is the final step in the quantitative risk assessment process. In this step, the results of the exposure assessment and hazard assessment sections are combined to provide numerical estimates of the risks to identified receptors.

Non-carcinogenic risks (threshold) are estimated in the form of Hazard Quotients (HQs), which are the ratios of the Mean Daily Intake (MDIs) to the Tolerable Daily Intakes (TDIs). The MDIs from each child age group via each exposure pathway can be summed to calculate the MDI for a child receptor aged 0 to 6 years. HQs can then be summed to calculate an overall risk level, or Hazard Index (HI), a procedure used to assess additive effects from concurrent exposure to a mixture of chemicals.

The maximum acceptable level of risk for non-carcinogenic risk is an HQ of one (1). An HQ of less than one indicates that the estimated level of exposure is below that at which health risks are expected to occur. Should the HI exceed one (1), then the 'risk driving' compounds and pathways need to be considered in more detail.

6.1.1 *Calculation Of Site Specific Target Levels*

Site Specific Target Levels (SSTLs) (i.e. clean-up levels) are developed based on the potential for selected components to give rise to potentially significant health risks. SSTLs are estimated by conducting the risk assessment in the forward direction to calculate a total risk from all relevant pathways for each contaminant using an arbitrary soil contaminant concentration. The level of risk is directly proportional to the observed concentration and therefore the SSTLs can be calculated by:

$$\text{Threshold SSTLs} = \frac{\text{MARL (1)}}{[\text{Sum of HQs by all pathways}]} * \text{Concentration (X)}$$

where:

'MARL (1)' is the Maximum Allowable Risk Level which is considered to be a Hazard Quotient of 1. Hazard Quotients greater than 1 are considered to present potentially significant risks.

'Concentration (X)' is an arbitrary soil concentration of 1.

'[Sum of HQs by all pathways]' refers to the sum of all hazard quotients for child receptors via vegetable ingestion soil ingestion, dermal contact and dust inhalation (indoor and outdoor) pathways.

This process leads to the generation of the SSTLs presented below.

6.2 RISK CHARACTERISATION RESULTS

Following a review of the URS and ERM site investigation reports (as listed in *Section 1*), the main mercury species assumed to be present on the Site is elemental mercury. Therefore, the risk-based SSTLs generated are for elemental mercury; however, as the oral toxicity for inorganic mercury is used the SSTLs presented in *Table* 8 should be regarded as a total mercury concentration.

The Mean Daily Intake (MDI) doses generated using probabilistic modelling for each residential age group are presented in *Table 6* below. To account for separate MDI calculation for the individual age groups, the individual MDIs for each age group have been summed to calculate the estimated MDI for the child residential receptors (0 to 6 years of age) via the different exposure pathways.

Table 6 ***Mean Daily Intake for Child Residential Receptors (mg/kg-day)***

Age	Soil Ingestion	Dermal Contact	Indoor Dust Inhalation	Outdoor Dust Inhalation	Vegetable Ingestion
0-1	1.90E-09	3.31E-09	1.62E-08	5.36E-09	9.89E-07
1-2	1.32E-09	2.95E-08	1.53E-08	7.98E-09	6.04E-06
2-3	1.01E-9	2.72E-08	1.50E-08	7.76E-09	5.03E-07
3-4	9.00E-10	2.75E-08	1.58E-08	8.22E-09	4.56E-07
4-5	7.62E-10	2.78E-08	1.65E-08	9.58E-09	2.18E-07
5-6	7.16E-10	2.77E-08	1.46E-08	5.85E-09	2.06E-07
ΣMDI	6.60E-09	1.43E-07	9.34E-08	4.48E-08	8.41E-06

1. MDI=Mean Daily Intake

2. MDIs are estimated from the 95th percentile

The reported SSTLs are for child resident /recreational receptors who are considered to be a more sensitive receptor than adults. In order to provide an indication of the relative significance of each pathway in the assessment, *Table 7* below provides the individual hazard quotients calculated for each pathway using an arbitrary input concentration of 1 mg/kg. The hazard quotients derived from this process are directly proportional to the input concentration and the SSTL is calculated from these two values, as shown in Section *6.1.1*. The SSTL value will therefore remain constant no matter what concentration is arbitrarily selected as an input.

6.2.1 *Hazard Quotients*

The calculated hazard quotients relate to both indoor and outdoor dust exposures, soil ingestion, dermal absorption and vegetable ingestion and are provided in *Table 7.*

Table 7 ***Hazard Indices Indicating the Relative Significance of Each Exposure Pathway for Child Residents/Recreational Users (0-6 years)***

	Soil Ingestion	Dermal Contact	Indoor Dust Inhalation	Outdoor Dust Inhalation	Vegetable Ingestion	Hazard Quotients (ΣHI)
Residents[1]	2.9E-05	6.36E-04	1.45E-03	6.96E-04	3.74E-02	4.02E-02
Recreational Users[2]	4.0E-06	3.5E-02	-	3.2E-04	-	3.5E-02

1. Hazard Indices calculated using probabilistic exposure modeling.
2. Hazard Indices calculated using point estimate exposure modeling.
3. – Indicates that exposure pathway is not considered to be present.

The hazard quotients presented in *Table 7* indicate that for child residents the most significant soil pathways in decreasing order of significance are vegetable ingestion, indoor dust inhalation, dermal contact, outdoor dust inhalation and soil ingestion. For recreational users, the most significant pathways in decreasing order of significance are dermal contact, outdoor dust inhalation and soil ingestion.

6.2.2 *Site Specific Target Levels*

The SSTLs are calculated in the manner described in *Section 6.1.1* and is as follows:

$$25 \text{ mg/kg} = \frac{1}{0.040} * 1 \quad \textit{(for child residents)}$$

$$29 \text{ mg/kg} = \frac{1}{0.035} * 1 \quad \textit{(for child recreational users)}$$

Table 8 *Risk-Based Site Specific Target Levels*

Compound	Residential with vegetable gardens	Recreational User
Total Mercury	25 mg/kg[1]	29 mg/kg[2]

1. SSTL calculated using probabilistic exposure modelling.
2. SSTL calculated using exposure point estimate modelling.

Child recreational users and child residents are considered to occupy the Site in the future and therefore the total mercury SSTL must be inclusive for both receptors. As such, the more conservative child resident (with vegetable gardens) SSTL should be adopted for both residential and recreational receptors.

7 UNCERTAINTY ANALYSIS

Uncertainty characterisation is essentially a qualitative process relating to the selection and rejection of specific data, estimates and scenarios, and can apply to each step of a risk assessment process (US EPA, 1992). When assessing risks, uncertainty can arise from missing or incomplete information, be incorporated into the scientific theory affecting the ability of a model to make predictions, and result from uncertainty affecting a particular parameter e.g. sampling errors. Such uncertainty has the potential to cumulatively over or under-estimate risk during an assessment. A consideration of uncertainty is a part of the risk assessment process and consequently must be addressed.

7.1 RECEPTORS

Following the proposed remediation of mercury impacted soils, ERM understands that the Site is to be redeveloped for residential/recreational use. The exact design of the redevelopment has not been made available at this stage and indeed could change in future. This uncertainty therefore needs to be taken into account in the selection of potentially exposed receptors and their exposure characteristics. It is understood that the proposed remediation works are being undertaken to a standard suitable for residential (with vegetable gardens) and recreational use and as a conservative approach has been adopted used to determine the SSTLs for this type of end-use. The receptors selected for this assessment are residents who consume to home-grown vegetables on the Site (adults and children).

7.2 EXPOSURE PATHWAYS

In order to derive SSTLs that are protective of health to an individual involved in a range of possible residential/recreational activities a range of potential exposure pathways has been selected. For residents these pathways include soil ingestion, soil dermal contact and soil indoor and outdoor dust inhalation. These pathways coupled with the accompanying exposure assumptions are likely to represent those with Reasonable Maximum Exposure (RME).

The RME concept is used to take account uncertainty associated with the exposure scenario for the potential Site users. In order to ensure a degree of health protection a "Reasonable Maximally Exposed Individual" (RMEI) is described. This is a term used to refer to exposure parameters that are conservatively selected from the 85-95 percentile of their individual distributions, a combination of all these factors is therefore extremely unlikely to be met in one person. Thus, the RME scenario is typically regarded as a very conservative exposure scenario, and is used as the base case for calculations. Therefore, uncertainty in the assessment is taken into account by erring on the side of over estimation and health protection.

7.3 *TOXICITY DATA*

Tolerable Daily Intakes (TDIs)(or Reference Doses (RfDs)) are set on the basis of no-observed-adverse-effect levels (NOAEL) with a number of tenfold safety factors applied to account for factors such as variability within populations, variability between species (when using animal data), and variability between sub-chronic and chronic exposures. As such they are intended to be well below any threshold for adverse health effects and can be interpreted as upper bounds on *de minimis* doses below which doses can be considered trivial (Criteria for Establishing *De Minimis* Levels of Radionuclides and Hazardous Chemicals in the Environment, US Department of Energy, Office of Environmental Management, 1996). Consequently, it is considered that the estimation of risks is a highly health conservative process.

7.4 *MERCURY SPECIATION*

Based on previous Site investigation reports, elemental mercury is considered to be the main mercury species present on the Site. The contribution of organic mercury (as methyl mercury) to the overall Site contamination is interpreted as minimal, based on the analysis of a limited number of soil and sediment samples, where a maximum concentration of 0.0094 mg/kg was identified. In addition, the presence of inorganic mercury in the soil cannot be discounted. Therefore, the exact contribution of elemental mercury in soil is unknown.

However, the toxicity data selected for mercury in the assessment comprise the IRIS inhalation value for elemental mercury which is highly conservative and the oral reference dose for mercuric chloride, which is more conservative than the limited provisional value published for elemental mercury by the US EPA. By applying more conservative toxicity data in the assessment, it is considered that potential variation in the exact proportions of residual inorganic and elemental mercury are catered for and that the SSTL derived refers to total mercury.

7.5 *SELECTION OF THE 95TH PERCENTILE*

The 95th percentile of the Mean Daily Intake exposures was adopted for this risk assessment and this value is consistent with the policy objectives behind the Soil Guideline Values (DEFRA, 2002a) and is consistent with other approaches to environmental risk assessment where a reasonable worst case is required. By selecting at the 95th percentile level, the most unlikely exposure scenarios are excluded but a wide range of more likely situations are included. It is not applicable to draw conclusions for an individual or a specific site from the selection of the 95th percentile. Therefore, it is incorrect to assume that a selection at the 95th percentile of expected daily exposure means that 5% of the individuals on any given site are likely to be unprotected.

8 *LIMITATIONS*

All conclusions made in the report are the professional opinions of the ERM personnel involved with the project and, while normal checking of the accuracy of data has been conducted, ERM assumes no responsibility or liability for errors in data obtained from regulatory agencies or any other external sources, nor from occurrences outside the scope of this project.

Risks have been assessed in this study from soil impacts reported in the URS and ERM investigation reports. The assessment has not considered potential health risks resultant from acute (short-term, unpredictable) exposure, such as may occur during intrusive works at the site. It is therefore possible for individual site workers to be exposed to levels of contamination not observed during the sampling events. Consequently appropriate health and safety measures, including wearing appropriate personal protective equipment should be adopted.

9 DUTCH INTERVENTION VALUES

9.1 INTRODUCTION

The 1994 Dutch Intervention Value (DIV) for mercury (10 mg/kg) has previously been recommended as a clean-up criterion for the Site and hence it is important to put this value in context. The 1994 Dutch soil guidelines include both Target and Intervention Values. Under the Dutch regime the Target Value is considered to be the baseline concentration below which compounds and/or elements are known or assumed not to affect the natural properties of the soil. The Intervention Value is considered to be the maximum tolerable concentration above which remediation is required and is a risk-based standard, founded on potential risks to humans and ecosystems.

The DIVs were modified and updated in 2000, and owing to new scientific data, views and exposure models, the DIVs were again reconsidered in 2001 (RIVM 2001). The RIVM report provides Serious Risk Concentrations (SRCs) related to human toxicological (SRC_{human}) and ecotoxicological (SRC_{eco}) risks. As stated in the RIVM report the *"human-toxicological risk level should not be treated as a serious risk since it equals the Maximum Permissible Risk level"*.

The choice of parameters used to determine the Intervention Values were based on the 'average' situation and 'average' human behaviour, which historically was the scenario of 'resident with garden'. The exposure model 'CSOIL' was used to calculate the soil intervention values and incorporates algorithms for the following exposure parameters:

- ingestion, inhalation and dermal uptake of soil;
- inhalation via air;
- intake through drinking water and dermal contact through showers
- consumption of home grown crops, comprising 10% of the vegetables consumed;
- lifetime exposure of 70 years for an adult, 6 years for a child; and
- vegetable/plant bio-concentration factor (BCF).

9.2 DERIVATION OF DUTCH INTERVENTION VALUE FOR MERCURY

The Dutch Intervention Value (DIV) of 10 mg/kg (total Hg) for all land uses was derived in 1994 from the integration of lowest serious risk concentration for humans (SRC_{human}) and serious risk concentrations for ecological systems (SRC_{eco}). A SRC_{human} of 197 mg/kg was derived from the model 'CSOIL' using the input parameters outlined above. The model used physicochemical, site and exposure parameters for a standard soil containing 10% organic matter, 25% clay and pH 6. Corrections were made to the "standard soil" to account for variations in organic and clay contents to determine the DIV.

In 2001, a re-assessment of the parameters used in the 'CSOIL' model resulted in the integrated Serious Risk Concentration (SRC) for inorganic mercury in soil of 36 mg/kg, based on ecotoxicity. The SRC_{human} also increased slightly to 210 mg/kg. This change resulted from refinement of the soil partition coefficient (K_d) for elemental mercury and a revision of the bio-concentration factor (BCF). Revision of the BCF was based exclusively on field data and average consumption of vegetables and potatoes compared to BCF used in the original determination; which was derived from a wide range of plants, including irrelevant plants and paying no attention to the relevant contamination level (RIVM, 2001).

Separate Maximal Permissible Risk (MPR) values have been determined for metallic and organic mercury due to the large differences in toxicity of the compounds. As no physicochemical data for organic mercury were available, only a SRC_{human} for inorganic mercury could be derived.

Therefore, in light of new scientific data and more recent revisions of the Dutch guideline values, it is considered inappropriate to use the outdated Dutch Target Value (0.3 mg/kg) or the Dutch Intervention Value (10 mg/kg) as a clean-up criterion for the Site. These outdated values are considered to be overly conservative and hence it is considered more appropriate to derive risk-based site specific clean-up criteria.

10 CONCLUSIONS

The HLL site in Kodaikanal, formerly used as a thermometer factory, has been found to be contaminated with mercury. A number of investigations have taken place on the Site and these have found that residual mercury is predominantly in the elemental form. There is some capacity for this mercury to be present as inorganic but significant formation of methyl-mercury is not apparent on the Site. Soil vapour investigations have only detected mercury soil vapour in excess of the WHO European Ambient Air Quality Guideline of 1 $\mu g/m^3$ at one location. This was also the location recorded as the having the highest concentrations of mercury in soil.

Remediation has been proposed for the Site and a remedial value was initially proposed based on the Dutch Intervention Value (DIV) of 10 mg/kg. The DIV considered potential impacts on both soil health and human health and the lower of the two values was selected as the DIV. In the case of mercury, the DIV of 10 mg/kg was an ecological value and the human health protection value was considerably larger. These DIV values were reconsidered in 2001 (Lijzen et al., 2001) and recommendations were made to raise the ecological value to 36 mg/kg and the human health value to 210 mg/kg.

Clearly, when selecting international soil screening numbers for use as remedial criteria it is important to understand how the numbers were derived and their application in the relevant jurisdiction. At Kodaikanal, it was considered that a more fundamental and site-specific understanding of the environmental mercury was required such that robust Site Specific Target Levels (SSTLs) could be derived for use as remedial criteria.

SSTLs are calculated on the basis of an assumed exposure scenario described as a Conceptual Site Model (CSM). In this case, the CSM described the Site after redevelopment for residential/recreational use. Using a probabilistic approach, ERM has derived a SSTL value of 25 mg/kg based on a residential scenario considering exposure via soil ingestion, dermal contact, indoor and outdoor dust inhalation, and ingestion of vegetables grown on the Site. Using point estimate exposure parameters, a SSTL of 29 mg/kg was derived for recreational users considering exposure via soil ingestion, dermal contact and outdoor dust inhalation.

The toxicity data used in the assessment take into account the mercury being present as potentially elemental and inorganic and the resultant SSTL is effectively a 'total mercury' value. The toxicity data were taken from current USEPA reference doses (RfDs) and reference concentrations (RfCs). These are the doses that someone may receive without exhibiting demonstrable health effects.

SSTLs are calculated using a combination of probabilistic density functions and exposure point estimates. The mercury soil SSTL is then back calculated to estimate the concentration in soil that, at the assumed level of exposure, would not lead to an individual receiving a dose via all pathways in excess of the RfD or RfC. In this instance a child is considered to be the most sensitive or risk driving receptor and hence the SSTLs are based on protecting children.

Under the assumed conditions of the Site, ERM considers that an SSTL of 25 mg/kg (total mercury) is a health protective clean-up value for the future potential residential receptors who may consume vegetables grown on the Site and future recreational users. Therefore, under the assumed conditions of the Site, ERM considers that an SSTL of 25 mg/kg (total mercury) is a health protective clean-up value for the future potential receptors. This assessment has considered and incorporated a degree of background exposure to mercury and was performed following a review of information and laboratory reports from URS and ERM site investigations.

11 *REFERENCES*

ATSDR (Agency for Toxic Substances and Disease Registry) (1999) Toxicological Profile for Mercury, US EPA web-based database, March 1999.

Alloway BJ Ed. (1995) Heavy Metals in Soil, 2nd Edition, Blackie, London.

ASTM (American Society for Testing and Materials) (1995) Standard Guide for Risk Based Corrective Action Applied at Petroleum Release Sites. E 1739-95 (Reapproved 2002). ASTM, USA.

ATSDR (Agency for Toxic Substances and Disease Registry). 1989. Toxicological Profile for Mercury. ATSDR/U.S. Public Health Service.

BP (British Petroleum) (2001) RISC $_{4.04}$: Risk-Integrated Software for Clean-ups User's Manual. BP Oil, Ltd.

Cross SJ & Taylor ER (1996) Human Exposure to Soil Contaminants through the Consumption of Home-Grown Produce. *Contaminated Sites Monograph Series, No. 6.*

Davis JC (1973) *Statistics and Data Analysis in Geology.* John Wiley & Sons, New York.

DEFRA (Department for Environment, Food and Rural Affairs) & Environment Agency (2002a) The Contaminated Land Exposure Assessment (CLEA) Model: Technical Basis and Algorithms, Report CLR10. Available from The R&D Dissemination Centre, WRC plc, Swindon, Wilts.

DEFRA (Department for Environment, Food and Rural Affairs) & Environment Agency (2002b) Contaminants in Soil: Collation of Toxicological Data and Intake Values for Humans, Report CLR9. Available from The R&D Dissemination Centre, WRC plc, Swindon, Wilts.

DH (Department of Health) (1991) Dietary Reference Values for Food Energy and Nutrients for the UK. Available from The Stationery Office, PO Box 29, Norwich NR3 1GN.

DH (Department of Health) (2000) Health Survey for England 1998 data set 4150. Available from the UK Data Archive at the University of Essex.

enHealth (2002) Environmental Health Risk Assessment Guidelines for assessing human health risks from environmental hazards. Department of Health and Ageing, Canberra ACT.

Gershuny J (2000) *Changing Times: Work and Leisure in Post-industrial Societies.* Oxford University Press.

Gershuny J, Miles I, Jones S, Mullings C, Thomas G & Wyatt S (1986) Time budgets: preliminary analyses of a national survey. *Quarterly Journal of Social Affairs* 2(1): 13-19.

Goyer, R.A. 1991. Toxic Effects of Metals. In: Casarett and Doull's Toxicology: The Basic Science of Poisons, fourth edition. M. O. Ammdur, J. Doull, and C.D. Klaassen, eds. pp. 623-680

Hawley JK (1985) Assessment of health risks from exposure to contaminated soil. *Risk Analysis* 5: 289-302.

Health Promotion England (2001) *Weaning Your Baby,* ISBN 0-7521-0872-7. Avaliable from Health Promotion England, 40 Eastbourne Terrace, London W2 2QR.

ICRP (International Commission on Radiological Protection) (1975) Report of the Task Group on Reference Man, International Commission on Radiological Protection No 23. Pergamon Press, Oxford.

Keenan RE, Sauer MM, Lawrence FH, Rand ER & Crawford DW (1989) Examination of potential risks from exposure to dioxin in sludge used to reclaim abandoned strip mines. In *The Risk Assessment of Environmental Hazards: A Textbook of Case Studies,* ed. Paustenbach DJ, John Wiley & Sons, Chichester.

Lijzen JPA, Baars AJ, Otte PF, Rikken M, Swartjes FA, Verbruggen EMJ & van Wezel AP (2001) Technical Evaluation of the Intervention Values for Soil/Sediment and Groundwater. Human and Ecotoxicological Risk Assessment and Derivation of Risk Limits for Soil, Aquatic Systems and Groundwater. RIVM Report 711701 023. RIVM, Holland.

McKone TE & Daniels JI (1991) Estimating human exposure through multiple pathways from air, water, and soil. *Reg. Toxicology and Pharmacology* 13: 36-61.

Mills A & Tyler H (1992) *Food and Nutrient Intakes of British Infants Aged 6-12 Months.* Available from The Stationery Office, PO Box 29, Norwich NR3 1GN.

National Environment Protection Council (1999) National Environment Protection (Assessment of Site Contamination) Measure. *Schedule B(7a) – Guideline on Health-Based Investigation Levels.*

Kocher DC (1996) Criteria for Establishing De Minimis Levels of Radionuclides and Hazardous Chemicals in the Environment. ES/ER/TM-187, Lockheed Martin Energy Systems Inc, Oak Ridge, Tennessee.

Baars AJ, Theelen RMC, Janssen PJCM, Hesse JM, van Apeldoom ME, Meijerink MCM, Verdam L, Zeilmaker MJ (2001) Re-evaluation of human-toxicological maximum permissible risk levels. RIVM Report 711701 025. RIMV, Holland.

Sandborgh-Englund G, Einarsson C, Sandstrom M, & Ekstrand J (2004) Gastrointestinal Absorption of Metallic Mercury. *Archives of Environmental Health* 59(9): 449-454.

Steinnes E (1995) Mercury. In *Heavy Metals in Soils,* 2nd edn., ed. Alloway BJ, Blackie Academic & Professional, London.

US DOE (Department of Energy) (1996) Criteria for Establishing *De Minimis* Levels of Radionuclides and Hazardous Chemicals in the Environment. US Department of Energy, Office of Environmental Management, Washington DC.

USEPA (United States Environmental Protection Agency) (1989) Risk Assessment Guidance for Superfund: Volume 1 – Human Health Evaluation Manual (Part A) EPA/540/1-89/002, Washington DC.

USEPA (United States Environmental Protection Agency) (1997) Exposure Factors Handbook. EPA/600/8-89/043. Office of Health and Environmental Assessment, Washington DC.

USEPA (United States Environmental Protection Agency) (1999) Exposure Factors Handbook (updated edition), EPA 600-P-95-002 Fa. United States Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency) (2006) IRIS (Integrated Risk Information System) Database for Risk Assessment. US EPA National Centre for Environmental Asessment, Washington, DC.

Van den Berg, R (1991) *Blootstellingvan de mens aan bodemverontreiniging. Een kwalitatiieve en kwantitatieveanalyse, leidend tot voorstellen voor humaan toxicologische C-toetsingswaarden.* Report no 725201006. Rijkinstituut voor Volksgezondheid en Milieu, The Hague.

Van den Berg, R (1994) *Human Exposure to Soil Contamination: A Qualitative And Quantitative Analysis Towards Proposals For Human Toxicological Intervention Values.* (Modified from the 1991 report). Rijkinstituut voor Volksgezondheid en Milieu, The Hague.

Veerkamp W, & ten Berge W (1995) *The Concepts of HESP (Human Exposure to Soil Pollutants) Version 2.10b.* Shell Internationale Petroleum Maatschappu BV, The Hague.

WHO (World Health Organisation) (1996) Guidelines for Drinking Water Quality. 2nd Edition, WHO, Geneva.

WHO (World Health Organisation) (2000) Air Quality Guidelines for Europe Second Edition. WHO Regional Publications, European Series No.91

Annex A

Figures

G:\Jobs\2006\0047735\27 06 06\0047735 F1 site location.cdr 27 06 06 JPM Environmental Resources Management Australia Pty Ltd

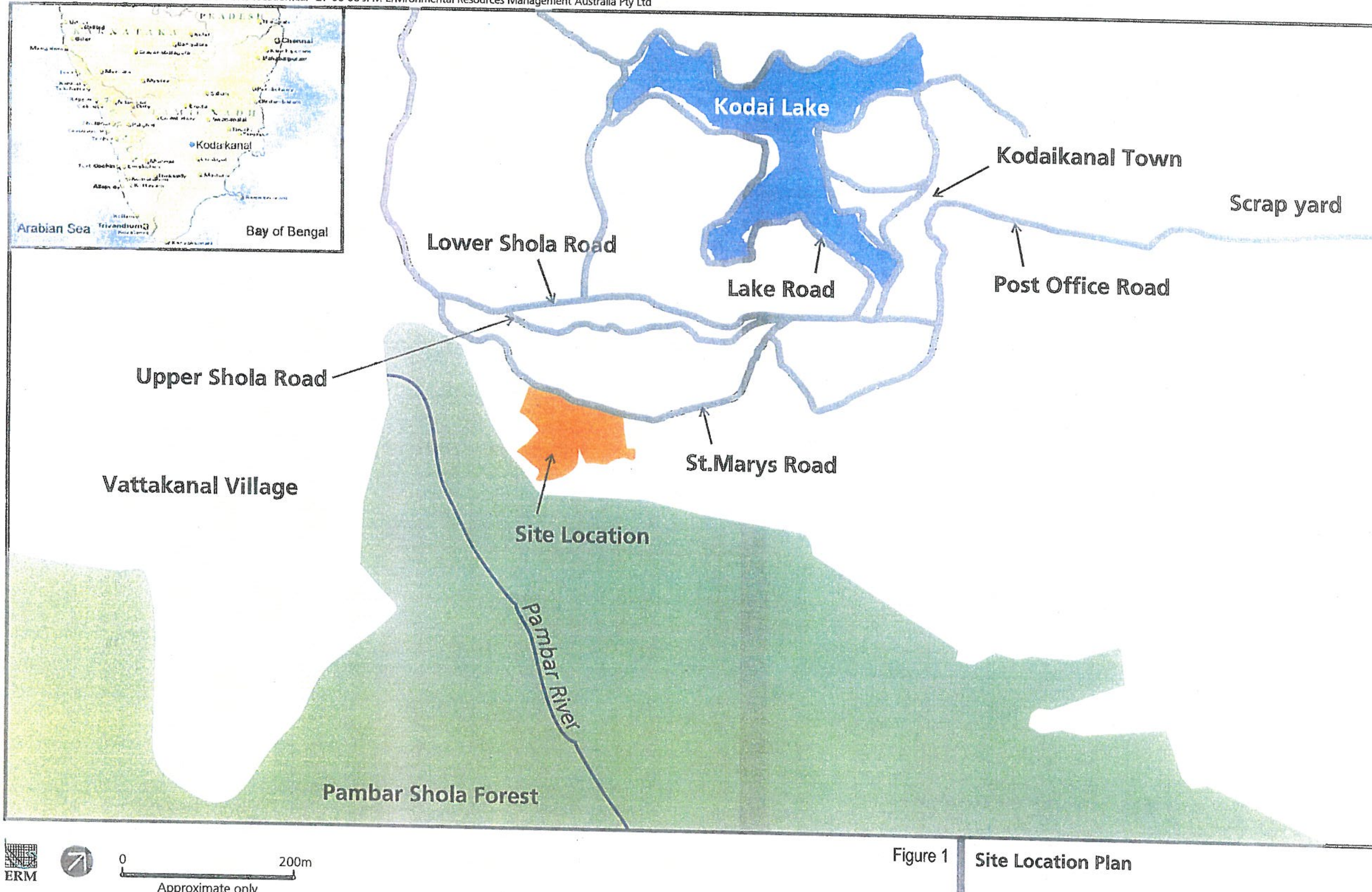

Figure 1 **Site Location Plan**

Hindustan Lever Limited
Site Specific Target Levels

G:\Jobs\2006\0047735\27 06 06\0047735 F2 site layout.cdr 27 06 06 JPM Environmental Resources Management Australia Pty Ltd

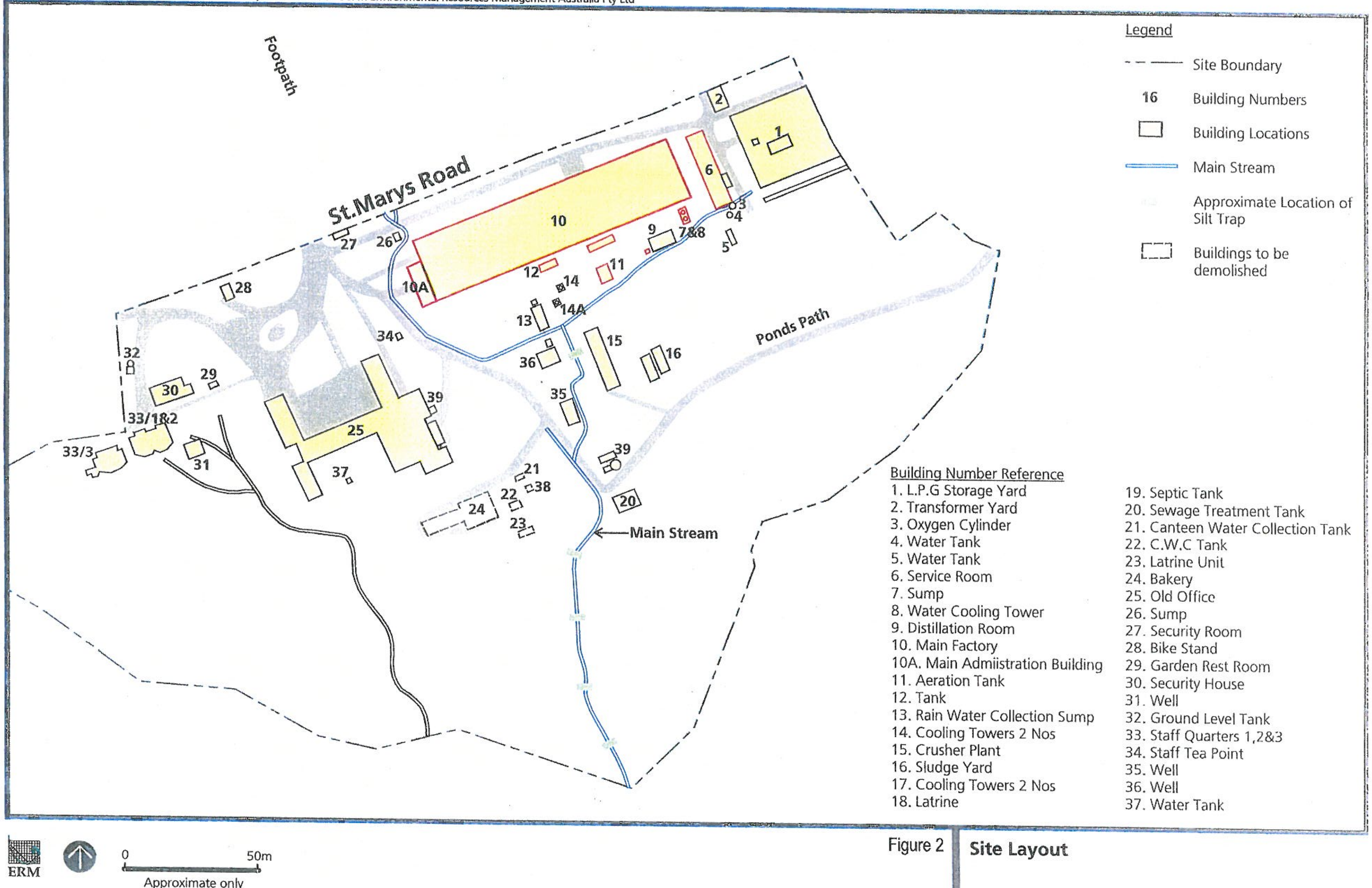

Figure 2 **Site Layout**

Hindustan Lever Limited
Site Specific Target Levels

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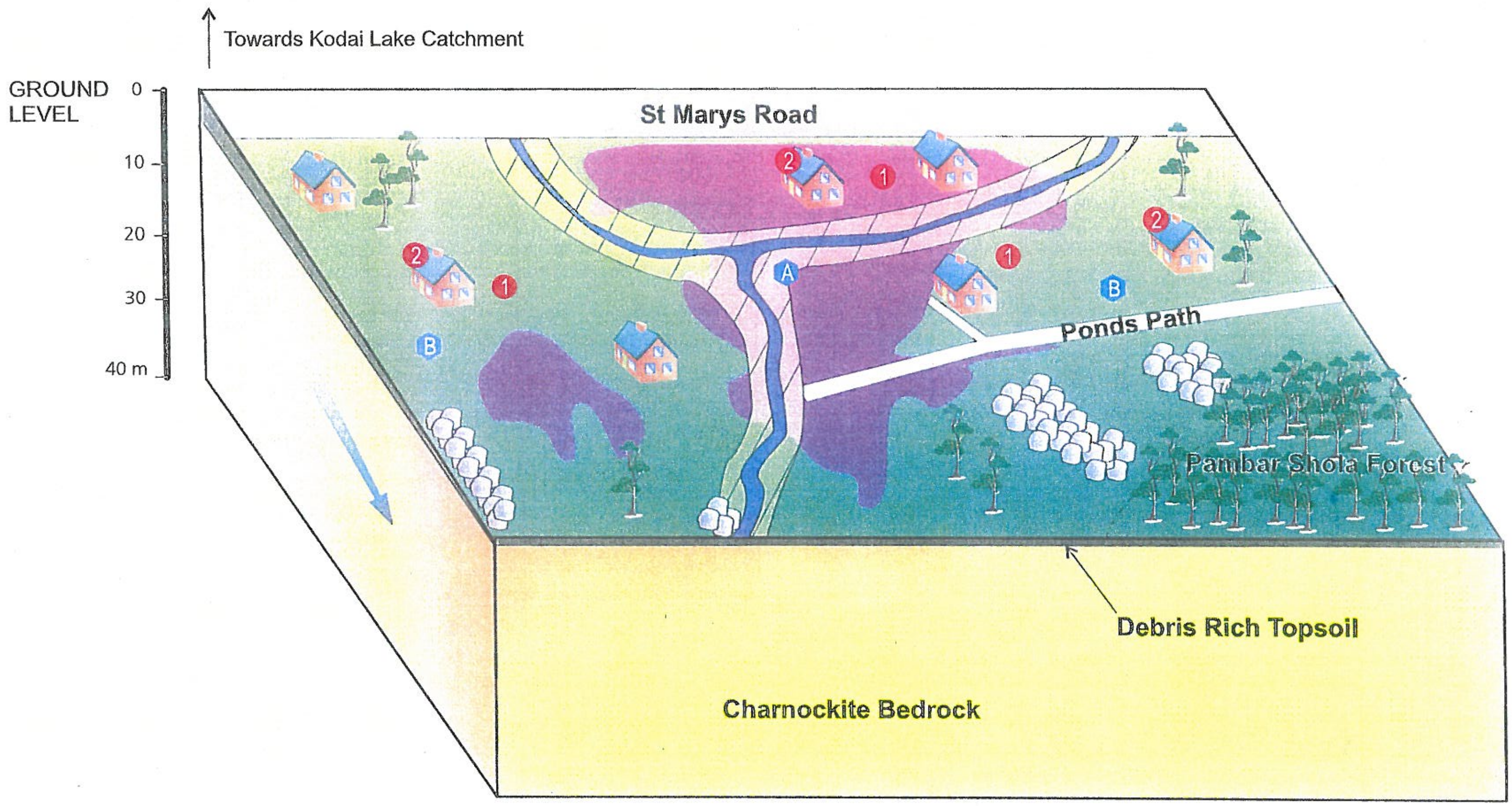


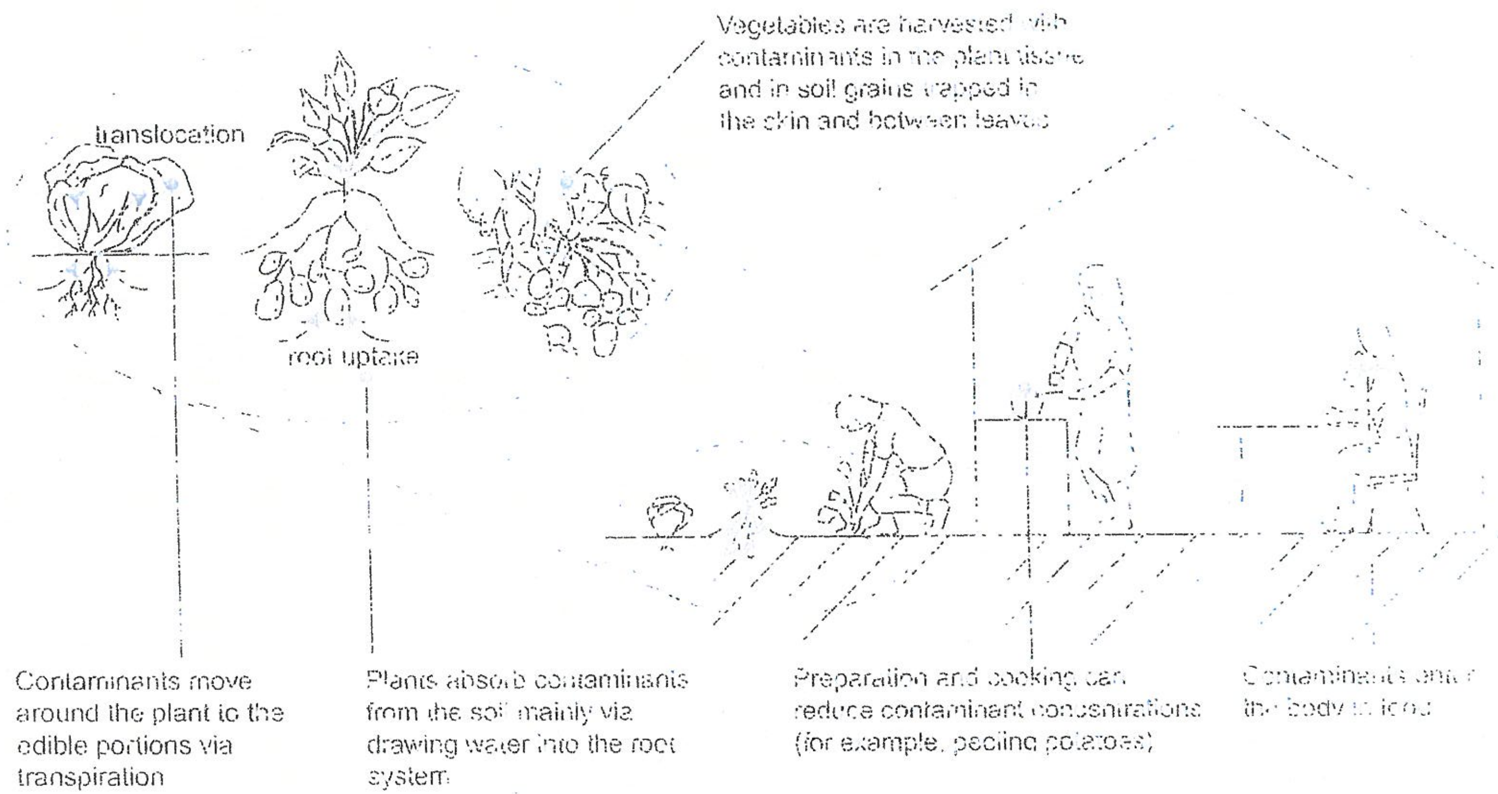
PATHWAYS	RECEPTORS	KEY
1 Dermal, oral and dust inhalation derived from soil contamination 2 Indoor inhalation of dust derived from soil contamination	A Adult and child recreational user B Adult and child resident	Direction of groundwater flow Proposed Open Space Charnockite Rocky Outcrop Site Boundary Approximate area of proposed remediation with 300mm fill layer Stream

ERM

Diagrammatic - **NOT TO SCALE**

Figure 3 **Conceptual Site Model**

Hindustan Lever Limited
Site Specific Target Levels



Source: DEFRA, R&D Publication, CLRIO, 2002

Figure 4 **Illustration of the Consumption of Garden Vegetables Pathway**

Annex B

Risk Assessment Formula

ESTIMATION OF HUMAN EXPOSURE

Introduction

Exposure is estimated for each chemical and pathway in the form of a maximum daily intake (MDI) and a chronic daily intake (CDI). MDIs and CDIs are used to estimate threshold (non-carcinogenic) and non-threshold (carcinogenic) risks, respectively.

The chronic daily intake represents the combined daily intake averaged over the lifetime of the exposed individual and is calculated by multiplying the MDI by the Exposure duration and dividing the result by 70 years (lifetime).

The equations used to calculate the MDIs for each pathway are presented below and these follow USEPA (1989).

Soil Ingestion

MDIs via soil ingestion are estimated as follows:

$$MDI = \frac{C_s \times IR \times 0.000001 \times EF \times AAF}{BW \times 365}$$

Indoor Dust Inhalation

MDIs via indoor dust inhalation may be estimated as follows:

$$MDI = \frac{C_{id} \times B_i \times EF \times F_{timein} \times F_{dustind}}{BW \times 365}$$

where:

C_{id} = indoor dust level (0.07 mg/m^3) x C_s (mg/kg) x 10^{-6} (mg/m^3)

Outdoor Dust Inhalation

MDIs via outdoor dust inhalation may be estimated as follows:

$$MDI = \frac{C_{od} \times B_o \times EF \times F_{timeout} \times F_{dustout}}{BW \times 365}$$

where:

C_{od} = outdoor dust level (0.07 mg/m^3) x Cs(mg/kg) x 10^{-6} (mg/m^3)

Dermal Contact With Soil

MDIs via dermal contact with soil may be estimated as follows:

$$MDI = \frac{C_s \, x CF \, x \, DAF \, x \, SSA \, x \, F_{exposed} \, x \, AF \, x \, EF}{BW \, x \, 365}$$

Vegetable Ingestion

MDIs via vegetable ingestion may be estimated as follows:

$$MDI = \frac{C_s \times ((CP_{root} \times CR_{root} \times HF_{root}) + (CP_{leafy} \times CR_{leafy} \times HF_{leafy}))}{BW}$$

Table B1 Summary of Term Definitions

Parameter	Notation
Area of site (m^2)	A
Intestinal absorption factor	AAF
Adherence factor (mg/cm^2)	AF
Breathing rate indoors (m^3/day)	B_i
Breathing rate outdoors (m^3/day)	B_o
Body weight (kg)	BW
Chronic daily intake (mg/kg-day)	CDI
Volumetric Conversion Factor for Water (1 litre/1000cm^3)	CF
Calculated soil-to-plant concentration factor for root vegetables	CP_{root}
Calculated soil-to-plant concentration factor for leafy vegetables	CP_{leafy}
Root vegetable ingestion rate ((g/kg-bw/day) (fresh weight))	CR_{root}
Leafy vegetable ingestion rate rate ((g/kg-bw/day) (fresh weight))	CR_{leafy}
Chemical concentration in indoor dust (mg/m^3)	C^{id}
Chemical concentration in outdoor dust (mg/m^3)	C_{od}
Chemical concentration in soil (mg/kg)	C_s
Dermal absorption factor	DAF
Diffusion coefficient in air (cm^2/s)	D^{air}
Exposure duration (years)	ED
Exposure frequency (days)	EF
Exposure time (hours/day)	ET
Fraction of indoor dust from soil	$F_{dustind}$
Fraction of outdoor dust from soil	$F_{dustout}$
Fraction of skin exposed	$F_{exposed}$
Fraction of organic carbon in soil (g-C/g-soil)	F_{oc}
% Soil particles in dust	F_{sd}
Fraction of time spent indoors	F_{timein}
Fraction of time spent outdoors	$F_{timeout}$
Home-grown fraction of root vegetables	HF_{root}
Home-grown fraction of leafy vegetables	HF_{leafy}

Parameter	Notation
Soil ingestion rate (mg/ day)	IR
Maximum daily intake rate (mg/kg-day)	MDI
Permeability coefficient (cm/hr)	PC
Outdoor dust concentration	PM_o
Indoor dust concentration	PM_i
Skin surface area (cm^2)	SSA
Soil adherence factor (mg/cm^3)	SL
Wind speed above ground surface in ambient mixing zone (m/s)	U_{air}
Width of source area parallel to wind or groundwater flow direction (m)	W
Ambient air mixing zone height (cm)	δ_{air}
Total soil porosity (cm^3/cm^3-soil)	θ_T
Volumetric water content in capillary fringe soils (cm^3-H_2O/cm^3-soil)	θ_{wcap}
Soil bulk density	ρ_s